Proceedings

12th Hanseatic India Colloquium, Germany

Solid Waste Management: an Indo-German Dialogue

7th April, 2022
at Consulate General of India, Hamburg, Germany

Supported by

German Agency for International Co-operation
(Deutsche Gesellschaft fur international Zusammenarbeit (GIZ), GmbH), Germany
&
Centre for International Migration and Development (CIM), Germany

Organised by

Centre for Environment and Development, India
&
Hanseatic India Forum e.V, Germany

CED HIF e.V.

Proceedings of
12th Hanseatic India Colloquium, Germany
Solid Waste Management: an Indo-German Dialogue

As Part of the Project
Modernisation of waste management practices in
India through capacity building (ReWACa)

7th April, 2022
at Consulate General of India
Hamburg, Germany

Supported by

German Agency for International Co-operation
(Deutsche Gesellschaft fur international Zusammenarbeit (GIZ), GmbH), Germany
&
Centre for International Migration and Development (CIM), Germany

Organised by

CED HIF e.V.

Centre for Environment and Development, India
&
Hanseatic India Forum e.V, Germany

Proceedings of

12th Hanseatic India Colloquium, Germany

Published by

Hanseatic India Forum e.V
&
Centre for Environment and Development, India

Design & Pre-press
Godfrey's Graphics
Thiruvananthapuram, Kerala

ISBN: 978-81-962252-0-9

Contents

Word of Greetings

Mr. John Ruonlgul
Consul General of India, Kohlhöfen 21,
20355 Hamburg, Germany

This Conference, 12th Hanseatic India Colloquium : “Solid Waste Mangement: an Indo German Dialogue” in Hamburg, Germany on 7th April, 2022, has been organized to discuss a topic which is of a paramount importance to both developed and developing world. Protection of environment is intricately interlinked with the survival of mankind no matter in which part of the world we live. Protection of environment is intricately connected with removal of waste or minimization of waste production, as mankind appears to get drowned by a problem created by mankind itself and that is too much production of garbage. It has in recent years exacerbated due to huge amount of medical garbage produced due to Covid-19. Therefore, I am so happy that today scientists and engineers from Germany and India have gathered in our auditorium to engage in a dialogue on how to manage “Solid Waste” efficiently while saving this beautiful planet from getting drowned in its own garbage.

This dialogue has been made possible due to initiatives taken by Hanseatic India Forum e. V., Hamburg and the Center of Environment and Development, Kerala, India. For this I must appreciate the efforts by Dr. Amal Mukhopadhyay and Dr. Babu Ambat as well as their team members. Dr. Weichgrebe must also be thanked for his support. Such a conference is only possible if they received adequate financial support and for that the grant from GIZ and NUE Foundation must be appreciated.

We welcome scientists and engineers coming from India and from different parts of Germany and even on from Holland. I welcome all delegates here today . My welcome is also extended all erudite experts who are contributing to the proceedings of this Conference to be published as a book.

I am sure that you are eagerly waiting to hear lectures and presentations by experts assembled here today but I will not leave the podium without emphasizing one aspect which is dear to my heart. The issue of finding a green solution of Solid Waste Management is in my opinion of paramount importance. I will request you to explore cutting edge developments in Circular Economy and Sustainability on Solid Waste Management. Please focus on research perspectives to solve existing problems on solid waste management system, industrial development and the latest green methodology for in Solid Waste conversion and regenerate products and materials, environmental solutions, social awareness and development on solid waste management and the future perspectives of Circular Economy for industrial revolution 4.0 with the mission of green chemistry and engineering on solid waste management.

With this, I may declare the 12th Hanseatic India Colloquium Solid Waste Management: an Indo-German Dialogue" as open. At the same time I convey my best wishes to the authors, editors and publishers of the book embodying the proceedings of the conference. I wish everyone good luck in this effort to make our planet greener.

From the desk of the organizers

Dr. Amal Mukhopadhyay
Hanseatic India Forum e.V.
Baumschulenweg 26, 22609 Hamburg, Germany
email: vorstand@hif-hamburg.de

Abstract

A summary of a project, entitled "MODERNIZATION OF WASTE MANAGEMENT PRACTICES IN INDIA THROUGH CAPACITY BUILDING (ReWaCa)" and of the Indo-German conference at the end of the project, partnered by Centre for Environment and Development (CED), Thiruvananthapuram, Kerala, India and the Hanseatic India Forum, e. V., Hamburg, Germany and financially supported by GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH), is presented here.

1. Introduction

Hanseatic India Forum e.V. (HIF), is a registered non-profit, charitable, association located in Hamburg which is focused on the promotion of German - Indian cooperation in the field of culture, international understanding, education and development cooperation. HIF is also involved in charitable projects in Sundarban region of India. It was a privilege for HIF to work together with Centre for Environment and Development (CED), Thiruvananthapuram, Kerala, India on a project entitled,

"Modernization Of Waste Management Practices In India Through Capacity Building (Rewaca)".

This project was possible because of the financial support received from GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH) .

2. Project and the Scientific Colloquium

To start with , let us get to know the activities of HIF a little more in detail. Hanseatic India Forum e.V (www.hif-hamburg.de) in Hamburg is a non-profit, registered association that aims to strengthen and expand global relationships between Germany, especially Hamburg, and India through special funding and specific activities. The association is actively involved, especially through its events in Hamburg, in relation to cultural exchange, promotion of education and the diverse social encounters in the sense of international understanding between Hanseatic/Germans and Indians.

The non-profit charitable association "Hanseatic India Forum e. V." was founded in 2009 and entered in the Register of Associations at the District Court of Hamburg under no. VR20531.

The association is registered for tax purposes at the tax office in Hamburg under tax number 17/432/13978. According to the notice of exemption dated November 7th, 2014 for the calendar years 2011 to 2013, the association is exempt from corporation tax and trade tax because it serves exclusively and directly tax-privileged charitable purposes within the meaning of §§ 51 ff. AO. The grants are used to promote development cooperation within the meaning of Section 52 Paragraph 2 Sentence 1 No. 15 AO. The association is entitled to issue donation receipts.

The HIF e.V. sees itself as an independent forum for information, the exchange of ideas and contacts between people who are interested in India, its culture, history, society, religions and politics. The association organizes events that give the Germans and Indians living in the Hamburg and North German area the opportunity to get to know each other's culture and mentality and thus promote understanding between the two countries. Topics ranging from Indian literature, art and documentaries to travelogues and cultural extravaganza like music and dance performances are offered at cultural events organized by HIF in Hamburg.

Apart from promoting cultural activities, HIF has been engaged in dissemination and exchanges of scientific ideas between the two partner countries, Germany and India. For this HIF is involved in organizing a series of scientific conferences called Hanseatic India colloquium. Since its inception it has already been carried out in twelve editions. In the previous eleven versions, the focus was on medicine and healthcare.

One of the highlights of HIF's activities has been to focus on issues of environment and waste management. This has been manifested in the successfully concluded project entitled, Modernization of waste management practices in India through capacity building, in cooperation with CED and funded by GIZ. This project was carried out in India with Hanseatic India

Forum coordinating the program from Germany and the Center for timeline of October, 2020 until April, 2022.

The objectives were:

1. To improve the quality of information & Knowledge on solid waste management (SWM) concepts to strengthen SWM practices in India.
2. To develop a Conceiving-Designing-Implementing-Operating (CDIO) based teaching/learning methodology which is specific.
3. To initiate knowledge exchange & transfer on SWM issues between Indian & German Diaspora experts & foster a long term collaboration.

4. To transfer the newly developed knowledge and enhanced teaching methods to desired target groups through pilot workshops and networking events.

It is with pleasure and satisfaction, we can state that all these objectives were successfully implemented with the able support of Dr. Babu Ambat, the director of CED, Thiruvananthapuram, Kerala, India. In this context, the active support and contribution of Ms. T.A. Jayanthi, the Scientific Associate, CED must be acknowledged as well.

Under the auspices of the above-mentioned Indo-German project, as the project was coming to close, it was decided to organize a conference in Hamburg, where scientists, researchers, activists and practitioners from academia and industry from India and Germany will participate to elaborate scientific ideas, share experiences, discuss environmental issues , and find innovative strategies for waste management. The aim was to identify and strengthen interdisciplinary, practice-oriented approaches to the healthy, sustainable development of urban areas and to develop strategies for the healthy and ecologically sustainable design of metropolises with the hope to learn and improve from each other's experiences and to develop recommendations and suggestions for the further development of the existing management systems on the basis of the know-how already available in Germany.

So again the CED and HIF jointly planned and organized the 12th Hanseatic India Colloquium: "Waste management: a German-Indian dialogue", in Hamburg , Germany, on February 10, 2022. This was organized in a hybrid mode as some Covid-19 related restrictions were still in place. This was possible because of an excellent indigenous software platform which was developed by CED for a combined "in-presence" and "on-line" participation of a large number of participants. It is with great happiness and satisfaction, we may state that not only the software platform worked perfectly without a flaw, but this conference also attracted an active participation by a large number of audience both in presence and on-line even from remote parts of India. As far as speakers are concerned (please see the attached program) , we could attract many highly reputed and acclaimed environmental and waste disposal scientists.

Since it was recognized that "Solid Waste" disposal is a challenge for city authorities in countries like India with increasing urbanization and economic growth that are leading to increasing waste generation and posing a serious threat to the environment. This threat has intensified with the outbreak of the Covid-19 pandemic. There is currently no specific and authoritative official guidance on the subject of PPE waste management for COVID 19 by municipalities or the waste management industry in India. It was therefore, an appropriate time that Indian waste management stakeholders started a dialogue with the German experts.

To this end, it was decided to publish the proceedings , containing not only papers presented at the conference, but also invited articles from high-level experts from both countries who may not be able to attend the conference.

We are very happy that this proceedings book has now been completed and published. This would not have been possible without the tireless efforts of Dr. Babu Ambat, and Ms T.A. Jayanthi. We also express our gratitude to all authors who agreed to contribute their manuscripts in a timely manner.

3. Concluding remarks

Finally, we hope that our efforts will ignite an active dialogue and cooperation between Indian and German stake holders to promote active cooperation between our two nations, India and Germany, to tackle the ever increasing menace of solid waste accumulation, which is faced by both developed and developing nations.

Foreword

Integrated Solid Waste Management (ISWM) is the application of suitable techniques, technologies and management options dealing with all types of solid wastes from various sources to achieve the twin objectives of (a)waste reduction, and (b) effective management of waste still produced after waste reduction.

Efficient delivery of public services and infrastructure are pressing issues for municipalities in most developingcountries; and in many countries, solid waste management has become a top priority. The Local Bodies are to be capacitated for implementation of sustainable SWM. Capability-building of stakeholders in implementation of solid waste management cannot be treated as an isolated training exercise.The rightful position of SWM as a potent tool that reflects the culture of citizens and the administrative efficiency of the Local Bodies will need to permeate all capability building initiatives.

This is particularly important as SWM is an important cornerstone of effective governance. Keeping this in mind,the capacity building strategy for SWM should aim at a holistic set of activities. Apart from the SWM functional areas, there are other supportive areas or activities that contribute substantially to the success of SWM activities.

Waste Management is a crucial challenge for India in terms of the conditions of far reaching economic, environmental and social impacts. The Waste Management System is poorly developed in the country and more than 70% of the waste is unloaded or incinerated. The Ministry of Housing and Urban Affairs, the Planning Commission and the World Bank clearly identified insufficient availability of technical and human skills as one ofthe key challenges in the Waste Management Sector. Therefore, a specific target oriented and participatory development program based on scientific data need to be developed to meet these challenges. With this objective the Hanseatic India Forum, Germany and Centre for Environment and Development, Kerala India formulated a proposal and submitted to GIZ – CIM (Centrum fur International Migration, German Agency for International Co-operation, Germany. The project-'Modernization of Waste management Practices in India through Capacity Building (ReWaCa)" was approved by CIM-GIZ. The objective of the project is to provide skills in sustainable waste management to re-establish various waste management practices. The activities included development of didactics based on the innovative CDIO model, development of curriculum and manual,Training of Trainers, Training of Trainees – both on technical and managerial and Final workshop in Hamburg etc.

Due to the continuing Covid situation in India, we are forced to conduct the training programs in online(digitalmode) mode instead of physical training.As part of this project, the Centre for Environment and Development jointly with Hanseatic India Forum developed the Curriculum and also a training handbook with inputs from various experts in the field, for the Training of Trainers.

After completion of the Training Programs,the 12th Hanseatic India Forum organized a Colloquium on Solid Waste Management at Indian Consulate, Hamburg,Germany. There are 15 presentations on various aspects of SWM by experts from Germany as well as from India and this Proceedings Volume consists of all the detailed papers presented in the Colloquium. The whole project happened only because of the support and sponsorship from GIZ – CIM (Centrum fur International Migration, German Agency for International Co-operation, Germany. We express our sincere gratitude to CIM-GIZ.

We are indebted to the support extended by the Indian Consulate in Hamburg, especially to the Hon'ble Consul General,Mr.John H.Ruolngul and his team.

We also place our sincere gratitude to the experts from various universities and other institutions from Germany and India for their participation and support.The program was organized by our partner in Germany- The Hanseatic India Forum Hamburg and they deserve high appreciation.

We express our sincere gratitude to all who supported us to make the project a great success

Dr Babu Ambat

Executive Director,
Centre for Environment and Development
Thiruvananthapuram, India

Review of Solid Waste Management- Approach and Strategy for India with Special Focus to State of Kerala

Dr. Babu Ambat[1] & Jayanthi T.A.[2]
[1]Executive Director
[2]Scientist
Centre for Environment and Development,
Thiruvananthapuram, Kerala, India.

Abstract

In the present scenario, Municipal Solid Waste Management is the most formidable challenge faced by civic bodies and is considered an essential service delivery for sustainable development. Environmentally sound and effective solid waste management is crucial in ensuring a healthy living environment. The present paper discusses the current policies, strategies and approach for SWM in India with special focus to Kerala. It presents an overview of waste generation, legal framework and management strategies. The paper reviews the evolution of decentralized waste management in Kerala as an alternate solution which represents a paradigm shift. It highlights the decentralized system involving the segregation and processing of waste at source to the maximum extent possible and then at the community level, making non-biodegradable waste available for recycling, source level and community level composting or biomethanation for the organic fraction of waste. The solid waste management strategies for products recycle are promising practices that positively impact circular economy and sustainable goals. The consequent development of an effective institutional mechanism is highlighted along with the green protocol activities in Kerala. This review has the potential of helping municipalities, government authorities, researchers and stakeholders in Solid Waste Management sectors to make effective decision for attaining sustainable goals. This comprehensive review not only provide with an insight into the status, challenges, and implementation of waste segregation at source but also to further plan, design and implement the strategies.

Keywords: Municipal Solid Waste Management, Sustainable development, circular economy, Decentralized, Participatory SWM.

1. Introduction

Sustainable development can only be achieved if society in general, and industry in particular, produces 'more with less' i.e. more goods and services with less use of the world's resources and less pollution and waste. Efficient delivery of public services and infrastructure are pressing issues for municipalities in most developing countries; and in many countries, solid waste management has become a top priority. Solid waste management (SWM) is costly and complex for local governments, but it is so essential to the health, environment and quality of life of the people. They must be safe for workers and safeguard public health by preventing the spread of disease. In addition to these prerequisites, an effective system of solid waste management must be both environmentally and economically sustainable. Solid Waste Management (SWM) is a system for handling of all types of garbage. The end goal is the reduction of the amount of garbage clogging the streets and polluting the environment, whether that garbage is disposed of or recycled into something useful.

Municipal solid waste management (MSWM) involves the application of the principle of Integrated Solid Waste Management (ISWM) in managing municipal waste. ISWM is the application of suitable techniques, technologies and management options dealing with all types of solid wastes from all sources to achieve the twin objectives of (a) waste reduction, and (b) effective management of waste still produced after waste reduction.

With rapid population expansion and constant economic development, waste generation both in residential as well as commercial/industrial areas continues to grow rapidly, putting pressure on society's ability to process and dispose of this material. Also, inappropriately managed solid waste streams can pose a significant risk to health and environmental concerns. Improper waste handling in conjunction with uncontrolled waste dumping can cause a broad range of problems, including polluting water, attracting rodents and insects, as well as increasing floods due to blockage in drains.

As well, it may bring about safety hazards from explosions and fires. Improper solid waste management can also increase greenhouse gas (GHG) emissions, thus contributing to climate change.

Having a comprehensive waste management system for efficient waste collection, transportation, and systematic waste disposal—together with activities to reduce waste generation and increase waste recycling—can significantly reduce all these problems. While nothing new, an ISWM approach provides the opportunity to create a suitable combination of existing waste management practices to manage waste most efficiently

2. Swm- Indian Scenario

2.1 Overview of Waste Generation in India

Waste generation is strongly dependent on the local economy, lifestyle, and infrastructure. It has been well established that waste generation of an area is proportional to average income of the people of that area. It is also observed that generation of organic, plastic, and paper waste is high in high income areas. Several studies were conducted by Central Pollution Control Board (CPCB) over the last 2 decades to arrive at waste generation details and composition of MSW generated in the country. Findings from several studies can be summarized as below

2.2 NEERI Study 1996

The study was carried out by National Environmental Engineering Research Institute (NEERI) in 43 cities of varying sizes across the country. Study revealed that quantum of waste generation varies between 0.2 and 0.4 kg/capita/day in the urban centres and goes up to 0.5 kg/capita/ day in metropolitan cities. The characterization studies indicated that MSW contains large organic fraction (30%–40%); ash and fine earth (30%–40%); paper (3%–6%); along with plastic, glass, and metal (each less than 1%). The calorific value of refuse ranged between 800 and 1,000 kilocalorie per kilogram (kcal/kg) and carbon-to-nitrogen (C/N) ratio ranged between 20 and30.

2.3 CPCB through EPTRI in 1999-2000

The study conducted by CPCB through Environment Protection Training and Research Institute (EPTRI) in 1999–2000 in 210 Class I cities and 113 Class II towns indicated that Class I cities generated an average of 48,000 tons per day (TPD) of MSW while Class II towns generated an average of 3,400 TPD of MSW. The study revealed that waste generation rate in Class I cities was approximately 0.34 kg/ capita/day while the waste generation rate in Class II towns was found to be 0.14 kg/capita/day

2.4 NEERI Study in 2004-2005

The study named "Assessment of Status of Municipal Solid Wastes Management in Metro Cities and State Capitals" conducted by NEERI in 2004–2005 assessed 59 cities (35 metro cities and 24 state capitals).The study revealed that waste generation rate varied from 0.12 to 0.60 kg/capita/day. Analysis of physical composition indicates that total compostable matter in the waste is 40%–60%, while recyclable fraction is 10%–25%. The moisture content in the MSW is 30%–60%, while the C/N ratio is 20–40. It is reported that an average of 39,000 TPD of MSW was generated from these cities/towns during the year2004–2005

Table 1
Overall Solid Waste Management Status In India

Sl. No.	State	Solid waste generated (TPD)	Collected (TPD)	Treated TPD)	Landfilled (TPD)
1	Andhra Pradesh	6898	6829	1133	205
2	Arunachal Pradesh	237	202	Nil	28
3	Assam	1199	1091	41	0
4	Bihar	4281	4014	Not provided	No
5	Chhattisgarh	1650	1650	1650	0
6	Goa	227	219	197	22
7	Gujarat	10374	10332	6946	3386
8	Haryana	5352	5291	3124	2168
9	Himachal Pradesh	346	332	221	111

10	Jammu & Kashmir	1463	1437	548	376
11	Jharkhand	2226	1852	758	1086
12	Karnataka	11085	10198	6817	1250
13	Kerala	3543	965	2550	Not Provided
14	Madhya Pradesh	8023	7236	6472	764
15	Maharashtra	22633	22584	15056	1355 (Unscientific ically disposed= 6221.5)
16	Manipur	282	190	109	82
17	Meghalaya	107	93	10	83
18	Mizoram	345	276	270	0
19	Nagaland	330	285	122	8
20	Odisha	2133	2097	1038	1034
21	Punjab	4338	4279	1894	2385
22	Rajasthan	6897	6720	1210	5082
23	Sikkim	72	72	20	52
24	Tamil Nadu	13422	12844	9430	2301
25	Telangana	9965	9965	7530	991
26	Tripura	334	318	214	13
27	Uttarakhand	1458	1379	780	-
28	Uttar Pradesh	14710	14292	5520	0
29	West Bengal	13709	13356	668	202
30	Andaman and Nicobar Islands	89	82	75	7
31	Chandigarh	513	513	69	444
32	DDDNH	267	267	237	15
33	Delhi	10990	10990	5194	5533
34	Lakshadweep	35	17	17	Nil
35	Puducherry	505	482	36	446
	TOTAL	**160039**	**152750**	**79956**	**29427**

(Source : CPCB,Annual Report 2020-2021)

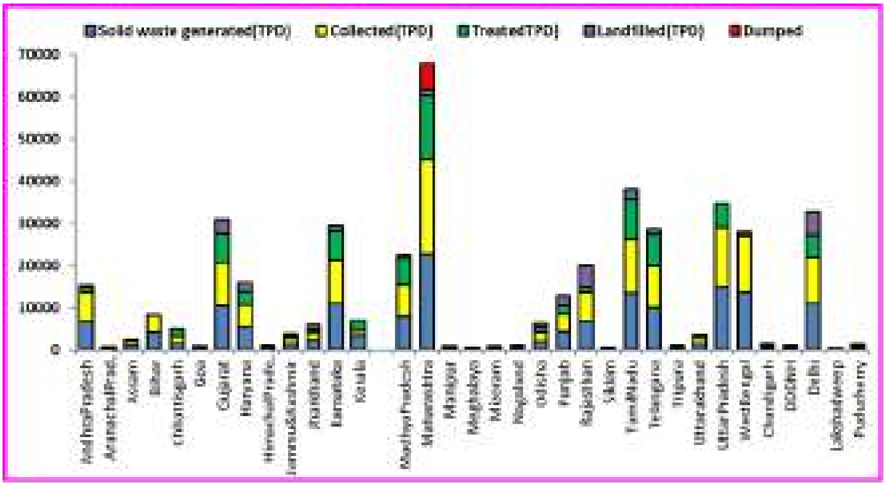


Fig. 1
Overall Solid Waste Management Status In India

(Source ; CED 2022- Adapted from CPCB 2021)

2.5 CIPET Study in 2010-2011

The survey conducted by the Central Institute of Plastics Engineering and Technology (CIPET) at the instance of CPCB has reported generation of 50,592 TPD of MSW in 2010–2011 in the same 59 cities. During the year 2011, about 1,27,486 TPD MSW was generated from across the country, out of which only 89,334 TPD (i.e. 70%) was collected and 15,881 TPD (i.e. 12.45%) processed or treated. According to CPCB, 2013, during the last decade, solid waste generation has increased 2.44 times

2.6 CPCB Study in 2014-2015

As per CPCB, 1,43,449 TPD of MSW was generated for 34 states and union territories during 2013–2014. The average rate of waste generation in India, based on this data, is 0.11 kg/capita/day. Other studies and observations indicate that waste generation rate is between 200 and 300 gm/capita/day in small towns and cities with a population below 2, 00,000. It is usually 300–350 gm/capita/day in cities with a population between 2,00,000 and 5,00,000; 350–400 gm/capita/day in cities with a population between 5,00,000 and 10,00,000; and 400–600 gm/capita/day in cities with a population above 10,00,000.

Recently, the Government of India and state governments realized the magnitude and challenges of scientific solid waste management in the urban local bodies and rural panchayats and formulated a number of Rules, Programs and Campaigns to establish Integrated Solid Waste Management in our Local Bodies and also to ensure its enforcement through strict rules and acts,legislative and administrative measures.

A detailed review of the various Rules and Legislations enacted in India in the area of waste management and the strategy to be adopted for implementing scientific and integrated SWM and a Framework for implementation is attempted in this Review paper.

3. Constitutional Provisions

A public interest litigation was filed in the Supreme Court in 1996 (Special Civil Application No. 888 of 1996) against the Government of India, state governments, and municipal authorities for their failure to perform their duty of managing MSW adequately. The Supreme Court then appointed an expert committee to look into all aspects of SWM and to make recommendations and the committee submitted the report to the Supreme Court in March 1999.

On the basis of the report, in September2000, the Ministry of Environment and Forests, Government of India issued the Municipal Solid Waste (Management and Handling) Rules 2000 under the Environment Protection Act, 1986.

Article 48-A and 51A (g) of the Constitution confer constitutional status to environmental protection. Article 42-A on the Environment provides that the State shall endeavor to protect and improve the environment and to safeguard the forests and wild life of the country.

Article 51-A (g) specially deals with fundamental duty with respect to environment that: “It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures”.

Recent Rules on waste management (MoEF&CC,2016)

1. Solid Waste Management Rules, 2016 - Ministry of Environment, Forest and Climate Change, 8th April,2016
2. The Plastic Waste Rules, 2016- Ministry of Environment, Forest and Climate Change, 18th March,2016
3. The Bio-Medical Waste Management Rules, 2016 - Ministry of Environment, Forest and Climate Change, 28th March,2016
4. The E-Waste (Management) Rules, 2016, Ministry of Environment, Forest and Climate Change, 23rd March2016
5. The Hazardous and other Waste (Management and Transboundary Movement) Rules 2016- Ministry of Environment, Forest and Climate Change, 4th April,2016
6. Construction and Demolition Waste Management Rules, 2016, Ministry of Environment, Forest and Climate Change, 29th March, 2016

3.1 Solid Waste Management Rules, 2016

Solid Waste Management (SWM) Rules, 2016 was ppublished by the Ministry of Environment, Forest and Climate Change in supersession of the Municipal Solid Waste (Management and Handling) Rules, 2000. These rules are applicable to every urban local body and stipulate that all municipal authorities to scientifically manage the solid waste generated in their respective jurisdictions.

A major change that is visible in the new rule from the MSW Rule 2000 is the focus on the processing of biodegradable portion of waste at source. The rule says that the biodegradable waste shall be processed, treated and disposed of through composting or bio-methanation within the premises as far as possible.

The Rule prescribes the duties of waste generators and various authorities in the state:

Every waste generator shall segregate and store the waste generated by him in three separate streams namely bio-degradable, non- biodegradable and domestic hazardous wastes in suitable bins and handover segregated wastes to authorized waste pickers or waste collectors. In the case of sanitary waste like diapers, sanitary pads etc., wrap the same in the pouches provided by the manufacturers or brand owners of these products or in a suitable wrapping material and hand over the same to the collection crew. Horticulture waste and garden waste need be stored separately in the premises and shall dispose of through local body and same is the case for Construction and Demolition Waste also.

The rule also prescribes the duties of the Secretary–in-charge, Urban Development in the States to prepare a state policy and solid waste management strategy for the state in a period not later than one year from the date of notification of the rules (8^{th}April,2016). While preparing State policy and strategy on solid waste management, lay emphasis on waste reduction, reuse, recycling, and recovery. Ensure identification and allocation of suitable land to the local bodies within one year for setting up of processing and disposal facilities for solid wastes and incorporate them in the master plans (land use plan) of the State. Facilitate establishment of common regional sanitary landfill for a group of cities and towns on a cost sharing basis and ensure professional management of such sanitary landfills. Arrange for capacity building of local bodies in managing solid waste, segregation and transportation or processing of such waste at source.

Clause 15 (a) of SWM Rules 2016 stipulates that the local authorities shall prepare a solid waste management plan as per State Policy and Strategy on Solid Waste Management within six months from the notification of State Policy and Strategy and submit a copy to respective Departments of State Government or Union Territory , Administration or Agency authorized by the State Government or Union Territory Administration.

The following rules related to various sectors / activities of SWM is also framed by the Ministry of Environment, Forests and Climate Change, Govt of India as a follow up of the planning for Solid Waste Management.

3.2 Plastic Waste Management Rules, 2016

These rules shall apply to every waste generator, local body, Grama Panchayat, manufacturer, importer, and producer. Carry bag made of virgin or recycled plastic shall not be less than fifty microns in thickness. The generator will have to pay user fee as prescribed by ULB and in case of violation there is spot fine. Producer/ Brand Owner needs to work out modalities for waste collection system for collecting back the plastic waste within a period of six months in consultation with local authority / State Urban Development Department and implement within two years thereafter. This plan shall be submitted to the SPCB while applying for Consent to Establish or Operate or Renewal. The local body is responsible for plastic waste management system and for performing the associated functions. They can seek financial assistance from producers to set up the Waste Management System. It should promote use of plastic waste for road construction as per Indian Road Congress guidelines or energy recovery or waste to oil etc. The local body should introduce collection of plastic waste management fee through pre-registration of the producers, importers of plastic carry bags / multilayered packaging and vendors selling the same. Plastic waste management fee shall be of minimum Rs.48,000/- @ Rs.4000/- per month. The local body may prescribe higher plastic waste management fee, depending upon the production or sale capacity.

The shopkeepers and street vendors willing to provide plastic carry bags for dispensing any commodity shall register with local body on payment of plastic waste management fee as mentioned above. Only the registered shopkeepers or street vendors shall be eligible to provide plastic carry bags for dispensing the commodities. The registered shop keepers shall display at prominent place that plastic carry bags are given on payment. They should not to sell or provide commodities to consumer in carry bags or plastic sheet or multilayered packaging, which are not manufactured and labelled or marked, as prescribed under these rules. Defaulters are liable to pay such fines as specified under the byelaws of the local bodies.

3.3 Bio-Medical Waste Management Rules, 2016

Segregation of biomedical waste at the source of generation is the first and essential step in biomedical waste management and it continues to be the key message and central theme of the Bio Medical Waste Management Rules, 2016. The 10 categories of biomedical waste are now simplified and categorized in 4 different color categories only. All types of wastes have been compiled in four categories for ease of segregation at a healthcare facility. Technically however, the categories of biomedical waste addressed through the Rule are now increased as some categories are further split into sub categories (e.g. sharps including metals & glassware are now considered as separate category and color code). Additional establishments are added e.g. AYUSH Hospitals,

The new Rule specifically enlists 20 points for the duty of the occupier and 17 points for the duty of the Common Biomedical Waste Treatment Facility (CBWTF) operator. Adding further on the clarity, the list of prescribed authorities and their corresponding duties are also clearly mentioned in the new Rule. Considering the environmental hazard due to the emission of toxic gases like dioxin and furan due to inadvertent burning of chlorinated plastics, the new Rule has made the provision to phase out use of chlorinated plastic bags, gloves and blood bags within 2 years. As per the new Rule, the CBWTF operator has to collect the biomedical waste even on holidays and in no case the time limit should cross the prescribed limit. The untreated biomedical waste shall not be stored beyond a period of 48hours.

3.4 Construction and Demolition Waste Management Rules, 2016

The Rules shall apply to every waste, resulting from construction, re-modeling, repair and demolition of any civil structure of individual or organization or authority that generates construction and demolition waste such as building materials, debris, rubble. As per Construction and Demolition (C&D) Waste Management Rules, there should not be any littering or deposition of construction and demolition waste so as to prevent obstruction to the traffic or the public or drains. Duties of Local Authority include:

Procurement of materials made from construction and demolition waste shall be made mandatory to a certain percentage (say 10-20%) in municipal and Government contracts subject to strict quality control. It shall make provision for giving incentives for use of material made out of construction and demolition waste in the construction activity including in non-structural concrete, paving blocks, lower layers of road pavements, colony and rural roads. The numerical targets for waste processing facilities utilizing C&D waste in cities are based on population. The large generators (who generate more than 20 tons or more in one day or 300 tons per project in a month) shall submit waste management plan and get appropriate approvals from the local authority before starting construction or demolition or remodeling work. They shall have environment management plan to address the likely environmental issues from construction, demolition, storage, transportation process and disposal/reuse of C&D Waste. Large generators shall segregate the waste into four streams such as concrete, soil, steel, wood and plastic, bricks and mortar

3.5 E-Waste (Management) Rules, 2016

The applicability of the previous Rule was only to producer, consumer or bulk consumer, collection centre, dismantler and recycler and is now expanded to manufacturer, dealer, refurbisher and Producer Responsibility Organization (PRO). The applicability of the Rule has been extended to components, consumables, spares and parts of Electrical and Electronic Equipment (EEE). Compact Fluorescent Lamps (CFL) and other mercury containing lamps are brought under the purview of these rules. Collection is now exclusively Producer's responsibility, which can set up collection centres or point or even can arrange buy back mechanism for such collection. No separate authorization for such collection will be required, which will be indicated in the Extended Producer Responsibility (EPR) Plan of Producers. Single EPR Authorization for Producers is now being made Central Pollution Control Board's(CPCB) responsibility to ensure pan India implementation. Procedure for seeking the authorization and for effective implementation has now been elaborated with various kinds of provisions. Option has been given for setting up of PRO, e-waste exchange, e-retailer, Deposit Refund Scheme as additional channel for implementation of EPR by Producers to ensure efficient channelization of e-waste. Collection and channelization of e-waste in Extended Producer Responsibility-Authorization shall be in line with the targets prescribed in Schedule III of the Rules.

Deposit Refund Scheme has been introduced as an additional economic instrument wherein the producer charges an additional amount as a deposit at the time of sale of the electrical and electronic equipment and returns it to the consumer along with interest when the end-of-life electrical and electronic equipment is returned.

3.6 Hazardous and Other Wastes (Management and Transboundary Movement) Rules,2016

In exercise of the powers conferred by sections 6, 8 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), and in supersession of the Hazardous Wastes (Management, Handling and Transboundary Movement) Rules, 2008, Ministry of Environment, Forest and Climate Change, Government of India, issued the Hazardous and Other Wastes (Management and Transboundary Movement) Rules,2016.The rules apply to the management of hazardous and other wastes as specified in the Schedules to the rules.

3.7 CPHEEO Manual on Municipal Solid Waste Management, 2016

The Manual on Municipal Solid Waste Management prepared by CPHEEO as part of SBM(Urban) is published by the Ministry of Housing & Urban Affairs (formerly MoUD) Government of India. This is a thorough revision of the earlier version of MSW Manual 2006. The Manual has three parts, Part I is an overview of SWM. Part II is actually the Manual and Part III contains a Compendium of national and international good practices and the relevant rules related to SWM.

The Manual on Municipal Solid Waste Management provides guidance to urban local bodies on the planning, design, implementation and monitoring of municipal solid waste management systems. The Manual clearly defines the planning process to be adopted by urban local bodies for preparing, revising and implementing Municipal Solid Waste Management Plans (MSWM Plans). The Planning process suggests the adoption of the integrated solid waste management hierarchy for deciding on processing or technology solutions for municipal solid waste. Guidance on the ULBs' responsibilities for managing specific special waste streams namely, plastic waste, bio-medical waste, slaughter house waste, E-waste, waste tyres and lead battery waste are included in this Manual.

3.8 SWM Bye-Laws

A few Urban Local Bodies in Kerala have formulated SWM Bye-Laws based on the SWM Rules,2016 to customize and strengthen the Rules to implement the Rules and to take stringent measures in case of violation. The Centre for Environment and Development has developed Bye-Laws for Thiruvananthapuram and Kochi City Corporations in Kerala and also a Model Bye-Law for Ministry of Housing & Urban Affairs, Government of India as part of the Centre of Excellence Program of MoHUA at CED. The Bye-Laws are very useful to fill the gap and deficiency in implementing the SWM Rule and to make it more locally-specific and customized

3.9 New Initiatives in Waste Management-Swachh Bharath Mission (Rural and Urban)

Solid and Liquid Waste Management is one of the key components of SBM (Rural). The total assistance for SLWM projects is Rs. 20 lakh for GPs having more than 500 households. Funding of SLWM project under SBM (Rural) is provided by central and state government in the ratio 75:25.

Urban Local Governments are required to prepare DPR for Solid Waste Management in consultation with State Government for the respective areas. 100% cost reimbursement for preparing the DPR shall be done by Government of India as per unit cost and norms set up by Government of India

4. Approach and Strategy for Solid Waste Management

4.1 Waste Stream Assessment

Waste Stream Assessment (WSA) is essential to plan and formulate a scientific and integrated solid waste management plan for any city. It is meant to determine the basic aspect of quantity (the amount of waste generated in the community, both in terms of weight and volume), composition (ie, the different components of waste stream) and source of wastes. The assessment will help us in the following way:

(i) It provides the basic data for planning, design and operation of the management system.

(ii) The analysis of the data helps detect changes in composition, characteristics and quantities of wastes, helps in deciding appropriate technologies and equipment

(iii) It quantifies the amount and type of materials suitable for processing, recovery and recycling.

(iv) Field investigations will have to be carried out in the absence of a reliable basic data through carrying out surveys using structured questionnaires and to generate data on the quantity, quality and characteristics of wastes generated in a location.

The management and disposal of solid waste could be premised on three approaches, viz., source level management, community level (decentralized) management and centralized management.

4.2 Source Level Management

The organic fraction of solid waste could be managed at source itself where adequate space is available, by composting or bio-methanation technology. Both the options return economic benefit to the person by way of compost, and manure slurry and bio gas. Government/ULB level support and strong IEC could motivate people to resort to source level management of waste. Reduce and reuse strategy of waste management could be applied to non-biodegradable fraction by individuals. A little motivation and some incentives will create good results.

4.3 Community Level Management

A cluster of houses or a housing colony/apartments, residents' association, local market, group of business establishments, etc., could join together and set up community facility like biogas plant, vermin-compost/compost unit etc. The technology suitable for source level management, in general, could be adopted for community level management also. For this purpose, they should identify suitable land in that locality. To manage the inorganic components, they can establish tie up arrangement with waste dealers/ recycling units. A Material Recovery Facility(MRF) can be established for storing the non-degradable waste collected from the members of the community.

4.4 Centralized Management

Despite existence of source level and community level management, there will still be solid waste left unattended like market waste, street sweepings, waste that are beyond the scope of source level and community level management and waste from bulk generators who presently do not possess facility to manage it. The solution for these items is establishment of a centralized facility. Since 50-70 % of the organic waste is likely to undergo source level and community level management, the volume to be handled by the central facility will be substantially less. There can be multiple number of such central facilities in different locations, so that the volume can further be reduced at one location. This helps to reduce the transportation cost also. The central facility can be a windrow compost plant or a combination of windrow compost unit, vermi compost unit and bio gas plant plus any other appropriate technology.

5. Integrated Waste Management

Segregation of Wastes at Source is the utmost important activity for any waste management program. The generators will be appraised of the importance of source segregation and also to collect it separately in differently coloured containers as per the instruction from the Local Body. There should be a proper plan as to choosing the right management approach from among the above three options, ensuring public cooperation and support in following the 4R strategy (Reduce, Reuse, Replace, Recycle)

For major cities, instead of bringing all the wastes into a single plant having huge capacity for processing, there can be a number of small and medium sized decentralized processing plants located at different regions. The biodegradable wastes collected from the peri urban regions can be processed in the mini-compost plants or biogas plants and only the final rejects need be brought to the common sanitary landfill site at the central facility or to a regional landfill. The central processing facility can handle additional waste quantities in exigency. Such a combination of centralized and decentralized options will also help to reduce the issues related to collection, storage and transportation of wastes to a large extent.

Quantifying waste generation according to season is an important precondition for infrastructure planning. Knowledge of physical and chemical composition helps authorities to determine the scope of retrieval of recyclable material and construction debris and to define appropriate technology for treating waste.The strategy should be in conformity with the Solid Waste Management Rules and other related legislations.

5.1 Waste Segregation and Storage at Source

The strategy to be adopted for efficient waste management and as per the SWM Rules is to separate the biodegradable wastes, (organic waste such as leftover food, vegetables and fruit peels, soiled paper, textile etc) and non-biodegradable wastes(recyclable materials such as plastic, paper, glass, cans, metals, etc) at the source itself by the generator and store the waste in different coloured bins. As per the revised rules domestic hazardous waste is to be stored in a separate container. In the case of sanitary waste the rules stipulate to wrap securely the used sanitary waste like diapers, sanitary pads etc., in the pouches provided by the manufacturers or brand owners of these products or in a suitable wrapping material as instructed by the local authorities and shall place the same in the bin meant for dry waste or non-biodegradable waste. Garden waste and construction waste has to be stored in the premises of the generator till removed as per the schedule.

5.2 Collection and Transportation

Door-to-door collection of segregated waste is mandatory as per SWM Rules, 2016. Collection of segregated waste (wet waste, dry recyclables, inert, domestic hazardous waste, sanitary, horticulture, construction and demolition wastes) from residential, commercial, and institutional areas is to be planned by the Local Body. Separate containers are required for collection of different fractions (wet, dry and domestic hazardous). For bulk waste generators such as hotels, restaurant, and large complexes, waste collection service can be given on demand basis.

This step refers to the transport of large quantities of waste to treatment sites and those to the landfill. The transport vehicle must be covered to ensure safe and hygienic transport. The transport system must be harmonized so that direct transfer from the collection vehicle to the truck to prevent manual and multiple handling of waste. In cities transportation at night is more efficient as trucks will not be slowed down by daily traffic.

Efficient routing of solid waste collection vehicles is essential for SW management system. A detailed network planning taking in to consideration of the collection area, geographic boundaries, amount of waste to be collected, condition of the road, traffic situation and time of collection, etc., has to be done using maps and GIS.

5.3 Waste Processing and Treatment of Waste

The policy for processing the biodegrade waste is based on the proximity principle that waste shall be processed and treated as close as possible to the place of their origin. The strategy for processing of biodegradable waste consists of source level treatment at households, apartment complexes, hotels, restaurants, auditoriums (bulk generators) as far as possible. The other option is decentralized treatment at community/ward level. Those households or bulk generators having no sufficient land to offer processing at their respective premises shall be brought under the decentralized/centralized systems. In the case of small hotels also this method is required. A centralized treatment facility with a landfill to be established at each local body or for a group of Local Bodies to cater to waste streams from streets, from markets, public places and in exigencies. Composting would be the preferred method of treatment for biodegradable waste.

Currently, there are several technologies for the processing and treatment of organic fraction of MSW, such as microbial composting and vermin composting, anaerobic digestion etc. Waste to energy process like gasification and other technologies like pyrolysis, which are still not in wide use in India.

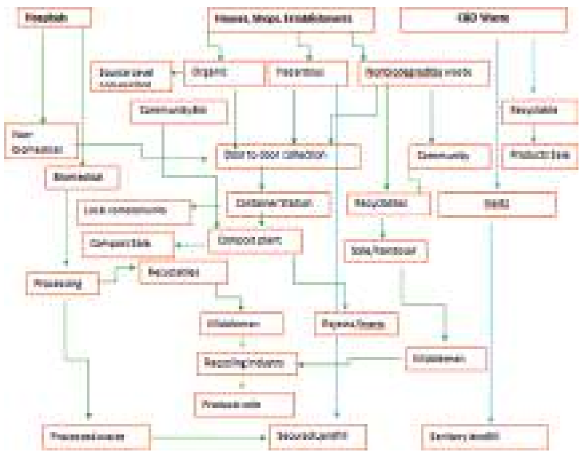


Fig 2
Flow chart of Typical SWM System

(Source KSUDP 2007 – Modified by CED – 2022)

Household waste can contain 60 or 70 percent organic matter. The SWM Rules,2016 mandate improved management and treatment of this fraction and the approach is treatment of biodegradable waste in centralized/ decentralized plants involving multiple technologies like compost, Vermicompost plants and biogas units.

Removal of slurry from biogas plants on a periodic basis has to be arranged by the Local Body and there should be a processing plant for drying and then for the sale of the dried product at the centralized facility.

5.4 Strategy for Non-biodegradable Wastes

In the case of non- biodegradable waste and hazardous waste the local body can arrange for collection on pre-informed dates from households and other establishments based on collection of user charges

The Local Body has to establish Material Recovery Facility(MRF) at suitable locations for storing non compostable waste / dry waste. Segregation at source, a prerequisite for effective waste management and shall be stored in separate containers at the source by the generators. The waste reaching the MRF need be further sorted into recyclable and non- recyclable. It shall be sorted into various fractions so that it can be transferred to the recycler as per demand. Materials Recovery Facility (MRF)means a facility where non-compostable solid waste can be temporarily stored to keep the sorted waste before the waste is delivered or taken up for its processing or disposal.

TREATMENT OF BIODEGRADABLE FRACTION

- Centralized Windrow Compost Plant of capacity not more than 50 tons.(forULBs
- Centralized Windrow Compost Plant of capacity not more than 10 tons.(for GPs)
- Decentralized vermi compost/ Biogas units/ Aerobins/ Waste to energy plants – gasification(ULBs)
- Follow the rules and standards specified by SPCBs/CPCB

Material Recovery Facility (MRF)

As per SWM Rules, 2016 local authorities should setup Material Recovery Facilities. This facility can be a place where non bio degradable waste could be sorted and kept for next level disposal. The disposal could be (i) the MRF will act as a local market from which anyone can take useful things (ii) the left over items will be sent for recycling. The MRF will be designed in such a way to have compartments to collect various types of wastes.

Establishing Recycling Units

Formal recycler with pollution control equipment and systems shall be set up through private entrepreneurs or by the state governments as a long term strategy and the state governments shall take active involvement in creating such facility. State Governments shall adopt the policy to become a recycling society.

Table 2
Important Recycling Materials – Advantages and Drawbacks

Material	Advantage	Drawbacks
Aluminum Aluminium	• Aluminum has a high market value. • It can be easily recycled by shredding and melting. • It can be recycled indefinitely because it does not deteriorate from reprocessing. • Aluminum recycling requires significantly less energy than producing aluminum from ore.	• Separate collection is important. • Recycling is suitable only if a processing plant is available.
Batteries	• Recycling recovers valuable metals. • Recycling protects the environment from heavy metals such as lead, cadmium and mercury.	• Large variation in type and size of batteries requires specific recycling processes. • Older batteries have high heavy metal content
Concrete and demolition waste	• Demolition waste can be crushed to gravel and reused in road construction and landscaping.	• Machinery required for crushing is maintenance intensive. • Recycled waste is valuable only if there is a lack of other construction material.
Glass	• Glass has a moderate market value • It can be sorted into colours and melted. • Use of recycled glass saves energy compared with processing raw material. • Glass can be recycled indefinitely because it does not deteriorate from reprocessing.	• Broken glass can contaminate and eliminate opportunities for recycling.
Other metal	• Scrap metal has a high market value (especially steel, copper, silver and platinum) • It can be recycled indefinitely because it does not deteriorate from reprocessing.	• High-value metals (such as copper and silver) are incorporated in electronic devices, but extraction can cause severe environmental impacts.
Paper	• Paper can be easily recycled; however, quality deteriorates with each cycle. • Paper or cardboard from recycled paper requires less energy to produce and protects forests.	• Appropriate technologies with circular processes are required to protect the environment.
Polyethylene terephthalate (PET)	• PET can be recycled if segregated from other waste. • Reprocessing into granulate is very easy. • PET has a high market value if processing plants are available.	• More 'downcyling' than recycling occurs because quality decreases with every processing cycle.

Other plastics	• Other plastics, such as polyethylene or polyvinyl chloride, can be recycled but has less value on the market than PET; the value depends on recycling and manufacturing options in the vicinity.	• Recycling requires specific machinery
Electronic waste	• Electronic waste (such as computers or mobile phones) contains high value metals. • Electronic items can be dismantled, reused or recycled.	• Metals are often covered with polyvinyl chloride or resins, which are often smelted or burned, causing toxic emissions.

Table 3
Common Types of Plastics that may be recycled

Sl. No	Chemical Name	Abbreviation	Typical uses
1	Polyethylene terephthalate	PETE	Soft drink bottles
2	High-density polyethylene	HDPE	Milk cartons
3	Polyvinyl Chloride	PVC	Food packaging, wire insulation and pipe
4	Low-density polyethylene	LDPE	Plastic film used for food wrapping, trash bags, grocery bags, and baby diapers
5	Polypropylene	PP	Automobile battery casings and bottle caps
6	Polystyrene	PS	Food packaging, foam cups and plates, and eating utensils
7	Mixed plastic		Fence posts, benches and pallets

Final Disposal by Constructing Sanitary Engineered Landfills

The SWM Rules mandate treatment of the organic fraction of solid wastes before final disposal of rejects and inerts in scientifically engineered landfills. Landfill is a vital component of any well designed SWM system. Environmentally safe landfill shall be part of long-term disposal strategy but the landfill should be restricted to waste that cannot be recycled, treated or recovered. This mechanism will cater to the remediation of already accumulated waste and confinement of subsequent rejects. The landfill can be operated directly by the Local Body or through competent agencies in the public or private sector, adopting the procedures and specifications defined in the 2016 SWM Rules as well as SPCB / CPCB norms.

With acute shortage of land, resources and other aspects, construction of landfills in each local body is not at all advisable and so a possible option is for going for regional landfills for a group of local bodies. State governments shall facilitate the construction of a few regional landfills for a group of local bodies.

6. Experience of Decentralised and Participatory Swm in Kerala, India

The State of Kerala has been engaged in an innovative experiment to implement Decentralised and Participatory Solid Waste Management in Urban Local Bodies and Grama Panchayats in the state since 2012.This was initiated to absorb the crisis emerged due to the social protest against the centralized system of waste management implemented in a few cities especially the Thiruvananthapuram City Corporation. Even before that, a system was evolved for segregated collection of wastes-degradable and non-degradable by segregating it by the households and other generators at the source itself and handing over to the SHG members(Kudumbasree workers), finally to transport it to the processing plants.

Once the processing plant at Vilappilsala closed down due to the social protest, there was no mechanism to manage the wastes generated in various sources especially the degradables and it was this crisis led the state and cities to think about source level management of the degradable wastes and also segregated collection and transfer of recyclable wastes to the recycling units through a coordinated collection and transportation. Necessary infrastructures and facilities have been established and a detailed Protocol for implementing it was also formulated.

One major issue was related to the huge quantity of plastic carry bags and other plastic objects generated. It is in this context that the Government initiated a massive **Campaign on 4-R concept-Reduce, Reuse, Recycle and Replace,** through which the government plans to reduce the generation of this kind of wastes, Reuse materials as much as possible, collect and Recycle all the recyclable materials and Replace the plastic materials with other materials which can be recycled or degradable like paper, cloth, etc.

Ban of plastic carry bags including selling by shops and other agencies was brought in which was strictly implemented throughout the state and encouraged the people to use cloth bags and paper bags in place of plastic carrybags. The entire community cooperated with these ideas and it was successful to a larger extent.

The Suchitwa Mission, which is the Nodal Agency for Sanitation in Kerala also brought out a ***GREEN PROTOCOL***, which framed the ***Do..s and Don'ts in Sanitation and Waste management and the Protocols to be followed to achieve the 4-R Principle.***

6.1 Implementation of 4-R Principle and Green Protocol

The first step taken by the Government was ban of all kinds of plastic carry bags below 50 micrones and this was implemented throughout the state -both urban and rural areas. It was made punishable offence if somebody sell the carrybags or give during purchase by both wholesale and retail merchants.This helped the government to made it successful to a certain extent the objective of **Reduce and Reuse options.** This was a major achievement since plastic wastes posed the major obstacle in waste management.

The Government had also brought out the Green Protocol, which stipulates the regulations and conditions to be observed when organizing various kinds of events, functions, meeting, marriages, even the conditions to be observed in office functioning, household activities, individual activities, etc. These protocols are being strictly followed. The basic intention of the protocol is to reduce/eliminate the use of plastic and other non-degradable waste materials which are causing problems of management and use materials which can be reused and not creating any major management issues. For example, the plastic and paper cups,plates,etc usually used during conferences,functions,etc is now replaced by steel and glass cups., and plates,which can be used repeatedly. A number of such changes have been suggested as part of the program which are being implemented in both urban and rural areas.

6.2 Recycle Options

The collection of Recyclable materials in frequent intervals have also been planned and implemented. This has been done through frequent collection from the source by the Kudumbasree workers(SHGs) or the people themselves putting it in common Material Recovery Facilities(MRF) established by the Local Bodies based on the requirement. The various types of recyclable materials are collected here separately after source segregation in separate assigned compartments of MRF and from there it is taken by the Clean Kerala Company, which is a government promoted company for managing the recyclable wastes, and from there to the different recycling units as per the agreement with them.

Through implementing the 4-R principle and Green Protocol, the Government and Local Bodies in Kerala could bring a perceptible change in the management of Non-degradable waste materials

6.3 Source Level Management of Degradable Wastes

The point of waste treatment at source has been advocated as a means to substantially decrease the burden of degradable waste disposal in Kerala and this has helped to process the wastes from 50-60% of the household wastes at source itself. Households, large hotels, function halls, institutions and offices having sufficient land shall adopt processing at source.

7. Institutional Architecture on SWM

Figure below represents a largely hierarchical institutional architecture of flows of ideas, funds and commands. In the center stands the municipality, the institution responsible for MSWM, whose practices however are determined by higher-level governments and global (expert) discourses, as well as influenced by interactions with local-level actors (e.g., resident associations, NGOs, private providers). (NC Narayanan,et al,2019)

Coupled with the institutional topography are the material flows of the waste chain, the waste practices and the labor applied to segregate, transport, recycle and dispose rubbish. The waste chain is conceptualized through the lens of urban metabolism –an understanding of the city as an organism that transforms resources (e.g., minerals, water, biomass, energy) into goods (e.g., buildings, piped water, food) but also into emissions and pollution .This concept not only focuses on the material and energy flow within and through the city, but also sheds light on the reproduction of social inequality through theses flows and altered social relationships . UPE studies link the concept of urban metabolism with the circulation of power [Hence, social and power relations are located at each point of the waste chain implying that the urban metabolism leads to an unequal accumulation of goods and services, as well as wastes and pollutions, in different parts of the city, often reinforcing spatial inequalities(N C Narayanan,et al,2019).

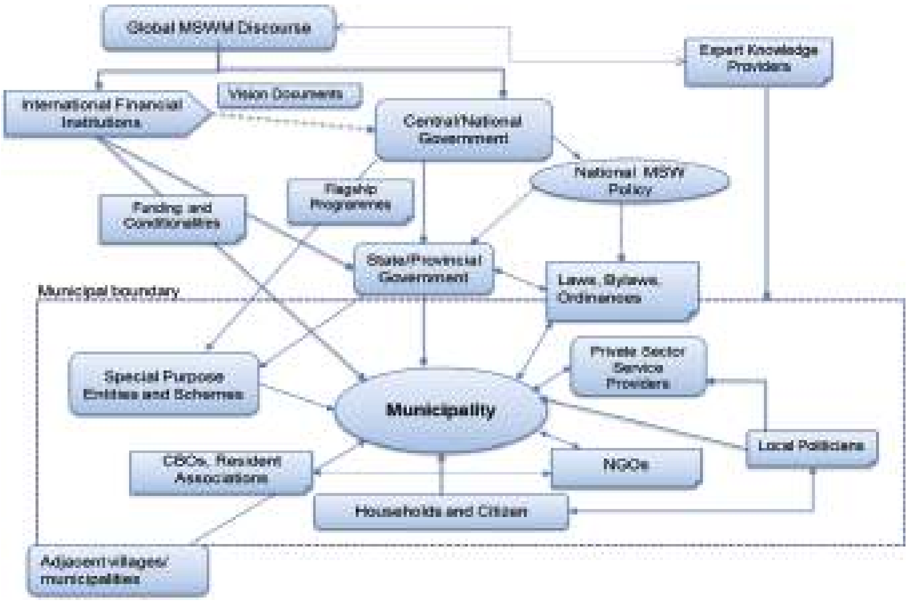


Fig.3.0

Schematic representation of the institutional MSWM architecture in South Asia

(Prepared by N C Narayanan, Professor, Indian Institute of Technology, Mumbai)

The figure below represents a case where segregation at source and decentralized waste recovery and recycling are taking place. More generally, waste chains begin at the site of the waste generator (household, markets, shops, schools, offices, etc.) where it is stored and perhaps segregated. Segregated or non-segregated waste is then either collected from door-to-door, or brought to community bins or dumped in open (public) spaces in the neighborhood or elsewhere. Informal waste workers often pick up valuable recyclables from the source or from bins and dumpsites; glass, paper, cardboard, plastics, etc. enter separate streams. Wastes are transported between primary collection points, secondary transition points and the disposal/treatment facility (open dumps, landfills, composting and recycling plants, incinerators, etc.).

8. Green Protocol-An Initiative of Government of Kerala

Having identified the long term havocs created by the excessive use of plastic, GREEN PROTOCOL concept evolved by Suchitwa Mission in Kerala, is gaining momentum. The Green Protocol concept has been implemented in every sphere of life and activities in Kerala,which focus on strictly reducing the use of plastic and other non-degradable materials and using recyclable or degradable materials in place.It was made customary and strictly enforced in conducting every event like meetings and conferences, marriages and other functions, festivals,etc. The overall objective is to considerably reduce the use of non-degradables from the society. It basically discourage the use of non-degradable materials like plastic and replace plastic as far as possible with natural or reusable product or utensils.

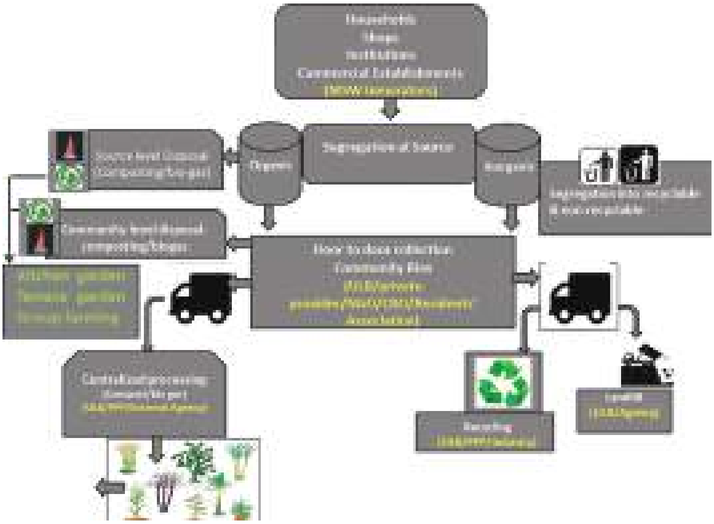


Fig 4.0
Schematic representation of partly decentralized waste chains in Kerala

Table 4
Framework for Green Protocol

1	Green protocol during festivals	• Avoid use of plastic and disposable items • Use utensils that can be washed and reused
2	Green Protocol for function	• Avoid paper and plastic cups,plastic bottles and plates in publicfunctions • Use utensils that can be washed and reused • Use energy efficientlighting and appliances • Grey water treatment in the premises and practice recycling Of treated effluent
3	Green protocol during sports and other events	• Avoid paper and plastic cups, PET bottles and plates • Use utensils that can be washed and reused
4	Green protocol for individuals	• Reduce waste generation. Avoid use and throw items. Develop habit of reuse • Use energy efficient lighting and appliances • Home composting and organic Cultivation • Plastic should be cleaned and segregated to be handed over to scrap dealers • Use of public transport
5	Green protocol in institution	• Reduce waste generation. • Avoid use and throw away items. • Use energy efficient lighting and appliances • Plastic free campus

9. Conclusions

The Government of Kerala has adopted a policy for solid waste management with two strategies: in consideration of the constitutional and legal framework governing waste management in India, and the contextual realities of the state as well. The two-pronged strategies are

1. Decentralised waste management comprising of source level and community level
2. Centralised waste management where ever nnecessary

The decentralized system has been credited for not only being sustainable and financially viable but also for helping to improve the quality of life and working conditions of the waste collectors.

It is to be pointed out, that the DSWM system for biodegradable waste with a successful institutional framework has been evolved through concerted efforts from the LSGIs and state government to change the behaviour of the community to waste management, through IEC campaigns to segregate and treat the waste at source. Mass protest against centralised dumpsites also contributed to the development of the model. Considering the nature of the waste generated in the state which is largely biodegradable, treatment at source also makes administrative and financial sense.

Now this shift towards decentralised and source level systems has the focus on to circular economy and has significant change in the approach of the administration and people as looking at 'waste' as a 'resource'. Slowly, but steadily, waste has come to be viewed as part of a larger ecosystem, the management of which is considered to play a critical role in the idea of sustainability and livelihood generation.

In a nutshell, waste management in Kerala now has multiple stakeholders working in close coordination with each other, exchanging knowledge and resources to bring decentralized waste management and the circular economy solutions. The multiple stake holders involving the local governments, who are the most significant stakeholders, the Kudumbashree Mission that empowers the Haritha Karma Sena, for sustainable livelihoods in waste management, the Clean Kerala Company which has been tasked with removing non-biodegradable waste and with converting it into resource wherever possible and technical support agencies such as Haritha Keralam Mission and Suchitwa Mission who are responsible for providing support, hand holding and IEC for behavioural changes. In addition to the monitoring, financial support and coordination are provided by the Directorate of Panchayats and the Directorate of Urban Affairs which further ensures the sustainability.

References

Aarne vesilind P and William Worrel, 2012. Solid Waste Engineering 2nd Edition.

(https://bawar.net/data0/books/5a61ab6f194b2/pdf/[William_A._Worrell,_P._Aarne_Vesilind]_Solid_Wast.pdf

Cointreau, Sandra, 2001. Declaration of Principles for Sustainable and Integrated Solid Waste Management SISWM. http//siteresources.worldbank.org /INTUSWM/ Resources/siswm.pdf.

CPCB (Central Pollution Control Board), 2000. Status of Municipal Solid Waste Generation,

Collection, Treatment and Disposal in class I cities.

CPCB (Central Pollution Control Board), 2000. Status of Municipal Solid Waste Generation,, Annual Report 2020-2021 https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvMTQwM18xNjU1MzU0NzkxX21lZGlhcGhvdG8xNjQ3MS5wZGY=

CUPS/48/1999-2000- CPCB, Ministry of Environment and Forest, New Delhi

CPHEEO, 2000. Manual on Municipal Solid Waste Management 1st Ed. Central Public Health and Environmental Engineering Organisation, Ministry of Urban Development, Government of India, New Delhi.

Da Zhu, Asnani P.U, Chris Zurbrugg, Sebastian Anapolsky and Shyamala Mani, 2008. Improving Municipal Solid Waste Management in India, World Bank, Washington, D.C.

Integrated Solid Waste Management for Local Governments: A Practical Guide. Published in June 2017 by the Asian Development Bank,

Kumar S, S.R. Smith, G. Fowler, C. Velis, S.J. Kumar, S. Arya, Kumar Rena, R., & Cheeseman, C. (2017) Challenges and opportunities associated with waste management in India. R. Soc. Open Sci., 4 (3) (2017), 10.1098/rsos.160764

Kerala Sustainable Urban Development Project,Trissur Municipal Corporation,2007

LSGD 2021 State of Decentralised Solid Waste Management in Kerala , LSGD, Government of Kerala, Report 2021

Manual on Municipal Solid Waste Management – 2016

Ministry of Housing and Urban Affairs, GoI, http://cpheeo.gov.in/cms/manual-on-municipal-solid-waste-management-2016.php

MoEF, 2000. Municipal Solid Waste (Management and Handling) Rules 2000. Ministry of Environment and Forests, NewDelhi.

Narayanan,et al,2019. Social processes in post-crisis municipal solid waste management innovations

NEERI, 1996. Municipal Solid Waste Management in Indian Urban Centres. Rep. National Environmental Engineering Research Institute. Nagpur.

NITI Aayog Waste Segregation at Source offer far-reaching benefits- optimal utilization of municipal machinery and workforce, efficient infrastructure operations, and enhanced environmental outcomes .

Promoting bbehaviour change for Strengthening Waste Segregation at Source, Policy Guidelines

National Institute for Transforming India, NITI Aayog New Delhi November 2021

Sini Mamminiyan 2022 Implementation of Green Protocol as policy initiative for environmental Sustainability: A Kerala Experience. 5th International Conference on Economic Growth and Sustainable Development: Emerging Trends, November 15-16, 2019, Mysuru, India

Suchitwa Mission, June 2020. Volume1 ,introduction and strategic enviromental assessment of waste management sector in Kerala,Kerala solid waste management project (KSWMP)

Tchobanoglous G. 2003. Solid Waste Management in Environmental Engineering (Ed. Salvato J.A., Nemerow N.L. and Agardy F.J). 5th Ed. John Wiley and Sons Inc. New Jersey

Waste reduction fact sheet. North Carolina Division of Pollution Prevention and Environmental Assistance, NC department of Environment, health and natural resources

https://p2infohouse.org/ref/01/00140.htm

UNDP: Developing Integrated Solid Waste Management Plan Training Manual. Volume 4. UNDP Division of Technology, Industry and Economics International Environmental Technology Centre, Osaka/Shiga, Japan

Smart City Concepts for Treatment of and Resource Recovery from Municipal Organic Wastes: Experiences from IGSTC 2+2 Projects

Dirk Weichgrebe[1], Moni M. Mondal[1], Rahul R. Nair[1], Sathish G.[2], Nishanthi R.[2] & S.V. Srinivasan[2]

[1]*Institute for Sanitary Engineering and Waste Management (ISAH), Gottfried Wilhelm Leibniz University Hannover*

[2]*Environmental Engineering Department, CSIR- Central Leather Research Institute, Chennai*

Abstract

Increasing urbanisation, industrialisation and social development in India is coupled with an increase in municipal solid waste (MSW) generation. Their collection, treatment, and disposal systems must be managed and organized in an integrated approach for a sustainable and economical result. In India, organic fractions contribute to about 50wt.-% of the MSW, which needs to be disposed in safe manner without polluting the environment. Wet and biodegradable fractions of organic MSW can be treated using anaerobic digestion process while dry and fibrous fractions through thermal treatment for the recovery of energy and value-added products. This concept is investigated with the case studies of two Indo-German collaborative research projects at pilot-scale level for recovery of energy and biochar from organic fractions of MSW funded by Indo German Science and Technology Center (IGSTC) 2+2 framework programme.

In the RESERVES project, urban organic waste from India's largest vegetable and flower market (Koyambedu Market Chennai), as well as waste from slaughterhouses (also Chennai) - which would otherwise end up in municipal waste - is fed into an innovative fermentation plant to enable material and energy recovery. In addition to biogas, hygienically safe digestate and fertiliser are produced. This could be achieved by introducing a bio-extrusion aggregate from Lehmann-UMT GmbH, Pöhl, Germany as pretreatment of the waste to better breakdown the fibres and ensure the necessary hygienic properties. In the PYRASOL project, urban organic waste, which is not directly accessible for biological treatment due to its high fibre content and digested municipal sewage sludge are pre-treated with the help of innovative solar drying and subsequently pyrolyzed in a single chamber pyrolysis boiler from Biomacon GmbH, Rehburg Germany to sustainably derive biochar, sequestering CO_2 and providing thermal energy, for land application.

After the successful completion of these projects, there is also the prospect to couple both project approaches in such a way that synergies between waste treatment, resource recovery, energy supply, and CO_2 sequestration are achieved in the sense of a SMART City approach.

Key Words: municipal solid waste, market wastes, anaerobic digestion, solar-updraft drying, single-chamber pyrolysis, smart city

1. Introduction

The growing world population is seen as one of the main causes of many of mankind's current problems. Not only hunger, crises and catastrophes are putting people under increasing pressure to act, but also the growing volume of waste (UN, 2019). The example of India clearly shows that especially in large cities the population boom has unpleasant consequences. An increasing number of solid waste and wastewater in fast-growing megacities are exerting increasing pressure on urban waste management systems, with organic residues posing a major challenge (Weichgrebe et al., 2017; Speier et al., 2018). Local treatment approaches with reduction of waste volumes are therefore an attractive option for urban areas. While sustainable treatment concepts for readily degradable organic waste and wastewater are already described in detail in the relevant literature, innovative concepts for important waste categories such as fibrous organic waste (FOW), dewatered municipal sewage sludge (MSS), anaerobic digestate (AD) and slaughter house waste (SHW) are hardly available and are the subject of current research (Speier et al., 2018; Mozhiarasi et al., 2019).

The implementation of a circular economy is also being pursued in India, but has to face the realities of the lack of infrastructure and technical possibilities (Weichgrebe et al., 2017; Speier et al., 2018). Based on many years of R&D work in the field of waste management in India, ISAH has initiated two research projects for the treatment and recycling of volume-relevant municipal waste streams and implemented them with the help of the 2+2 funding programme of the Indo German Science and Technology Centre (IGSTC). The prerequisite for IGSTC 2+2 Framework is that one research institution and one industrial partner from each of the partner countries, Germany and India, cooperate and support each other to move forward.

RESERVES is one of the IGSTC approved project that was designed to generate bioenergy (biogas) from the bulk generators of organic fractions of municipal solid waste especially from vegetable markets and slaughter houses. The co-digestion of vegetable and slaughterhouse wastes were evaluated in lab and pilot scale studies with bio-extrusion aggregate from Lehmann-UMT GmbH, Pöhl, Germany as pre-treatment. Under this project, pilot plant has been installed at CSIR-CLRI, Chennai which consists of bio-extruder system an innovative technology as pre-treatment to improve the treatment efficiency and biogas production. The digester is equipped with two numbers of agitators for uniform mixing which mix the reactor for 5 min every one hour. This ensures the uniform mixing and distribution of substrate inside the digester.

The occurrence of the vegetable market waste was studied in detail and its valorisation and nutrient recovery potential were identified. The combination of vegetable market waste with slaughterhouse waste was selected not only to treat waste that requires treatment but also to provide an adequate C/N ratio for the anaerobic digestion process. Moreover, the designed plant contains a bio-extrusion unit to increase the biodegradability of fibre containing market waste as well as to disinfect the slaughterhouse waste.

The pilot plant was operated with average capacity of 500 kg/day with mixed proportions of vegetable market and slaughterhouse wastes in 3:1 ratio. The pilot plant operation results in the specific biogas yield of 0.78 m^3/kg VS for bio-extruded waste, which is 44.4 % higher than for non-extruded waste (only shredded). The composition of the methane was constantly ranged between 45 to 60 vol.-%. As part of biogas purification studies, the scrubbing system composed of iron fillings and activated alumina has installed which ensures the H_2S concentration below 40 ppm. The residual digestate produced every day with a high water content of 95 wt.-% - 97 wt.-% is dewatered using a screw press and the collected liquid and solid digestate are used as manure for plant growth.

In the PYRASOL project, simple and robust processing technologies for urban organic waste is combined in a synergetic manner and further developed to improve sanitation and generate regenerative energy. In this study, innovative organic waste drying system using the solar natural chimney effect followed by an efficient single-chamber pyrolysis pyrolysis boiler from Biomacon GmbH, Rehburg Germany is designed to convert organic fraction of municipal solid waste (OFMSW) into value added product and reduce the carbon footprint from Smart Cities. As in RESERVES project, main waste fractions in PYRASOL are fibrous organic waste from vegetable market but here combined with municipal sewage sludge. The project aims to offer an innovative solution to transform urban organic solid waste (fibrous waste and sewage sludge) into biochar and energy in urban areas. Pyrolysis of OFMSW will generate biochar and therefore sequestrate 30% of the input carbon. This process will thereby reduce the greenhouse gas considerably. Thus, the optimum process and operation parameters of the solar updraft dryer are being studied and pyrolysis process with a unique condensing boiler technology CBT has been developed and investigated. This is supplemented through a comprehensive evaluation of the value-added chain from urban organic waste into biochar and energy and the application of biochar for land reclamation. This project contributes to Zero Waste Approaches of Smart Cities in India as the generated biochar and heat energy are consequently utilized. The energy can be used to support the drying process at night but also for chilling of vegetable market stores to avoid fruit spoilage.

After both approaches have been intensively studied, there is also the prospect of their combination or the establishment of a treatment center for OFMSW. Dependent on the characteristics of OFMSW (easy biodegradable, hygienic relevant, containing fibers and lignin, containing nutrients (e.g. N, P, K) etc.) the waste fraction is sent to the appropriate treatment method. As products are generated i.e., biogas as energy carrier, liquid digestated to recover nutrients, solid digestate to recover nutrients by composting, biochar to improve the compost or for direct land application as well as heat for internal reuse or for external energy supply.

2. Objectives

The main focus of the RESRVES project is to demonstrate sustainable and locally adapted urban organic waste management systems with an innovative combination of advanced pre-treatment and biochemical conversion processes in India. The specific objectives of the study are to achieve the following milestones for the case of Chennai city:

- Demonstration of a pilot plant for biogas production from vegetable market waste and slaughterhouse waste.
- Sustainability and cost-effectiveness of renewable energy generation in India,
- Demonstration of the Innovative bio-extrusion for hygienisation of slaughterhouse waste and improved digestion of fibrous substrates,
- Digestate processing for nutrient recovery, and
- Integration of a progressive anaerobic process in an economic, social, and environ-mental context in Chennai, India.

The main focus of the PYRASOL project is to demonstrate a SMART City approach along the treatment and valorisation of fibric organic waste as well as sewage sludge with an innovative combination of nature induced drying and single chamber pyrolysis in India. The specific objectives of the study are to achieve the following milestones for the case of Chennai city:

- Plant prototype and demonstration of a solar drying (with vortex convection) and pyrolysis with condensing boiler technology for FOW and sewage sludge (SS) treatment.
- Biochar generation from FOW and SS in Chennai for CO_2 sequestration and soil improvement,
- Sustainability and cost-effectiveness of renewable energy generation in India, and
- Integration of the PYRASOL approach in Chennai to provide cold storage for the Koyambedu Market to avoid food spoilage.

3. Materials & Methods

3.1. Study area

The concepts are being investigated and demonstrated as pilot projects in Chennai city of India. Chennai is one of the most populous cities in India with over 9.1 million inhabitants and was announced as one of India's first 20 Smart Cities by the Government of India (IOP, 2019). Chennai is the fourth largest metropolitan City in India where approximately 5400 tons of MSW is being generated and disposed everyday (Greater Chennai Corporation portal, 2019). Currently, the MSW collected along with organic fractions of MSW is being disposed in landfills, which leads to significant environmental problems and CO_2 emissions on the city's landfills (Mozhiarasi et al., 2019; Mozhiarasi et al., 2020a).

For this research, waste feedstocks investigation were performed in the major urban waste generation centres in Chennai, that includes:

- Vegetable market wastes were collected from the Koyembedu Wholesale Market Complex (KWMC) which is one of Asia's largest wholesale vegetable, fruit and flower market located in Chennai city, which generates around 150-200 Mg/d of wastes in the form of vegetables, fruits and flowers (Mozhiarasi et al., 2020a; Mozhiarasi et al., 2020b; Murugesan and Amarnath, 2015). It has more than 1,000 wholesale shops and 2,000 retail shops. The KWMC contributes approx. 4 wt.-% to the generated MSW in Chennai.

- Post-fermentation municipal sewage sludge (MSS) was collected from Perungudi sewage treatment plant (STP) operated by Chennai municipal corporation. Based on initial investigations, it is estimated that about 250 Mg/d of dewatered MSS are generated from urban STP. STPs in Chennai have a capacity of 769,000 m^3 sewage per day, while two additional units with a capacity of 60,000 m^3/d are under construction (Greater Chennai Corporation portal, 2019).
- Anaerobic digestate (AD) from two anaerobic digestion plants under Chennai Municipality that process food and market wastes.
- Cattle slaughter house wastes (SHW) and goat rumen contents (GRC) were taken from three (3) SHWs in Chennai. The daily waste generation rate is around 10 Mg/d of SHW or GRC namely split between Perambur (8–9 Mg/d of SHW), Villivakkam (0.5 Mg/d of GRC) and Saidapet (0.5 Mg/d of GRC) (Mozhiarasi et al., 2019).

An investigation by the authors confirmed that daily organic waste at KWMC contain 40 % of fibrous banana peduncles. Fibrous wastes are not only generated in market areas, but are also ubiquitous in MSW (e.g. flower garlands, banana leaves, coconut shells). The organic wastes from KWMC and the MSW system are disposed together with MSS on the city's two dumping sites, Kodungaiyur and Perungudi, which are currently reaching their capacity limits and pose serious health and environmental harm (Mozhiarasi et al., 2019; Mozhiarasi et al., 2020a; Mozhiarasi et al., 2020b).

3.2. Substrate characteristics
(urban organic wastes for RESERVES and PYRASOL)

The elemental analysis, proximate analysis, fibre analysis, nutrient analysis, and heavy metal analysis of MSS, FOW (banana peduncles - BP), anaerobic digestate (AD), vegetable market waste (VMW) and slaughterhouse waste (SHW) were conducted for physico-chemical characterisation of feedstock.

The elemental analysis was done as per German and European standards. The nutrient contents (P, Ca, K, Mg, Na, S, silica, iron) and heavy metals (Pb, Cd, Cr, Ni, Cu, and Zn) were determined following DIN EN ISO 11885 (E 22): 2009-09. Mercury and arsenic contents were obtained from tests according to DIN EN 1483: 2007-07 and DIN EN ISO 17294-2 (E 29): 2005-02, respectively. Chlorine was measured according to DIN 38405-D 1: 1985–12. The CHNO (elemental) analysis used DIN 51732: 2014–07. For crude fiber, lignin, cellulose, hemicellulose and proximate analysis were determined following the LUFA standard (VDLUFA III 6.5). Mineral and volatile matter were determined using DIN EN 12880-S 2a: 2001–02 and DIN 51720:2001-03, respectively. A detailed analysis and interpretation of feedstock characteristics by the authors are available in (Nair et al., 2020 and Mozhiarasi et al., 2019).

3.3. Process principles (for RESERVES and PYRASOL)

As mentioned in previous section, RESERVES project investigated and evaluated the biogas production through co-digestion of VMW and SHW after pre-treatment using bio-extruder. Besides, PYRASOL project dealt with specific urban organic wastes such as FOW, MSS and AD to convert into energy and biochar through a well-coordinated solar drying and pyrolysis process. Moreover, a combination of bio-chemical (e.g. RESERVES) and thermo-chemical (e.g. PYRASOL) processes are set to manage selected organic fraction of municipal solid waste (OFMSW) to ensure energy efficiency and maximise resources recovery from urban organic waste. Dependent on the characteristics of OFMSW (easy biodegradable, hygienic relevant as well as fibre, nutrients and lignin content etc.) the waste fraction is sent to the appropriate treatment method. As products are generated i.e., biogas as energy carrier, liquid digestated to recover nutrients, solid digestate to recover nutrients by composting, biochar to improve the compost or for direct land application as well as heat for internal reuse or for external energy supply. The process flows of the both approaches are shown in Fig. 1.

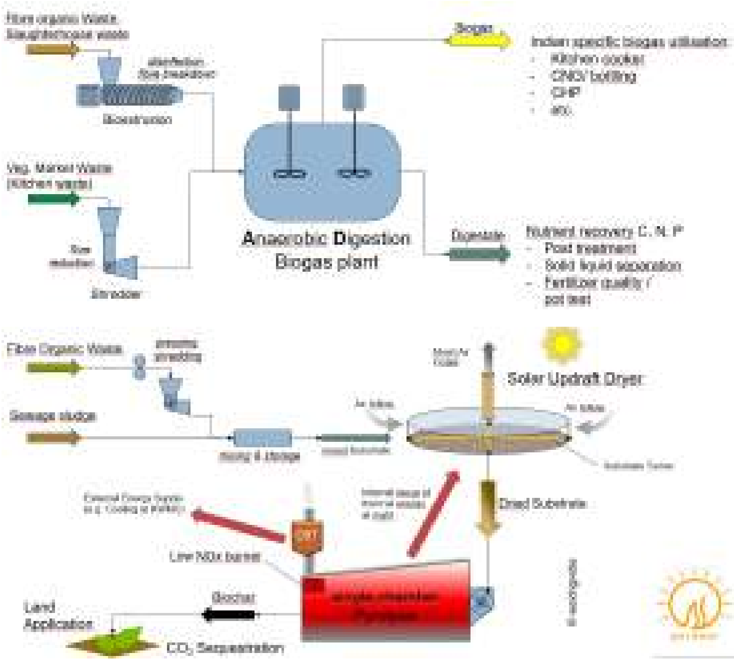


Fig. 1: Process flows of RESERVES (top) and PYRASOL (bottom)

4. Results and Discussion

4.1. Reserves

Initially, a comprehensive analysis on the availability of organic waste hotspots and its biogas potential for Chennai, India was carried out using qGIS. Within this inventory analysis, major urban organic waste streams in Chennai were investigated individually: vegetable market waste (VFF), fruit market waste (FRW), flower market waste (FLW), slaughterhouse wastes (SHW), chicken waste (CHW), fish market waste (FMW), canteen food waste (CFW), and residential organic waste (ROW). The Chennai Corporation wards and the hotspots of bio-reserves are plotted in Figure 2 with their daily contribution of waste in kg/km²/day.

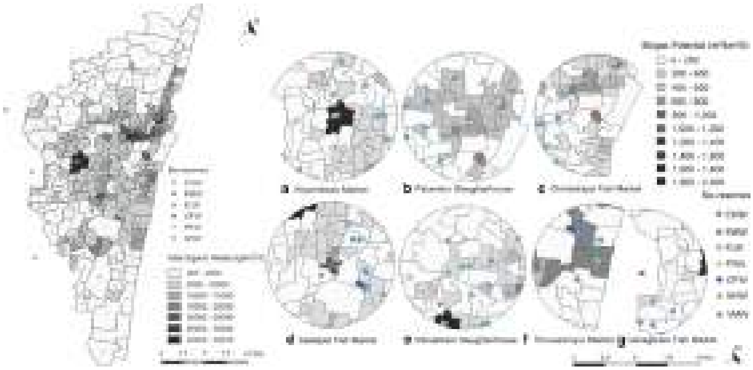


Fig. 2: GIS mapping of Chennai city (left) including bio-reserves within 5 km radius from the hotspots (right)

Based on the inventory, sampling and variations of the market's waste generation from Wholesale Koyambedu Market Complex, the waste composition and biogas potential have been analysed and evaluated. The impacts of bio-extruder on specific methane yields for different types of vegetable market wastes are visualized in Fig. 3. With respect to RESERVES project, vegetable market and slaughterhouse wastes are used as substrates for anaerobic co-digestion, in which lab scale batch & continuous reactor and pilot scale studies with and without bio-extrusion pre-treatment were carried out. In lab scale batch and continuous studies with co-digestion and pretreatment using bio-extrusion, enhancement of biogas/bio-methane yield was observed. The maximum biogas yield of 618.5 mL(STP)/g oDM was obtained in 1:3 mixing ratio of SHW and VFF.

The pilot plant operation results in the specific biogas yield of 0.78 m^3 (STP)/kg oDM for the bio-extruded waste, which is 44.4% higher than for non-extruded waste (only shredded). The composition of the methane was constantly ranged between 50 to 62%, respectively. Biogas purification through scrubbing system composed of iron fillings and activated alumina ensured H_2S concentration below 40 ppm.

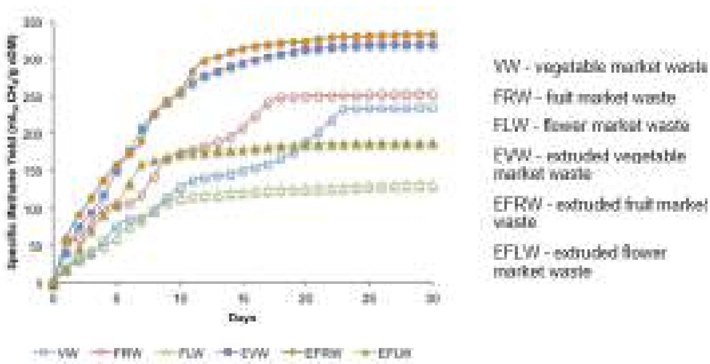


Fig. 3: Specific methane yield of extruded and non-extruded wastes

Based on the operational results of the pilot plant, the environmental pollution potential was determined using the LCA software umberto®. The specific environmental impact of the supplied substrate mixture and the electricity used were determined equal to 0.23 mPt/MJ and 23.07 mPt/MJ, respectively. The environmental impact for the amount of biogas produced was calculated as 117.5 kgCO_2-eq per day and 116.33 kgCO_2-eq for fermentation residues (digestate). However, the biogas can be substituted for natural gas which has a higher GHG emission (CO_2-eq) factor of 56.1 gCO_2-eq/MJ. Thus, through the pilot plant operation alone with a biogas production of 45 m^3/d, around 90.88 kgCO_2 -eq/d can be saved. The current practice of dumping vegetable market and slaughterhouse waste can also be avoided by further processing and using the digestate as fertilizer. This would save a net emission of 64.9 kgCO_2 -eq/d (emission factor 139 gCO_2 -eq/kg digestate). For the KWMC's daily waste of 200 Mg/d, this would mean a total saving of 62.3 t CO_2-eq/d. Moreover, the bio-extruder and the digester were identified as the system components with the highest values of the relative difference in the specific environmental impacts as the pilot plant was operated with smaller capacity. At higher plant capacities, the specific environment impacts due to these components can be lower.

Suitable biogas utilization studies were evaluated using multiple-criteria decision analysis (MCDA) to compare different options for using biogas in India based on the pilot plant results. Three techniques (water scrubbing, pressure swing adsorption and membrane filtration) for upgrading biogas to biomethane quality, three different processes for combined heat and power generation (stirling engine, gas turbine and fuel cell) as well as the direct use of the biogas for cooking with a gas flame were analyzed. The results of the MCDA showed that Stirling engine and gas turbine options are the best alternatives if the heat generated by the CHP systems can be used. Otherwise, the option of using the biogas directly for cooking should be preferred.

4.2. Pyrasol

PYRASOL feedstocks (FOW, SS and AD) are characterised through extensive laboratory experiments and analyses – elemental analysis, proximate analysis, fibre content, nutrient contents and heavy metal analysis. After that, lab scale solar drying experiments were carried out to estimate the drying rates and impacts of drying parameters. The study was conducted for different substrate ratios of BP to MSS - 1:1, 2:1, 3:1, 1:2, 1:0. 0:1 and BP, SS and AD ratios of 1:1:1. At the end of the test period of 18 days, the moisture loss varied between 80 % - 52 %. The maximum moisture loss was observed at a 3:1 ratio of FOW to MSS. Fig. 4 shows the drying rates and weight loss rates respectively of different feedstocks within the laboratory scale solar dryer.

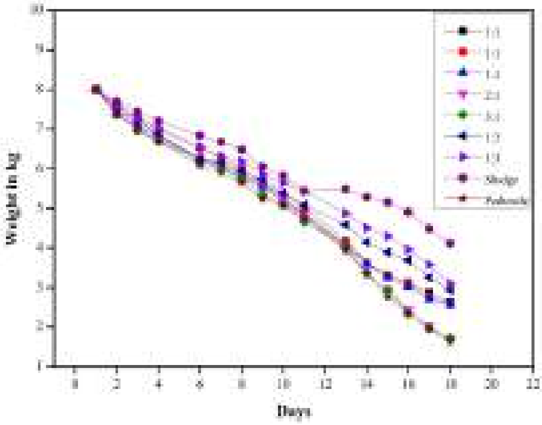


Fig. 4: Graph indicating the weight loss in the substrate over the drying period.

The solar drying properties and influencing parameters are determined from the results of the laboratory drying and compared with the theoretical estimation, which shows good agreement. Based on this data, the dimensioning of the pilot-scale solar updraft dryer, including chimney effects, was completed. It is estimated that the solar updraft dryer requires approximately 113 m^2 area having a round shape with 12 m radius and a chimney height of 8m, as shown in Fig. 5.

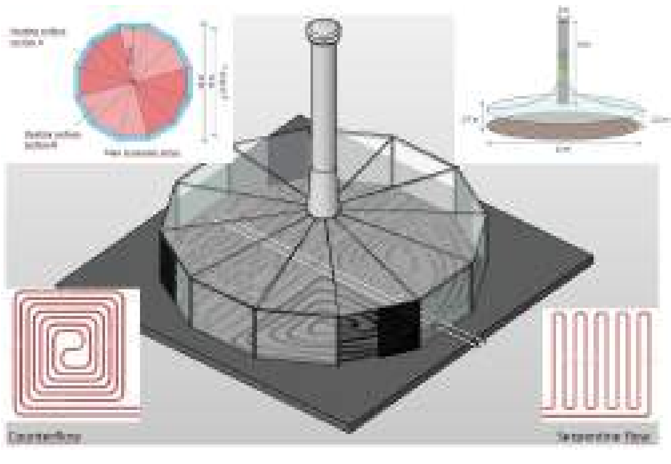


Fig. 5: The solar updraft dryer sketch including floor heating option

An extensive TG and lab scale pyrolysis experiments were carried out with the PYRASOL feedstock to design and dimensioning the Pyrolysis unit. Fig. 6 represents the thermal decomposition profiles of the substrates and their blends are determined by TGA-FTIR analysis which shows three notable reaction steps - removal of water and volatiles at < 200°C, loss of lignocellulose with a peak between 250°C and 300°C, loss of recalcitrant carbon from lignin between 400°C and 650°C.

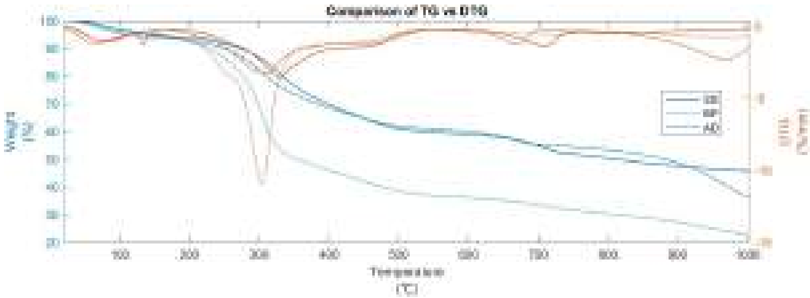


Fig. 6: TG - DTG curves during the slow pyrolysis (at 15°C/min) of BP, SS, and AD

The Biomacon pyrolysis converter (model AC63-F) installed in the PYRASOL project has a thermal capacity of 63kW and can be operated with a minimum capacity of 30 kW. The substrate mixtures (fuel) must have a water content of less than 30% and the inorganic content must not exceed 10%. Externally, a flue gas heat exchanger is adapted to the system, which requires a return temperature of approx. 30°C to achieve a condensation effect.

Based on the pyrolysis heat generated, the design of the underfloor heating and the thermodynamics of heat transfer are estimated. The theoretical estimation of the effects of the floor heating (evaporation rate of 6.9 kg water /m^{2}d) shows that it can accelerate the drying performances, shorten the drying time and reduce the required drying area. In particular, the natural temperature drop at night can be counteracted. The physical heat transport model of the PYRASOL solar updraft dryer shows that the largest share in the heat transport model is taken up by convection with up to 70%, because convection has the essential tasks of heating the material to be dried and transporting away the evaporated water. Solar radiation accounts for 25-30%, as cloud cover, night, weather, climate zone and non-vertical radiation have a considerable influence on how much solar radiation reaches to the dryer. The remaining 0% to 5% is due to heat conduction and biochemical degradation of biomasses. A mass and energy balances of the projected PYRASOL process is shown in Fig. 7.

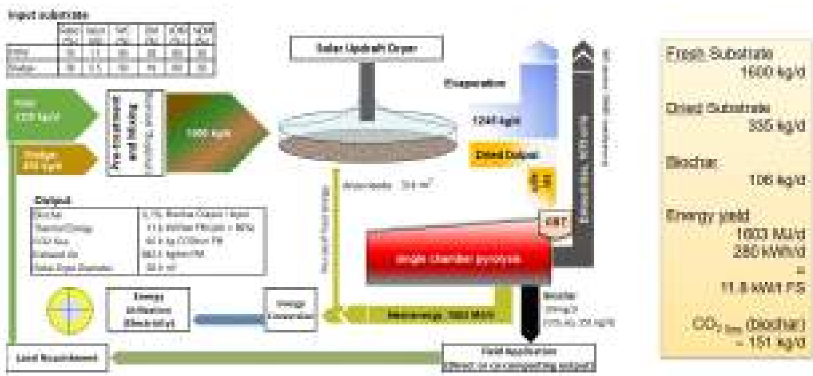


Fig. 7: Mass and energy flows within PYRASOL process

4.3. Further prospect

From both approaches could be learned, that all organic fractions of urban waste have a value and a special characteristics which can be addressed and used for a favourable biomass valorisation as well as nutrient and energy recovery. That's why a combination of both approaches will come to the focus of further research and application ideas.

Figure 8 shows how the various waste streams can be smartly treated, processed and coupled to produce applicable products that make a valuable contribution to climate protection, soil improvement and food security.

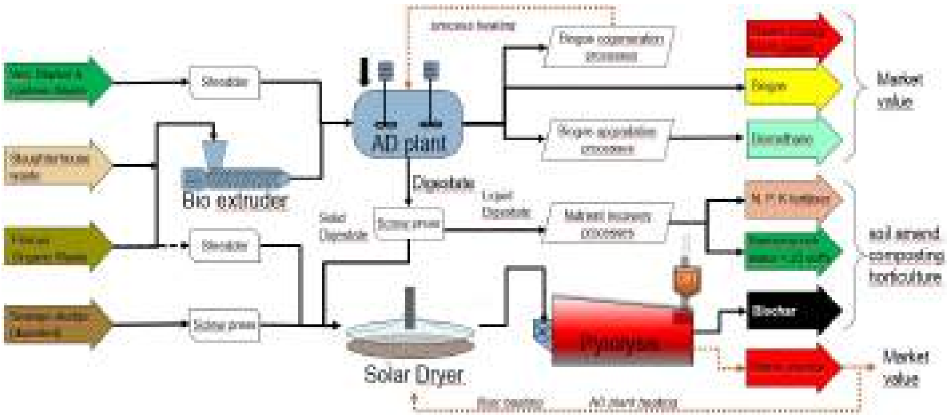


Fig. 8: Combined biochemical and thermochemical process

However, to achieve SMART City solutions, all participants – responsible persons of the veg market, the slaughter houses and the sewage plant, the waste producer and transporter, the plant operator as well as the local political bodies must work together. Still the veg market is not interested in cold storage rooms, as this will change the present operation, also the separate collection of waste at the premises seems to be difficult.

5. Conclusions

Urban organic waste provides high potential for biomass valorisation, material & energy recovery in the context of smart city approach. The pilot plant established at CLRI, Chennai under RESERVES project has been successfully demonstrated for co-digestion of vegetable market waste and slaughter house waste using bio-extruder as pre-treatment. This pilot plant with proven technology at TRL 8- can be used as demonstration model plant to stakeholders and policy makers involved in the waste management of smart cities. Further, it shall also be used for basic and advanced training for operating personnel in Indian biogas plants to improve their skills. To conduct such trainings, all the project partners shall together apply for funding for the expenses. This may help the Indian biogas industry flourish with proper collaboration and exchange programs. The outcome of the project created better visibility for proper substrate management and pre-treatment of waste generated in urban areas through co-digestion and Bio-extruder as pre-treatment. In addition, the results showed considerable increase in biogas production through co-digestion and pre-treatment with bio-extruder. Also a sanitation of the slaughterhouse waste could be achieved.

From the progress of the PYRASOL project, it was seen that biochar, a multifunctional material, can be sustainably (minimal energy requirements and GHG emissions) derived from UOW in India. The PYRASOL pilot plant investigation also presents a potential for utilizing the RESERVES by-product as one of the feedstock thereby creating a net carbon-neutral process for the sustainable production of renewable energy and biochar for advanced applications in India. The industrial applications of biochar are still limited in India. Enabling a renewable source for them can accelerate further research and development in the direction of advanced bio-carbon materials.

Based on the overall outcome of the pilot plant studies and subsequent sustainability assessment, the organic waste management through pretreatment, co-digestion, draying and pyrolysis supports a **sustainable environment and renewable source of energy due to:**

- *safe treatment and disposal of sewage sludge, slaughterhouse waste and fibrous organic wastes from MSW currently ending up in dumps/landfill,*
- *avoiding GHGs emission and reducing ground water and air pollution from landfill,*
- *carbon sequestration and Zero waste after PYRASOL for disposal,*
- *utilization of solar energy for waste treatment,*
- *reducing the volume of waste and using the fermentation residues and biochar produced as fertiliser and soil conditioner respectively,*
- *the possibility for decentralized system thereby reducing the transportation of wastes and subsequently reduces emission from transport and spillages.*
- *using the Biogas direct for cooking, and exploiting the potential of heat energy for chilling,*

The result may also help the stakeholders/urban and landscape planners during their planning and execution. Further, enhanced biogas yield and utilisation of digestate as organic fertiliser would attract the stakeholders and Government to implement the waste to energy technologies either as decentralized or in centralized manner so as to meet the national missions and Sustainable Development Goals (SDGs) of United Nations.

Acknowledgements

The authors acknowledge the Indo-German Science and Technology Centre (IGSTC) under Department of Science and Technology (DST) and the German Federal Ministry of Education and Research (BMBF) for funding the RESERVES (Grant no. 01DQ15007A) and PYRASOL (Grant no. 01DQ18001A) projects within the IGSTC 2 + 2 Project Framework. The authors also thank the industrial partners Lehmann-UMT and Biomacon GmbH in Germany as well as Ramky Enviro Engineers Ltd. India for their support.

References

Greater Chennai Corporation portal (2019). Solid waste management department. http://www.chennaicorporation.gov.in/NorthMonSoon2017/ZONE_1.pdf. Accessed on 10 April 2022.

IOP (2019). Chennai population data portal (India online pages (IOP)). http://www.indiaonlinepages.com/population/chennai-current-population.html. Accessed on 10 April 2022.

Jha AK, Sharma C, Singh N, Ramesh R, Purvaja R and Gupta PK (2008). Greenhouse gas emissions from municipal solid waste management in Indian mega-cities: a case study of Chennai landfill sites. Chemosphere 71(4):750–758. https://doi.org/10.1016/j.chemosphere.2007.10.024

Mozhiarasi V, Speier CJ, Rose PMB *et al.* (2019). Variations in generation of vegetable, fruit and flower market waste and effects on biogas production, exergy and energy contents. *J Mater Cycles Waste Manag* 21, 713–728. https://doi.org/10.1007/s10163-019-00828-2

Mozhiarasi V, Speier CJ, Michealammal BRP et al. (2020a). Bio-reserves inventory—improving substrate management for anaerobic waste treatment in a fast-growing Indian urban city, Chennai. Environ Sci Pollut Res 27, 29749–29765. https://doi.org/10.1007/s11356-019-07321-1.

Mozhiarasi V, Raghul R, Speier CJ, Benish RPM, Weichgrebe D and Srinivasan SV (2020b). Composition Analysis of Major Organic Fractions of Municipal Solid Waste Generated from Chennai. In: Ghosh, S. (eds) Sustainable Waste Management: Policies and Case Studies. Springer, Singapore. https://doi.org/10.1007/978-981-13-7071-7_13.

Murugesan V and Amarnath J (2015). Control of greenhouse gas emissions by energy recovery from the organic fraction of municipal solid waste through Bio Methanation process. Int J Chem Tech Res 8(3):1168–1174

Nair RR, Mondal MM and Weichgrebe D (2020). Biochar from co-pyrolysis of urban organic wastes—investigation of carbon sink potential using ATR-FTIR and TGA. Biomass Conv. Bioref. . https://doi.org/10.1007/s13399-020-01000-9.

Speier CJ, Mondal MM, Weichgrebe D (2018). Evaluation of compositional characteristics of organic waste shares in municipal solid waste in fast-growing metropolitan cities of India. J Mater Cycles Waste Manage 20(4):2150–2162. https://doi.org/10.1007/s10163-018-0757-y.

Weichgrebe D, Speier C and Mondal M (2017). Scientific approach for municipal solid waste characterization. In: Goel S (ed) Advances in solid and hazardous waste management, 1st edn. Capital Publishing Company, New Delhi, pp 63–96.

Weichgrebe D (2015). Kompendium Biogas. Habilitation. Publications of the Institute of Sanitary Engineering and Waste Management (ISAH), Leibniz University Hannover. Book 155, Hannover.

World population review (2018) Chennai population 2018. http://worldpopulationreview.com/world-cities/chennai-population/. Accessed on 11 April 2022.

UN (2019) World population review data. World Population by Country. http://worldpopulationreview.com. Accessed on 10 April 2022.

Sewage Sludge Management: Scientific approach and conceptual design of a solar sludge-drying greenhouse for India

Moni M. Mondal, Rahul R. Nair & Dirk Weichgrebe
Institute of Sanitary Engineering and Waste Management (ISAH), Gottfried Wilhelm Leibniz University Hannover, Germany

Abstract

Rapidly increasing amounts of wastewater and solid waste exert pressure on urban disposal systems in the megacities of emerging economies, of which organic residues like sewage sludge pose a major challenge. Local management approaches with the volume reduction of sewage sludge, therefore, are an attractive option for urban areas. This paper investigated sewage sludge drying characteristics and elaborated on the theoretical background of designing a sludge-drying greenhouse for its volume reduction, as an alternative option in comparison to costly mechanical or thermal dewatering/ pretreatment process. The vapor balance equations are used to calculate evaporation rate where the multiplicative model is applied for the prediction of humidity ratio differences. Estimation of design parameters for a sludge-drying greenhouse is conducted for an example of sub-tropical Indian climate conditions. Especially the case study is presented based on the actual data from the sewage sludge generation at Infosys IT-Complex campus in Bangalore city with its local meteorological information. A sensitivity analysis has also been performed & presented to see the impacts of one drying parameter on the others and vice-versa. This design calculation model for sewage sludge drying greenhouse is developed in a way that it can be adapted for any other locations by replacing the actual sludge characteristics and meteorological data.

Keywords: sewage sludge, solar drying, greenhouse, tropical areas

1. Introduction

In the major cities of emerging economies, wastewater and solid wastes are rapidly increasing due to urbanization and development in social and industrial sectors. Organic residues, in particular sewage sludge generated from wastewater treatment, represent a major challenge for the existing urban waste management systems (Speier et al., 2018). Sewage sludge is a residual product of wastewater treatment and is rich in valuable nutrients such as N, P, and K. However, if used untreated, it poses great risks to human health and environmental pollution due to possible hazardous levels of heavy metals, chemical pollutants, pathogens, and parasites (LeBlanc et al., 2008; AbfKlärV, 2017). The controlled hygienization of sewage sludge and its environmentally sound disposal is of great importance, especially for densely populated areas with large quantities of sludge generated.

Various methods and techniques are applied worldwide for the treatment and disposal of sewage sludge. The most common method is the stabilization of the sludge by aerobic or anaerobic treatment (Bauerfeld et al., 2014; Weichgrebe, 2015; DWA, 2019). Other methods include conditioning, dewatering and drying, and pasteurization. Due to the high water content of untreated sewage sludge (usually <5% dry solids), it is unsuitable for standard disposal methods (i.e., composting, landfilling, incineration) (DWA, 2019). In addition, transporting untreated sewage sludge (e.g., from urban centers to farmland in rural areas) is significantly more costly than transporting dewatered sewage sludge due to its larger volume.

In addition to landfilling and agricultural recovery, energy recovery from sewage sludge is an attractive option for large urban areas with immense sewage sludge generation and limited space for sewage sludge disposal, minimal odor tolerance, and less demand for agricultural application (Werther & Ogada, 1999). Dried sewage sludge with water content below 20% can achieve calorific values of up to 13 - 18 MJ/kg, while its thermal degradation (i.e., incineration, pyrolysis) further ensures complete degradation of hazardous organic compounds such as drug residues, pathogens, and parasites (Fytili & Zabaniotou, 2008; Wiechmann et al., 2013).

Currently, mechanical dewatering technologies can remove 15% to 30% of the original moisture content (DWA, 2016; DWA, 2019). Some technologies (e.g., filter presses) can remove water contents as high as 35% to 50%, but require significantly more time, energy, and chemical additives for dewatering (Novak, 2006; Wiechmann et al., 2013). To achieve dry matter contents above 50%, sewage sludge and other organic residues are mainly dried using two existing approaches, thermal and solar drying (Arlabosse et al., 2012). Thermal drying requires high investment and has significant energy demand, resulting in high operating costs (Collard et al., 2016; Bux, 2013).

As an alternative drying method with lower operational costs, drying sewage sludge using solar radiation as an energy source for evaporation is getting popular in sub-tropical countries. The process of solar drying is described in detail in the relevant literature and shows high potential for replacing thermal-mechanical dryers, especially in tropical countries such as India (Bux, 2013; Bennamoun, 2012; Mathioudakis et al., 2009 & 2013; Meyer-Scharenberg & Pöppke, 2010; DWA, 2019). The general suitability of solar drying of sewage sludge in India has already been investigated and demonstrated in India by the project partner ISAH, Hannover and Thermosystem GmbH, Esslingen. The positive effect of solar drying on pathogen removal in organic waste is demonstrated by Mathioudakis et al., 2009 & 2013; Shanahan et al., 2010 and DWA (2016). Leonard et al. (2005) and Seginer & Bux (2005, 2006, 2013) show that drying performance is highly dependent on individual organic waste characteristics. All relevant studies report a significant reduction in the weight and volume of organic waste due to the evaporation of water and an increase in calorific value (Chai, 2007).

Therefore, in this paper, the scientific background and design of a greenhouse for solar drying of sewage sludge are studied and presented for the climatic conditions of India. A model calculation of solar drying parameters is carried out for Bangalore city. This design and calculation model can be transferred to other cities by substituting the local meteorological data and sewage sludge characteristics.

2. Principles of solar sludge drying within the greenhouse

The sludge drying in the greenhouse is a dewatering process carried out with the help of solar energy that follows the thermodynamic law of evaporation and air conditioning. The driving force is the difference between the partial vapor pressure inside the sludge and that of the air above the sludge layer. In order to avoid equilibrium between the vapor pressure inside and outside the sludge, the air must be circulated and moved out. This circulation occurs naturally since water vapor is lighter than dry air. According to *Mollier´s h+x* Diagram, the warmer the air, the more water vapor can be transported. The partial vapor pressure in the air, therefore, increases with the amount of water dissolved in the air.

In the absence of proper air movement, a saturated layer of air can form above the sludge surface. This humid air layer leads to a reduced evaporation rate, which should be avoided. For this reason, the greenhouse for sludge drying should be well-ventilated (IST-Anlagenbau, 2012). The fresh air is let in through openings on the side walls and the exhaust air is discharged through the exhaust ventilator (as shown in Figure 1).

Air mixing fans are placed in the hall and can be moved in a way that the air turbulence is created above the entire surface of the drying bed. This helps to destroy the moist boundary layer on the sludge surface. This artificial wind is important for the drying process as it prevents stratification of the moisture (IST-Anlagenbau, 2012).

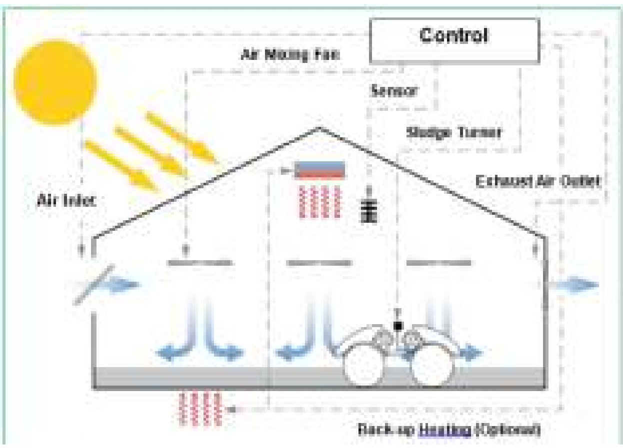


Fig. 1
Solar sludge drying principle (modified after Thermo-System, 2014)

3. Theoretical background for dimensioning of solar drying greenhouse

3.1 Drying rate - vapor balance model

The evaporation rate (E) within the controlled solar drying environment is predicted through the vapor balance equation to estimate the drying rate of sewage sludge, using the following expression.

$$E =\cdot \rho_{air} \cdot Q_v \cdot (\varphi_{out} - \varphi_{in}) =\cdot \rho_{air} \cdot Q_v \cdot \Delta\varphi \left[\frac{\text{kg (water)}}{\text{m}^2 \cdot \text{h}}\right] \tag{1}$$

With, E as evaporation rate in [kg (water)/$m^2 \cdot h$], Q_v as exhaust ventilation rate in [$m^3/m^2 \cdot h$], φ_{out} as the relative humidity of air at drying outlet in [%], and $\Delta\varphi$ as humidity ratio difference in [%].

The solar drying model of Seginer & Bux (2006) is used for the estimation of humidity ratio difference ($\Delta\varphi$) where they suggested three statistical models (multiplicative model, additive model, and neural network model). In direct comparison, the available data set was represented with the highest accuracy by the multiplicative model due to its limited number of parameters and small residual error. The humidity ratio difference ($\Delta\varphi$) is thus modeled as a product of power factors and predictors.

$$\Delta\varphi = \alpha \prod_{j=1}^{p} \left(P_j + \beta_j\right)^{\gamma_j} = 1.96 \cdot 10^{-11} \cdot [(R_{amb} + 1100)^{2.322} \cdot (T_{amb} + 13.0)^{1.292} \cdot (Q_v)^{-0.577} \cdot \text{Qm+0.00010.013·DSCin+0.26−0.353} \tag{2}$$

With, T_{amb} as the ambient temperature in [K], q_m as air mixing rate in [$m^3/m^2 \cdot h$], DSC_{in} as dry solid content of the wet sludge at the beginning of the drying period in [%], α_j, β_j, γ_j as constants, P_j as predictors (T_{amb}, R_{amb}, Q_v, Q_m, & DSC_{in}), and p as the number of predictors.

The resulting equation for projecting the evaporation rate (E) inside the drying hall is generated by combining equations 1 and 2 (Seginer and Bux, 2006).

$$E = \rho_{air} \cdot Q_v \cdot 1.96 \cdot 10^{-11} \cdot [(R_{amb} + 1100)^{2.322} \cdot (T_{amb} + 13.0)^{1.292} \cdot (Q_v)^{-0.577} \cdot (Q_m + \text{0.00010.013·DSCin+0.26−0.353kg (water)m2h} \tag{3}$$

3.2 Calculation of drying period

The drying period is projected according to Traub (2006), Kawongolo (2010), and Coulson et al. (2002) following the drying characteristics of porous materials. The drying period (t_{Tot}) is divided into three characteristics drying phases - warming-up (t_{WU}), constant rate period (t_{CD}) and reduced drying period (t_{RD}). In the warming-up period, the material is heated by conduction to room temperature. The respective time is calculated by the following equation.

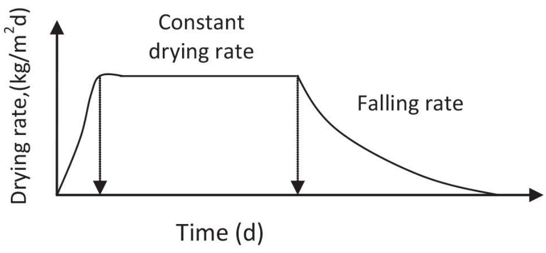


Fig. 2
Typical air-drying curves

$$t_{WU} = \frac{4 \cdot L^2 \cdot \rho_{mat} \cdot c_{mat}}{k \cdot \pi^2} \ln\left\{\left(\frac{T - T_s}{T_i - T_s}\right) \cdot \left(\frac{\pi}{4}\right)\right\} \cdot \frac{1}{3600} \quad [h] \qquad (4)$$

With, t_{WU} as warming-up drying period in [h], L as thickness of material for drying in [m], ρ_{mat} as bulk density of fresh input substrate in [kg/m³], c_{mat} as specific heat capacity of the material [4,187 J/kg·K], k as thermal heat conductivity of material in [W/m·K], T as drying temperature in [°C], T_s as average wet-bulb temperature of the drying air in [°C] and T_i as room temperature in [°C].

During the constant drying period (t_{CD}), the rate of mass flow is equal to the rate of heat transfer (Coulson & Richardson, 2002) and is estimated from the following expression.

$$t_{CD} = m_{wet,d} \frac{(m_o - m_c)}{A_d \cdot r_{ev}} \cdot \frac{1}{3600} \; [h] \qquad (5)$$

With, t_{CD} as constant drying period in [h], $m_{wet,d}$ as wet substrate input per day in [kg/d], m_0 as initial moisture content in [kg water/kg solid], m_c as critical moisture content in [kg water/kg solid] and A_d as area demand for drying in [m²].

The reduced drying period (t_{RD}) is estimated according to Fick's second law for unsteady state diffusion. An approximation of drying time during the reduced drying rate for which moisture movement in the material is controlled by capillary flow can be obtained from Kawongolo (2010).

$$t_{RD} = \frac{\rho_{mat} \cdot L \cdot \lambda_h \cdot (m_c - m_e)}{h \cdot (T - T_s)} \cdot \ln\left(\frac{m_c - m_e}{m_f - m_e}\right) \; [h] \qquad (6)$$

With, t_{RD} as reduced drying period in [h], λ_h as latent heat of vaporization in [kJ/kg], m_e as the equilibrium moisture content in [kg water/kg solid], h as heat transfer coefficient of material in [W/m²·K] and m_f as the final moisture content in [kg water/kg solid].

The **total drying period** t_{Tot} is calculated based on t_{WU}, t_{CD} and t_{RD}.

$$t_{Tot} = t_{WU} + t_{CD} + t_{RD} \, [h] \qquad (7)$$

3.3 Estimation of drying area

The drying area is estimated from the average evaporation rate, sludge amount, and the input and output sludge dry solid content according to Ficza (2010).

$$A_d = \frac{1}{\bar{E}} \cdot m_{wet} \cdot \left(1 - \frac{DSC_{in}}{DSC_{out}}\right) \quad [m^2] \qquad (8)$$

With, $\bar{E}$ as average drying rate in [kg (water)/m²·a], m_{wet} wet substrate input per year in [kg/a], and DSC_{out} as dry solid content of the sludge at the end of drying period in [%].

3.4 Ventilation rate

The authors (Mondal and Weichgrebe, 2014) identified a process optimum for Q_v at 80 m³/m²h and Q_m at 40 m³/m²h for a solar sludge drying greenhouse in southern India which are also considered for this model calculation. The required capacity of the blowers can be easily estimated from the amount of area required for the drying hall.

4. Example calculation of design parameters for Bangalore city

4.1 Sludge quantity and characteristics

For this example calculation, sewage sludge quantity and characteristics data are taken from one of our previous projects in South India (STPs of Bangalore campus, Infosys Ltd.). The sludge generation data are presented in the box below.

Box: sludge generation data			
STP capacity	*10000 PE*	*Sludge generation*	*0.9 t/d (328.5 t/a)*
Sludge Holding Tank capacity	*220 m^3*	*Sludge DSC*	*12%*
Sludge DSC before centrifuge	*0.8%*	*Sludge density*	*1005 kg/m^3*
Sludge dewatering technology	*Centrifuge*		

4.2 Local meteorological data

The required meteorological data (i.e. temperature, solar radiation, relative humidity, barometric pressure, etc.) are collected from satellite-based weather station data for Bangalore. Air density is calculated from collected air pressure records. Average monthly meteorological data are summarized in Table 1.

Table 1
Meteorological data in Bangalore

Months	**Outdoor Temperature** (□C)			**Relative Humidity** (%)	**Solar Radiation** (W/m^2)	**Atmospheric Pressure** (hPa)	**Air Density** (kg/m^3)
	MAX	MIN	AVG				
January	26.63	15.83	20.70	61.3	188.26	1008.86	1.20
February	28.51	17.99	22.62	51.1	193.14	1006.69	1.19
March	30.84	19.97	24.85	46.2	224.67	948.73	1.11
April	33.57	22.36	27.25	61.0	200.93	907.80	1.06
May	32.09	21.48	25.81	66.3	201.94	909.03	1.06
June	27.53	20.03	23.12	72.8	170.46	971.29	1.14
July	26.02	19.65	21.94	73.3	132.52	1000.81	1.18
August	26.53	19.63	22.38	71.4	159.12	1002.07	1.18
September	26.73	18.95	22.45	67.7	174.70	1002.07	1.18
October	27.1	19.75	22.73	70.9	184.43	1003.56	1.18
November	26.75	18.37	21.92	69.3	185.57	1005.81	1.19

December	25.83	16.12	20.37	66.4	185.77	1006.94	1.20
Average	**28.18**	**19.18**	**23.01**	**64.8**	**183.46**	**981.14**	**1.16**

Source: Meteorological Station, Bangalore (2020-21)

4.3 Calculation of water evaporation from sludge

The evaporation rate (E) within the sludge drying greenhouse is calculated using the vapor balance model according to (Seginer and Bux, 2006) as expressed in equations (1) – (3). Monthly effective evaporation (E_{eff}) is calculated considering 18h/d as active daily drying hours per day with experience data from Thermosystem GmbH. Calculation results of evaporation rates are summarized in Table 2.

Table 2
Calculation of monthly average evaporation rate using all parameters

Months	Outdoor Temp. T_0 (°C)	Outdoor Solar Radiation R_0 (W/m²)	Air Density ρ (kg/m³)	Potential Evaporation Rate E_{pot} (kg w/m²·h)	Effective Evaporation Rate E_{eff} (kg w/m²·d)
Jan	20.70	188.26	1.20	8.32	6.24
Feb	22.62	193.14	1.19	8.94	6.70
Mar	24.85	224.67	1.11	9.56	7.17
Apr	27.25	200.93	1.05	9.42	7.07
May	25.81	201.94	1.06	9.06	6.79
Jun	23.12	170.46	1.14	8.41	6.31
Jul	21.94	132.52	1.18	7.77	5.83
Aug	22.38	159.12	1.18	8.29	6.22
Sep	22.45	174.70	1.18	8.55	6.42
Oct	22.73	184.43	1.18	8.80	6.60
Nov	21.92	185.57	1.19	8.61	6.45
Dec	20.37	185.77	1.20	8.17	6.13
Avg.	**23.01**	**183.46**	**1.15**	**8.66**	**6.49**

With fixed values of Q_v = 80 [m³(air)/m²h]; Q_m = 40 [m³(air)/m²h]; = 0.12 [kg (air)/m³ (air)]

4.4 Calculation of drying periods

The total drying period for a batch of sludge is estimated by calculating the time required for every drying stages such as the **warming-up period**, **constant rate drying period,** and **falling drying period** as elaborated in equations (4) – (7). The monthly drying period per batch is summarized in Table 3.

Table 3
Calculation of drying period of a full drying cycle

Months	Effective evaporation rate E_{eff} (kg water/ m²d)	Warming up period t_W (days)	Constant drying period t_{Con} (days)	Falling drying period t_F (days)	Total drying time per batch $t_{Tot}=t_W+t_{Con}+t_F$ (days)
January	6.24	2.2	8.5	2.2	13
February	6.70	1.8	7.9	2.8	12.5
March	7.17	1.3	7.4	2.8	11.5
April	7.07	1.6	7.5	3.0	12
May	6.79	1.8	7.8	2.8	12.5
June	6.31	2.1	8.4	2.5	13
July	5.83	2.7	9.1	2.2	14
August	6.22	2.3	8.5	2.2	13
September	6.42	2.1	8.3	2.2	12.5
October	6.60	2.0	8.0	2.2	12
November	6.45	2.1	8.2	2.2	12.5
December	6.13	2.5	8.7	2.3	13.5
Average	**6.49**	**2.0**	**8.2**	**2.5**	**12.5**

A detailed view of changes in sludge moisture content and different drying rates for the month of May, as an example, is visualized in Fig. 3.

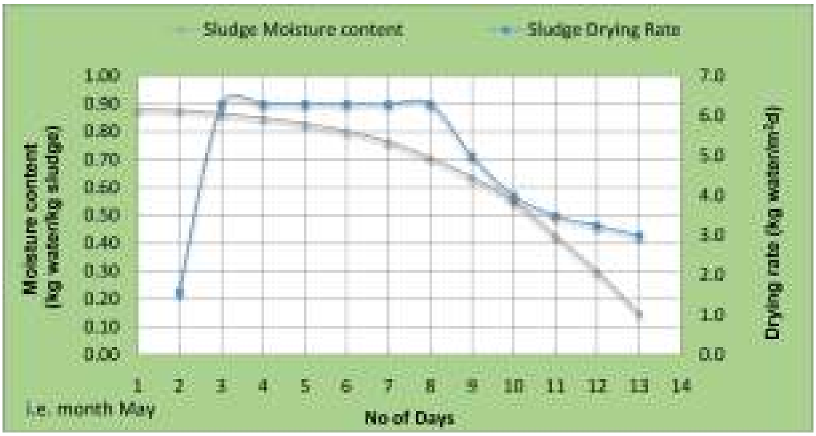


Fig. 3
Changes in moisture content and drying rate during drying in a batch mode (i.e. month of May)

4.5 Area for the drying bed

The drying area A_D in [m^2] required for a greenhouse to dry the given sewage sludge is calculated using equation (8), as mentioned below:

$$A_D = \frac{1}{\bar{E}} \cdot M_{wet} \cdot \frac{(б_{out} - б_{in})}{б_{out}} = 170\, m^2$$

With $\bar{E}$ = 1,643 [kg/m²a] (estimated); = 328,500 [kg/a] (given); = 12% (given); = 80% targeted)

Under consideration of a safety factor of 15%, the total area for the complete greenhouse can be estimated as 200 m² with **10 m x 20 m** as a possible dimension. With these dimensions the construction of one greenhouse with one drying bed is sufficient. According to a comparative study by the authors (Mondal & Weichgrebe, 2014), a controlled solar drying greenhouse can save up to 45-55% drying area in compare to open bed drying.

Fig. 4 shows the schematic layout of the greenhouse bed for the batch operation system (not drawn with scale).

4.6 Area for the intermediate storage tank for batch mode operation

The daily sludge generation from the connected STPs is given with 900 kg/d (DSC 12%). 2 m³ shall be delivered every two days to the drying bed. With the max drying period ($t_{D,max}$ = 14 days), the volume of the storage tank can be calculated as

$$V_{St} = t_{D,max} \cdot Q_{sl}/\rho_{sludge} = 14[d] \cdot 900[kg/d]/1{,}005[kg/m^3] = 12.5\, m^3 \; or \; 14\, m^3 \; max$$

As the possible dimension of the sludge storage tank (for batch drying) are suggested,

= 14 m length x 1 m width x 1 m depth (dimension assumed)

= 14 m² (area) x 1 m (depth) = 14 m³ (max)

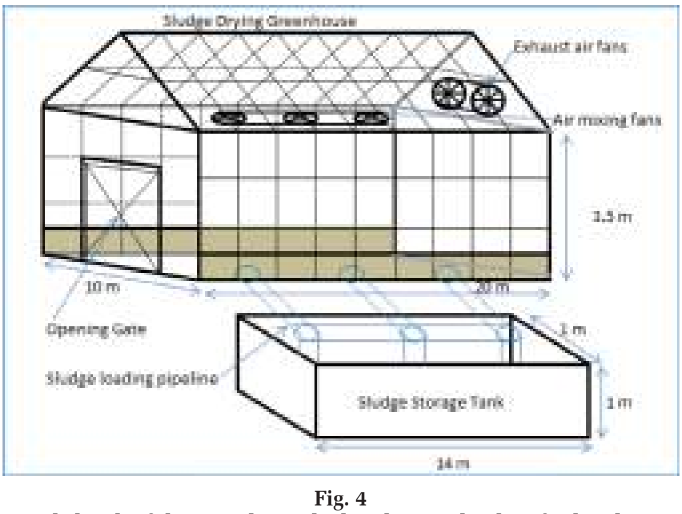


Fig. 4
General sketch of the greenhouse bed and pump loading for batch system

4.7 Drying Performances (Input vs Output)

For the given input sewage sludge, having 12% DSC, 78% of the mass reduction can be reached. Thus, among the raw sludge input of 330 t per year, only 72 t (output as bio-solids) per year will be remained after drying. Mainly sludge mass reduction in the greenhouse is occurred through evaporation of 251 t of sludge moisture and partial stabilization of organic dry solids (7 t), which are shown in Table 4.

Table 4
Summary of sludge drying (sludge input, output, and amount of water removed)

Month	**Sludge Input** (t/mon)	**Water removed** (t/mon)	**DS Stabilization** (t/mon)	**Sludge output** (t/mon)	**Mass reduction** (%)
January	27.90	21.23	0.5	6.14	77
February	25.20	19.21	0.4	5.54	77
March	27.90	21.32	0.4	6.14	77
April	27.00	20.63	0.4	5.94	77
May	27.90	21.18	0.6	6.14	78
June	27.00	20.46	0.6	5.94	78
July	27.90	21.09	0.7	6.14	78
August	27.90	21.14	0.6	6.14	78
September	27.00	20.43	0.6	5.94	78
October	27.90	21.11	0.6	6.14	78
November	27.00	20.50	0.6	5.94	78
December	27.90	21.23	0.5	6.14	77
Total$_{\text{(avg basis)}}$	**330 t/a**	**251 t/a**	**7 t/a**	**72 t/a**	**78 %**

Fig. 5 summarizes the design calculations to dry the entire sludge (0.9 t/d) with the existing climatic conditions and sludge quality; ca. 200 m^2 (20 m x 10 m) of area is required for installing the greenhouse bed and 14 m^3 for storage tank. The raw sludge of 330 t/a will be reduced to only 72 t/a having 80% DSC. In this drying process, nearly 251 t/a of water from raw sludge are evaporated, and remaining 7 t/a of organic dry solids are stabilized aerobically through solar greenhouse drying.

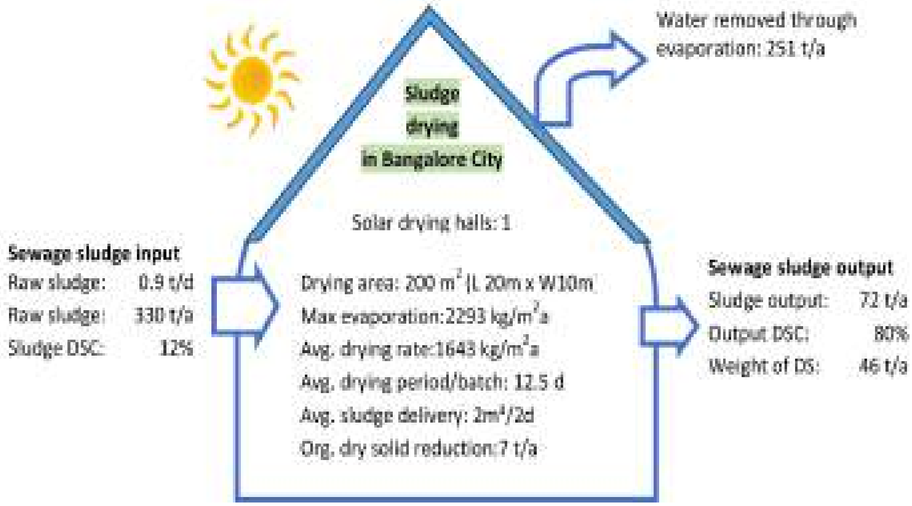


Fig. 5
Conceptual design of sewage sludge drying greenhouse

5. Sensitivity Analysis of the Parameters

5.1 Effects of exhaust air ventilation rate on evaporation

Figure 6 confirms that the exhaust air ventilation rate (Q_v) has a strong positive relationship with evaporation rate. The higher evaporation rate is obtained for higher values of Q_v.

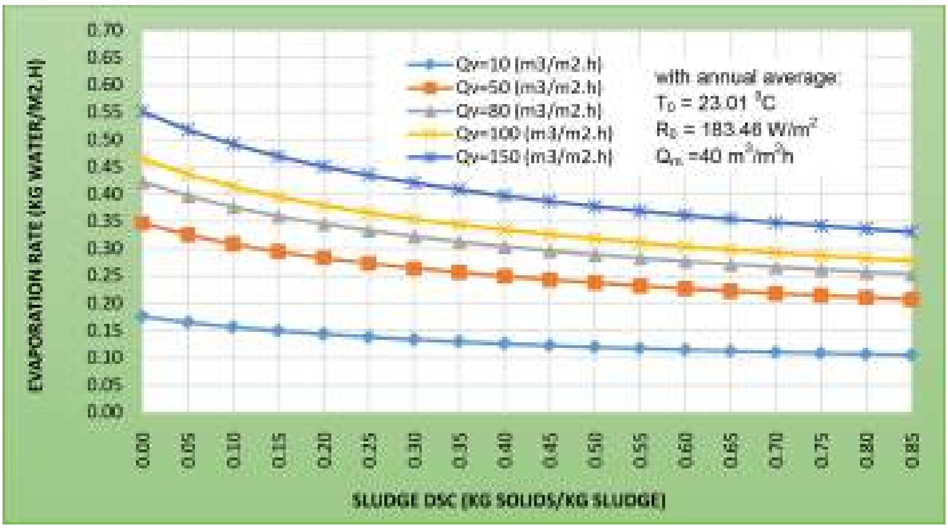


Fig. 6
Effect of exhaust air ventilation rate on evaporation

It is also found that the air mixing rate (Q_m) has also a positive relationship with evaporation rate, but there is no considerable effect of Q_m on evaporation when it increases from 40 to 150 m^3/m^2h. Based on these correlations, the values of Q_v = 80 (m^3/m^2h) and Q_m = 40 (m^3/m^2h) are selected for an efficient operation with less energy consumption.

5.2 Impacts of temperature on drying performances

Drying performances are strongly affected by temperature changes. Past solar greenhouse experiences show that at least 10^0C temperatures will be increased due to the greenhouse effect (Thermo-System, 2014). Thus, if the incoming air temperature can be increased from 25^0C to 45^0C by external heat, the drying performance will be doubled as shown in Table 5.

Table 5
Impacts of temperature on drying performances (for batch drying system)

Ambient Temperature (^0C)	**Greenhouse Temperature** (^0C)*	**Annual Sludge Generation** (kg/a)	**Average drying rate** (kg/m^2a)	**Area required for drying bed** (m^2)	**Drying period per batch** (d)
25	35	328500	1635.32	180	12.5
30	40	328500	2057.37	145	10
35	45	328500	2371.62	130	8.5
40	50	328500	2695.61	115	7.5
45	55	328500	3028.68	100	6.5
50	60	328500	3370.26	90	6

**A minimum of 10 0C increase in temperature within the greenhouse is considered*

5.3 Combined impacts of temperature and ventilation rate on drying performances

Drying temperature has a stronger positive impact on the solar drying performance than the exhaust air ventilation Q_V and the air-mixing rate Q_m. Thus, the drying performance can be intensified by increasing inlet air temperature through any external heating system and heat exchanger. The combined effects are shown in Fig. 7.

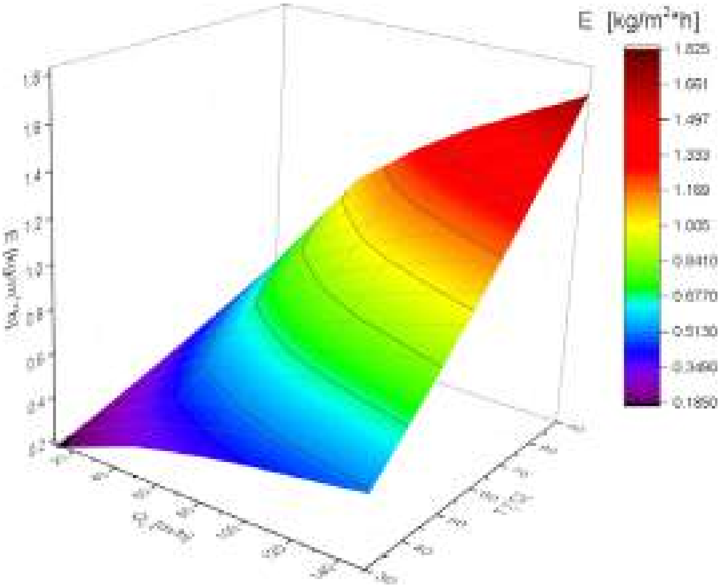


Fig. 7
Impacts of air temperature Tair and air ventilation rate QV on the evaporation rate E

6. Conclusions and Recommendations

The scientific background and design of a greenhouse for solar drying of sewage sludge are investigated and a model calculation is performed for Bangalore city. This design and calculation model can be transferred to other cities. Moreover, for the successful installation and operation in India, the following steps are recommended:

- Sewage sludge drying activities should comply with prevailing local, regional and national rules, regulations and standards i.e. exhaust emission, usage of dried sludge in agriculture, noise from sludge loading pump etc.
- Usage of exhaust heat, heat exchanger or any other heating options from external sources is preferably included with the main control system in advance. The external heating can be applied easily in future operations at any time.
- Another external arrangement can be installed outside of the greenhouse area to ensure complete pathogen removal of dried sludge i.e. exposure of 70^0C temperature for one hour by exhaust heat energy.
- Civil construction and building structure can be installed on-site with respect to local requirements (i.e. water protection, material and maintenance etc.).
- Bio-scrubber and bio-filter can be arranged and implemented after operative experiences and odor or dust measurement. However, in the new installed unit at Infosys campus in Bangalore, no exhaust gas treatment was needed. Moreover, the drying performances showed even better results as calculated.

Finally, batch or semi-batch sludge drying options with a loading pump can be chosen as a priority with external heat usage options and the addition of external heating arrangements for pathogen removal in the control system.

Acknowledgments

The authors acknowledge the project partner Infosys Limited, Bangalore, India for providing sewage sludge characteristics data and all the required local meteorological data. We also thanks to Thermo-System, Industrie- & und Trocknungtechnik GmbH for providing some specific technical information regarding solar drying in Greenhouse.

References

AbfKlärV (2017 & 2020). Verordnung über die Verwertung von Klärschlamm, Klärschlammgemisch und Klärschlammkompost, (Sewage Sludge Ordinance for Germany) last amended by Article 137 of the Ordinance of 19 June 2020 (BGBl. I p. 1328).

Arlabosse P., Ferrasse J., Lecomte D., Crine M., Dumont Y., Léonard, A. (2012). Efficient Sludge Thermal Processing: From Drying to Thermal Valorization. In: Tsotsas, E., Mujumdar, A. Modern Drying Technology Volume 4: Energy Savings. Wiley-VCH.

Bauerfeld K., Dellbrügge R., Dichtl N., Großer A., Paris S. (2014). Solar Sewage Sludge Drying. "Technology transfer-oriented research and development in the wastewater sector - validation at industrial-scale plants" (EXPOVAL).

Bennamoun L. (2012). Solar drying of wastewater sludge: a review. Renew Sustain Energy Rev 2012; 16(1):1061–1073

Bux M. (2013). Solar drying of sewage sludge - BAT and selected examples. In: Sewage sludge treatment, Training course O/4. DWA, Hennef, Germany, pp. 395-416.

Chai L. (2007). Statistical dynamic features of sludge drying systems. Int. J. Therm. Sci. 46, 802–811.

Collard M., Teychené B., Lemée L. (2016). Comparison of three different wastewater sludge and their respective drying processes: Solar, thermal and reed beds – Impact on organic matter characteristics. Journal of Environmental Management, 1-8. Doi:10.1016/j.jenvman.2016.05.070

Coulson J.M., Richardson J.F., Backhurst J.R., Harker J.H. (2002) Drying. In: Coulson and Richardson's Chemical Engineering (eds.) Fluid Flow, Heat Transfer and Mass Transfer. Butterworth-Heinemann, Oxford

DWA (2016, 2019). Topics T4/2016 - Design of wastewater treatment plants in hot and cold climates (EXPOVAL) - corrected version May 2019 (DWA - German Association for Water, Wastewater and Waste), Hennef, Germany.

Ficza I. (2010). Mathematical model of solar drying of sewage sludge. Master's Thesis, Faculty of Mechanical Engineering, Institute of Mathematics, Brno University of Technology, Brno, Czech Republic.

Fytili D., Zabaniotou A. (2008). Utilization of sewage sludge in EU application of old and new methods – A review. Renewable and Sustainable Energy Reviews, 12, 116-140.

Infosys Limited (2012). Infosys Sustainability Report 2012/13, Green Initiatives Team, Infrastructure Unit, Bangalore campus, Infosys, Karnataka, India.

IST-Anlagenbau GmbH (2012). Solar Drying of Sewage Sludge: An Old Method with Modern Technology using Wendewolf, Rheinweg 9, D-79395 Neuenburg.

Kawongolo J. (2010). Phase Change Boundary Condition for Heat Conduction Problem: The Drying Problem. College of engineering, Michigan State University, East Lansing, MI 48824-1226

LeBlanc R., Matthews P., Richard R. (eds.) (2008). Global Atlas Of Excreta, Wastewater Sludge, And Biosolids Management: Moving Forward The Sustainable And Welcome Uses Of A Global Resource. United Nations Human Settlements Programme (UN-HABITAT).

Léonard A., Blacher S., Marchot P., Pirard J.P., Crine M. (2005). Convective drying of wastewater sludges: Influence of air temperature, superficial velocity, and humidity on the kinetics Drying technology 23 (8), 1667-1679.

Majumdar A.S. (2006). Handbook of Industrial Drying. 3rd edition. CRC Press, 2006. ISBN 1-57444-668-1.

Mathioudakis V., Kapagiannidis A., Athanasoulia E., Diamantis V., Melidis P., Aivasidis A. (2009). Extended dewatered of sewage sludge in solar drying plant. Desalination 248(1–3), 733–739.

Mathioudakis V., Kapagiannidis A., Athanasoulia E., Paltzoglou A., Melidis P., Aivasidis A. (2013). Sewage sludge solar drying: experiences from the first pilotscale application in Greece. Dry. Technol. 31, 519-526

Meyer-Scharenberg U., Pöppke M. (2010). Large-scale solar sludge drying in Managua/Nicaragua. Wasser Abfall 12 (SI), 26-27.

Mondal M. and Weichgrebe D. (2014). Sewage Sludge Management Concept for the STPs of Commercial IT Campuses Operated by INFOSYS LTD., India. Master Thesis. Institute of Sanitary Engineering and Waste Management (ISAH), Leibniz Universität Hannover, Germany

Novak J. (2006). Dewatering of Sewage Sludge. Drying Technology, 24(10), 1257-1262.

Seginer I. and Bux M. (2005). Prediction of Evaporation Rate in a Solar Dryer for Sewage Sludge. Agricultural Engineering International: The CIGR Ejournal. 8, 1-8.

Seginer I. and Bux M. (2006). Modeling Solar Drying Rate of Wastewater Sludge, Drying Technology: An International Journal, 24:11, 1353-1363.

Seginer I., Ioslovich I., Bux M. (2007). Optimal control of solar sludge dryers. Dry. Technol. 25 (2), 401-415.

Shanahan E., Roiko A., Tindale N., Thomas M., Walpole R., Kurtböke I. (2010). Evaluation of Pathogen Removal in a Solar Sludge Drying Facility Using Microbial Indicators. Int J Environ Res Public Health; 7(2): 565–582

Speier C.J., Mondal M.M. & Weichgrebe D. (2018). Evaluation of compositional characteristics of organic waste shares in municipal solid waste in fast-growing metropolitan cities of India. J Mater Cycles Waste Manag 20, 2150–2162. https://doi.org/10.1007/s10163-018-0757-y

Thermo-System, Industrie- & und Trocknungtechnik GmbH. [online], [cit. 2010-05-21]. (URL: http://www.thermo-system.com/en/home/)

Traub D. (2002). The drying curve, part 2: applying the drying curve to your drying process. Process heating Magazine.

Werther J., Ogada T. (1999). Sewage Sludge Combustion. Progress in Energy and Combustion Science, 25, 55-116.

Weichgrebe D. (2015). Habilitationsschrift Kompendium Biogas, Veröffentlichungen des Institutes für Siedlungswasserwirtschaft und Abfalltechnik der Leibniz-Universität Hannover; Heft 155. ISBN: 978-3-921421-85-7.

Wiechmann B., Dienemann C., Kabbe C., Brandt S., Vogel I., Roskosch A. (2013). Sewage sludge management in Germany. Umweltbundesamt. Bonn, Germany.

Management of Municipal Solid Waste (MSW) in India

Sathish G.[1], Nishanthi R.[1], Moni M. Mondal[2], Dirk Weichgrebe[2], Srinivasan S.V.[1]*

[1]*Environmental Engineering Department, CSIR-Central Leather Research Institute, Chennai - 600020, India.*

[2]*Institute for Sanitary Engineering and Waste Management (ISAH), Gottfried Wilhelm Leibniz University, 30167 Hannover, Germany.*

**Corresponding author e-mail id: srinivasansv@yahoo.com, svsrinivasan@clri.res.in*

Abstract

Solid waste management (SWM) including generation, storage, collection, transportation, treatment and disposal of wastes has become the nation's primary concern as the population and generation of municipal solid wastes in India are in an increasing trend. The lifestyle of the people has also changed considerably and impacted the quality and quantity of solid waste in urban cities. Hence, the current conventional method of combined treatment and disposal of mixed municipal solid waste could not serve the current generation of MSW in urban areas and this gap needs to be filled with innovative treatment methods and strategic approaches. Therefore, various innovative approaches and research works are being carried out to meet the gap. Based on CSIR-CLRI expertise in tannery liquid and solid waste management especially using aerobic, anaerobic, membrane, phyco-remediation, advanced and thermal treatment methods, different strategies for treatment and disposal methods for municipal solid waste in urban areas have been planned and investigated under laboratory and pilot scale studies.

1. Introduction

Municipal solid waste (MSW) generation has increased globally and received much attention from researchers, technologist and policymakers. The increased generation of MSW, treatment and disposal methods have a significant impact on the environment especially ground water, odour nuisance, air pollution and emission of greenhouse gases. The United Nations summit on the environment have stressed the world to minimize the solid waste generation, maximize the environmentally sound waste disposal of waste with reuse and recovery [1]which is a consequence of day-today activity of human kind, needs to be managed properly. We face problems associated with poorly managed solid waste operation. Increased attention has been given by the government in recent years to handle this problem in a safe and hygienic manner. Most cities do not collect the totality of wastes generated, and of the wastes collected, only a fraction receives proper disposal. The insufficient collection and inappropriate disposal of solid wastes represent a source of water, land and air pollution, and pose risks to human health and the environment. Solid waste management is characterized by inefficient collection methods, insufficient coverage of the collection system and improper disposal. An integrated planning and capacity building is required backed by financial support to control the situation. Life cycle assessment, categorization, recycling and reduction in all types of wastes and proper land filling are required. This paper proposes a discussion about solid waste types, their Impact on Human Health and the Environment, structure of integrated solid waste and Solid Waste Policy.”,”author”:[{“dropping-particle”:””,”family”:”Sridevi”,”given”:”V”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Modi”,”given”:”Musalaiah”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Lakshmi-”,”given”:”M V V Chandana”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Kesavarao”,”given”:”L”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Tech”,”given”:”M”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””}],”container-title”:”International Journal of Engineering Science & Advanced Technology “,”id”:”ITEM-1”,”issue”:”5”,”issued”:{“date-parts”:[[“2012”]]},”page”:”1491-1499”,”title”:”a Review on Integrated Solid Waste Management”,”type”:”article-journal”,”volume”:”2”},”uris”:[“http://www.mendeley.com/documents/?uuid=39c93966-cfa5-47d3-9ec1-a1d71ef6f986”]}],”mendeley”:{“formattedCitation”:”[1]”,”plainTextFormattedCitation”:”[1]”,”previouslyFormattedCitation”:”(Sridevi et al., 2012. It also urged the world nations to avoid disposal of waste in open landfills. It is reported that the estimated quantity of 11.2 billion tonnes of solid waste globally every year resulting in contribution of about 5% of global greenhouse gas emissions due to decay of the organic proportion of MSW.

Asia alone generates about one-third of total global waste with significant contributions from China and India [2]transport, treatment and disposal. Current systems in India cannot cope with the volumes of waste generated by an increasing urban population, and this impacts on the environment and public health. The challenges and barriers are significant, but so are the opportunities. This paper reports on an international seminar on ‘Sustainable solid waste management for cities: opportunities in South Asian Association for Regional Cooperation (SAARC. India alone accounts for about 18% of the world’s human population and corresponding MSW generation is expected [3]. It is pertinent to mention that the solid waste management has direct impact on United Nations Sustainable Development Goals (SDGs) like Clean Water and Sanitation (SDG-6), Affordable and Clean Energy (SDG-7), Sustainable Cities and Communities (SDG – 11) and Climate action (SDG – 13) and indirectly on other SDGs like Good Health and Well-being, Life below water and Life on land.

Fig 1.
United Nations Sustainable Development Goals
(Source: https://www.un.org/sustainabledevelopment)

2. Composition of MSW in India

The nature and characteristics of MSW generated varies from country to country, region to region based on the geography and living habitat in that area. As per the Indian Central Pollution Control Board data, the per capita generation of solid waste has increased at an exponential rate from 0.26 kg/day to 0.85 kg/day [2, 4]transport, treatment and disposal. Current systems in India cannot cope with the volumes of waste generated by an increasing urban population, and this impacts on the environment and public health. The challenges and barriers are significant, but so are the opportunities. This paper reports on an international seminar on ‘Sustainable solid waste management for cities: opportunities in South Asian Association for Regional Cooperation (SAARC. It is reported that about 62 million tonnes of Municipal Solid Waste generated annually during 2016 in India, out of which, 82% was collected and only 28% was treated and disposed out of the total collected waste [5].

The composition of MSW also has significant impact on the waste management and treatment techniques. In India, generally MSW contains 40 - 60% of degradable organic matters, 30 to 50% of non-biodegradable inert matters and about 10 to 30% of the recyclables. It has been already reported that the generation of paper and plastic waste increased considerably [6, 7] and the changes in the composition of the waste over the years is given in Table 1.

Table 1
Composition of MSW over years

S.No	Year	Organic matter (%)	Paper	Plastics/ rubber	Metal	Glass	Rags	Others	Inerts
1.	1996	42.21	3.63	0.6	0.49	0.6	Nil	Nil	45.13
2.	2005	47.43	8.13	9.22	0.5	1.01	4.49	4.016	25.16
3.	2011	52.32	13.8	7.89	1.49	0.93	1	-	22.57

Source: [4, 7, 8]an attempt is made to evaluate the major parameters of MSWM, in addition to a comprehensive review of MSW generation, its characterization, collection, and treatment options as practiced in India. The current status of MSWM in Indian states and important cities of India is also reported. The essential conditions for harnessing optimal benefits from the possibilities for public private partnership and challenges thereof and unnoticeable role of rag-pickers are also discussed. The study concludes that installation of decentralized solid waste processing units in metropolitan cities/towns and development of formal recycling industry sector is the need of the hour in developing countries like India.","author":[{"dropping-particle":"","family":"Joshi","given":"Rajkumar","non-dropping-particle":"","parse-names":false,"suffix":""},{"dropping-particle":"","family":"Ahmed","given":"Sirajuddin","non-dropping-particle":"","parse-names":false,"suffix":""}],"container-title":"Cogent Environmental Science","id":"ITEM-1", "issue":"1", "issued": {"date-parts": [["2016"]]}, "page": "1-18","title": "Status and challenges of municipal solid waste management in India: A review","type":"article-journal","volume":"2"},"uris":["http://www.mendeley.com/documents/?uuid=91e898f4-3fe5-474a-9d07-652b777ba1da"]},{"id":"ITEM-2","itemData":{"DOI":"10.1061/(asce

The daily MSW generation of major urban cities in India are shown in Fig. 2 [5, 9]the exponential population growth, high density of urban areas, diverse culture, changing food habits, and lifestyles have seen an unresolved problem in terms of Municipal Solid Waste Management (MSWM. The amount of MSW generated state-wise and union territories are given in Table 2 [8]**urbanization, and population. However, another aspect of higher economic development has resulted in increased waste generation and consumption of natural resources, and hence ecological degradation and pollution. As awareness increases of the detrimental effects of currently used waste disposal methods on the environment, accountability is needed for an effective waste management system. This paper presents the existing situation of municipal solid waste (MSW**. There is considerable improvements in the collection and treatment of solid wastes in most of the states and union territories.

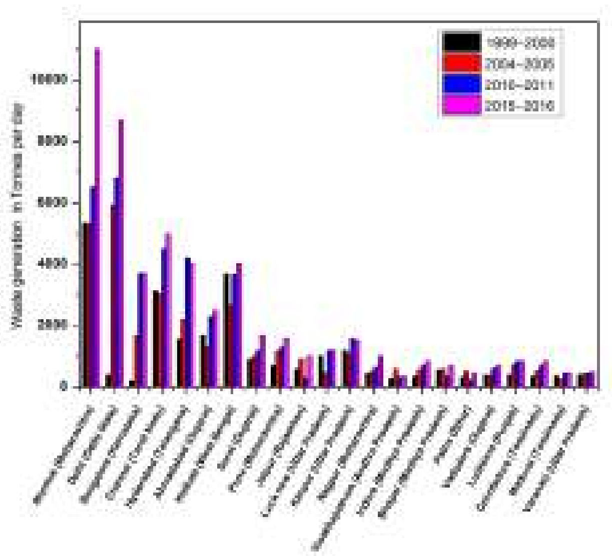


Fig 2
Generation of solid waste from urban cities of India (Tonnes per day)

Table 2
Amount of waste treated per day in states and union territories in India

S. No	State and Union Territories	2010 Treated in MT/day	2015 Treated in MT/day
1.	Andaman & Nicobar	-	5
2.	Andhra Pradesh	3,656	9,418
3.	Arunachal Pradesh	-	74
4.	Assam	73	100
5.	Bihar	-	-
6.	Chandigarh	300	250
7.	Chhattisgarh	250	168
8.	Daman Diu & Dadra	-	-
9.	Delhi	1,927	4,150
10.	Goa	-	182
11.	Gujarat	873	1,354
12.	Haryana	-	570
13.	Himachal Pradesh	153	150

S. No	State and Union Territories	2010 Treated in MT/day	2015 Treated in MT/day
14.	Jammu & Kashmir	320	320
15.	Jharkhand	50	65
16.	Karnataka	2,100	2,000
17.	Kerala	4	470
18.	Lakshadweep	4.2	-
19.	Maharashtra	2,080	4,700
20.	Manipur	3	-
21.	Meghalaya	100	98
22.	Mizoram	-	-
23.	Madhya Pradesh	975	802
24.	Nagaland	-	18
25.	Orissa	33	30
26.	Puducherry	-	-
27.	Punjab	-	32
28.	Rajasthan	-	490
29.	Sikkim	32	0.3
30.	Tamil Nadu	603	1,607
31.	Tripura	40	-
32.	Uttar Pradesh	-	5,197
33.	Uttaranchal	-	-
34.	West Bengal	607	1,415

(Source: [8]**urbanization, and population. However, another aspect of higher economic development has resulted in increased waste generation and consumption of natural resources, and hence ecological degradation and pollution. As awareness increases of the detrimental effects of currently used waste disposal methods on the environment, accountability is needed for an effective waste management system. This paper presents the existing situation of municipal solid waste (MSW)**

During the start of twentieth century, the landfilling and open dumping have become common disposal method for solid waste generated in urban cities. However, with considerable increase in population and per capita solid waste generation, environmental pollution and land issues caused concern to the municipal administrators. In addition, the gas emitted from the landfill sites have become an major contributor and the landfills alone accounts for 5% of the global greenhouse gas (GHG) emissions and also for spreading of anthropogenic diseases. The landfill gases are methane and carbon-di-oxide which are produced during aerobic and anaerobic degradation process of organic fractions of solid waste [10–12]detailed information on the variation over time of the concentration and the load in wastewater effluents and rivers and on the fate of these compounds in the aquatic environment are lacking. We measured the concentrations of six pharma- ceuticals, carbamazepine, clofibric acid, diclofenac, ibuprofen, ketoprofen, and naproxen, in the effluents of three wastewater treatment plants (WWTPs.

3. Hierarchy of MSW

The Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India revised Solid Waste Management Rules in 2016, in supersession of Municipal Solid Waste Rules 2000, to improve the collection, segregation, recycling, treatment and disposal of solid waste in an environmentally sound manner. The hierarchy of treatment and disposal options of MSW is shown in Fig. 3. In this hierarchy, source reduction, reuse, recycling and composting are the most preferred methods followed by waste to energy and landfills which are less preferred methods.

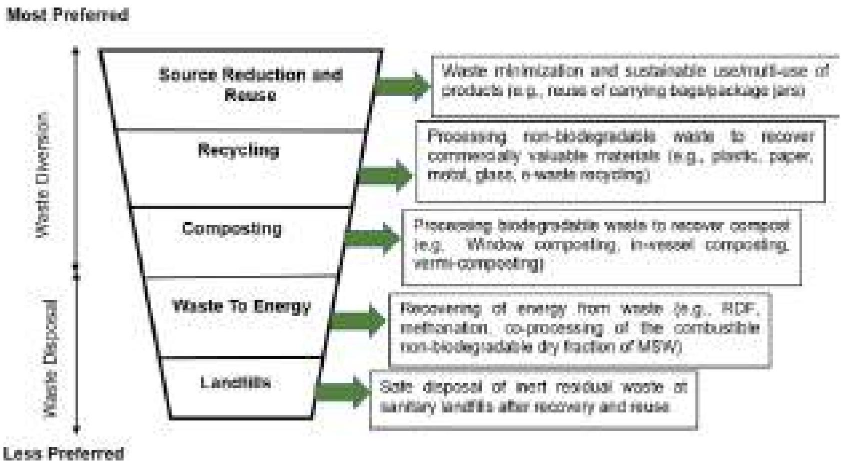


Fig 3
Hierarchy of MSW

The success of source reduction, reuse and recycling methods depends on the waste generators and consumers behaviour while the composting method requires proper segregation of organic waste by waste generators and also availability of considerable land area in the city. The city administers have limited role in the success of these MSW treatment and disposal methods. But these methods requires less capital investment and operation and maintenance cost. Next alternative of MSW treatment and disposal in hierarchy is Waste To Energy (WTE), which is practised by developed countries. But this incineration technology of WTE could not be successfully demonstrated in India due to poor quality of MSW (low calorific value) generated in early 90's at New Delhi [13]. However, it is observed that there has been considerable change in the quality of wastes (increase in calorific value of wastes) in developing countries like India due to change in life style and packaging system used. Some of research studies carried out by B. J. Alappat and his team at IIT, Delhi showed that there is increase in incinerablity of wastes and hence many WTE plants has been installed and operated in India [14]consequently, aimed at waste minimisation with material and energy recovery. Rising MSW generation rates, acute shortage of land resources and improving thermal characteristics have collectively contributed to the growth of waste-to-energy sector in developing countries like India. Negligible source segregation and the resultant heterogeneity of the MSW necessitate ascertaining its incinerability to assess the feasibility of the technology. Incinerability index or i-Index is, hence, used to estimate the incinerability of MSW generated in cities across the Indian sub-continent. An incinerability-based map is developed to illustrate the variations in incinerability across the country. The lifestyle habits, topography, income level of the residents, culture and food habits are found to affect the composition and in turn the incinerability. The variations in incinerability of MSW generated in the northern, southern, eastern and western regions are graphically identified using incinerability plot or i-Plot. The reported power generation potential from MSW in Indian states is also found to be consistent with the incinerability of the MSW feed and the daily waste generation rates. Graphic abstract: [Figure not available: see fulltext.]”,”author”:[{“dropping-particle”:””,”family”:”Sebastian”,”given”:”Roshni Mary”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Kumar”,”given”:”Dinesh”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””},{“dropping-particle”:””,”family”:”Alappat”,”given”:”Babu”,”non-dropping-particle”:””,”parse-names”:false,”suffix”:””}],”container-title”:”Clean Technologies and Environmental Policy”,”id”:”ITEM-1”,”issue”:”1”,”issued”:{“date-parts”:[[“2020”]]},”page”:”91-104”,”publisher”:”Springer Berlin Heidelberg”,”title”:”Mapping incinerability of municipal solid waste in Indian sub-continent”,”type”:”article-journal”,”volume”:”22”},”uris”:[“http://www.mendeley.com/documents/?uuid=153aa63e-e0e2-43b4-a4de-65dfe29d4442”]}],”mendeley”:{“formattedCitation”:”[14]”,”plainTextFormattedCitation”:”[14]”,”previouslyFormattedCitation”:”(Sebastian et al., 2020.

Apart from WTE through incineration, biomethanisation of MSW has been implemented in many cities of India with different capacities ranging from 1 tonnes to 30 tonnes per day in decentralized approach. Some of cities (like Pune, Goa) are operating the biogas plant successfully with proper segregation of solid wastes but most of these biogas plants in other cities are facing problems due to lack of proper segregation of organic fractions of MSW or other issues like lack of proper pre-treatment of wastes [9]the exponential population growth, high density of urban areas, diverse culture, changing food habits, and lifestyles have seen an unresolved problem in terms of Municipal Solid Waste Management (MSWM. In addition to WTE through incineration and biomethanisation, mechanical processing plant for Refused derived fuel (RDF) also been implemented in some of cities and RDF is being sold to many industries including cement factories [15].

With respect to landfill, it is least preferred disposal methods for inert wastes after recovery of recyclables and reusables and segregation of organic fractions. It is pertinent to mention that some of states and major cities have taken up the task of restoring the environment around landfills and open dumpsites i.e., existing legacy landfills which is filled with unsegregated mixed solid wastes for past 20 or more years. The current task of cleaning is being addressed in many cities under bio-mining concept based on the first success story in small town of Kumbakonam, Tamil Nadu, India [16, 17].

Under these circumstances of different options available for treatment and disposal of solid wastes and gaps / difficulties faced by the waste managers of cities for successful management of MSW generated in India, the various innovative approaches and research works are explored by research team at CSIR-CLRI, Chennai, India and ISAH, Leibniz university, Germany to fill the gap in waste management. Based on the joint study, it was identified in the Chennai city that many bulk organic generators like vegetable market, flower market, fruit market, slaughter house, fish markets, hotels and restaurants, canteen of schools, college and large commercial establishments, chicken shops etc., are available which are fully organic in nature which could be potentially treated by biological methods like composting and biomethanisation. In addition, the quantity, characteristics mainly in terms of Carbon/Nitrogen (C/N) ratio, biomethane potential (BMP) and their location of availability of these bulk organic wastes were studied. Based on the quantity, C/N and BMP of bulk waste and its availability in the particular location, potential amount of biogas that can be generated has been estimated with and without considering the residential organic fractions of MSW within the radius of about 5 km to reduce the cost of transportation. The composting of these bulk organic solid wastes was not possible due to space constrains in urban areas [18]. Research outcomes including the pilot scale studies with co-digestion of vegetable market and slaughter house wastes have been illustrated in detailed manner in another chapter of this book on the "SMART city concepts for treatment of and resource recovery from municipal organic wastes: Experiences from IGSTC 2+2 projects on joint study by this Indo-German research consortium".

It is pertinent to mention that some of the bulk organic wastes like banana peduncle, sugarcane bagasse, tender coconut etc., generated in urban areas are not suitable for biomethanisation due to fibrous nature and presence of non-biodegradable lignin content in the wastes. Further, the sludge generated from sewage treatment plants (STPs) in urban areas also contain pathogens which needs to be thermally treated for safe disposal. In order to address the treatment and disposal of fibrous and lignin containing bulk organic solid wastes and pathogen containing STP sludge, an innovative method of co-pyrolysis of fibrous waste and STP sludge has been suggested based on the studies carried by this Indo-German research consortium. Further, to meet the initial moisture of wastes (10 - 20%) of pyrolysis, accelerated solar drying has been suggested which is more suitable for tropical countries like India. It is appropriate to mention that the end product of pyrolysis is biochar and energy. This energy could be used for various applications including for drying/ reducing the moisture of feed wastes into pyrolysis system. Biochar could be used as soil amendments for providing organic carbon and nutrients to soil. In addition, this method of pyrolysis also ensures carbon sequestration which help in meeting reducing the carbon footprint. Research outcomes including the proposed pilot scale studies with co-pyrolysis of fibrous waste and sewage sludge are also illustrated in detailed manner in another chapter of this book on "SMART city concepts for treatment of and resource recovery from municipal organic wastes: Experiences from

IGSTC 2+2 projects on joint study by this Indo-German research consortium" on joint study by this Indo-German research consortium.

4. Integrated Solid Waste Management (ISWM)

Based on the research outcomes of these studies, the integrated approach for treatment and disposal of MSW as shown in Fig. 3 has been suggested for developing countries like India. This integrated approach would meet the requirements of National Missions like Swachha Bharat, Smart City and also meet United Nationals SDGs (like Clean Water and Sanitation (SDG-6), Affordable and Clean Energy (SDG-7), Sustainable Cities and Communities (SDG – 11) and Climate action (SDG – 13) and indirectly on other SDGs like Good Health and Well being, Life below water and Life on land).

Fig 3
Integrated approach for treatment and disposal of bulk organic fractions of MSW

5. Conclusions

In order to meet the increasing generation of MSW, the suggested integrated approach for treatment and disposal of organic fractions of MSW is more appropriate and suitable meeting the requirements of National and UN Sustainable Development Goals. The end products of biomethanisation system i.e., biogas and digestate could be very well used for various applications. Similarly, biochar and energy obtained from pyrolysis system also could be used for various applications. This integrated approach insures safe and sustainable disposal of organic fractions of MSW and leaving no residual wastes for disposal in landfill under Zero Waste concept.

Acknowledgements

The authors are grateful to Director, CSIR - Central Leather Research Institute (CLRI) for providing the lab facilities and permitting this research work. The authors also thank Indian and German Industrial partners (M/s. Ramky Enviro Engineers Ltd., India, M/s. Lehmann-UMT GmbH, Germany and M/s. Biomacon Gmbh, Germany) for their support in this 2+2 projects (RESERVES and PYRASOL). The authors also acknowledge ISAH team, Leibniz University, Hannover, Germany for their technical support for this work. The authors acknowledge the Indo-German Science and Technology Centre (IGSTC) under Department of Science and Technology (DST) and the German Federal Ministry of Education and Research (BMBF) for funding the RESERVES (Grant no. 01DQ15007A) and PYRASOL (Grant no. 01DQ18001A) projects within the IGSTC 2 + 2 Project Framework.

References

Sridevi V, Modi M, Lakshmi MVVC, et al (2012) a Review on Integrated Solid Waste Management. Int J Eng Sci Adv Technol 2:1491–1499

Kumar S, Smith SR, Fowler G, et al (2017) Challenges and opportunities associated with waste management in India. R Soc Open Sci 4:. https://doi.org/10.1098/rsos.160764

Rajkumari BP (2022) Delhi-based EcoEx is regulating the waste management process in India. 1–10

Central Pollution Control Board (2020) Annual Report

MNRE (2016) Twentieth Report: Ministry of New and Renewable Energy. 1938:

Gupta N, Yadav KK, Kumar V (2015) A review on current status of municipal solid waste management in India. J Environ Sci (China) 37:206–217. https://doi.org/10.1016/j.jes.2015.01.034

Joshi R, Ahmed S (2016) Status and challenges of municipal solid waste management in India: A review. Cogent Environ Sci 2:1–18. https://doi.org/10.1080/23311843.2016.1139434

Sharma KD, Jain S (2019) Overview of Municipal Solid Waste Generation, Composition, and Management in India. J Environ Eng 145:04018143. https://doi.org/10.1061/(asce)ee.1943-7870.0001490

Kumar A, Agrawal A (2020) Recent trends in solid waste management status, challenges, and potential for the future Indian cities – A review. Curr Res Environ Sustain 2:100011. https://doi.org/10.1016/j.crsust.2020.100011

Parthasarathy P, Narayanan SK (2014) Effect of Hydrothermal Carbonization Reaction Parameters on. Environ Prog Sustain Energy 33:676–680. https://doi.org/10.1002/ep

Bogner JE, Spokas KA, Chanton JP (2011) Seasonal Greenhouse Gas Emissions (Methane, Carbon Dioxide, Nitrous Oxide) from Engineered Landfills: Daily, Intermediate, and Final California Cover Soils. J Environ Qual 40:1010–1020. https://doi.org/10.2134/jeq2010.0407

Omar H, Rohani S (2015) Treatment of landfill waste, leachate and landfill gas: A review. Front Chem Sci Eng 9:15–32. https://doi.org/10.1007/s11705-015-1501-y

Ritu Gupta (2006) Timarpur waste management company in Delhi set to revive plant. Down To Earth 2–3

Sebastian RM, Kumar D, Alappat B (2020) Mapping incinerability of municipal solid waste in Indian sub-continent. Clean Technol Environ Policy 22:91–104. https://doi.org/10.1007/s10098-019-01771-4

CPHEEO (2018) Guidelines on Usage of Refuse Derived Fuel in Various Industries. 1–104

L.Renganathan (2016) Kumbakonam Municipality adopts bio mining , reclaims garbage dump 7 Start 14 Days Free Trial or Subscribe to The Hindu. 5–7

Kartik Kapoor (WtERT) (2015) Biomining of a Landfill in Kumbakonam , India. 5–7

Velusamy M, Speier CJ, Michealammal BRP, et al (2020) Bio-reserves inventory—improving substrate management for anaerobic waste treatment in a fast-growing Indian urban city, Chennai. Environ Sci Pollut Res 27:29749–29765. https://doi.org/10.1007/s11356-019-07321-1

Performance of the Anaerobic Digester (AD) for Municipal Solid Waste (MSW) Treatment at Goa, India

Aparna Kapoor
SFC Environmental Technologies Pt. Limited., Navi Mumbai, India

Abstract

Bio-methanation of the organic fraction in municipal waste is a key treatment process, which can be effectively used for treating municipal waste having more than 50% organic fraction. This process is also prescribed by the Indian statutory framework, SWM 2016 rules. Effectiveness of the process solely depends on pre-treatment and preparation of the mixed waste using extraction techniques, which not only extracts 95% of the organics but also makes a pulp of the organic material. The organic material is anaerobically digested to produce methane gas which is then used to generate electricity in gas engines. Excellent results have been obtained from the anaerobic digester (AD) working for last 6 years at the municipal solid waste treatment plant at Calangute/ Saligoan Goa. This article explains the key design features used for designing the AD unit. By effectively deploying extraction techniques AD process is the solution to treat Indian waste and generate green power. Alternatively, biogas can also be converted to compressed biogas (CBG) for other applications.

Keywords: Bio methanation, Anaerobic Digestion (AD), Thermophilic, Organic Extruder (OREX), Extraction, Refuse derived fuel (RDF), Volatile fatty acids (VFA), Alkalinity, Methane

1. Introduction

The State of Goa has installed a modern MSW treatment plant comprising waste segregation and anaerobic digestion (AD) which treats the incoming wet waste / garbage and converts it into useful products like electricity and compost.

Besides the AD process, the MSW treatment plant also treats the inorganic dry waste, by recycling 10 nos. of different recyclable fractions like paper, plastic film, hard plastics, PET bottles, glass, metal, cloth, tetra packs, coconut, rubber & leather articles, and aluminium cans. These items are sold to recycling vendors.

The complete plant treats 150 to 170 tons per day of incoming municipal solid waste out of which wet organic waste is 70-90 TPD. This fraction is fermented in the AD process, to generate electricity via the bio-methanation route. Surplus electricity is exported to the State electricity grid. The residual digestate is compost and is used by the farmers and local organizations for green belt development.

The residual non- recyclable inorganic product is sent to cement factories as Refuse derived fuel (RDF) having 3000 plus Kcal/kg calorific value. RDF is Used by Cement Companies for co-processing in their cement manufacturing process. Less than 10% inert, sand, grit is sent to the sanitary landfill. Part of this inert fraction is used as construction material for building of roads, bridges, buildings etc. Process flow diagram for the MSW Treatment plant is given in Fig. 1. The resource recovery from the plant is given in Table 1.

Table 1
Outputs generated from the plant

Sl. No	Resource or Output from treatment of MSW	% of Input waste
1	Recyclables like paper, plastic, cloth, rubber, glass, metal etc. sold to recycling vendors	5 to 8%
2	Compost sent to farmers	5 to 8%
3	Electricity generated used to operate the plant and excess power is exported on the grid	8000 Kwh/day
4	RDF sent to cement companies for co-processing, and used as a low-grade fuel for coal replacement	25 -30 %
5	Inert fraction sent to construction sites and land fill	Less than 5%

2. The Anaerobic Digestion Process:

A two - stage thermophilic anaerobic digestion system is provided, in which microorganisms break down biodegradable material in the absence of oxygen. The process provides volume and mass reduction of the input organic material while generating useful products like biogas and a nutrient rich solid, which can be used as compost.

The stage 1 of the AD process is a buffer tank and stage 2 are the main digester tank with gas holder on top of the tank to store biogas (Fig.2). The digester comprises 3 tanks (with common wall) each of 5 m wide by 15 m long with paddle mixers / agitators inside it to keep the contents in a mixed condition. The 3 numbers of tanks provide redundancy in case of cleaning the tanks or during agitator maintenance.

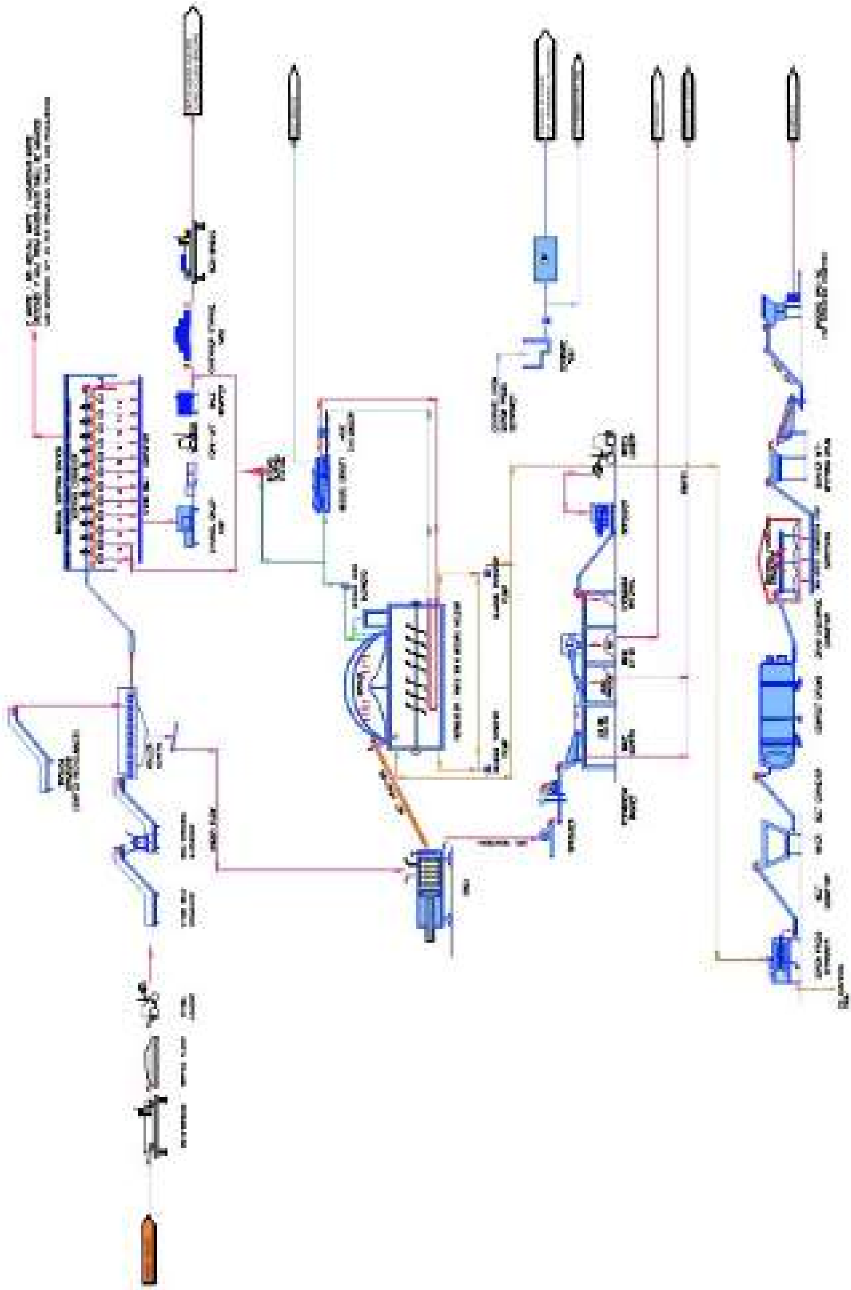


Fig. 1
Process Flow Diagram for the MSW Treatment plant:

The two principal products of anaerobic digestion are

Fig.2
AD tanks with gas holder, Paddle agitator inside the digester tank

biogas and digestate. Biogas comprises 60 to 65% methane, 35% Carbon-di-oxide and traces of moisture, hydrogen, ammonia, and hydrogen sulphide. The gas is passed through a bio-scrubber to remove hydrogen sulphide and a chiller unit to remove moisture. This cleaned gas is then used in a gas engine to generate electricity.

2.1 Preparation of feed into the Digesters (AD process) using the Organic Extruder (OREX)

The wet waste comprises 60-75% of organic material and 25-40% of the fraction is paper, plastics, metal, packaging material, rags etc. To feed this material into the AD process stage 1 (buffer tank) the wet fraction (95% organic) must be extracted from the waste, pulped, and mixed with water to form a 10-12 % solid concentration slurry. This is the most critical step and is achieved in the organic extruder press unit in a single step automatic process. By using the OREX unit the wet / or organic fraction is extracted from the inorganic/ dry fraction in the waste (Fig3).

Mixed Municipal Solid Waste

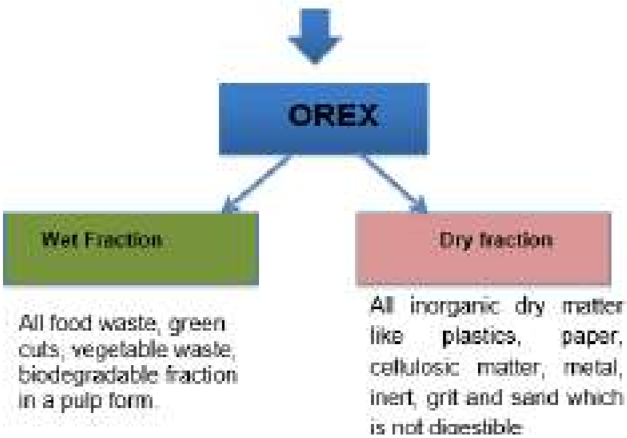


Fig.3
Wet fraction as pulp after extraction

The wet fraction from the extrusion unit is pumped into a hydro-cyclone system- to remove any grit, stones, and heavy particles from the wet fraction prior to feed into the AD process. Parameters maintained inside the AD unit is given in Table 2.

Table 2
Parameters maintained inside the AD unit

Sno.	Parameter	Range
1	pH	Buffer tank: 2 – 3 Digesters: 6.7 to 7.3
2	Temperature	48 to 52 deg. Celsius
3	VFA/Alkalinity ratio	0.25 to 0.4
4	TSS % Concentration	8 to 10%
5	HRT	15 to 17 days
6	VSS loading rate	5 to 7 kg/day/m3

The organic fraction is 65-75 % stabilized in the digester via VSS destruction and biogas yields are high. The sludge or the digestate is taken out at about 5 to 7% consistency and dewatered in a centrifuge to up to 20% solids consistency.

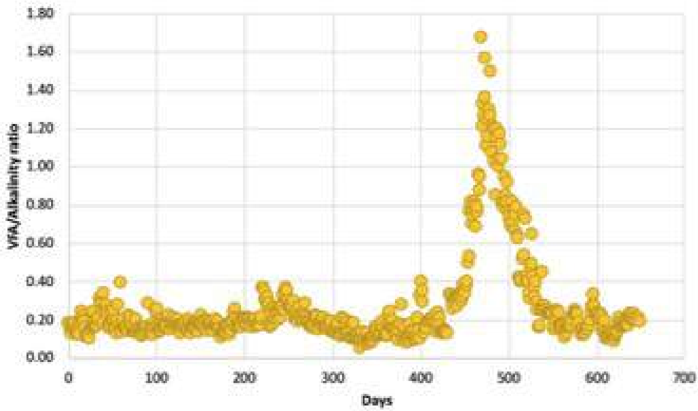


Fig.4
VFA/Alkalinity ratio less than 0.3

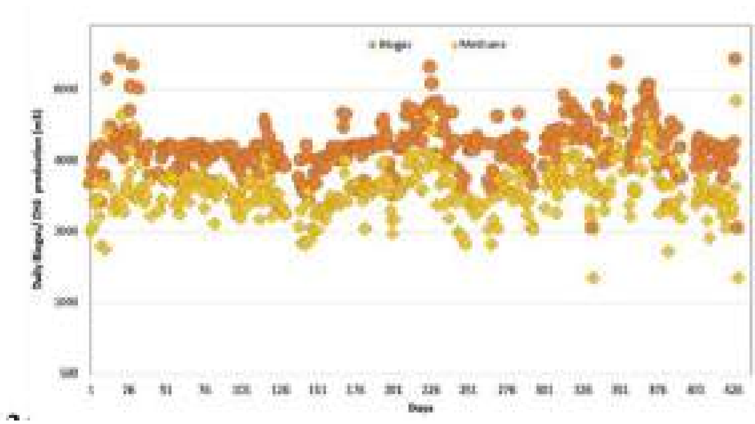


Fig. 5
Methane % in biogas more than 60%

The centrate is then taken to the nearby STP for disposal. The dewatered sludge is mixed with residual reject fraction from the OREX and taken into the in-vessel composting drum for further stabilization of the sludge into a good quality compost/soil conditioner. Alternatively, it can also be stored in windrows, for degradation of the organics and then screened for extracting good quality of compost. The reject fraction is RDF which needs to be disposed of to cement/ power plants.

Fig. 6
Gas engines and electricity production

The Biogas is cleaned and taken into 2 Nos of 172 KW biogas engines for electricity generation (Fig. 6). Excess power is exported on the Goa State electricity board.

3. Conclusions

Goa MSW plant is the first of its kind, in India which has been working successfully for the last 6 years (since August 2016) using AD process to treat the wet MSW and convert it into electricity and compost. The plant is being expanded to treat 250 TPD of MSW for the norther region of Goa. By using this technique, the State of Goa has effectively found a method to take care of their garbage problem and are also 100% complaint as per SWM 2016 rules.

References

Data collected from the MSW treatment plant at Calangute / Saligoan Goa – SFC Environmental Technologies Pvt limited in coordination with Department of Civil Engineering IIT Roorkee.

Tyagi V.K. Aparna Kapoor, Pratham Arora, Rajesh Banu J, Sukanya Das, Shubham Pipesh and Kazmi A.A. (). Mechanical biological treatment of municpal solid waste: Case study of 100 TRD Goa Plant, India. Journal of Environemntal Management.

[a] Environmental Biotechnology Group (EBiTG), Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, 247667, India [b] SFC Environmental Technologies Pvt Limited, Vashi, Navi Mumbai, India [c] Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, Roorkee, 247667, India[d] Department of Life Sciences, Central University of Tamil Nadu, Neelakudi, Tiruvarur, Tamil Nadu, India [e] Department of Policy Studies, TERI School of Advanced Studies, New Delhi, 110070, India

Digital Modelling of Solid Waste Management – Application of the TOSCA Toolkit in the Indian Urban Development Context

Jörg Rainer Noennig, Arjama Mukherjee, Maria Dale Moleiro
Digital City Science, HafenCity University Hamburg (HCU), Germany

Abstract

Drawing on the background of smart city policies and general digitalization in the context of urban development in India, the paper discusses the potentials of data-driven tools for city planning and analysis. Exploiting the growing sources of geospatial and sociographic data, promising strategies for intelligent solid waste management on urban level can be lined out. Establishing a cross scale approach towards waste management, spanning from the source level to the larger scale of a city, can offer deep insights into patterns of waste created in a city, waste streams, types of waste, thus expanding the decision-making capacities for city authorities and local governments. To this end, digital tools play a central role which, on the one hand, enable the comprehensive convergence of complex urban data, but on the other also facilitate the inclusion and participation of a multitude of stakeholders and decision makers, including the wider public. On this background, the text introduces the Toolkit for Open and Sustainable City Planning and Analysis (TOSCA) – an open source GIS software developed by HafenCity University Hamburg – as framework for the development of specific solid waste management use cases, and their local-specific application in Indian cities.

Keywords: Urban development, Smart city, GIS, Machine Learning, India

1. Introduction and Background

India is undergoing an upheaval in a sweeping digital revolution in the last few years. 1.2 billion people are now registered on Adhar, the national bio-metric identity program announced in 2009. More than 80 percent of Indian adults have at least one digital financial account. India has more than 450 million mobile internet users and is expected to grow to 667 million by 2022 (Rao 2019), second only to China. With one of the lowest data costs in the world, the trend is set to continue. In 2020, approximately a third of

Indians lived in cities, the trend is only set to grow. This explosion of urbanisation is being met with equal rigour by the Indian government where focus had radically shifted to urban policies, programs and digitalisation.

Various digital platforms like India Urban Data Exchange (IUDX) and Smart Cities Open Data Portal (under the Smart Cities Mission) and SmartCode allow new levels of sharing urban data between data producers and data consumers. These digital reforms are aimed at improving conditions of urban areas to address long pending issues of data availability, development of custom solutions and capacity building of stakeholders. In 2021, a National Geospatial Policy was launched to develop the geospatial ecosystem in the country and intends to make it easier to create and share geospatial data.

At the same time, exploding urbanisation has also put pressure on current urban local bodies where solid waste management has emerged as a major problem, especially in cities with high population density. There is an urgent need for a move towards sustainanable solid waste management, this requires new management systems and waste management facilities (Kumar et al. 2017).

2. The role of Spatial digital technologies in Indian Urban Waste Management

Urban planning is traditionally a technocratic, top-down process in India. More often than not, planning tools like the Master Plan are not in touch with ground realities. However, there have been a few changes in the last decades with some governments and civil society trying to use participatory models of planning. The overwhelming response to the citizen engagement component of the Smart Cities Mission in India highlighted the fact that digital technology plays and will continue to play an important role in the sphere of engaging citizens in the future as well. The openness to digital technology of citizens and huge demographic advantage of a young population coupled with affordable internet and a strong IT base makes this possible in India.

Urban planning and waste management being a spatial subject, is automatically signifying the urgent need of spatial information in the use of digital tools. While digital tools have huge potential to reach a large number of people, which is crucial in a country with a high population like India, spatial information can further reduce barriers such as languages, social boundaries and allow citizens to relate to spatial characters, see patterns and eliminate the complication of scale (particularly in the case of digital maps which can be zoomed out or in as required) thereby also contributing to creating data invaluable to public authorities. These factors are particularly crucial in an extremely diverse country like India with multiple languages, social differences and diverse characteristics. Mapping has already been identified as a crucial tool by the Main Bhi Dilli Campaign, Janaagraha and Shelter Associates.

Connected online and on-site experiments and pilot projects have indicated the effectiveness of interactive digital tools that make spatial data accessible to local people and communities. For example, the project U_CODE (run by the TU Dresden Laboratory of Knowledge Architecture and funded by the EU Horizon 2020 program) and Pulse (India Smart Cities Fellowship) designed a novel digital work environment to facilitate the co-creative redesign of a 10 year old dumpsite that was selected in a neighbourhood of the city of Pimpri Chinchwad in India that was cleaned so citizens could present new design ideas (Noennig et al. 2020) (Fig.1). The experiment showed how spatial information and maps can very effectively aide communication due to the visual nature of information, and the technical affordance of an interactive digital system.

Fig. 1 U_CODE / Pulse pilot application of a digital interactive system for citizen co-design of a waste dumpsite in Pimpri Chinchwad (2019) (Source: TU Dresden Knowledge Architecture)

3. New Approaches to Digital Waste Management

Digitalisation has made collection of large amounts of data easier, however, a huge amount of data signifies the need to analyse data in such way that they become usable and value-creating. Thus, data analytics plays a huge role in extracting information, identifying patterns, discovering trends and so on to make insights from the data collected understandable- where visualisation plays an important aspect of data analysis as well (Hick et al. 2018). Even though it is not always apparent at first glance, data analytics plays an important role in the recycling industry - examples could be the evaluation of sensor data for automated sorting plants, control of waste incineration plants, or the monitoring of waste quantities and material flows at the regional or national level (Berg et al. 2020).

Deep learning AI based image recognition models can be a starting point to identify waste that is being collected on a conveyor belt (Fig. 2). These types of models can automatically identify dry waste and categorise them into different types e.g. plastics, paper, glass, cardboard and so on. While this works only for dry waste, it is still an eminent step towards identifying waste automatically at source, thereby, cutting out the need for manual sorting and eliminating hygiene issues. This type of data can be easily pre-processed and parsed so that it creates labels for the datasets to be used in geographical information systems (GIS) leading to identification of waste at the city level. Generating this cross scale approach of waste collected from the source level to the larger scale to a city level can offer deep insights into patterns of waste created in a city, waste streams, types of waste and expand the decision-making capacities in the area of solid waste management for city authorities and local governments.

Fig. 2 Image processing of dry waste using deep learning AI models (Source: towardsdatascience.com)

Once this data is ingested in GIS systems, the data can be analysed in various ways such as filtering specific waste types, calculating routing options for waste-collection trucks, calculating catchment areas. When updated in real-time, such tools may become invaluable for decision-makers and waste management companies (Lopez-Baeza et al. 2021). An integrated view of waste data overlaid with other socio-economic data in cities (Fig. 3) leads to valuable insights for decision-makers, whereas new user-friendly spatial tools and technologies can help cities prepare visions and strategies. Ideally, such tools and technologies are prepared and applied in a way that communities not need to hire technicians to run the investigations when needed. A common practice of capacity building here is to engage for a short period of time an expert who teaches the community members the particular software, and enables them in the long run for an independent usage (Falco 2016).

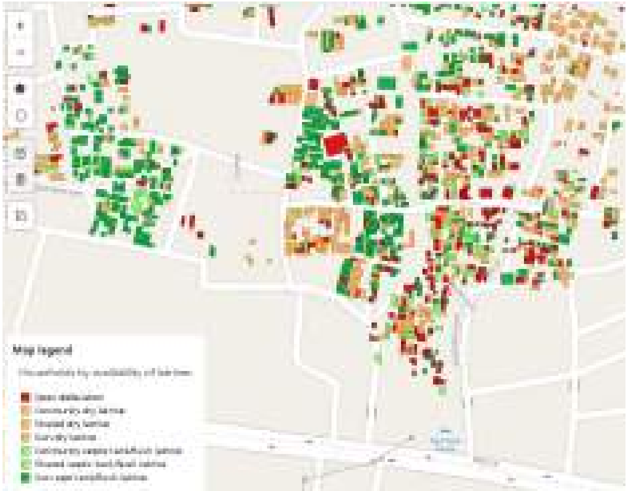


Fig. 3 Mapping of households by availability of latrines in TOSCA Toolkit for Open and Sustainable City Planning and Analysis (Source: HCU Digital City Science)

4. Toolkit for Open and Sustainable City Planning and Analysis (TOSCA)

New and recent developments in open data, open-government and ICT have allowed positive outcomes, for example mapping technologies, Public Participation GIS (PPGIS), blogs and social media, decision support systems and simulation technologies. Thus, user-friendly, free, open-source software and open data are tools to empower governments and citizens allowing them to produce their own community waste management plans (Stelzle et al. 2021). The Toolkit for Open and Sustainable City Planning and Analysis (TOSCA) has been developed within a cooperation project between the Digital City Science at HafenCity University Hamburg and German Association for International Cooperation (Gesellschaft für Internationale Zusammenarbeit GIZ) in India and Ecuador. Further partners were the municipal administrations in Ecuador and India, local tech companies and universities. The first phase of the project ran for 1.5 years between autumn 2019 and spring 2021. The outcome of this R&D cooperation is a web-based geographic information system (GIS) for multi-touch tables that is optimised for the use by non-GIS-experts. It can support integrated and participatory urban planning processes anywhere in the world, fostering dialogue between governments and citizens and exchange of knowledge and data between government departments.

The software for this project is based entirely on open-source-components (GRASS GIS and GeoServer for the spatial calculations and analyses in the background, Node.js and Angular for the user interface and internal communication between the systems) and has been made available as open-source-software.

The Toolkit has been piloted in two cities: 1. Bhubaneswar, India (identification of land for affordable housing) and 2. Latacunga, Ecuador (volcanic risk governance strategies). It is tailored to the local planning requirements of these two pilot cities, but at the same time offers open interfaces for the development of further functionalities in new contexts.

Fig. 4 The three basic components of TOSCA: Interactive touchtable-interface, GIS-Software, Tutorials / Manuals (Source: HCU Digital City Science)

The infrastructure of TOSCA can be broken down into three components, meaning hardware, software and online support information. The hardware consists basically of a multi-touchtable device, with the characteristic of allowing to process highly complex data through easy-to-understand visualizations (Fig. 4). In addition, the advantage of the touchtable is the possibility to have a hands-on manipulation of the available data, among different users, therefore reducing significantly the time dedicated to iteration and thus facilitating consensus for decision-making processes for city planning and regional governance.

The idea of the software is relatively simple. There is a frontend communicating to the user and displaying results as maps, data, and graphs, and there is a backend processing calculations, queries, data storage, and serving maps. The backend has two pillars. GeoServer is to serve maps, and GRASS GIS is to process calculations. Map data is stored in GRASS GIS mapsets, allowing direct access for calculations. GRASS GIS map outputs are exported into the GeoServer's data directory, so GeoServer can serve those maps to the client. A Node.js server manages the processes and sends and receives information from and to the user. Thus, all requests—input data and dialogue messages—are managed by the Node.js server.

This architecture makes the system flexible: since the frontend and backend are separated from each other, any of them can be changed, or completely replaced, without the need to change its counterpart.

The various pilot applications (Fig. 5) not only showed the great potential of the solution, but led to a number of new potential use cases and implementation requests in the Indian context. In order to respond to this, TOSCA is being further developed and scaled as part of the individual measure in cooperation between GIZ, HafenCity University and the Indian partners.

Fig. 5 Application of the interactive toolkit in a stakeholder workshop run by the GIZ India in Bhubaneswar, India (Source: GIZ India)

5. Towards Urban Waste Intelligence

By integrating the new technical capabilities of geoinformation science and spatial analytics on the urban (macro) level the one hand, and the powers of machine learning algorithms for the visual analysis of waste components on the scale of waste objects (micro-level) on the other, a cross-scale "urban waste intelligence" (Fig. 6) can be established. The targets of this integrated approach are twofold: a) policy and decision makers who are informed and supported in the establishment of higher level plans and strategies, b) local communities and citizen groups "on the ground" who can be stimulated towards new and different behaviors in regards to waste production, consumption patterns, etc. The approach directs to a number of promising use cases and applications e.g. local-specific waste collection strategies, routing and operation management for targeted waste collection, predictions of waste types for specific urban areas in accordance to sociographic, cultural, or economic data.

On the "input side", the component *Urban Intelligence* refers to data analytics & visualisation on city-level. This may include sociographical data, topological data, as well as transport & mobility – the various information bases that are relevant to waste management strategies and operations – and which may be fed from open source portal like Open Street Map, or through administrative data from local authorities and city data hubs (Jannack et al. 2020).

The other "input-component" *Waste Intelligence* refers to vast possibilities through Artificial Intelligence applications, especially for image processing on Object-level. The application of machine learning algorithms gives detailed analytic insight into the amount and frequency, the physical properties (e.g. material, geometry, energy) and object typology of the various forms of waste collected.

The connective term *Urban Waste Intelligence* integrates the previous components in a cross-scale perspective, by way of mapping spatially the detailed waste analytics to specific places, districts, or urban regions. Thus, not only on the level of data integration substantial added value can be generated. The application of learning algorithms also allows for predictive models in urban planning and management – an highly innovation prone area, as the application of AI in urban development issues is still a largely unexplored area (Urban et al. 2021).

On the "output side", the newly established Urban Waste Intelligence directly feeds *Policy & Decision Making*. It supplies new "deep" knowledge to authorities, planners, and governments, empowering them in their regular tasks of planning, operating, and managing (not only) the waste flows in cities. To adequately inform and support them, the new knowledge may be conveyed through interactive monitors, dashboard systems, or planning cockpits which imply specific user protocols and choreographies (Schulz et al. 2020).

Before all, Urban Waste Intelligence needs to be communicated to *local citizens* – to the communities and individuals in urban neighbourhoods, wards, and districts. The new intelligence made accessible with interactive technologies provides the opportunity to effectively inform and train citizens on waste-related issues. Innovative formats and protocols for citizen participation can raise awareness, establish new attitudes, and catalyse civic engagement (Noennig & Stelzle, 2019). Fuelled by social and frugal innovation momentum, a transformative, bottom-up behavior change may be catalysed thus that leads to improved patterns of consumption and waste avoidance.

Fig. 6 Conceptual map of urban waste management (Source: HCU Digital City Science)

6. Conclusions

Digital, data-driven tools like TOSCA have large potential in the area of solid waste management in the Indian context. Coupled with deep learning algorithms like image recognition of dry waste, they potentially stimulate strong waste incentivisation strategies and smart behavioural changes of citizens. Their provision on an open-source basis helps to form an open-source community that is able to take such tools in their own hands and promote the organic growth of an open-source ecosystem especially in India, where an existing strong tech ecosystem will strongly fuel such development dynamics. The adoption of these technologies needs to proceed incrementally and cautiously, in order to integrate within existing processes and methodologies. On such premises, India has a unique opportunity to ensure the sustainability, smartness, and liveability of its cities, and provide a strong blueprint also for cities in other regions and countries worldwide.

References

Berg, H.; Sebestyén, J.; Bendix P.; Le Blevennec K.; Vrancken, K. (2020). Digital Waste Management. European Topic Centre on Waste and Materials in a Green Economy, Mol 2020

Falco, E. (2016). Digital community planning: The open source way to the top of arnstein's ladder. International Journal of E-Planning Research, 5(2), 1–22. https://doi.org/10.4018/IJEPR.2016040101

Hick, D.; Urban, A.; Naumann, F.; Noennig,J. (2018) Data4City – Data-based business modeling for service design and urban planning, in: Proceedings of the International Forum for Knowledge Asset Dynamics IFKAD, Delft 2018

Jannack, A., Noennig, J. R., Skaletzki, D., Streidt, F., Breidung M. (2020) Urban Platform Dresden – New Solutions for Collaboration, Knowledge Sharing, and Urban Value Creation, in: Proceedings IEEE KhPI Week on Advanced Technology 2020, pp 293-298

Kumar, S., Smith, S. R., Fowler, G., Velis, C., Kumar, S. J., Arya, S., & Cheeseman, C. (2017). Challenges and opportunities associated with waste management in India. Royal Society open science, 4(3), 160764.

López Baeza, J.; Sievert, J. L.; Landwehr, A.; Luft, J.; Preuner, P.; Bruns-Berentelg, J.; Noyman, A.; Noennig, J. R. (2021) CityScope Platform for Real-Time Analysis and Decision-Support in Urban Design Competitions. International Journal of E-Planning Research, 10(4) – Part of ISSN: 2160-9918; DOI: 10.4018/ijepr.20211001.oa8

Noennig, J.R. Hick, D.; Doll, K.; Holmer, T.; Wiesenhuetter, S.; Sha, C.; Mahanot, P.; Arya, C. (2020). Upgrading the Megacity. Piloting a Co-design and Decision Support Environment for Urban Development in India. In: Czarnowski, I,; Howlett, R.J.; Jain, L.C. (eds.) Proceedings of the 12th KES International Conference on Intelligent Decision Technologies (KES-IDT 2020) pp.533-544, 10.1007/978-981-15-5925-9_47

Noennig, J., Stelzle, B. (2019) Citizen Participation in Smart Cities – Towards an User Engagement Protocol, in: Proceedings of the International Forum for Knowledge Asset Dynamics IFKAD, Matera 2019

Rao, V. D. (2019). India's quiet digital revolution. Retrieved June 27, 2021, from https://knowledge.insead.edu/blog/insead-blog/indias-quiet-digital-revolution-12956

Schulz, D.; Degkwitz, T.; Luft, J.; Zhang, Y.; Stradtmann, N.; Noennig, J. (2020) Cockpit Social Infrastructure - Developing a planning support system in Hamburg. Proc. eCAADe Conference on Education and Research in Computer Aided Architectural Design in EuropeAt: Berlin Volume: 2, 341-351

Stelzle B., Jannack A., Holmer T., Naumann F., Wilde A., Noennig J.R. (2021) Smart Citizens for Smart Cities -. In: Auer M.E., Tsiatsos T. (eds) Internet of Things, lnfrastructures and Mobile Applications. IMCL 2019. Advances in Intelligent Systems and Computing, vol 1192. p571-581 Springer, Cham. https:/ /doi.org/10.1007/978-3-030-49932-7_54

Urban, A., Hick, D., Noennig, J. R., & Kammer, D. (2021). With a Little Help From AI: Pros and Cons of AI in Urban Planning and Participation. International Journal of Urban Planning and Smart Cities (IJUPSC), Special Issue: ICT Enabled Participatory Urban Planning and Smart Governance 2(2), 19-33. ttp://doi.org/10.4018/IJUPSC.2021070102

Towards a Closed Loop Recycling of CFRP within Circularity Concept processed with a Novel Infusible Thermoplastic Matrix

Magnus Gebhardt[1,2], Souvik Chakraborty[1*], Gerhard Kalinka[3], Ioannis Manolakis[4] & Dieter Meiners[1]

[1]*Institute of Polymer Materials and Plastics Engineering, Clausthal University of Technology, Agricolastraße 6, 38678, Clausthal-Zellerfeld, Germany.*

[2]*Junior Project Leader, Otto Bock HealthCare Deutschland GmbH, Max-Näder-Straße 15, 37115 Duderstadt, Germany.*

[3]*Abteilung 6: Materialchemie, Bundesanstalt für Materialforschung und-prüfung (BAM), Richard-Willst¨atter-Straße 1, 12489, Berlin, Germany*

[4]*Precision Engineering, Materials & Manufacturing (PEM) Research Centre, Institute of Technology Sligo, Ash Lane, F91 YW50, Sligo, Ireland*

[*]*corresponding author: souvik.chakraborty@tu-clausthal.de*

Abstract

Within the aegis of closed loop recycling herein, the impact of a facile recycling process for CFRPs processed with an infusible thermoplastic matrix on the fibre characteristics and 2nd generation composites is presented. The primary focus being to explore the reuse potential of these recycled CF scrims, the fibre properties (structural integrity and surface) and the composite performance under bending (shear and flexure) is explored. Similar performance virgin and 2nd generation composites keeps the hope alive of a step towards closed-loop recycling of the these composites.

Keywords: Carbon fibre composites, Recycling, ILSS, Flexure.

1. Introduction

The negative impact of fossils fuels on our environment and climate in general have led us to embrace alternative sources of sustainable fuel for daily energy needs. In this regards, wind energy is one of the major player besides solar and tidal. Although currently accounting for <20% of Europe's energy demands [WindEurope 2020], projections show that by 2050, approximately 40-50% of Europe's energy demands will be met by wind. This will be possible with the commissioning and installation of longer blades on wind turbines. The length of the blades is quintessential in the energy harvesting capacity of each wind turbine (WT). In other words, longer the blades, greater is the energy harvested by the turbines. In 1985 when the rotor diameter was approx. 15m, the wind turbines were capable of generating 1MW on an avg. By 2012, this has increased to 2.5MW with rotor diameter ranging at 100m [ewea site in bookmark]. This has only been possible with increased usage of composite materials to manufacture these modern blades. These are mostly reinforced with glass and carbon fibres (for blades >35m in length) encapsulated within an epoxy matrix which makes it not only stiffer but also lightweight.

As with any engineering component, these wind turbines have an operational lifetime of 20-25 years after which they need to refurbished or decommissioned. Current estimates suggests that by the end of 2023 we are looking at 14000 WT blades which are slated for decommissioning. This will generate about 40k-60k Tn of composite waste which the industry needs to handle and recycle. A major challenge towards recycling this waste stream is to remove the epoxy matrix from the fibres at an industrial scale sustainably. Since, epoxies cure via a permanent crosslinking reaction, it is a major challenge to break the crosslinks to separate the matrix from the valuable fibres. Current industry mature recycling process is only pyrolysis in which the matrix component is completely lost. However, across Europe there is work ongoing to recover both the composite components in a sustainable manner – albeit, its still not available on an industrial scale [Dreamwind project]. Also, given the challenge that epoxies pose in its recycling, alternative matrices are also being assessed as alternative solutions. An important step towards this is the commissioning if the ZEBRA (Zero wastE Blade ReseArch) Project with major industrial entities (e.g., LM Power, Arkema, Owens Coring, etc) [Zebra project].

A major emphasis of the ZEBRA project is to explore the possibility of using Arkema's Elium® resin as an alternative resin (to epoxy) to build completely recyclable WT blades. Herein, we discuss the impact of our in-house developed recycling strategy for Elium based CFPRs on the cost intensive carbon fibres. Also, presented here and discussed is the overall influence on the bulk properties of composites processed with these recycled fibres. This work falls within the aegis of EU's waste Framework directive of 'Recycling' and 'Preparing for re-use' and also strives to provide future solutions on handling composite waste at the end of their service life.

2. Experimental Section

2.1. Materials

CFRPs were processed with Elium150 (Arkema, France), a thermoplastic resin that is processable and curable at room temperature as common epoxy systems. Under such conditions, Elium takes about 24 hrs to cure (ambient conditions considering). However, in order to reduce the cure cycle to 1.5hrs, the curing was carried out at 65^{o}C in a thermal blanket. 2.5wt% of initiator Perkadox CH-50X (dibenzene peroxide containing dicyclohexyl phthalate) supplied by AzkoNobel was used as the curing agent. The epoxy resin used was EPIKOTE MSG RIMR 135 and cured with the EPIKURE MGS RIMH 1366 from Hexion. Vinylester ATLAC 580 ACT from Aliancys was cured with CUROXM-303 from United Initiators. Urethane acrylate based Crestapol 1260 was cured with PEROXAN CU-40 M and PERGAQUICK CP12 (from Pergan).

CFRPs were reinforced with 0/90 Carbon fibres from SAERTEX (B-C-636gsm) with polyester stitches (6 gsm) were used as reinforcement. A difference is made between reference (1st generation) and 2nd generation composites: reference composites were processed with virgin fibres and virgin resin, whereas 2nd generation composites were produced by fibres recovered from recycling the Elium CFRPs and infused with virgin resin. The mould release agent was Frekote 770NC and analytical grade acetone (Henkel, 99.5%) was used for dissolution to recycle the Elium CFRPs.

2.2. CFRP Processing

CFRPs (400mm x 300mm) were processed via VARI with 2 layers for CF as reinforced for a target fibre volume fraction (V_f) of 45-50% (approx., ISO 14127 method B) and a thickness of 1.7-2.0mm. Table 1 details the cure regime along with the mixing ratios for each resin system used. For every resin system, the curing agent was initially manually mixed and then degassed for 10min to remove any entrapped air. After cure specimens were machined from the laminate for subsequent testing.

Table 1
Mixing ratios and cure regime for the CFRPs processed.

Sample name	Resin	Resin system	Hardener mixing ratio	Cure Regime
EL	*Acrylic Thermoplastic*	*Elium 150*	*Perkadox CH-50X, 2.5wt%*	1.5h @ 65°C
EP	*Epoxy resin*	*EPIKOTE Resin MGS RIMR 135*	EPIKURE MGS RIMH 1366, 30wt%	8h @ 80°C
UA	*Urethan Acrylate*	*Crestapol 1260*	Peroxan CU-40 M, 2wt% and Pergaquick CP12, 2wt%	24h@ RT postcure: 3 h @ 80°C
VE	*Vinyl Ester*	*ATLAC 580 ACT*	CUROXM-303, 1.5wt%	24 h @ RT postcure: 3 h @ 100°C

2.3. Recycling

Recycling was carried out by dissolution of CFRP laminates (200mm x 180mm) in an acetone bath (weight ratio - 1:20) for 24hrs at RT. After 24hrs in the enclosed bath, the pliability and layer separation of the fibre pre-form was checked (Fig. 1 Gebhardt 2019). At this point fibres were also randomly selected for the single fibre tests. A closer look also revealed a layer of matrix remnant on the fibres (Fig. 1b). The undamaged pre-form was removed and dried for 24hrs at RT (Fig. 1c). Simultaneously, the matrix was recovered by evaporating the acetone under ambient conditions. To remove any acetone remnants, both fibres and matrix were vacuum dried for 8hrs at 65^0C before further testing. For details of the process please refer to our previous work Gebhardt (2019).

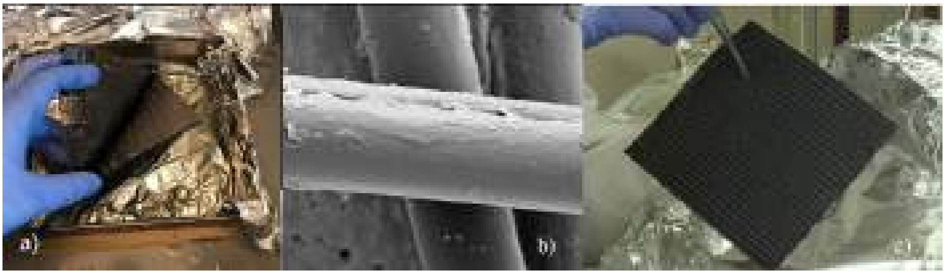


**Fig. 1: a) Preform pliability right after removal at the end of dissolution in acetone .
b) SEM micrograph of a single fibre with matrix remnants after recycling.
(After Gebhardt 2019)**

2.4. 2nd generation CFRPs

To understand and demonstrate the influence of the recycling process, the reclaimed fibre pre-form was re-infused via VARI using the resin system and cure regimes as detailed in Table 1. The 2nd generation CFRPs were observed to have a lower V_f of 43-46% (ISO 14127 Method B) due to the bridging effects as observed in the Fig. 2 [Gebhardt 2021).

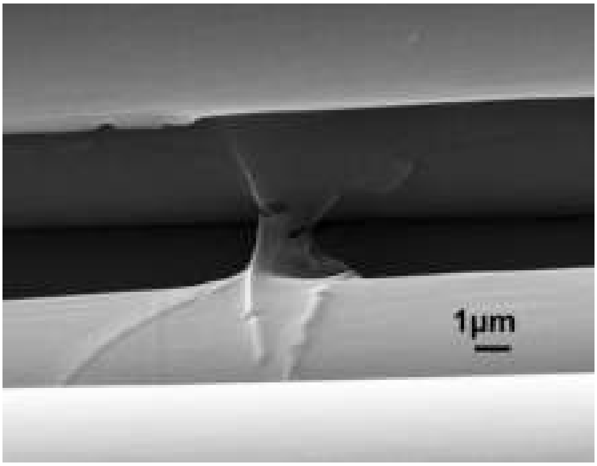


**Fig. 2
SEM image of a bridge of remaining Elium in the pre-form. (After Gebhardt 2021)**

2.5. Characterization Techniques

Single fibre tests (SFT) were performed on both virgin and recycled carbon fibres (length: 50-60mm) in accordance to ISO 11566. The single fibres were extract under an optical microscope and fixed (Araldite AW4859/HW4859) to a piece of paper (free length between glued edges: 30mm). This paper fixture was clamped to a Zwick/Roell ZMART.PRO UTM and tested under tensile loading with a load cell of 20N at pre-load of 0.001N (Fig. 3a). Each sample was loaded till failure and tests repeated atleast 20 times for statistical relevance.

Fig. 3
The setup – Single fibre tensile strength. (After Gebhardt 2019)

Scanning electron microscopy (SEM, Carl Zeiss EVO 50) was used to investigate the surface characteristics of both the virgin and recycled carbon fibres. Measurements were conducted in secondary electron mode with an accelerating voltage of 5 kV. The aim was to investigate the surface quality of the fibres and the recycling process' impact on it.

The thermomechanical characteristics of virgin and 2nd generation CFRPs was investigated via dynamic mechanical analysis (DMA, DMA2980 TA instruments). The measurements were carried out between 10^{o}C - 160^{o}C, ramp of +2^{o}C/min, 1Hz. The temperature values corresponding to the max of tan δ peak ($T_{g\ \tan\delta\ max}$) is reported here.

Interlaminar shear stress (ILSS) tests were carried out in accordance to ISO 14130 to investigate for any differences in the shear properties arising from the recycling process. These tests were carried out at a span to thickness ratio of 1:5 under ambient conditions of 23^{o}C and 45% humidity.

Three-point bend tests (3PB) according to DIN EN ISO 14125 was used to characterize the flexural properties under a similar ambient condition as ILSS. The universal testing machine used was a Zwick/Roell BZ2-MM100TL.ZW01. Tests were carried out with a 100kN load cell and at a preload of 5 N. The thickness to span ratio was 1:16 and the specimen orientation was chosen to have the outer fiber layer at 90°. At least 12 test specimens were tested for each sample class to make the measurements statistically relevant.

3. Results and Discussion

The primary objective for assessing the quality of the recycling process is to understand its impact on the fibre properties (structural properties and surface characteristics) and on the properties of the 2nd generation CFRPs processed with these rCF being re-infused with the virgin resins. For this current discussion the focus is only on the shear (ILSS) and flexural (3PB) characteristics of the composites (both virgin and 2nd generation).

3.1. Impact of recycling on the fibre properties

Being not only cost intesive but also the main load bearing and reinforcing component, the recovery of the fibres (in this case carbon fibres) in an undamaged form would be ideal. In the present scenario (Fig. 1c), visually this seems to be the case. But to have a tangible evidence of it, single fibre tests were carried out on the virgin carbon fibres and those recovered after recycling at RT. To test the impact of our recycling processs on the fibre properties under harsher conditions, CFRPs were recycled at 40^{o}C (acetone being volatile, the temperature range under ambient atmospheric conditions was limited).

The overall results are presented in the Fig. 4 and it's interesting to note that the breaking strength of the recovered fibres are comparable to the virgin ones. Even at a comparatively harsher recycling condition of 40ºC, the structural integrity of the fibres seems to remain unchanged. This is one part of an exciting finding that there is now recycling process which do not structurally deplete the recovered fibres as if often observed with current industrially accepted processes (Oliveux 2015)

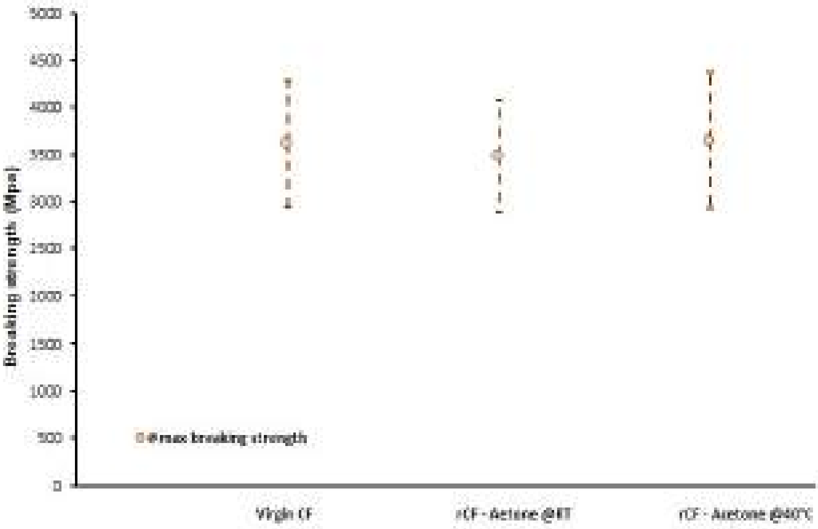


Fig. 4
Overview of Single fibre tensile strength. (After Gebhardt 2019)

3.2. Impact of recycling on 2nd generation CFRPs

The 2nd aspect towards assessing the impact of recycling is how the bulk properties of the composite processed with rCF compare to those processed with virgin CF. In order to understand this, the impact of the recycling process on the sizing of the fibres need to probed. Sizing is a polymer coating (mostly epoxy based) applied on to synthetic fibres during manufacture to make it compatible to the matrix/resin. Needless to say, a good compatibility ensures improved structural properties through a better load transfer to the reinforcing fibres. The most industry mature recycling processes like pyrolysis and solvolysis strips away the sizing from the fibres (Fig. 5c) which leads to downsizing of structural properties (Oliveux 2015).

Upon a closer look under SEM, when compared against its virgin counterpart (Fig. 5a), the rCF seems to have a coating on its surface (Fig. 5b). A detailed investigation with EDX and XPS revealed this coating contain Elium remnants with the sizing anticipated to remain unaffected [Gebhardt M. (2019), Gebhardt M. (2021_2)]. This is evidence that the recycling process not only have a limited impact on the recycled fibres structurally, but also it doesn't strip away the sizing.

Fig. 5
Fibre surface under SEM a) Vrigin b) in-house recycled and c) representative pyrolysis recycled carbon fibres (Moosberger-Will 2018)

Given that our investigations revealed Elium remnants on the rCF coating, the 2nd generation CFRPs were processed with virgin Elium and tested to investigate the impact of ideal compatibility on the bulk response. ILSS and 3PB flexure was conducted to explore the impact of the interfacial behavior (primarily). This would lead to a direct interpretation on the rCF-matrix compatibility and provide a first baseline on the reuse potential of the rCF as raw materials for engineering applications.

As evident from Fig. 6 below, detailed investigations revealed that interfacial shear strength and the flexural modulus of the 1st and 2nd generation composites were fairly comparable with the shear strength being almost unchanged [Gebhardt M. (2019)]. This highlight the impact of the interfacial compatibility between the coating remnant and the virgin Elium.

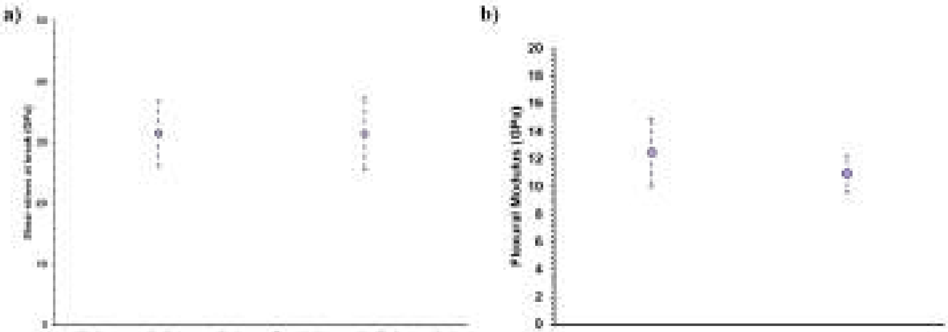


Fig.6
Comparative structural performance of 1st and 2nd generation Elium composites wrt ILSS and Bending load (After Gebhardt 2019)

Given the impressively surprising observation of the bulk response of the CFRPs processed with Elium as in Fig 6, similar tests were carried out with composite processed with different industrial resins as detailed in Table 1 (Gebhardt 2021). The cure regime for all resin systems were in accordance to Table 1. The overview of the shear strength and flexural modulus are presented in Fig 7. The choice of the industrial resins were based on their chemical compatibility to Elium (as the coating on the rCF shows Elium remnants), ranging from some similarities (Urethane Arcyclate and Vinylester) to no compatibility at all (Epoxy). The objective of these wide variant of resins were to investigate whether these rCF can find a more general applicability as a reinforcing element.

As can be observed from Fig. 7 that the bulk response of the CFRPs are almost comparable irrespective of the resin system used. Hence it can be said that given the comparable bulk response (shear strength and flexural modulus), the rCF (from the current recycling process) shows the potential of being used as reinforcement with limited downsizing – atleast to the scale presented here. A main reason for this is hypothsized as the micromechanical interlocking anticipated at the fibre-matrix interface of the 2nd generation composites. For more details, the readers are advised to look into our previous works (Gebhardt 2021).

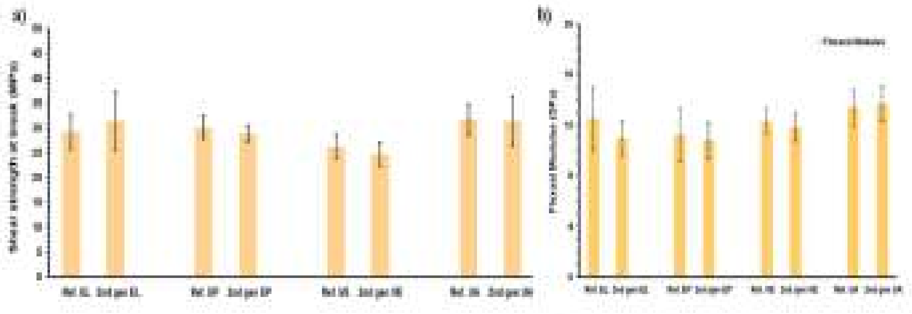


Figure 7
Comparative structural performance of 1st and 2nd generation composites wrt ILSS and Bending load processed with different industrial resins (After Gebhardt 2021).

4. Conclusions

This work briefly discusses the impact of recycling Elium CFRPs on the rCF and the 2nd generation bulk properties processed with various industrial resin systems. The detailed investigations (SEM, ILSS and flexure) reveal a minimal impact of the recycling process on the rCF as well as the composites processed with it. Overall these observations would warrant the question – Is the loop closed?

In order to close the loop and establishing these rCF as a new raw material further tests and work needs to be done. Amongst the available tests, those of primary importance is tensile, fatigue and creep all of which will help benchmark the engineering applicability of these rCF. Also remaining is the reprocessing of the matrix and benchmarking its properties. The assessment of the test results will truly help to close the loop. All of these are currently the focus on the ongoing in-house research.

Acknowledgement

The authors thank Mrs. Peggy Knospe from the Institute of Mechanical Process Engineering, TU Clausthal for the SEM measurements.

References

Wind energy in Europe 2020 Statistics and the outlook for 2021-2025

Dreamwind Project. https://www.dreamwind.dk/en/about/

ZEBRA Project. https://www.lmwindpower.com/en/stories-and-press/stories/news-from-lm-places/zebra-project-launched

Gebhardt M. (2019). Closed loop room temperature recycling of CFRPs with an infusible thermoplastic matrix and its effect on 2nd generation properties. Journal of Plastics Technology. 16 (5): 180-210.

Gebhardt M. (2021). Re-use potential of carbon fibre fabric recovered from infusible thermoplastics CFRPs in 2nd generation thermosetting matrix composites. Composites Communications. 28: 100974.

Oliveux G. (2015). Current status of recycling of fibre reinforced polymers: review of technologies, reuse and resulting Properties. Prog. Mater. Sci. 72: 61–99.

Gebhardt M. (2021_2). Reducing the raw material usage for room temperature infusible and polymerisable thermoplastic CFRPs through reuse of recycled waste matrix material. Composites Part B, 216 : 108877.

Moosberger-Will J. (2018). Interaction between carbon fibers and polymer sizing: Influence of fiber surface chemistry and sizing reactivity. Appl. Surf. Sci. 439: 305-312

Biomedical Waste Management: The Experience of IMAGE – CBWTF, Kerala (Indian Medical Association Goes Eco-friendly - Common Biomedical Waste Treatment & Disposal Facility)

Dr. Sharafudheen K.P.

Hanseatic India Forum, e. V., Baumschulenweg 26, 22609 Hamburg, Germany
Hon. Secretary, IMAGE - CBWTF, Indian Medical Association, Kerala
H.O.D & Senior Consultant ENT Surgeon, EMS Memorial Co-Op. Hospital, Perinthalmanna, Malappuram, Kerala 679322
imageimaksbtvm@gmail.com, sharafkpdr@yahoo.com

Abstract

Healthcare waste is an important and hazardous environmental pollutant, and its processing and proper disposal is a very important for preserving environment [2]. The need for proper disposal became more important during COVID-19 pandemic as the care of these patient's generated even higher amounts of healthcare waste. This article shares the experience of healthcare waste processing by IMAGE (Indian Medical Association Goes Eco-friendly), the Common Biomedical Waste Treatment & Disposal Facility (CBWTF) in Kerala, India.

1. Introduction

All developmental activities lead to the generation of wastes. These wastes cause environmental degradation and consequent health effects to humans. These matters were brought to the attention of the United Nations and the first UN Conference on Environment and Development held in Stockholm in 1972 helped in a big way to create higher awareness among all member countries [9]. In India also, the people began to think about the dangers of pollution after the UN declaration. Until then, there were only isolated regulations to prevent and control the "pollution". These thoughts at home gave birth to the first comprehensive legislation in the country at national level to control water pollution and thereby to protect the environment. Thereafter, over the years, there was a series of legislations in this direction. One such major piece of notification under the Environment (Protection) Act of 1986 is the Biomedical Waste (Management and Handling) Rules, 1998[10]. In India, State of Kerala is having the highest number of healthcare institutions as per the 2001 census. About 26% of the health care establishments in India are in Kerala [11]. The number of hospital beds in all these institutions together is about 1,20,000. It is roughly estimated that about 2 kg per bed of solid wastes are generated in these hospitals. The biomedical waste is about 20% of this solid waste generated. This gives a picture of the quantity of biomedical waste to be managed by the hospitals in Kerala. IMAGE (Indian Medical Association Goes Eco-friendly), the Common Biomedical Waste Treatment & Disposal Facility (CBWTF) is owned by the Kerala Chapter of the Indian Medical Association, the world's largest professional organisation of Modern Medicine Doctors. IMAGE was established in the year 2003 at Kanjikode in Palakkad District of Kerala, which is currently the largest Common Biomedical Waste Treatment & Disposal Facility in the country with the highest treatment capacity available in a single such facility [1]. IMAGE is serving the healthcare facilities of the entire state of Kerala, and it was the only biomedical waste management facility for the entire State of Kerala till May 2021. IMAGE project is a testimony of the grit, determination and social commitment and its persistence has achieved resounding success by overcoming the difficulties in dealing with a ravaging issue of biomedical waste generated in the state of Kerala. IMA Goes Eco-friendly or "IMAGE" has become a "synonym" for the Biomedical Waste Management for Kerala. During this Covid pandemic, IMAGE is still the only agency in the state managing the biomedical waste generated during the diagnosis, care & treatment of Covid Patients in Kerala. Currently, there are 19,062 Healthcare facilities in Kerala which are affiliated to the IMAGE for their biomedical waste management, which includes both the Government & Private healthcare facilities including Medical Colleges, Hospitals, Healthcare Clinics, Clinical Laboratories, Blood Banks, Dental Clinics, Veterinary Centres, Medical Research Centres & Ayush healthcare centres. Biomedical and healthcare waste generated from all these institutions is processed effectively abiding to all protocols and rules at the IMAGE - CBWTF there by contributing immensely to the environmental protection.

2. Review of Literature

Healthcare waste constitutes general (municipal) waste (75-85%), infectious biomedical waste (10-15%) and chemical waste (less than 5%)[2]. The importance of segregation of healthcare waste is that when a part of this infectious biomedical waste materials is mixed with non-infectious waste, then all the waste becomes infectious and hazardous. The hazards of biomedical waste include transmission of infections, hazards from pharmaceutical waste, hazards from chemical waste, public sensitivity and environmental risks.

Biomedical waste is defined as the waste which is generated during the diagnosis, treatment or immunization of human beings or animals or in research activities pertaining thereto or in the production or testing of biologicals, or health camps [3].

The *Biomedical Waste Management Rules, 2016* explains the

i) Duties & Responsibilities of the Occupiers (healthcare facilities), the operators & the authorities.

ii) Biomedical waste Categories, Segregation, Collection, Packaging, Transportation, Treatment & Disposal processes.

iii) Standards of various treatment processes.

iv) Monitoring & Implementation of the Rules.

The **Biomedical Waste Management Process** involves

i) Segregation of waste into four categories (Yellow, Red, Blue & White);

ii) Collection in colour-coded; barcoded bags & containers.

iii) Internal transportation within the healthcare institutions in covered trolleys.

iv) Temporary storage up to 24 hours in designated storage space within the HCFs.

v) Barcode scanning of the waste-collected bags & containers using designated Mobile Applications.

vi) Transportation of collected waste in specially designed GPS enabled leak-proof vehicles to the Common Biomedical Waste Treatment Facility.

vii) Unloading & receiving of segregated waste to a temporary storage area within the CBWTF.

viii) Barcode processing and Weighing of the received bags & containers.

ix) Treatment of waste according to the approved treatment processes within next 24 hours of waste reaching the IMAGE - CBWTF Plant.

x) Sorting, Washing & Shredding of sterilised plastic, rubber & metallic waste; and sending out these treated scrap materials for recycling through authorised recyclers

xi) Disposal of Incinerator Ash & Sludge generated from Effluent Treatment Plant.

Certain biomedical waste like highly infectious microbiological & biotechnological waste needs pre-treatment at the HCFs to disinfect these items before handing over the same to the CBWTF. The liquid biomedical waste has to be pre-treated for disinfection & managed by the HCFs itself through a Sewage / Effluent Treatment Plant [3].

The Four **Categories of Biomedical waste** are

i) Yellow Category Waste (Infectious waste for Incineration): collected in yellow colour-coded barcoded bags and these are to be treated by either incineration or pyrolysis at the CBWTF Plant. This includes human/animal anatomical waste, soiled materials with blood or body fluids, discarded linen & dressing materials, pre-treated microbiological & biotechnological waste, discarded medicines etc.

ii) Red Category Waste (Contaminated Recyclable Waste): collected in red colour-coded barcoded bags and these are treated by Autoclaving/Hydroclaving/ Microwaving at the CBWTF Plant. This includes all plastic & rubber recyclable items like syringes, needle caps, IV bottles, Surgical or Examination Gloves, blood sample collection bottles or tubes or vacutainers, plastic catheters, plastic personal protective equipment used at HCFs etc.

iii) White Category Waste (Waste Sharps): includes sharps like needles, blades, lancets etc. These are separately collected by the HCFs in sharps containers which are treated for sterilisation by either autoclaving or dry-heat sterilisation techniques at the CBWTF. Later these sterilised sharps are shredded to separate the metallic parts from it and send for recycling.

iv) Blue Category Waste (Glass & Metals): includes glass bottles, ampoules and metallic implants which are collected in leak-proof barcoded blue cardboard boxes for treatment by chemical disinfection followed by washing and shredding at the CBWTF plant and sent for recycling [3].

The concept of ***Common Biomedical Waste Treatment Facility*** **(CBWTF)** was introduced in India in 1998. A CBWTF is a set-up where the biomedical waste generated from member healthcare facilities is imparted necessary treatment to reduce adverse effects that this waste may pose on human health and the environment. The Biomedical Waste Management Rules-2016 restricts HCFs for the establishment of on-site or captive biomedical waste treatment and disposal facilities, as installation of individual treatment facilities by healthcare facilities (HCF) requires comparatively high capital investment, separate dedicated trained skilled manpower and infrastructure development for proper operation and maintenance of treatment systems. The concept of CBWTF does not only address such problems but also prevents the proliferation of treatment facilities in a particular town or city. In turn, it reduces the monitoring pressure on the regulatory agencies. By running the treatment equipment at CBWTF to its full capacity, the cost of treatment of per kilogram biomedical waste gets significantly reduced. Its considerable advantages have made CBWTF, a popular and proven concept in most parts of the world [4]. Currently, there are 208 CBWTFs functioning in the country and another 29 are under construction. As per the Annual report of the Central Pollution Control Board for the year 2019, the total quantity of biomedical waste treated through these 208 CBWTFs together is an average of 544 tonnes per day [8]

The Central Pollution Control Board (CPCB) has published the ‘***Guidelines for Common Biomedical Waste Treatment and Disposal Facilities***’ in December 2016 [4]. As per this guideline, the approved Treatment Processes for biomedical waste in India are,

i)	Incineration/Plasma Pyrolysis	(Yellow Category Biomedical Waste)
ii)	Autoclaving	(Red/White/Blue/White Category)
iii)	Hydroclaving	(Red/White/Blue/White Category)
iv)	Microwaving	(Yellow/Red/White/Blue Category)
v)	Chemical Disinfection	(Blue/White Category waste)
vi)	Sharps encapsulation pits	(White category)

- Mechanical treatment processes like shredding, grinding, mixing and compaction technologies supplement other treatment methods used for the recyclable wastes (Red/White/Blue Category) to reduce the scrap volume.
- Deep Burial is permitted only if there is no access to a CBWTF

The *Biomedical Waste Management Rules-2016* in its Schedule II explain the standards for the different treatment processes that are approved for biomedical waste management.

The ‘***Guidelines for Biomedical Waste Incinerators***’ released by the Central Pollution Control Board in April 2017 [7] explains the

i) Design guidelines including the requirements for Biomedical Waste Incinerators with Wet / Dy Air Pollution Control Devices, Static or Rotary Kiln type incinerators.

ii) Requirements of the Air Pollution Control Devices (APCDs).

iii) Requirements of the stacks (chimneys) attached to these incinerators.

iv) Operating room requirements.

v) Operating & Emission Standards for Incineration.

vi) Monitoring frequency of stack emission including real-time continuous monitoring system.

vii) Incineration Ash Management etc.

There needs to be an Effluent Treatment Plant attached to every CBWTF for the effective management of the Liquid Wastewater generated during the biomedical waste management process. The Standards for the Liquid Waste Effluent is also included in the Biomedical Waste Management Rules & related guidelines.

As per the guidelines, the Incineration Ash & ETP Sludge of the CBWTFs are to be managed by the Hazardous Waste Treatment Facilities (TSDFs) using engineered landfilling [7].

The sterilised plastic, rubber, glass & metallic items are sorted separately, washed and shredded within the CBWTF; and sent for recycling through authorised recyclers.

3. IMAGE-CBWTF Experience

The installed capacity of the IMAGE-CBWTF plant is currently 78 TPD. The average quantity of biomedical waste treated at the IMAGE plant is 52 to 56 TPD. In the present Covid pandemic scenario, the covid related biomedical waste & the regular biomedical waste are managed separately at the IMAGE - CBWTF.

The average quantity of biomedical waste generated "per-bed per-day" in private hospitals of Kerala is 200-250 grams and in government hospitals, it is 500-650 grams. The proportion of recyclable biomedical waste quantity received at the IMAGE plant is about 25-30% of the total biomedical waste.

IMAGE-CBWTF plant has 5 biomedical waste incinerators (plus one standby incinerator) with a capacity to incinerate up to 48 TPD; 5 Horizontal Autoclaves with a capacity to treat up to 24 TPD; Shredders with a capacity to manage up to 24 TPD; ETP of 450 KLD capacity; STP of 25 KLD [3].

The average distance covered by the 74 Nos waste collection & transportation vehicles together in a day is 16,500 KMs. IMAGE - CBWTF has a total of 764 employees involved in the entire biomedical waste management process working in 3 shifts. IMAGE plant is functioning 24 Hours x 365 Days.

Currently, IMAGE-CBWTF is affiliated with 19,062 Healthcare Facilities (HCFs) in Kerala for their biomedical waste management. Amongst the affiliated HCFs; 2,185 are bedded hospitals (including Medical Colleges); 9,682 are Clinics; 7,015 are Clinical Laboratories; 173 are Veterinary centres, and 12 are Research centres. The chart 1 shows that there is progressive increase in the quantity of biomedical waste collected and the quantity processed at the plant from 2018 till 2022, especially during the COVID-19 pandemic. There is trend towards falling waste generation in 2022, coinciding with falling caseload of COVID-19.

Chart 1

Biomedical Waste Collection and processing - Year wise Data (2018 - 2022)

(Chart 1)

The tables 1, 2 and 3 shows the air quality parameters, water and noise level respectively in IMAGE Plant from 2018 to 2022. This data shows that all the protocols regarding the quality indicators and recommendations are strictly followed during waste processing at IMAGE-CBWTF, Kerala. Table 4 shows the expenses incurred in its operations.

Table 1

Air quality monitoring data at IMAGE-CBWTF: 2018-2022

Air Quality Monitoring Data																	
Year	Month	Incinerator 1 (Rotary)			Incinerator 2 (Static Double Chamber)			Incinerator 3 (Static)			Incinerator 4 (Rotary)			Incinerator 5 (Static Double Chamber)			
		PM (mg/Nm^3)	HCl (mg/Nm^3)	Oxides of Nitrogen (mg/Nm^3)	PM (mg/Nm^3)	HCl (mg/Nm^3)	Oxides of Nitrogen (mg/Nm^3)	PM (mg/Nm^3)	HCl (mg/Nm^3)	Oxides of Nitrogen (mg/Nm^3)	PM (mg/Nm^3)	HCl (mg/Nm^3)	Oxides of Nitrogen (mg/Nm^3)	PM (mg/Nm^3)	HCl (mg/Nm^3)	Oxides of Nitrogen (mg/Nm^3)
2022	Jan	21.4	3.6	34.4	23.1	4.9	26.3	23.7	4	33.5	19.8	5.11	38.4	22.8	3.6	26.7
	May	21.2	3.78	29.7	15.8	3.5	26.7	20.8	4.23	33.1	20.8	4.89	25.2	19.6	3.49	23.7

2021	Jan	20.7	2.34	16	23.9	3.04	14.7	23.5	2.96	17.5	20.2	5.1	22.3	22.7	2.81	19.7
	May	21.5	4.4	28	15.3	2.29	14.1	19.1	2.35	10.5	19.8	2.2	16.8	22.5	3.26	22.5
	Oct	21.7	5.1	29.2	16.8	3.6	21.7	21.9	4.5	26.7	20.8	3.55	25.1	23.8	3.65	24.4
	Dec	20.8	4.1	30.9	24.8	4.7	25.1	25.1	3.8	34.7	21.7	5.24	39.8	21.6	3.11	24.9
2020	Jan	30.7	6.2	26.9	24.1	5.5	22.6	29.4	4.7	32.1	29.2	5.7	28.3	25.2	5.1	28.1
	May	41.5	15.4	125.7	37.2	16.1	131.5	44.5	23.2	201.5	32.5	25.2	141.1	43.9	22.7	195.5
	Oct	43	18.3	157.3	35.3	17.5	142.1	45.2	25.8	210.3	34.3	24.1	135.2	45.8	26.1	202.6
	Dec	24.8	2.8	13.7	21.6	2.54	12.8	26	2.51	14.1	32	25	122.7	26.5	3.11	16.3
2019	Jan	37.4	8.4	16.8	41.2	8.6	19.5	35.5	5.2	18.5	30.1	6.1	19.5	39.7	6.2	18.4
	May	40.2	7.85	18.7	35.2	6.87	17.5	38.2	5.53	19.1	30.8	6.5	22.5	31.3	6.2	18.5
	Oct	31.2	6.4	17.4	37.9	6.85	19.8	33.9	5.68	20.5	32.2	6.41	19.4	36.1	7.25	20.8
	Dec	37.7	7.29	20.4	37	6.7	18.8	35.1	5.7	21.4	34.5	7.1	23.3	35.1	6.6	20.4
2018	Jan	43	3.2	19.7	36	3.7	17.8	41.2	3.9	18.4	34.2	4.6	18.7	31	3.4	18.2
	May	32.7	3.4	21.5	25.2	2.5	13.8	30.6	2.9	20.2	24.1	2.8	19.4	26.9	2.9	15.4
	Oct	32.4	3.2	21.9	42.1	4.3	26.1	38.1	3.8	25.3	24.8	3.1	19.3	35.8	3.6	22.7
	Dec	45.8	8.9	18.1	44.5	8.3	17.1	39.4	5.5	21.3	25.3	5.9	17.5	34.1	5.5	16.1

Table 2

Water quality monitoring data at IMAGE - CBWTF: 2018 - 2022

Water Quality Monitoring Data						
Year	Month	ETP Parameters				
		pH	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	Oil & Grease (mg/l)
2022	Jan	8.23	6.2	19.1	70.3	<1
	May	7.05	16	19.1	60.2	1.8
2021	Jan	7.99	41	11.7	40	1.1
	May	8.8	48	18	60.1	1
	Oct	8.41	13.8	11.4	39.9	<1
	Dec	7.84	<1	5.8	20.1	< 1
2020	Jan	7.25	29.4	21.2	108	2
	July	7.79	BDL	10.2	84	BDL
	Oct	8.2	BDL	4.5	24	BDL
	Dec	7.75	19.7	16	76.3	BDL

2019	Jan	6.92	32.3	18.8	88.2	<1
	May	7.43	12	28	224	BDL
	Oct	7.19	25.1	22.8	112	1.8
	Dec	7.19	23.1	17.5	88	1.6
2018	Jan	7.21	24.5	16.4	73.5	3.98
	May	7.03	<1	14.9	48.6	1.89
	Oct	6.98	29.8	8.14	42.6	<1
	Dec	7.03	29.6	15.3	65.8	<1

Table 3

Noise level monitoring data IMAGE-CBWTF: 2018 – 2022

Noise Level Monitoring Data			
Year	Month	Parameters	
		Ambient sound level (Daytime) (dB)	Ambient Sound Level (Nighttime) (dB)
2022	Jan	52.2	41.6
	May	51.7	41.1
2021	Jan	52.6	40.1
	May	51.6	40.9
	Oct	51.2	38.1
	Dec	52	41.2
2020	Oct	52.6	41.8
2019	Jan	52.5	41.8
	Oct	50.7	41.9
	Dec	52.3	40.2
2018	Jan	51.2	42
	May	50.4	40.2
	Oct	52.4	39.8
	Dec	51.3	41.5

Table 4
Year wise Expenditure (in Rs) Incurred by IMAGE-CBWTF, Kerala

No	Expenditure Statement	2018 - 19	2019 - 20	2020 - 21	2021 - 22
1	Operational Expenses	239,913,251	262,258,046	336,098,822	354,666,817
2	Repair and Maintenance	27,537,317	68,941,256	53,385,770	37,017,250
3	Administration and Staff Expenses	4,744,170	7,310,487	7,274,682	8,610,954
4	Software and Renewal Expenses	2,586,687	2,571,961	4,409,587	3,709,607
5	Rate and Taxes	19,094,673	14,954,802	17,425,433	16,874,077
6	Consultancy and Other Expenses	3,164,654	1,107,931	1,477,783	7,575,372
7	Miscellaneous Expenses	1,085,264	1,211,388	1,752,081	1,427,643
	Total Expenses	298,126,016	358,355,871	421,824,156	429,881,719

4. Conclusions

Scientific management of healthcare waste is important as this can lead to environmental pollution as well as hazards related to its exposure [2]. We need to invest in developing more facilities for its collection, processing and proper disposal with utmost care. It's a challenge before us, to manage the growing quantities of biomedical waste that go beyond past practices, if we want to protect our environment [6]. The IMAGE - CBWTF in Kerala and its operations over the years shows the way forward for rest of country and world for a proper processing of healthcare waste and it is the best example for our responsibility to the Society. We need to develop innovative methods and research to reduce as well as effectively process the healthcare waste to work with motto of 'Let the waste of sick not contaminate the lives of healthy' [5].

References

IMAGE (Indian Medical Association Goes Eco-friendly), 2018, "Bio- Medical Waste Management System- About Us" https://www.imageima.org/about-us.

WHO (2016). World Health Organization (WHO), "Safe management of wastes from healthcare activities. Page 3, 2nd Edition.

Anon (2016). Bio-Medical Waste Management Rules. 2016 Published in the Gazette of India, Extraordinary, Part II, Section 3, Sub-Section (i), Government of India Ministry of Environment, Forest and Climate Change. Notification; New Delhi, the 28th March 2016.

Anon (2016). "Revised Guidelines for Common Bio-medical Waste Treatment and Disposal Facilities", Central Pollution Control Board & Ministry of Environment, Forest and Climate Change., December 21, 2016.

Lipika Singhal, Arpandeep Kaur Tuli, Vikas Gautam (2017). "Biomedical Waste Management Guidelines 2016: What's doneand what needs to be done" Indian Journal of Medical Microbiology, 35(2)i, 194-198.

Priya Datta, Gursimran Kaur Mohi, and Jagdish Chander (2018). "Biomedical waste management in India: Critical appraisal" J Lab Physicians. 10(1): 6–14.

Anon (2017). "Guidelines for Biomedical Waste Incinerators", Central Pollution Control Board & Ministry of Environment, Forest and Climate Change., April 28, 2017.

Anon (2019). "Annual Report on Biomedical Waste Management as per Biomedical Waste Management Rules, 2016 for the year 2019", Central Pollution Control Board & Ministry of Environment, Forest and Climate Change.

Anon (1973). Report of the United Nations Conference on the Human Environment Stockholm 5 to 16 June 1972, "Declaration of the United Nations Conference on the Human Environment" A/CONF.48/14/Rev.1 November 1973.

Anon (2021). Pollution Control Law Series, PCLS/02/2021, "Pollution Control Acts, Rules & Notifications Issued Thereunder", Central Pollution Control Board & Ministry of Environment, Forest and Climate Change April 2021.

ENVIS Hub: Kerala State of Environment and Related Issues-Health; http://www.kerenvis.nic.in/Database/HEALTH_6745.aspx

Recycling Methods of Plastic Waste and its Application

Mamta Tembhare & Sunil Kumar*

CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nehru Marg, Nagpur 440020, Maharashtra, India

**Corresponding Author: E-mail: s_kumar@neeri.res.in*

Abstract

In 1850, the first concept of plastic polymer was introduced **(Freinkel, 2011)**, which led to the foundation to develop first plastic product in 1907 **(ACS, 1993).** Plastic is a synthetic polymer made up of small molecular bonds. In 1920s, the simple plastic polymer was reinvented to develop polyvinyl chloride (PVC) plastic, which was blend with the additives to enhance the property of plasticity. The invention of synthetic plastic polymer (SPP) was inspired by some of the naturally occurring polymer i.e., silk, rubber, muscle fiber, DNA and cellulose. Presently, SPP has a wider range of applications in industries, based on its chemical properties. It has a higher calorific value than paper, wood, glass, or metals (excluding aluminum), ranging from 60 to 100 MJ/kg (Rafey and Siddiqui, 2021). In past few decades, the plastic products have replaced metals, woods, glass etc. in day-to-day living standards, which has led to substantial increase in plastic waste (PW). This exponential increase in PW has led to environmental issues such as ground water contamination, air pollution, and other health hazards. Presently, health impacts related to PW is still poorly understood. It has been observed that the entrapment and destruction of natural habitat for wildlife due to PW (Lamb et al., 2018). Human are suffering from respiratory, circulatory, lymphatic, endocrine system with the deposition in kidney and liver **(Deng et al., 2017)**. The inappropriate PW management scheme within the cities is a major concern. The policy maker, inventors, researchers, entrepreneurs and urban local bodies have diverted their focus toward sustainable PW management, which implies the concept of recycling, reuse, recovery and reprocessing.

2. Introduction

The major emphasis is also to bring in the concept of circular economy and transform it into a successful business model.

The continuous usage and mass production of multiple plastic products has caused accumulation of PW into the environment. It has also led to the penetration of PW into the marine ecosystem. It is estimated that by 2025, 28 million metric tons per year of PW would penetrate into the marine ecosystem via oceans, rivers and tributaries (Jambeck et al., 2015). Therefore, it is essential to manage pre- and post-consumer utilization channel of PW. The pre-consumer utilization channel includes appropriate and minimized production of virgin plastic polymer (VPP). The VPP is a first life-chain cycle of plastic, which has been synthetized in laboratory or industries. It is essential to minimize such large production of VPP to avoid future load on post-consumer utilization facilities.

In most of the developed countries, the post-consumer utilization of PW includes five step process: (1) upgrading (2) downgrading (3) recycling (open or closed loop) (4) waste-to-energy plants and (5) disposal, as indicated in Fig. 1 (Chidepatil et al., 2020). Prior to the post-consumer utilization, it is essential to develop on-site collection and sorting facilities to strength the management scheme. Awareness programs through rallies and mass media need to be introduced into the management scheme to inculcate the practice of source segregation of waste. This chapter discusses various PW recycling methods to overcome the load on treatment and disposal facilities.

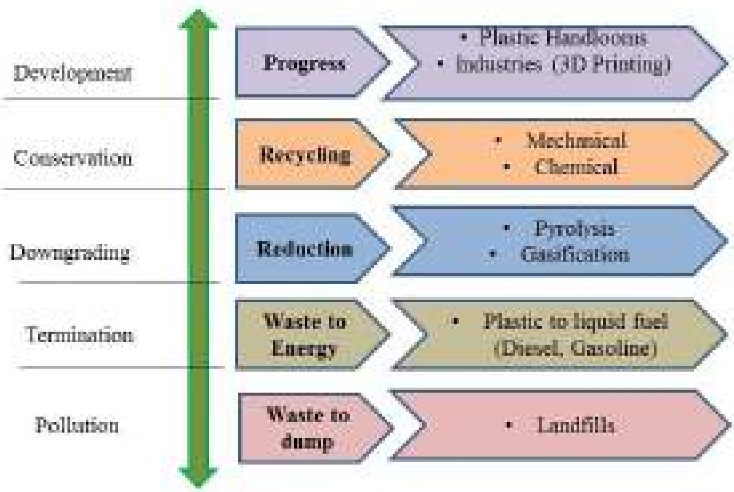


Fig. 1 Plastic Waste Processing Pathways

2. Global Scenarios

Plastic is used in everyday life across the globe. The PW generation is one of the growing concerns for countries with proper waste management rules. Unsound waste management of plastic leads to plastic leakage which affects the environment as well as ecosystem. European Union (EU) has initiated the plastic recycling targets and revised the legislation rules for plastic waste management. Sweden has also started the waste management practices.

2.1 Developed Countries

Over the last 10 years the EU has gradually developing the plastic recycling facilities with double recycling rate of post-consumer since 2006 (Plastics Europe, 2016). But still the recycling rate of plastic was very less as compared to other materials such as metal and paper. The breakthrough moment was happened in the year 2016 where the recycling rate of plastic is higher than 30% (Plastics Europe, 2016). Countries in EU claims the collected 27 million tons of PW products from residential and commercial areas, out of which 8.4 million tons are recycled **(Plastics Europe, 2016).** In Germany and Sweden plastic recycling rate around 40% and 20% in Malta. Several countries have restricted the landfill sites for dumping of PW that leads to increase in the plastic recycling rate e.g. Are Germany, Denmark, Netherland, etc.

2.2 Developing countries

In developing countries, mishandling and littering of PW is mostly predominant. India contributes 71% to PW generation in Asia, which also include mismanaged and poor PW management comprising of poor collection, segregation, treatment, and disposal methods (Neo et al., 2021). Though there are several sources for PW, the post-consumer market are the major contributors. The post-consumer market includes industries utilizing recycled plastic (which is in form of granules, molds and sheets), retail shops etc. Prior to the post-consumer market, the collected PW must be separated, cleaned and shredded in order to meet the required standards for recycling (Rafey and Siddiqui, 2021). As per a study conducted by the Federation of Indian Chambers of Commerce and Industry (FICCI), India is expected to gain a loss of approximately 133 billion dollars by 2030, due to inappropriate management, handling and packaging of PW product (FICCI, 2016). In India, about 5.5 million metric tons of PW are reprocessed/ recycled each year, out of which 70% is recycled in certified industries (formal) facilities and 20% by the informal sector. While, 10% is recycled at the domestic level (CSE, 2020).

3. Recycling Methods

3.1 Mechanical Recycling

Before the mechanical recycling of waste plastic undergoes several mechanical processes like collection, separation, grinding, washing, drying, and compounding. After these processes the granules converted into final new products. Mechanical recycling of plastic material such as Polyethylene terephthalate (PET), Polypropylene (PP), and Polyethylene (PE) is very common and well recognized. Collection and separation process plays a very important role in generation of quality recycling material. Mechanical and optical separations are unable to separate biodegradable PW due to their analogous appearance and densities. Now a day, recent technologies have been introduced which allows automatic sorting but this facility is not available at most of the recycling sites (Mudgal et al., 2012). The basic terminology for mechanical recycling is shown in Fig 2.

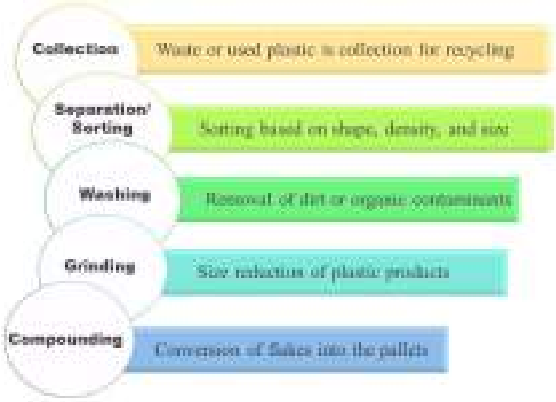


Fig. 2 Basic Terminology of Mechanical Recycling

3.2 Collection

In Belgium for plastic, metal, and drink packages (PMD), there is separate collection and sorting schemes. The municipalities collect plastic-based products from curbsides, which are classified as Polyethylene terephthalate (PET), High-density polyethylene (HDPE), and Polypropylene (PP), Low-density Polyethylene (LDPE) etc. These plastic products are shredded and shorted based on its size through progressive rotating sieve. The medium size (40-120 mm) and large size (120-220 mm) plastic flakes are sorted using wind sifter. Further mixed waste is passed through a magnetic conveyor belt to collect ferrous metals. While, eddy current separators are preferred for collection of non-ferrous metals (aluminum). The large size of fraction is passed via ballistic separator, which eliminates the all kind of soft plastic. The remaining plastic is separated by FT-NIR (Fourier Transform near Infrared) into PET and HDPE. All the sorted plastic transported to off-site such as blue PET, green PET, and HDPE. Mostly FT-NIR automated sorting method is used for plastic separation **(Hopewell et al., 2009).**

3.3 Sorting of Mixed Polymers

The separation of mixed plastic is one of the challenging tasks for recyclers. While collection of curbsides plastic bags several type of mixed plastic is present such as PET, PP, and HDPE. The non-packaging polymers like acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polyamide (PA), and organic food also contaminates the mixture. This huge waste is sorted in large hall. First the waste is loaded on belt conveyer which carries the waste to crude shredder. The crude shredder cut in small particles and then it is transported to feed silo. The rotating drum washer separates glass, rocks, and metals using gravitational method and applies water flow to wash the waste material. After that again friction washer (2nd washing) is used to eliminate organic remnants. One more time grinding process performed to grind the large particle sized plastic into smaller one (1-12 mm) size. Immediately, friction washer is used (3rd washing) and it is shown in **Fig. 3**. In float-sink separation process material is separated using density mechanism. The water bath process helps to float PE and PP whereas polymers like PS, PET, and PVC will sink. After that the sink material is passed through mechanical drier and we get secondary raw material. The float particles are dried in wind sifter. In this process airflow will remove soft particles like LDPE and PP, and heavier particles will fall down against the airstream **(Ragaert et al., 2017).**

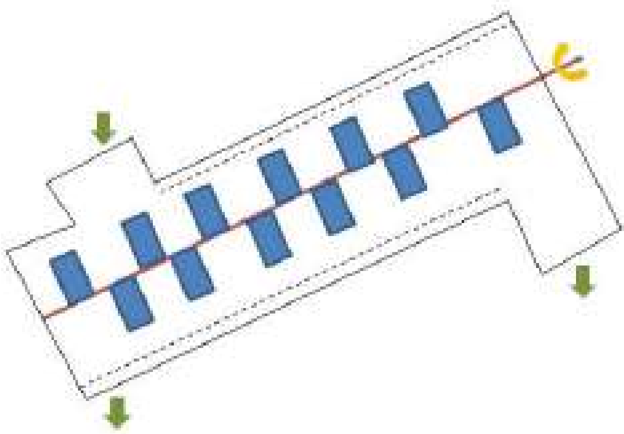


Fig. 3 Friction Washer

3.4 Removal of Impurities

Before proceeding the material into further step and also about the machine protection concern removal of impurities is necessary step. Using magnetic separation magnetic contaminants are removed. Weak magnet particle are difficult to separate so; it is removed by inductive sorter method. Moreover, non-ferrous metals are removed by eddy current separation **(Feil and Pretz, 2020).**

3.5 Electrostatic Separation

The dielectric constants and conductivities of plastic are broken using corona roller for separation. The fundamentals of this method is to separate narrow range of plastic (6-12 mm) size by using loading. This method operated on specific parameters are >100 kV, 10^{-3} A and electric field of 5 kV cm^{-1}. The sorting is not only depending on physical parameters (electrical conductivity, dielectric constants) but also the surface characteristics of plastic material. These particles are generally covered with an adsorbing water layer in moist air that enhances the surface conductance of nonconductors substantially. As a result, water should be evacuated prior to the procedure (thermal treatment), and the treatment must take place in controlled moisture conditions (climatization). Besides the conductor and nonconductor fractions, separation techniques usually generate an intermediate product that should be cleaned at some point (Feil and Pretz, 2020).

3.6 Chemical Recycling

Chemical recycling is widely accepted technology that adheres 'sustainable development concept'. This method is useful for the production of fuel and chemical material. The current focus isn't just on energy recovery, but also on the formation of beneficial products like monomers and petrochemical feedstock. For chemical recycling methods are suitable for the recycling of materials such as PET, nylon, and Polyurethane (PUR) with hydrocarbon content. Plastic trash, biomass, and particularly polyolefin waste, does not contain considerable amounts of oxygen level. De-polymerization methods, such as hydrolysis and glycolysis, and thermolysis methods, like gasification and pyrolysis, are examples of chemical recycling procedures for PW recycling. Chemical recycling of plastic is the permanent solution for biodegradable plastic but it is useful concept for circular economy. The lactic acid is recovered from polylactide (PLA) and then it again used for making PLA resin.

3.7 Chemolysis

Chemical recycling is widely accepted technology that adheres 'sustainable development concept'. This method is useful for the production of fuel and chemical material. The current focus isn't just on energy recovery, but also on the formation of beneficial products like monomers and petrochemical feedstock. The chemical recycling methods are suitable for the recycling of materials such as PET, nylon, and Polyurethane (PUR) with hydrocarbon content. Plastic trash, biomass, and particularly polyolefin waste, does not contain considerable amounts of oxygen level. De-polymerization methods, such as hydrolysis and glycolysis, and thermolysis methods, like gasification and pyrolysis, are examples of chemical recycling procedures for PW recycling. Chemical recycling of plastic is the permanent solution for biodegradable plastic but it is useful concept for circular economy. The lactic acid is recovered from polylactide (PLA) and then it again used for making PLA resin. The several process of chemical recycling are explained below;

3.8 Pyrolysis

The pyrolysis is very engrossing method for plastic waste recycling. Here the waste like PE, fiber-reinforced composites, PP, and PS are unable to depolymerize. Currently this waste is not recycled but incinerated or dumped at landfill sites. This process operated under moderate to high temperature range i.e. (500°C) and pressure 1-2 atm in absence of oxygen. Due to high temperature the larger molecules breaks into smaller one **(Angyal et al., 2007).**The pyrolysis products of solid waste plastic are degraded into three different segments are liquid, solid and gas (AI-Salem et al., 2009a, 2010). The availability of PVC in flow is another major concern with solid PW pyrolysis (Sadat-Shojai and Bakhshandeh, 2011). Despite the large density variance between PVC and other types of polymers, poor separation will constantly retain a small portion of PVC in the mixture. In addition, the presence of this acid will place significant metallurgical constraints on the equipment material. The existence even of low contents of halogens in the oil/waxes prevents it from being used as a fuel.

3.9 KDV Process

A German company Alphakat GmbH developed a KDV process, stands for Katalytische Drucklose Verolung. This method deals with the catalytic conversion of plastic and biomass into liquid fuel. The key benefit of this process is that it completely removes oxygen atom from product and fuel can directly use in combustion engine. Using this process oil, kerosene, and petroleum can be obtained (Reza and Bahram, 2015). A KDV process is widely used in several countries. A supplementary development of KDV process is the elimination of ashes from turbine reactor but the residue ash remains the

KDV fuel. So, to remove whole fuel ashes it is heated at 500°C temperature and separated through distillation column. Finally an ash contains certain amount of mineral which is used as a fertilizer in agriculture (Koch, 2011). KDV diesel contains high amount of sulphur content and it is very harmful for KDV fuel. The KDV process is still in development phase. It is quite similar with deoxyliquefaction method. Moreover, this method has lack of technical and chemical information; hence the further study is required (Labeckas and Slavinskas, 2013).

3.10 Gasification

It is the process of conversion of solid fuel into chemical energy and then gaseous fuel. Initially it converts solid fuel into syngas containing carbon monoxide and hydrogen. While converting in solid fuel the no of reactions performed this generates products like CO2, CH4, tar, and so on. Now days, gasification of waste plastic is widely used not only for lab scale but at industrial level too. In United State Texaco gasification process is installed at pilot level. The gasification process performs with oxygen and steam temperature at (1200-1500°C). After that cleaning process performed for removal of HCL and HF, finally clean and dry gas produced **(Brems et al., 2015).**

3.11 Biological Recycling

Biological recycling, often known as organic recycling, is the process of breaking down PW using microbes like fungi, bacteria or algae to generate biogas (CO_2 for aerobic operations and CH_4 for anaerobic operation). PW can biologically recover using aerobic composting and anaerobic digestion (Singh and Ruj, 2015). Koshti et al. (2018) consider an enzymatic method for PET biodegradation to be an economically feasible recycling technology. Oxo-plastics one of the major class of bio plastic that challenges because of rapid breakage into micro - plastics when the conditions like sunlight and oxygen are suitable (Kubowicz and Booth, 2017). This process has some challenges that include energy consumption for recycling and degradation time for the micro plastic as well as with socioeconomic constrains such as longer time duration and capital expenditure, as well as a shortage of resources. Additional challenges to bio-based polymers and recycling include assembly and sorting of bio-PW, as well as absence of appropriate policy regulation.

4. Waste to Fuel

The plastic is made of synthetic polymer which is obtained from fossil fuel. Polymerization is the process by which molecules combined together because of chemical reaction and form long chain. At final stage the desired product is made by heating the material and molded as per requirement. The final product contains not only the polymers but also the other materials such as lubricants, catalysts, filler etc. This addition enhances the products performance and economic value too. Generally, plastic is classified into two main types are thermoplastics and thermosetting plastics. Here thermoplastic can be softening by giving the heat that includes polyethylene (PE), polypropylene (PP), polycarbonate, and nylon. Whereas, thermosetting cannot be soften by heat once it shaped, it includes epoxy resin, melamine, and formaldehyde. Disposal of PW is one the serious matter of concern. Worldwide, in many countries plastic is dumped at landfill sites. Another way of plastic disposal is incineration, chemical recycling, and mechanical compaction. All these above activities lead to environmental pollution which emits undesirable gaseous. Newly, researchers have been found out a liquid fuel from waste plastic material using pyrolysis process. Few kind of plastic can produce better quality of liquid fuel from pyrolysis which are PE, PP, and PS. Among all types of plastics PP and PE are good for liquid fuel. But the process needs more energy to produce liquid fuel. So, still it is ongoing discussion as to whether it takes more energy to produce the fuel than there is in the fuel itself. The major contribution of PW is from industries like electronics, construction, packing sector, transport, and many more. The graphical presentation is shown in **Fig. 4**. **(Chandran et al., 2020).** Hydrocracking, thermal cracking and catalytic pyrolysis are used to convert waste plastic into liquid fuel are explained below.

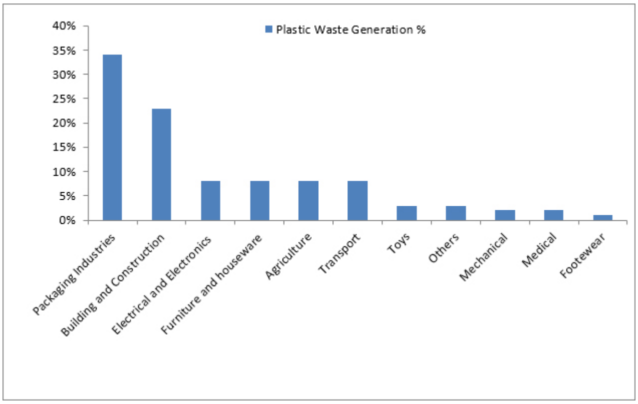


Fig 4 Plastic Generation from Different Industries

4.1 Cracking

It is the process where large molecules of polymer are broken down into smaller hydrocarbon chemical and useful fuel. Basically, there are three different methods of cracking are;

• Hydrocracking:

Hydrocracking of plastic includes the reaction of hydrogen with catalyst under the temperature between 230C to 380C and pressure between 3 to 10 bar. After cracking process gasoline is obtained as a final product. Using this method any kind of plastic can be cracked. The catalyst used are ferrous, sulfated zirconia, and nickel.

• Thermal Cracking:

Thermal cracking of plastic includes oxygen free heating under the temperature range between 340 and 920C. After condensation process paraffins, olefins, naphthenes, and aromatics final products obtained and remaining residue is char. The major limitation of this process is it requires high temperature.

• Catalytic Pyrolysis:

It is the cost-effective process to transform PW into the energy based products like fuels. In this process catalyst can be used for multiple times and temperature is lower than the thermal cracking and hydrocracking. In catalytic pyrolysis zeolite is most preferable catalyst is used; operating at lower temperature it produces higher liquid hydrocarbon **(Lopez et al., 2011).** The fluid catalytic cracking (FCC) generates more gasoline than any other catalyst **(Liu and Meuzelaar, 1996).**

4.2 Application of Plastic Oil in Diesel Engine

Plastic oil is used as fuel in diesel engines. Researchers have analyzing the basic property of distilled plastic oil and waste plastic oil that results the fuel are better suitable for diesel engines than spark ignition engines. The result proves that enhanced engine performance as it comprises of carbon (84%), hydrogen (15.5%), and oxygen (0.5%). Diesel engine produces high level of particulate matter and nitrous oxide (NO_x). Studies have suggested that blending of pyrolysis oil (40% by volume) with diesel can enhance engine performance and reduces the emissions of harmful pollutants **(Frigo et al., 2014).** For mitigation of hazardous emissions, various types of additives are blended with waste plastic oil. Usage of proper catalyst with pyrolysis process will reduce the overall cost of the process **(Chandran et al., 2020)**.

5. Conclusions

The existing policy must include active participation of both residents and stakeholders in regenerative economic model. It was observed that the developing countries lacked in technical advancement and revised policy schemes, which led to unorganized PW management. It is essential to focus on aspect such as resource recovery, and recycling to meet the target for sustainable PW management. The pillars for sustainable environment need to be built on advance technologies and revised policies. Formalizing the informal sector with appropriate incentives is also necessary, as they play a vital role in plastic supply chain. It is recommended to prefer non-virgin plastic (made from recyclable plastics) over new virgin plastic, as it might reduce the load on production cost and overall rate of PW generation.

References

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste management*, *29*(10), 2625-2643.

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2010). The valorization of plastic solid waste (PSW) by primary to quaternary routes: From re-use to energy and chemicals. *Progress in Energy and Combustion Science*, *36*(1), 103-129.

American Chemical Society (ACS), 1993. Leo Hendrick Baekeland and the invention of Bakelite. https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/ bakelite.html.

Angyal, A., Miskolczi, N., & Bartha, L. (2007). Petrochemical feedstock by thermal cracking of plastic waste. *Journal of analytical and applied pyrolysis*, *79*(1-2), 409-414.

Brems, A., Baeyens, J., & Dewil, R. (2012). Recycling and recovery of post-consumer plastic solid waste in a European context. *Thermal Science*, *16*(3), 669-685.

Chandran, M., Tamilkolundu, S., & Murugesan, C. (2020). Conversion of plastic waste to fuel. In *Plastic waste and recycling* (pp. 385-399). Academic Press.

Chidepatil, A., Bindra, P., Kulkarni, D., Qazi, M., Kshirsagar, M., & Sankaran, K. (2020). From trash to cash: how blockchain and multi-sensor-driven artificial intelligence can transform circular economy of plastic waste?. *Administrative Sciences*, *10*(2), 23.

CSE (2020), Managing PW in India: challenges and Agenda. Retrieved from https:// www. csein dia. org/ conte nt/ downl oadre ports/ 10352.

Fakhrai, R., & Saadatfar, B. (2015). Feasibility study and quality assurance of the end-product of Alphakat KDV technology for conversion of biomass.

Feil, A., & Pretz, T. (2020). Mechanical recycling of packaging waste. In *Plastic Waste and Recycling* (pp. 283-319). Academic Press.

FICCI (2016) Indian plastic industry: challenges & opportunities. Retrieved from https:// www. slide share. net/ TSMG- Chemicals/ indian-plastic- industry- challenges- opportunities

Freinkel, S. (2011). A brief history of plastic's conquest of the world. *Science America*. https://www.scientificamerican.com/article/a-brief-history-of-plasticworld- conquest/.

Frigo, S., Seggiani, M., Puccini, M., & Vitolo, S. (2014). Liquid fuel production from waste tyre pyrolysis and its utilisation in a Diesel engine. *Fuel*, *116*, 399-408.

George, N., & Kurian, T. (2014). Recent developments in the chemical recycling of postconsumer poly (ethylene terephthalate) waste. *Industrial & Engineering Chemistry Research*, *53*(37), 14185-14198.

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2115-2126.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768-771.

Koshti, R., Mehta, L., & Samarth, N. (2018). Biological recycling of polyethylene terephthalate: a mini-review. *Journal of Polymers and the Environment*, *26*(8), 3520-3529.

Koch, C., 2011. The KDV Technology [Company Presentation]. Alphakat GmbH.

Kubowicz, S., & Booth, A. M. (2017). Biodegradability of plastics: challenges and misconceptions.

Labeckas, G., & Slavinskas, S. (2013). Performance and emission characteristics of a direct injection diesel engine operating on KDV synthetic diesel fuel. *Energy conversion and management*, *66*, 173-188.

Lamb, J. B., Willis, B. L., Fiorenza, E. A., Couch, C. S., Howard, R., Rader, D. N., Ahmad, A., & Harvell, C. D. (2018). Plastic waste associated with disease on coral reefs. *Science*, *359*(6374), 460-462.

Liu, K., & Meuzelaar, H. L. (1996). Catalytic reactions in waste plastics, HDPE and coal studied by high-pressure thermogravimetry with on-line GC/MS. *Fuel processing technology*, *49*(1-3), 1-15.

López, A., De Marco, I., Caballero, B. M., Laresgoiti, M. F., Adrados, A., & Aranzabal, A. (2011). Catalytic pyrolysis of plastic wastes with two different types of catalysts: ZSM-5 zeolite and Red Mud. *Applied Catalysis B: Environmental*, *104*(3-4), 211-219.

Mudgal S, Muehmel K, Hoa E, Gremont M. Options to improve the biodegradability requirements in the packaging directive. DG Environment e European Commission; 2012. http://ec.europa.eu/environment/waste/packaging/pdf/options_to_improve_biodegradability_in_ppwd_2012.pdf.

Neo, E. R. K., Soo, G. C. Y., Tan, D. Z. L., Cady, K., Tong, K. T., & Low, J. S. C. (2021). Life cycle assessment of plastic waste end-of-life for India and Indonesia. *Resources, Conservation and Recycling*, *174*, 105774.

Plastics Europe, E. P. R. O. (2016). Plastics—The Facts 2019. An Analysis of European Plastics Production, Demand and Waste Data. Plastics Europe.

Rafey, A., & Siddiqui, F. Z. (2021). A review of plastic waste management in India–challenges and opportunities. *International Journal of Environmental Analytical Chemistry*, 1-17.

Ragaert, K., Delva, L., & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. *Waste management*, *69*, 24-58.

Sadat-Shojai, M., & Bakhshandeh, G. R. (2011). Recycling of PVC wastes. *Polymer degradation and stability*, *96*(4), 404-415.

Singh, R. K., & Ruj, B. (2015). Plasticwaste management and disposal techniques-Indian scenario. *International Journal of Plastics Technology*, *19*(2), 211-226.

Development of Bioplastic Films from Neglected Crops and It's Plant Waste with Potential Application in Food Packaging Industry

Susmita Shukla* & Ritambhara Bhutani

Applied Plant Biotechnology Research Lab, Centre for Plant and Environmental Biotechnology, Amity Institute of Biotechnology,
Amity University, Noida (U.P) - 201313, India

Abstract

Bioplastic is one of the eco-friendly alternative to plastics, which could be an excellent replacement since their manufacturing results in fewer emissions of greenhouse gasses. Unlike plastics, bioplastic are made from organic biomass sources such as corn starch and sugarcane. Neglected crops are primarily grown by traditional farmers. Such species may be widely distributed in the local production and consumption systems. They are important for the subsistence of local communities yet remain neglected by the mainstream research and development activities. The present study is based on in utilization of neglected crops for production of biodegradable plastic films with potential in food packaging Industry at the same time mass multiplication of such crops are much required in order to suffice the need of raw material for large scale production. Bioplastic films development through such mechanism using low-cost plant parts and biowaste have displayed properties with potential application in food packaging industry. The present study highlights the preparation of biopolymer from such neglected crops that has proper flexibility and also showed improved tensile strength. Keeping view the potential of plant parts and waste of such crops further largescale production is proposed.

Keywords: Bioplastic, Plant waste, neglected crops, biodegradable, food packaging Industry

1. Introduction

Today's era everything for packaging goods rely on the use of plastic bags which has become common means of carrying merchandise. Retailers, markets, and shops distribute these bags for carrying goods free of charge. After being used these bags reaches to homes where most of the bags are disposed of or stored for reuse and eventually reach the landfills. Plastic pollution poses a major problem to the environment. In just one year, it was estimated that 8 million metric tons of plastic entered the ocean which were non biodegrade and caused disastrous impact on marine life specifically whales and sea turtles (Karoui and Marzouk 2013). It has been reported that every year, 8 million tons of plastic slips through wastewater treatment plants and ends up in the ocean. This is equivalent to five grocery bags full of plastic for every foot of coastline on Earth (Barceloux 2009). The major problem with traditional bioplastic is that it can't be recycled into other plastic products and results in methane gas emission (Vivita Priedniece et al. 2016). To protect the environment from this major source of pollution, many countries are looking for alternatives to plastic which should be eco-friendly and biodegradable in nature. The most effective way to combat plastic pollution is to replace plastics with bioplastic derived from renewable sources. Bioplastic on the other hand has many benefits: it can be biodegradable, compostable, or recyclable and it needs less energy to make than traditional plastics (Maria Assunta Acquavia et al., 2021). Knowing the impact of plastic bags which is creating plastic pollution many companies worldwide has introduced degradable/ biodegradable plastics suggesting their consumers to avoid the use conventional plastic shopping bags. There are many companies worldwide working on the production of bioplastics some are given in Table 1.

Table 1
List of few companies manufacturing Bioplastics

Companies	**Country**	**Source**	**Bioplastic products**	**Reference**
Agrana	Central and Eastern Europe	Fruit	thermoplastic starch	https://bioplasticsnews.com/agrana/
Biologiq	USA	potato processing	sustainable plastic products	https://www.biologiq.com/contact
Biomer	Germany	feedstock	Polyhydroxybutyrate (PHB)	http://www.biomer.de/IndexE.html
Deinoplast	France	plant protein-based food products	Biobased muconic acid	https://bioplasticsnews.com/2016/06/21/deinove-award-worldwide-innovation-challenge/
Ellen MacArthur Foundation (EMF)	England	--	Oxo-biodegradable Plastics	https://bioplasticsnews.com/2022/04/11/michael-stephen-ellen-macarthur-foundation/
Green Dot Bioplastics	USA	corncob and sugarcane	bio-based and biodegradable bioplastics and biocomposites	https://www.greendotbioplastics.com/
Woodly	Finland	wood-based	Packaging of Consumer Packaged Goods (CPG)	https://woodly.com/

2. Highlights on National and International Bioplastic Market

The market for bioplastics in India is no longer nascent with many industry players taking pioneering steps. India has the raw material biomass required for bioplastics in abundance. Combining this with the rising awareness among consumers, India could become the potential fulcrum for global behaviour change in turning away from plastics. Quite a few manufacturing firms like Envigreen, Ecolife, Plastobags, Earthsoul India and Truegreen have come up with different forms of bioplastics, which are already supplying these environment-friendly forms of plastics in regional markets (Mominul Sinan, 2020). Various Govt. schemes are in place to combat the harmful effect of plastic pollution and other initiatives are being taken to promote use of bioplastics. The global bioplastic market is projected to reach USD 30 billion by 2025. There are a lot of new companies in the industry that are working on creating affordable, sustainable plastics from plants. India is at the forefront of the industry with an increase in innovation and investment in this field. Bioplastics are a new type of plastic with a low carbon footprint. They are made from organic materials such as starch, rice, corn, and soy. The world is leading in bioplastic production with 54% of the global share while India has 24%. China leads the pack in manufacturing bioplastics at 68% while India has only 8%. The United States is the leader in bioplastic production. Bioplastic production in the world has increased rapidly over the past decade, from 2 million metric tonnes in 2005 to 4.5 million metric tonnes in 2015.. Currently, bioplastics market growth is at 10% annually covering approximately 10–15% of the total plastics market. This number would increase to 25–30% by 2020 (Nor Izaida Ibrahim et al., 2021). Currently, the demand for bioplastics is increasing due to its renewability and availability of raw material, advanced functionality and technical properties, and the recycling option that they present.

3. Bioplastics: Types and sources

Plant-based plastics can be made from renewable biomass sources such as corn, sugarcane and other organic materials, which means they are biodegradable and even compostable under right condition (Beck, 2005).Bioplastics made from renewable resources can be naturally recycled and can limit the use of fossil fuels thereby protect the environment. Non-biodegradable bioplastics are made from plastics like polyethylene terephthalate (PET) which does not break down in the environment. Biodegradable plastics take anywhere from 6 months to 2 years before it fully breaks down in a landfill or compost bin (Swift G., 2003). Non-biodegradable plastics never break down and can cause environmental issues. Biodegradable plastics are made from renewable sources. The most common bioplastic is polylactic acid or PLA. Biodegradable plastic can degrade in landfills, compost piles, and even under natural conditions. Non-biodegradable bioplastics, also known as petro-plastics, are made from petroleum and usually include the word “poly” in their name. (Md Hafizur Rahman and Prakashbhai R. Bhoi, 2021).

Environmentally degradable plastics are increasing in popularity because of environmental issues facing by the society. The biodegradable plastics currently developed can be categorized into the following: (Kathiresan, 2003). Natural polymers that use polysaccharides such as starch. Microbial polyesters that use the biological activity of microorganisms. Blends with accelerated degradation properties that are regular plastics with degradation accelerator additives. Chemical synthetics that include aliphatic polyesters. Bioplastic can be made from any agricultural waste product that grows back quickly - it can even be created by using plants that otherwise would not have been farmed. In some developing countries, these crops are grown just to make more bioplastics and keep their economy running (Artham and Doble 2008).

Bioplastic can come from a variety of sources, including corn, sugarcane, wheat, and other crops that are often neglected. These crops can be grown on marginal land to produce bioplastic without displacing food production (Chris E Talsness et al., 2009). This is an attractive option for farmers in developing countries. Bioplastics are a sustainable material that can be made from crops that are not usually harvested for food or feed. This includes grasses like wheat, hemp, and sorghum. These crops take less water to grow and don't require fertilizers or pesticides (Lang et al. 2008). Bioplastic is a type of plastic made from plant material which doesn't need to be heated like traditional plastic so it has lower energy costs and can be produced with a smaller carbon footprint. Bioplastic is made by using leftover crops that would otherwise go to waste because they are too small, too ripe, or not the right shape for food-production purposes. Additionally, those plants can grow in contaminated soil, which reduces the number of fertilizers needed (Moore 2008). Synthesis of Bioplastics from Bio-Waste are, on the other hand, synthetic materials that are not derived from renewable sources but instead, petroleum. In recent years, scientists have been experimenting with ways to create synthetic bioplastics from waste products like corn stalks or sugar cane. One of their latest breakthroughs is the creation of a new type of starch that acts as an additive to produce bioplastics (Steinbuchel 2001). Bioplastics can be classified according to their source as well, which can be divided into three subgroups, first are the bioplastics generated directly from the biomass, that is, from the extracted starch, such as Polylactic Acid (PLA), the second are those generated from vegetable oils and the last, those generated from Polyhydroxyalkanoates (PHA) (Endres 2017). Some of the major sources of Bioplastics production mentioned in the following text.

3.1. Agri based Biowaste

Agri-food industries generate enormous amounts of fruit and vegetable processing wastes which has lead to huge amount of agri – biowaste which can be convert into wealth and has opened up an important research area aiming to minimize and managing them efficiently to support zero wastes and/or circular economy concept. These wastes remain underutilized owing to lack of appropriate processing technologies and one way to do this is by converting these biowaste into bioplastic. Scientists have already found a way to convert the waste into biopolymers which could then be used in the production of biodegradable plastic products. This would drastically reduce the amount of waste converting into biodegradable biowaste (Calabrò and Grosso 2018). Biowaste which has been converted into biodegradable bioplastic products is been depicted in figure 1.

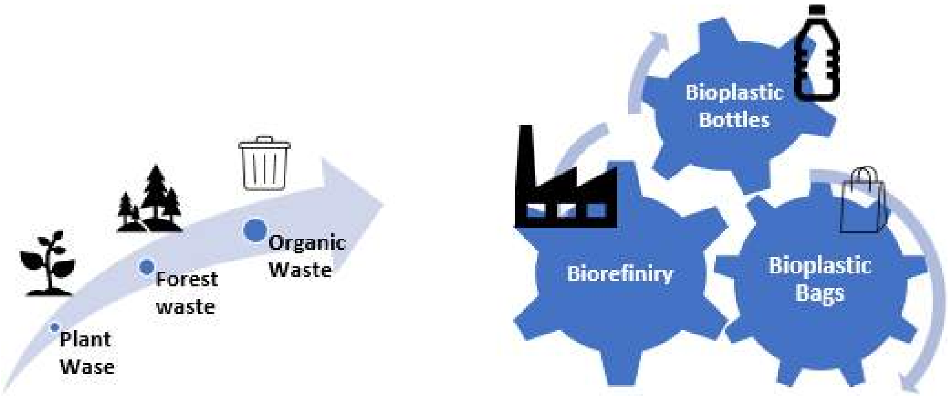


Figure 1: Biowaste into bioplastic products

3.2. Cellulose-based plastics

Cellulose plastics are bioplastics manufactured using cellulose or derivatives of cellulose. Cellulose plastics are manufactured using softwood trees as the basic raw material. Barks of the tree are separated and can be used as an energy source in the production of cellulose based bioplastics.. Cellulose bioplastics are mainly the cellulose esters, (including cellulose acetate and nitrocellulose) and their derivatives, including celluloid. Cellulose can become thermoplastic when extensively modified. An example of this is cellulose acetate, which is expensive and therefore rarely used for packaging. However, cellulosic fibres added to starches can improve mechanical properties, permeability to gas, and water resistance due to being less hydrophilic than starch (Gregory MR, 2009). A group of scientist at Shanghai University was able to construct a novel green plastic based on cellulose through a method called hot pressing (Hegazy AE and Ibrahium MI., 2012). Softwood is the dominant raw material used in the production of cellulose plastics and increasing number of deforestation regulations is a major restraint for the market. Major restraint for cellulose plastics market growth is easy availability, low cost of conventional plastics, high efficiency and comparative cost benefit of conventional plastics over cellulose plastics has restrained market growth for cellulose plastics. Therefore, there is need of increasing research and development to produce high efficiency and low cost cellulose plastics which is anticipated to offer huge growth opportunity in cellulose ester market.

3.3. PLA (polylactic acid):Biodegradable thermoplastic Polyester

PLA (polylactic acid) is typically made from the sugars in corn starch, cassava, or sugarcane. It is biodegradable, carbon-neutral and edible. General methodology to transform corn into plastic is done via immersing corn kernels in a slurry of bacteria and yeast which ferments the sugars to produce lactic acid. Lactic acid then reacts with glycerol, a by-product of soap manufacture, to produce long-chain polyesters that can be used to make food containers such as cereal boxes and cups (Bhatnagar S and Milford A Hanna.,1996). It is now widely used in packaging sector right from a niche product in organic trade to premium packaging for branded goods.It has huge potential in industrial areas like medicine, textile and food packaging.

The two main groups of bioplastics are biobased polymers and biodegradable plastics. Biobased polymers are derived from biomass sources, which are not necessarily biodegradable. Biodegradable plastics, on the other hand, can be either made of natural or fossil sources. These biodegradable and non-biodegradable polymers has huge applications in Food and Packaging Industries. Applications of biopolymers based on various sources is listed in Table 2.

Table 2
Applications of biopolymers derived from various sources

Type	**Biodegradable/ Non-Biodegrad-able**	**Source**	**Applications**	**Reference**
Starch based polymers	Biodegradable	Corn, pota-toes	food packaging, dispos-able tableware and cutlery, coffee machine capsules, bottles	Avella M et al., 2005
Cellulose based polymer	Biodegradable	Wood pulp, cotton	Coated, compostable cel-lulose films are used for the packaging of all kinds of food (e.g. bread, fruits, meat, and dried products)	European Commis-sion. 2007
Polylactide (PLA)	Biodegradable	Corn	Transparent, rigid contain-ers (e.g. cups, bowls, bot-tles), bags, jars, films	Plackett DV et al., 2006
Polyhydroxyal-kanoates (PHA)	Biodegradable	GMO bac-teria	biocontrol agents, drug carriers, biodegradable im-plants, tissue engineering, memory enhancers, and an-ticancer agents	Subhasree Ray, Vipin Chandra Kalia. 2017
Biobased poly-propylene (PP) and polyethyl-ene (PE)	Non-Biodegrad-able	Corn, sugar-cane	films and sheets in packag-ing	Jakubow-icz I et al., 2011
Partially based PET	Non-Biodegrad-able	Fossil fuel	PlantBottleTM introduced by The Coca Cola Com-pany (TCCC) in 2009 and also used for Heinz ketchup since 2011. Greener Bottle or Bouteille Végétale intro-duced by Danone in 2010.	Roes AL, and Patel MK. 2007
Biobased polyethylene furanoate (PEF)	Non-Biodegrad-able	Biomass	Bottles, fibers, films	Food Packaging Forum. 2013.
Aliphatic (co) polyesters	Biodegradable	Fossil fuel	Disposable cutlery	Niaounakis M. 2013

Polyamides (PA)	Non-Biodegradable	Vegetable oils and plants raw material	Automotive fuel lines, pneumatic air brake tubing, electrical cable jacketing, flexible oil and gas pipes, and powder coatings etc	Brehmer B. 2014
Polyvinyl alcohol (PVOH)	Biodegradable	Fossil fuel	Coatings (e.g. carbon dioxide barrier of PET), component of adhesives, additive in the production of paper and board	Vert M et al., 2012
Polycaprolactone (PLC)	Biodegradable	Starch	Pure PCL is mainly used in medical applications due to the low melting temperature and good biodegradability. PCL blends are used as FCMs	Plackett DV et al., 2006

4. Exploring potential of underutilized and neglected crops for bioplastic production

Neglected and underutilized species are either cultivated, semi-domesticated, or wild plant species which are not included in the group of the major staple crops and these do not meet the global market requirements as well. The present study is based on exploration of such crops for production of bioplastics.Horse gram [Macrotyloma uniflorum Lam. (Verdc.)], is an underutilized (Aiyer 1990)and unexplored (Reddy et al. 2008) food legume. It is considered as a good source of protein, carbohydrates, energy (Bravo et al. 1998). Horse gram mainly grown in India, Africa, Australia, Burma, Malaysia, Mauritius, and the West Indies (Jeswani and Baldev 1990) under low soil fertility status with few inputs (Witcombe et al. 2008). It is adapted to wide range of temperature regimes (Smartt 1985) where other crops invariably fail to survive. Researchers has reported proteins extracted from the common legume horse gram and were made into films The novel horse gram protein films has shown properties suitable for both tissue engineering and food packaging applications(Shakkara et al., 2020) Globally palms are utilized for various products such as seed oil, leaves for thatching houses, the fruits of some palms are edible and possesses medicinal properties. Although many of the members of palms have the potential to be explored commercially some of them still fall into the underutilized category. These underutilized palm tree has vast potential to be explored for commercialization. It has been reported that palm sugar can be used as a potential raw material for the preparation of biopolymers and can be used as biodegradable plasticizer (Sahari et al., 2012). Some of the indigenous tuber crops are still unexploited sources of starch with interesting characteristics in terms of potential uses as starch-based products. Starch is a natural biopolymer that is biodegradable, inexpensive, renewable and widely available in various plants (Ashogbon and Akintayo, 2014). It comes in a variety of shapes, sizes and properties allowing for a wide range of applications with high technological value in both the food and nonfood industries. Compared to common starches, these starches have far fewer studies on their food and industrial applications. It has been proposed that starch-based bioplastics would be a better alternative material to be used in packaging industries.

5. Bioplastics for Food Packaging Industry

Petroleum derived plastics dominate the food packaging industry even today. These materials have brought a lot of convenience and attraction to agro, food and packaging industry. Packaging materials with biodegradable plastic is more expensive than traditional petroleum based plastic. Packaging materials based on these natural materials may be a solution to help control the environmental pollution and resolve other problems posed by non-degradable synthetic polymers [20]. The implementation of sustainable practices will help minimize our impact on the environment and conserve resources for future generations. Industrial progress in packaging technology in future appears to be moving forwards newer breed of bio-materials. Target markets for biodegradable polymers include packaging materials like trash bags, loose-fill foam, food containers, film wrapping, laminated paper, hygiene products like diaper back sheets and cotton swabs, consumer goods like fast-food tableware and containers, egg cartons, and toys, and agricultural tools like mulch films and planters etc. [18].Focused research is needed in bringing more values such as making the packaging material simpler yet smarter, where consumer is able to assess the quality, safety, shelf-life, and nutritional values of the contents of packet with cost effectiveness.

6. Conclusions

The present study is focusses on exploring the potential of underutilized or neglected crops for bioplastic production and its application in food and packaging industries as well as other relevant industries. In the coming future generation, with increase in huge population worldwide there is emergent need to mitigate the risk of environmental pollution. Use of bioplastics is one of the important step towards minimizing the pollution at the same time its one has to think about continuous supply of raw material required for the production of Bioplastics. Therefore identifying and exploring the potential of natural resources and continuous availability of raw material for Bioplastic production need to be addressed.

Acknowledgements

Authors are thankful to Amity University Uttar Pradesh for rendering support during the preparation of the manuscript throughout and are also thankful to Dr Amal Mukhopadhayaya and team of 12th Hanseatic India Colloquium “Solid Waste Management: an Indo-German Dialogue” for giving me opportunity to present our work in the conference proceeding and special thanks to Dr Diksha for letting me know about the important colloquium.

References

Artham T, Doble M. (2008). Biodegradation of Aliphatic and Aromatic Polycarbonates. Macromol Biosci. 8(1): 14- 24.

Avella M, De Vlieger JJ, Errico ME. 2005. Biodegradable starch/clay nanocomposite films for food packaging applications. Food Chem. 93:467-74.

Barceloux DG. (2009). Potatoes, Tomatoes, and Solanine Toxicity (*Solanum tuberosum* L., *Solanum lycopersicum* L.). Disease-a-Month. 55(6): 391–402. doi:10.1016/j.disamonth.2009.03.009.

Beck, R.W., 2005. 2004 National post-consumer plastics recycling report. American Plastics Council, Division of American Chemistry Council, Arlington, VI, USA.

Bhatnagar S, Milford A Hanna. (1996). Starch based plastic foams from various starch sources, Cereal chemistry. 73(5): 601-604.

Brehmer B. 2014. Polyamides from biomass derived monomers. In: Bio-Based Plastics: Materials and Applications. S. Kabasci, ed., John Wiley & Sons, Ltd. pp 275-93.

Calabrò, P.S.; Grosso, M. Bioplastics and waste management. Waste Manag. 2018, 78, 800–801.

Chris E Talsness, Anderson JM, Andrade, Sergio N Kuriyama, Julia A Taylor and Frederick S.vom Saal. (2009) Components of plastic: experimental studies in animals and relevance for human health. 364: 1526.

European Commission. 2007. Commission Directive 2007/42/EC of 29 June 2007 relating to materials and articles made of regenerated cellulose film intended to come into contact with foodstuffs.

Food Packaging Forum. 2013. PEF: New food contact polymer on the horizon. [http://www.foodpackagingforum.org/News/PEF-New-food-contact-polymer-on-the-horizon]

Gregory MR. (2009). Environmental implications of plastic debris in marine settings-entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Phil. Trans. R. Soc. B. 364: 2013–2025.

Hegazy AE, Ibrahium MI. (2012). Antioxidant activities of orange peel extract. World Appl Sci J. 18: 684–688.

Jakubowicz I, Yarahmadi N, and Arthurson V. 2011. Kinetics of abiotic and biotic degradability of low-density polyethylene containing prodegradant additives and its effect on the growth of microbial communities. Polym Degrad Stabil. 96:919-28.

Karoui IJ, Marzouk B. (2013). Characterization of bioactive compounds in Tunisian bitter orange (Citrus aurantium L.) peel and juice and determination of their antioxidant activities. Bio Med Res Int. 1: 1-12.

Kathiresan. (2003). Polythene and Plastics degrading microbes from the mangrove soil. Revista de biologia tropical. 51: 3-4.

Lang IA, Galloway TS, Scarlett A, Henley WE, Depledge M, Wallace RB, Melzer D. (2008). Association of urinary bisphenol A concentration with medical disorders and laboratory abnormalities in adults. J. Am. Med. Assoc. 300: 1303–1310.

Maria Assunta Acquavia, Raffaella Pascale, Giuseppe Martelli, Marcella Bondoni and Giuliana Bianco. 2021. Natural Polymeric Materials: A Solution to Plastic Pollution from the Agro-Food Sector. Polymers 13, 158.

Md Hafizur Rahman and Prakashbhai R. Bhoi. 2021. An overview of non-biodegradable bioplastics, Journal of Cleaner Production, Volume 294,126218.

Mominul Sinan. 2020. Bioplastics for Sustainable Development: General Scenario in India. Current World Environment. 15(1): 24-28.

Moore CJ. (2008). Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environ. Res, 108: 131–139.

Niaounakis M. 2013. Biopolymers: Reuse, Recycling and Disposal. Elsevier, Amsterdam.

Nor Izaida Ibrahim, Farah Syazwani Shahar, Mohamed Thariq Hameed Sultan, Ain Umaira Md Shah, Syafiqah Nur Azrie Safri and Muhamad Hasfanizam Mat Yazik. 2021. Overview of Bioplastic Introduction and Its Applications in Product Packaging. Coatings MDPI. 11, 1423.

Plackett DV, Holm VK, Johansen P. 2006. Characterization of L-potylactide and L-polylactide-polycaprolactone co-polymer films for use in cheese-packaging applications. Packag Technol Sci. 19:1-24.

Roes AL, and Patel MK. 2007. Life cycle risks for human health: a comparison of petroleum versus bio-based production of five bulk organic chemicals. Risk Anal. 27:1311-21.

Steinbuchel A. (2001). Perspectives for biotechnological production and utilization of biopolymers: Metabolic engineering of polyhydroxyalkanoate biosynthesis pathways as a successful example. Macromolecular Bioscience. 1(1): 24.

Subhasree Ray, Vipin Chandra Kalia. 2017. Biomedical Applications of Polyhydroxyalkanoates. Indian J Microbiol. 57(3):261–269.

Swift, G., 2003. Biodegradable water-soluble polymers. In: Andrady, A.L. (Ed.), Plastics and the Environment. Wiley, New Jersey, USA, pp. 491–519.

Vert M, Doi Y, Hellwich K-H. 2012. Terminology for biorelated polymers and applications (IUPAC Recommendations 2012). Pure Appl Chem. 84:377-410.

Vivita Priedniece, Kriss Spalvins, Kaspars Ivanovs, Jelena Pubule, Dagnija Blumberga. (2016). Bioproducts from Potatoes. A Review, Environmental and Climate Technologies. 21: 18–27. doi: 10.1515/rtuect-2017-0013.

Endres HJ (2017) In Advances in Biochemical Engineering/Biotechnology 166: 427-468.

Seema Sakkara , Krishna Venkatesh, Roopa Reddy , G.S. Nagananda, Murlidhar Meghwal,Jagadish H. Patil d and Narendra Reddy *(2020) Characterization of crosslinked Macrotyloma uniflorum(Horsegram) protein films for packaging and medical applications, Polymer Testing 91: 106794

Sahari J, Sapuan SM, Zainudin ES, Maleque MA. A new approach to use Arenga pinnata as sustainable biopolymer: Effects of plasticizers on physical properties. Procedia Chemistry. 2012; 4:254-9

A.O. Ashogbon, E.T. Akintayo, Recent trend in the physical and chemical modification of starches from different botanical sources: a review, Starch/Staerke 66 (1–2) (2014) 41–57

Challenges and Perspectives for a Sustainable and Carbon Neutral Circular Economy

Fabian Schott, Jessica Wilhelm & Rüdiger Siechau
Stadtreinigung Hamburg AöR, Bullerdeich 19, 20537 Hamburg, Germany

Abstract

As a public company, Stadtreinigung Hamburg supports the Senate of the Free and Hanseatic City of Hamburg in achieving its climate protection goals and aims to become climate-neutral by 2035. For this reason, Stadtreinigung Hamburg is currently developing series of measures to significantly reduce CO_2 emissions. These include modernisation of buildings, the expansion of electric mobility and fuel cell technology in the vehicle fleet and projects to increase climate-neutral energy generation. In addition, Stadtreinigung Hamburg sells second-hand goods from bulky waste collections and from the recycling centres as second-hand goods, thus avoiding waste generation and emissions from the waste incineration process and saving resources. Furthermore, through its separate collection, Stadtreinigung Hamburg guarantees the recycling of recyclable materials such as paper and plastics. Through these measures, Stadtreinigung Hamburg contributes to reducing emissions and a functioning circular economy in the Free and Hanseatic City of Hamburg. The changes in European and German legislation regarding climate protection have also significantly accelerated the work of Stadtreinigung Hamburg in concretising it's measures and schedules.

1. Introduction - Stadtreinigung Hamburg at a glance

The city cleaning service of Hamburg (Stadtreinigung Hamburg - SRH) is a public law institution owned by the Free and Hanseatic City of Hamburg. With over 4,000 employees it ensures the collection, treatment and environmentally friendly disposal of waste from over one million private households and around 100,000 industrial companies in

Hamburg, making it one of the largest public city cleaning service companies in Germany. This results in an economic, environmental and social responsibility that Stadtreinigung Hamburg aims to fulfil. With its comprehensive service for the citizens of Hamburg, from waste collection to thermal treatment in the waste incineration plants and in a Biogas- and composting plant (BKW Bützberg), Stadtreinigung Hamburg ensures a high level of independence, disposal security and price stability.

As a public company of the Free and Hanseatic City of Hamburg, Stadtreinigung Hamburg has to implement the objectives of the Hamburg Senate as well as the tasks resulting from the respective current coalition agreement. In order to become more climate-friendly, the Senate of the free and Hanseatic City of Hamburg has developed a climate plan with defined climate protection targets and implemented this into law with the introduction of a Climate protection Act in 2020 [1].

These statutory requirements clearly instruct the public companies to develop their own concepts and strategies to significantly reduce their CO_2 emissions and to achieve balance climate neutrality by 2040 at latest. This requires long-term strategic development and consequent efforts in all areas of activity of Stadtreinigung Hamburg in order to be able to achieve the ambitious goals.

2. Strategic development

The transformation to a climate-neutral company is based on the further development in five thematic blocks, which are illustrated in Fig. 1 as the pillars of the SRH concept: Waste prevention and reuse, Recycling offensive, Projects regarding the waste treatment plants, Infrastructure and vehicle fleet and Future projects.

Fig. 1. Climate protection concept of Stadtreinigung Hamburg based on 5 solid pillars

Each of the pillars presented contains a large number of projects aimed at making both the company itself and its participations and subsidiaries more sustainable and reducing CO_2 emissions. The respective solid pillars are discussed individually in the following.

2.1. Waste prevention and reuse

The german Circular Economy Act (KrWG) defines the levels of the waste hierarchy. The primary goal is to avoid the generation of waste as much as possible and to reuse objects instead of disposing of them as waste. Stadtreinigung Hamburg follows this request and offers second-hand goods, which are collected by the bulky waste collection service, from private deliveries and from the recycling yards as second-hand goods in its subsidiary Stilbruch.

Stilbruch, founded in 2001, offers currently a wide variety of second-hand goods like furniture, bicycles, toys, fashion as well as vinyl records. The goods delivered and the demand have risen continuously over the years. In 2019, Stilbruch had a sales volume up to 400,000 articles per year and an annual sales of 3.7 Mio. €. With its current two shops, Stilbruch offers goods on more than 3,000 m^2 [2].

The operation of the Stilbruch department stores offers several advantages. On the one hand, the reuse of goods significantly reduces the amount of waste and thus also the CO_2 emissions from incineration. On the other hand, it offers the citizens the opportunity to purchase good goods at a cheap price, which have been restored, which have previously been restored to a good condition through cleaning and repair, if necessary. Finally, the foundation has also created meaningful new jobs with long-term perspectives in Hamburg.

2.2. Recycling offensive

For a development towards a climate-friendly circular economy, it is indispensable to further increase recycling rates for recyclable materials. Requirement for this is an effective separate collection of the recyclable material fractions plastic, paper, glass and biowaste, separately from the residual waste, by the citizens. In order to achieve this, Stadtreinigung Hamburg launched a campaign called „Recycling offensive" in 2011. This was supported by public relations campaigns and by a new fee structure to strengthen the interest of citizens in separate collection.

Fig. 2. Development of collected waste fractions in thousand tons per year

As shown in Fig. 2, the quantities of recyclable material increased continuously in recent years due to separate collection, while the quantities of residual waste, on the other hand, declined slightly. Due to Corona pandemic, there was a break in this trend for residual waste and paper waste fraction, which can be explained by shop closures (Lockdown) and increased online shopping (and thus a higher volume of waste from packaging), among other things. This expansion of separate collection makes it possible to recover recyclable materials and use them for recycling, which can make a significant contribution to resource preservation and a circular economy.

2.3. Waste treatment plants

Even though Germany already has a functioning 4-bin system (household waste, biowaste bin, plastic waste and paper bin), important raw materials that could actually be recycled still end up in the residual waste bin. On the one hand, this is due to improper separation behaviour. On the other hand, there are still households where a 4-bin system is not feasible for reasons of space. In addition, the existing facilities are also subject to a certain amount of depreciation and will have to be replaced or maintained over the next decades.

For this reason, Stadtreinigung Hamburg is building a modern waste treatment plant on the former site of the Stellinger Moor waste incineration plant in the west of the city, which will contain a sorting plant and two incineration lines/boilers. Once completed, the so-called Centre for Ressources and Energy (ZRE) will not only reduce the volume of household waste, but will also recover more than 9,600 tons/a of recyclable materials like paper, glass, plastics, Fe-metals and NE-metals from the residual waste and become also an important supplier of energy. With the energy generated from the combustion process, the ZRE can supply more than 40,000 households with electricity and around 39,000 households with district heating per year [3]. Fig. 3 shows the ZRE as it will look when completed.

Fig. 3. Illustration of the Centre for Resources and Energy

The heat generated by the combustion will be fed into the district heating grid of the city of Hamburg and supply households with climate-friendly energy, while the electricity produced in the plant can be either fed into the electricity grid of the city or will be used to operate an electrolyser that will produce hydrogen for refuelling vehicles from Stadtreinigung and other local companies.

In this way, the ZRE can help to ensure waste disposal security in Hamburg, close even more loops and preserve resources. In addition, it makes an important contribution to a more flexible and price-stable energy supply in the Free and Hanseatic City of Hamburg.

2.4. Infrastructure and Vehicle fleet

Stadtreinigung Hamburg has one of the largest vehicle fleets of all companies in Hamburg to fulfil its duties. The vehicles are very diverse, both in terms of their functionalities and their performance class.

In line with the Clean Vehicles Directive (EU) 2019/1161, the „Climate Protection Master Plan for Hamburg“ also provides for a comprehensive conversion of municipal vehicle fleets to zero-emission drive systems, which is also implemented by SRH. Small vehicles and small commercial vehicles with storage electric drive have been successfully operated by SRH, and the conversion is underway accordingly as part of new and replacement procurements. More than 170 vehicles from Stadtreinigung Hamburg already have an electric or hybrid drive instead of an internal combustion engine. With these vehicles, local emission-free use/operation within Hamburg is already ensured at the present time. While the conversion to electric drives in the small vehicle sector is taking place without any issues, the conversion in the sector of larger utility vehicles is still a great challenge.

Fig 4. Left: Electric cargo bike (H. Hass, Stadtreinigung Hamburg). Right: Electric sweeper

However, it is precisely in this vehicle sector that the greatest CO_2 savings potentials arise. With each diesel truck replaced by a battery or fuel cell vehicle, approximately 31 tons of CO_2 can be saved per year. With a number of approx. 222 street sweepers and approx. 287 waste collection trucks out of altogether 1098 vehicles, it becomes clear what enormous savings potential there is in this vehicle class.

Stadtreinigung Hamburg has already undertaken research and development in the field of electric drives with partners from the industry in order to test an electric sweeper and an electric garbage collection vehicle in day-to-day operations and optimize them for daily operation. These first test periods were successful, further electrification of the vehicle fleet now depends on funding opportunities, price developments and market supply. In addition, Stadtreinigung Hamburg is also expanding and modernizing its vehicle fleet with new types of vehicles, such as electric cargo bikes. These bikes were developed together with the German Aerospace Centre as part of the TRASHH project [4]. These simplify cleaning in areas that are especially difficult for vehicles to access, such as parks, and are gaining a high level of acceptance due to their emission-free and low-noise operation.

All the electric vehicles need a sufficient charging infrastructure for continuous operation, which still needs to be expanded for carefree operation in the future. The electricity supply for the vehicle fleet can be at least partially covered by the company’s own thermal waste treatment plants.

2.5. Future projects

In addition to the above-mentioned measures in the fields of waste prevention, separate collection and recycling, waste treatment plants and infrastructure/vehicle fleet, further innovative projects are being planned at Stadtreinigung Hamburg, which require further financial support and further development in the state of the art of science and technology for optimal realization. One of these projects is the capture of CO_2 from the exhaust gases of the incineration plants, the so-called Carbon Capture and Storage (CCS) and the utilisation of this CO_2 for the production of alternative industrial products, the so-called Carbon Capture and Utilisation (CCU). This could strongly reduce emissions from waste incineration, as the thermal waste treatment continuously produces the greenhouse gas CO_2 as a product of complete combustion.

Fig. 5. Key issues of the innovation hub

Another project is the concentration of various projects in the field of resource and climate protection at one location, to form a so-called innovation hub. The site on which the projects are to be implemented is in the direct neighbourhood of one of the incineration plants of Stadtreinigung Hamburg as well as other industrial plants whose flue gases and energy generation can be used for processes at the innovation hub. For energy production, projects in the field of hydrogen technology and bio-methanation are planned at the innovation hub. In addition, the site has excellent and trimodal infrastructure connections (rail, roads, canals) so that goods can be transported to and from the site by ship. Therefore, also projects for recycling of plastic waste and building material are planned.

In Hamburg, a city with over 1.8 million inhabitants, there are always various construction projects, whereby the excavated soil has so far been disposed of and replaced by fresh sand. In the intended project, however, the excavated soil is to be recycled directly by using washing processes, pneumatic processes and microbiological processes. This will make an important contribution to a circular economy and significantly reduce CO_2 emissions from the construction sector. The recycling of plastic waste has great potential, as the amount of plastic waste is increasing, also due to the increasing separate collection of the waste fractions. The plastic waste can be easily delivered via the existing infrastructure, and the energy required for recycling can be partly covered by the energy supply of the neighbouring plants.

3. Outlook

Through its current development and stronger co-operation with municipal partners, Stadtreinigung Hamburg can contribute significantly to a carbon-neutral circular economy in the region of Hamburg. After the completion of the ZRE, the SRH will be able to cover more than 50 % of Hamburg's district heating demand. The expansion of co-operation with other municipal companies such as energy service providers (Energiewerke Hamburg) and the gas grid operator (Gasnetz Hamburg), can lead to a functioning municipal economy and, in the ideal case, achieve energy self-sufficiency or reduce energy dependence on external sources. Nevertheless, the above mentioned projects are also dependent on the price trend and further financial support, as the costs for these are not to be covered, or not entirely covered, by the fee payers (citizens).

Energy generation from waste also contributes to climate protection by substituting fossil fuels. However, this climate protection through thermal waste treatment is controversial, as the current debate about pricing CO_2 emissions from waste incineration shows. The Fuel Emissions Trading Act (BEHG) is intended to serve as an instrument for achieving climate protection targets by setting financial incentives to replace climate harmful technologies with lower-emission ones. However, since waste incineration will continue to have the task of removing pollutants from the biosphere, this financial burden on waste incineration will only make waste disposal more expensive but will not have a steering effect on climate protection. The waste management community sees a need for further discussion here.

In principle, of course, only waste that cannot be (re)used or recycled should be thermally treated. The recyclable material fractions should be collected separately to a greater extend, so that recycling rates can be increased, the raw materials can be returned to the recyclable material cycle and the waste quantities in the waste incineration plants can be reduced. All stakeholders (government, industry, citizens) involved must help to ensure that these goals can be achieved in the coming years.

References

Landesrecht Hamburg. Hamburgisches Gesetz zum Schutz des Klimas (Hamburgisches Klimaschutzgesetz – HmbKliSchG), HmbGVBI. 2020, 148, 754-1. https://www.landesrecht-hamburg.de/bsha/document/jlr-KlimaSchGHA2020rahmen

Stilbruch. Gut zu wissen. https://www.stilbruch.de/Gut-zu-wissen-ueber-Stilbruch-Hamburg.html

Stadtreinigung Hamburg AöR. ZRE – Zentrum für Ressourcen und Energie. Müllverwertung der Zukunft. https://www.stadtreinigung.hamburg/zre/

Deutsches Zentrum für Luft- und Raumfahrt (DLR). TRASHH-Abfallentsorgung mit Hilfe von Lastenrädern.

https://www.dlr.de/content/de/artikel/news/2016/20160711_trashh-abfallentsorgung-mit-hilfe-von-lastenraedern_18552.html

Wastewater: Solutions from German – Indian Partnerships

Sanchita Khandelwal
aqua & waste International GmbH, Hanover, Germany

Abstract

India is the one of the largest water consumers in the world, and its thirst is far from being quenched. However, insufficient treatment of municipal and industrial wastewater, as well as improper water resource management, is leading not only to rising water insecurity, but also significant adverse impacts on the environment and human health. In the recent years, India and Germany have strengthened their cooperation ties. As a direct result of these strengthening relations, several solutions have been conceptualised and implemented in the field of water, wastewater as well as water resource management. This presentation provides a brief insight into some of these solutions.

Keywords: wastewater; sludge; water security; cooperation; resource recovery.

1. Introduction

The Indian and German water sectors cooperate at several levels. This cooperation and the resulting solutions can be divided into 3 tiers based on their complexity, number of actors involved, and level of cooperation. The first tier is at a company level, where individual consulting companies, small, medium, and large, actively participate in cooperation projects in the water sector financed by either private entities or by (international) financing agencies like the Asian Development Bank or Federal German ministries. The second tier is at organisation level, typically consisting of one or several individual Tier 1 players. The third tier is at larger project levels, which bring together several Tier 1 and Tier 2 players into cooperation, as well as raise the cooperation level to a government/public institutions level. The following sub-sections will explore some case studies under each tier.

2. Case Study: Tier 1

aqua & waste International GmbH is an example of Tier 1. They are an independent engineering and planning office in the field of environmental protection and are based in Hanover, Germany. Since its foundation in 2000, they have successfully implemented numerous projects worldwide in the fields of water, industrial & municipal wastewater treatment & management, stormwater management, solid waste management, biogas, greenhouse gas emission reduction, energy efficiency and process optimisation as well as overall project management worldwide (LATAM, Asia, MENA, Africa, Europe).

The management consists of Prof. Dr.-Ing. Peter Hartwig and Dr.-Ing. Niklas Trautmann, as well as Prof. Dr. -Ing. Klaus Nelting (advisory board member), who have worked on numerous research projects in addition to their long-standing experience in planning and consulting. Owing to their many years of activity in various associations, committees and working groups, aqua & waste International GmbH has established a large worldwide network of experts and professional bodies.

The interdisciplinary and diverse team, consisting of civil, environmental and process engineers as well as draughtspersons from around the globe, allows them to develop and deliver holistic and comprehensive solutions and results. Furthermore, the established broad professional network of numerous national and international external experts expands the spectrum of work greatly by including the fields of WASH, Agriculture, Fish farming, Wastewater treatment and management, Socio-economic assessments, Renewable energy, etc.

The range of their services includes the preparation of (pre-)feasibility studies, baseline studies, detailed planning & design (including 3D modelling and dynamic simulations), consulting services, optimization measures, research activities as well as the implementation of turnkey projects. Equally active for municipal and industrial clients in both German and international markets, they also actively participate in international and/or development cooperation projects for clients such as the Kreditanstalt für Wiederaufbau (KfW Development Bank), Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the United Nations Industrial Development Organization (UNIDO).

Their special focus is on the development and implementation of innovative solutions aimed at energy efficiency as well as climate and environmental protection. To this end, they work closely with universities as well as various expert committees and working groups. Likewise, they also actively contribute to knowledge transfer and capacity building in the form of further education, seminars, trainings and workshops.

Their approach focuses on designing solutions that are not only innovative, but are also socially, economically, and environmentally sustainable. To this end, our solutions are designed to be relevant in and applicable to the local context, majorly sourcing locally available resources and capacities.

India has been a region of prime importance and focus for them. Some of their notable projects in the region have been summarised below:

a. Project management for the construction of an industrial wastewater treatment plant in India

Timeline	2019
Sector	Industrial wastewater treatment and management
Project Description	Data and time management for overall project supervision
Services Rendered	Development of a data structure; Time planning / scheduling

b. Floating pilot plant for wastewater treatment on Dal Lake, Srinagar

Timeline	2015
Sector	Industrial wastewater treatment and management
Project Description	Conceptual design of a floating small sewage treatment plant for house-boats on Dal Lake in Srinagar, India for the treatment of domestic waste-water
Services Rendered	• Conceptual design • Compilation of basic data • Development of requirement profile

c. Wastewater treatment plant for Jammu and Kashmir based on the H-Batch System

Timeline	2009 - 2010
Sector	Municipal wastewater treatment and management
Project Description	Planning and realization of two wastewater treatment plants (5.4 MLD ~ 36,000 PE, 16.1 MLD ~ 95,000 PE) in Srinagar, India. The specially developed, patented H-Batch System enables an efficient and space-saving wastewater treatment. The aerobic biological treatment stage comprises the decomposition of organic wastewater components as well as the elimination of nitrogen by means of integrated nitrification and denitrification.
Services Rendered	• Basic evaluation • Preliminary planning • Conceptual design • Execution planning • Delivery of machine technology from German manufacturers

3. Case Study: Tier 2

German Water Partnership e.V. (GWP) is an example of Tier 2 German – Indian cooperation. It is the largest and only network in the German water sector with an international focus and unites over 350 companies, trade associations and institutions from business, science, and research.

The sustainable use of water is not only important for environmental protection, human health and social justice but also plays a decisive role in crucial economic areas such as infrastructure, industrial production and agriculture. With the help of German Water

Partnership, the German water sector is tackling these issues globally with proven know-how and innovative technologies.

GWP aims to bundle information & interests and drive innovation, thereby facilitating the promotion of approaches to solving water management problems, especially in developing and emerging countries. It brings together over 150 years of know-how in water supply and wastewater management. One of the core values of this network is that quality is just as important as affordability, reliability, and sustainability.

The German water sector is known for pioneering research and development of future-oriented, sustainable and resilient solutions, materials, technologies and products. GWP also works on strengthening the international competitive position of German water sector actors by improving business development framework conditions. The goal is to facilitate the sustainable use of water resources and water management across the globe.

Some of the core competencies of GWP members that GWP brings together and harmonises are:

- Offering locally adapted solutions.
- Energy-efficient solutions with long lives.
- Education, research, development and innovation.

Through this combined pool of resources and with the support of projects funded by the German Federal Government, it contributes to achieving the Sustainable Development Goals (SDGs). In service of fair and ethical cooperation, GWP and its members are committed to clean business and corruption-free action.

Through the GWP network, international water sector players and decision-makers have direct access to the competencies and services of more than 350 members.

German Water Partnership works in two structures:

- Through working groups
- Through regional sections

The working groups are an important part of the GWP community. They enable the exchange of views on and know-how of different fields and challenges of the water industry, and to jointly develop solutions. Currently, the members organise themselves into the following working groups:

- Operation & Capacity Development
- Industrial Water Management
- Innovation & Scientific Cooperation
- Agricultural Irrigation
- Water 4.0
- Water & Energy
- Sponge City/Stormwater Management (TBD)

The focus of the working group sessions is set by the members through a common vote. They define the key aspects of the sessions and steer the focus of events such as GWP Days, trade fairs, conferences and symposia.

The regional sections function similar to the working groups. However, in these sections, the focus is on the water challenges in the specific region instead of on a particular subject. They enable nurturing of contacts with partners and decision makers in the focus countries/regions to kick off (cooperation) projects, involve local stakeholders in the same and co-develop customised solutions. Experts from water industry and research have joined forces in twelve regional sections to bring together their competences to the various water sector challenges posing these regions:

- Africa
- China
- EECCA (Eastern Europe, Caucasus and Central Asia)
- Gulf States
- **India**
- Iran
- Latin America
- North Africa & Jordan
- North America
- South-East Asia
- South-East Europe
- Turkey

The regional section India was established in 2009 with then nonuniform and often vague ideas about the Indian water sector. With the support of embassies, chambers of commerce, ministries and funding institutions, this regional section has successfully established a network with local peers and decision-makers in India. The understanding of what approaches and solutions are successful and practicable in the Indian water sector has grown significantly through shared experiences and know-how between the two water sectors. GWP regional section India has been represented at all five IFAT India trade fairs, and four GWP Days have been successfully realised.

India is aware of the oncoming water crises, which will perhaps be the greatest challenge in the coming years. However, due to the non-transparent and intricate bureaucracy, tangible investments in this field are still scarce. The "Clean Ganga Mission", which has been in existence for 25 years, has used only a small fraction of the available budget so far. The new "Smart City Program" is supported by the German government in three cities – Kochi, Bhubaneshwar and Coimbatore.

With growing population, agriculture and industry, the demand for water is growing rapidly as well. And with this, so is the demand for functioning drinking water treatment plants as well as wastewater treatment plants. Currently, India has over 800 Sewage Treatment Plants (STPs) and over 190 Common Effluent Treatment Plants (CETPs). However, experience has shown that a major challenge is the life span and operation and maintenance of these plants. Very often, there is inadequate operation and management knowledge and action. This, along with the cost over quality rendering process and technical know-how gaps in the decision-making chain, often lead to plants that are either only partially functional or have a very short lifespan. In response to this challenge, the GWP regional section India has taken up the initiative of the ShowCaseIN project, which is an example of Tier 3 Indo-German cooperation.

4. Case Studies: Tier 3

4.1. ShowCaseIN

Insufficient treatment of municipal and industrial wastewater is leading not only to rising water insecurity, but also significant adverse impacts on the environment and human health. Inaccurate design and incomplete know-how regarding the operation of wastewater treatment plants are often the reasons for plant malfunction.

The project ShowCaseIN was initiated and developed within the framework of the German Water Partnership – Regional Section India and is supported by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany. It brings together German and Indian water sectors on a large scale by promoting knowledge exchange and future co-operation between the two sectors, as well as climate resiliency.

ShowCaseIN aims to develop a conceptual design for the upgrade of an existing/a new wastewater treatment plant under local conditions in India, which will then serve as a show case plant for German wastewater technologies and know-how and will also be used for training purposes. The project contributes to achieving the Sustainable Development Goals (SDGs) of the United Nations (UN). It addresses SDG 6, "Ensure availability and sustainable management of water and sanitation for all", with a deeper focus on SDG 6.3, "Improvement of water quality, wastewater treatment and reuse", SDG 9, "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", and SDG 4, "Equitable quality education and promote lifelong learning opportunities for all".

The objectives of the project are as follows:

- Functional non-profit application and establishment of sustainable wastewater treatment technologies in India.
- Improvement of the environmental conditions on-site and promotion of health care through modern wastewater treatment.
- Development of a holistic technical and educational concept adapted to the regional conditions for the upgrade of an existing wastewater treatment plant as a showcase.
- Use of the showcase wastewater treatment plant as a training centre for knowledge transfer and knowledge anchoring in India.

The project has three main pillars defined by the following aspects:

- Technical Concept: To design an end-to-end solution, taking into consideration the interdependencies of the various treatment stages. Ensuring the design closes the resource loop wherever possible and applicable. Factoring climate resiliency, energy efficiency, land use (compact solutions), decentralised sources and water security into the design to develop a future-resilient solution.
- Knowledge Transfer: Using the ShowCaseIN Plant to train water sector players at various skill levels, thus ensuring a long lifespan of the plant through appropriate operation and maintenance as well as informed decision-making.

Enabling a structured and long-term project ownership and handover to the local stakeholders.

- Standardised Guideline: Scaling-up measure through the development of a step-by-step guideline enabling a systematic transfer of the concept to other locations and regions.

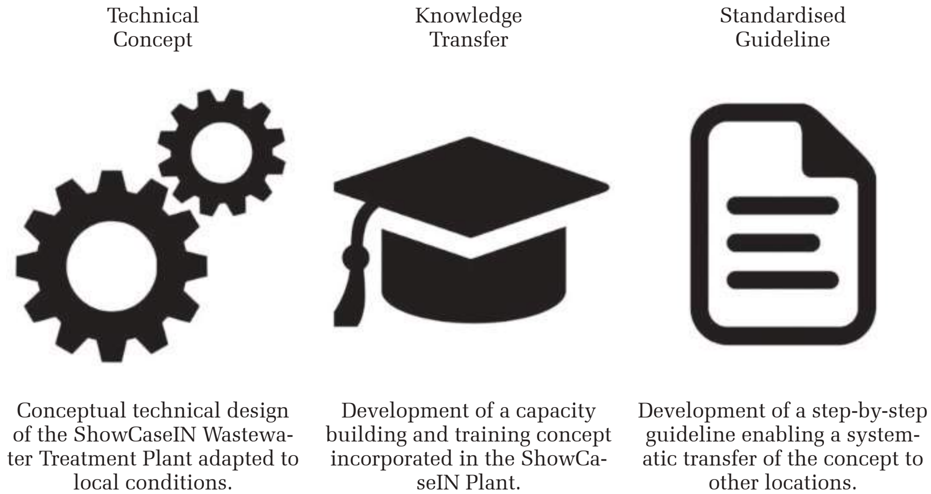


Fig. 1: The three guiding pillars of the ShowCaseIN Project

The project's essential elements put together a holistic, end-to-end solution that takes the interdependencies of the individual elements into account. In addition to the influent and effluent quality parameters, the technical concept takes the following aspects into consideration:

- Land use
- Water reuse and security
- Faecal sludge
- Sludge from wastewater treatment
- Sludge treatment, management and upcycling
- Energy efficiency
- Biogas potentials
- Automation and control to enable data monitoring, evaluation, performance analysis and optimisation over time

Fig. 2: The essential elements of the ShowCaseIN Plant

4.2. AQUA-Hub

Water insecurity, increasing demand for wastewater treatment as well as access to and knowledge of technological solutions are some major stresses for the Indian water sector. AQUA-Hub addresses the needs of the identified local water sectors, as well as the challenges faced by the German water industry in developing projects, relationships, and business in the Indian market. It is implementing Water Innovation Hubs in two Indian Smart Cities, Coimbatore, Tamil Nadu and Solapur, Maharashtra. These are accompanied by pilot measurements of German water quality monitoring technology applied within the framework of local context. AQUA-Hub creates the basis for strengthening the Indo-German co-operation by contributing to solving water-related challenges and driving innovation in the water sector.

In addition to network activities and the mediation between business partners, the hubs also function as project centres for the realization of technical demonstration projects and increase the exposure of Indian partners to German technologies. These demonstration projects are identified by the local stakeholders and are supported by German water industries. The envisaged piloting of German water monitoring technologies thus offers the opportunity to meet local needs with manageable investments and risks. Additionally, it also aims to lay a strong foundation for both subsequent technology transfer and better on-site data availability as a starting point for meeting environmental goals.

As network and project centres, Water Innovation Hubs in Coimbatore and Solapur contribute to the sustainable development and consolidation of Indo-German cooperation in the water sector and demonstrate the potential of technology transfer using the example of smart water monitoring. With the help of local Hub Managers as focal points, a continuous dialogue on new developments and technological solutions is established. Water Innovation Hubs link stakeholders from business, administration, and civil society with the goal to identify and implement measures for sustainable water management. With the help of water quality monitoring, technologies made in Germany are piloted in an exemplary manner and serve on the one hand as reference projects and on the other hand promote data-based decision-making in the two smart cities Solapur and Coimbatore.

5. Conclusions

The examples described in this presentation and manuscript are only some of the numerous successfully completed, ongoing and in-the-making solutions resulting from strong German – Indian cooperation ties in the water sector. Given the increasing water stress, these will have an increasingly important role to play in achieving water security in the future. Both sides continue to exchange invaluable know-how and combat environmental challenges together. While there is great progress on the technical side, these must be supported by corresponding governance, monitoring and compliance frameworks. This translates to capacity building at all levels, from students to decision-makers. Likewise, stakeholder integration is of prime importance as well for this provides a better understanding of the local needs, gaps and systems as well as facilitates ownership and handover of initiatives and solutions to the local peers. Hence, it is important that cooperation solutions are developed in an inclusive, comprehensive, and holistic manner. This is the way forward to achieving ecologically, economically, and socially sustainable solutions with long term positive impacts.

Acknowledgements

The author would like the express their deep gratitude to the organisers of the 12th Hanseatic India Colloquium “Solid Waste Management: an Indo-German Dialogue”, the Hanseatic India Forum as well as The Consulate General of India, Hamburg, for providing them with this great opportunity to share experiences and solutions from the water sector. A vote of thanks also goes to their local cooperation partners in India as well as those in Germany. A special recognition goes to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany for supporting and encouraging the ShowCaseIN and AQUA-Hub projects. Last but not the least, the author thanks their colleagues and mentors for their endless support and inspiration.

References

aqua & waste International GmbH, https://aquawaste.de/en/321-2/

AQUA-Hub, https://www.aqua-hub.de/

National Status of Common Effluent Treatment Plants (CETPs), ENVIS Centre on Hygiene, Sanitation, Sewage Treatment Systems and Technology, 2019, http://www.sulabhenvis.nic.in/Database/National_16254.aspx

German Water Partnership e.V., https://germanwaterpartnership.de/en/

“Indo-German urbanization partnership begins”, Federal Ministry of the Interior and Community, 14 December 2018, https://www.bmi.bund.de/SharedDocs/pressemitteilungen/EN/2018/st-adler-indien-en.html

ShowCaseIN, https://showcaseindia.aquawaste.de/

Food Waste Management: Experiences from Germany Applicable in Indian Scenario in A Proof of Concept Composting Technology

Sugand S. & Sharma S.
Greengrahi Solutions Private Limited, Delhi, India

Abstract

To reduce environmental degradation and public health impacts, India is striving to improve its solid waste management practices since the last 10 years. Germany joined this stride way earlier than India due to early onset of industrialisation and subsequent environmental and public health degradation in early 90's. Since then, Germany has adopted a wide spectrum of measures to deal with the challenges largely driven by regulatory and technological factors and implemented a modern waste management system. On the other hand, market & regulatory drivers were the major forces responsible for development of waste mgmt. industry in India. In spite of very different development trajectory & waste mgt. scenario in both countries, several important lessons could be learnt and exchanged in waste sector. This research focuses on how a composting technology prototype was developed as a lesson from Germany's organic waste recycling practices. Decentralised Intensive composting technology discussed in this paper can augment the situation of organic waste recycling in India. It discusses results derived from a pilot scale implementation of intensive composting technology in India and future scope of its development through collaboration between both countries.

1. Introduction

Every year, approximately 52 metric tonne of Municipal Solid waste (MSW) is generated in India (S. Kumar et al., 2017). The MSW constitutes 51% of organic waste,17.5% recyclable waste (plastic, paper, metal and glass) and 31% inert. As organic waste(OW) represents a major stream, more than 30 metric tonne of the MSW is organic in nature. For the proper management of OW, various methods are suggested such as vermicomposting, windrow composting, and aerobic (Indore) composting, anaerobic (Bangalore) composting (MOUD Manual, CPHEEO,2016 & 2020). However, composting is the most prominent method of treating organic waste at both centralized as well as decentralized level in India, because of its simplicity and low cost of infrastructure. Currently 9-10% of total organic waste is recycled using composting. Currently, the composting technologies available in Indian market are open, partially manual or semi-mechanical processes and takes 3-5 months for composting (Kanujia, P and Dohare, D., 2020). Though composting is being practice for decades, there are major challenges with respect to quality of compost, financing available to build composting infrastructure, market demand and prices of compost, which affect business viability negatively in compost industry unless capital cost is shared through govt. subsidy or external funding.

In the recent years, new in-vessel composting technologies can be seen in the market where composting process occurred in a closed system made of plastic, metal or anything else. Some of these technologies include: Drum composters and OWC machines or 24 hour composters. The adoption of these technologies is seen mostly by institutional/ commercial waste producers and is driven by various regulatory, market and environmental which includes:

a) Bulk waste generation Law 2016 which mandates recycling on site for all bulk producers of waste (restaurants, Grocery stores, hotels, schools with meal programs, hostels, Banquets/community event halls) producing more than 100 kg waste/day.

b) Ease of operations- In vessel technologies are flexible to different types of organic waste streams and can prevent organizations hassle to depend on a 3rd party for their collection and treatment.

c) Space constraint in cities –Due to high population density and shortage of land, land prices in urban cities are skyrocketing. Because of this, landfill disposal is becoming increasingly expensive, thus, bulk waste generators find it easier to treat their waste faster in onsite in-vessel composters. These technologies being space efficient can sometimes reduce costs by in long term by avoided costs from transportation and gate fee for disposal. However, such savings are not realized because illegal dumping of waste is still rampant across cities.

Application of these technologies are mostly limited on community scale upto 5-10 tonnes per day and tend to have a high upfront capital cost and operations cost. However, there is potential to improve the in-vessel composting technology- in India with regard to controlled composting process (Zurbrügg et al.,2014). Many of these learnings can be derived from Intensive Composting technologies used in Germany for medium to large scale operations. Intensive composting Technology (ICT) is an advanced in-vessel composting technology which uses active aeration system to process and stabilize highly putrescible organic materials such as food waste. It has several advantages over conventional windrow or open composting systems: a) Accelerating composting process b) Prevents odour formation c) Sanitizing organic waste making it pathogen free d) Occupies less space due to higher vertical height. The advances of this technology are discussed widely in literature (Bhave, P.P.& Kulkarni, B.N., 2019, Haug, R.T,1993).

Inspired from the German ICT, a proof of concept was developed of a closed and controlled bioreactor (humidity, temperature, oxygen) for effective treatment of organic waste with minimal operational effort and very low space requirement. The objective of this research is to share the results of the proof of concept for a scalable Automated Compost bioreactor (ACB) used for organic waste recycling. The study aims to showcase how optimizing some of the operational parameters in the bio-reactor can achieve operational simplicity, process efficiency, and cost-effectiveness as key factors for Indian market. Furthermore, it was the aim of this study to provide evidence for the economic benefits of implementation of an automated Compost bio-reactor at both decentralised as well as centralised scale. To the authors' knowledge, it is the first time that the concept of such an Automated Compost bio-reactor with active aeration and odour control features has been proposed for Indian market. The study is conducted at semi-technical scale with a 1000L reactor, which can treat kitchen waste of 150 person equivalents (PE), while the envisaged commercial system could serve an entire city if applied at centralized scale in the Tier 1 & 2 cities of India.

2. Material & Methods

2.1. Research Approach

The research approach is structured into three phases: (i) design of reactor and experiments based on literature review, (ii) conduction of experiments and analyses

i. Composter Design- The automated composter prototype was designed as a closed vessel, stationary cubicle system equipped with active aeration and watering system. The capacity of the prototype was 1000L. The frame of cube was constructed using stainless steel and supported by insulated frames made of treated wood. The opening situated at the upper part of the reactor (2) (300 mm x 600 mm) serves as solid organic waste loading point. Aeration of 50m^3/hour was provided using an air pump through a pre-designed perforated ventilation system at the bottom of the reactor which served as air inlet. The air outlet pipe is situated at the top of the reactor while at the bottom right of the reactor, the leachate drainage plate is located which drains all the leachate in leachate tank of 60-liter capacity. The collected and filtered leachate is recirculated back into composter as a moistening agent using a pulse width modulation controlled diaphragm pump and sprayed on the composted material through a sprinkler situated at the interior of the reactor. The internal temperature & moisture was monitored through a temperature probe inserted at 3 different locations for evenly recording temperature and moisture, the online data were logged using a programmable logic controller.

   Restaurant's kitchen waste was used as a primary substrate for experimental runs. This waste was received from 7 different restaurants kitchens over a period of 1 week and random samples were selected for characterization. It specifically consisted of vegetable waste (70%FW), cooked food (10%FW), Indian bread (5%FW) fruits (6%FW) & meat waste (4%FW). Small quantity of dry leaves & saw dust (5%FW) were also added as a bulking agent, to add carbon material to achieve the carbo ratio and to test its effect on the structure and porosity to the composted material, achieving a final composition of 30:1 (FWW: Sawdust).

ii. Experimental Setup: The bioreactor was operated at fed-batch mode, mimicking a simplified waste disposal behavior of the restaurants. The waste was loaded once every day into bioreactor (total quantities are illustrated in Table 1 and then closed for a batch process to start. Similarly, each bioreactor could be filled over a week and then left for composting to happen over next 21 days, followed by 6 days of curing.

Table 1
Quantity of Input streams

S. No.	**Input stream (Day 1- Day 5)**	**Quantity (kg)**	**Percentage**	**Density (m3/kg)**	**Volume (m3)**
1	Food waste	550	94.0	800	0.69
2	Dry Leaves	15	2.6	60	0.25
3	Saw dust	20	3.4	320	0.06
	Total	**585**	**100**		**1.00**

Once composting began, it was not disturbed and one turning was performed on the 12th day of composting. Forced aeration was provided using an air pump on a set interval every day until the end of composting. The aeration intervals became shorter and non-aeration intervals became longer as the composting process came to end. Temperature & Moisture change was recorded at 4-hour interval, **3 times a day until 27 days.** Samples were extracted before feeding and as after the termination of complete run after composting had occurred. The C:N, pH, TOC, Ash, bulk density of feedstock is mentioned in the **Table 2.**

Table 2
Chemical composition of feedstock and final compost

Chemical Composition	**Feedstock**	**Compost**	**Units**
pH	6.78	7.25	-
Conductivity	1566	1625	μS/cm
Moisture	76	46	%
C:N ratio	27.4	18:1	-
Bulk Density	585	545	Kg/m3
Organic matter	96.7	55.35	%
TOC	45.6	30.0	%
Ash content	4.23	8.16	%

Table 3
Maturity & Stability test of compost

S. No.	Parameters	Compost	Unit
1.	Maturity (bengal gram seedling germination test - emergence & vigour)	91%	
2.	Stability/Respirometer (CO_2 Evolution)	0.8 (Very stable)	mgCO/gOM/day

3. Results

3.1. Quality of matured compost

The overall mass reduction was 68% while the volume was reduced by 70% in a period of 27 days using forced aeration. The best removal performance reported in literature with Kitchen waste was 33# achieved in a period of 28 days (Yang et al., 2013). Therefore, in this research it was almost double which can be attributed to active aeration process. With respect to volume of kitchen waste, Nair et al., 2006 achieved a 79-85% reduction in 21 days using tumbler composting so there is still scope to improve this component. The largest part of this reduction was due to the removal of water due to leaching & evaporation. Despite the water removal, the moisture content was estimated to be 46% for compost The higher degradation of organic carbon shows optimization of the system's design and an efficient aeration efficient system.

Table 2 shows Solid Waste characterization shows notably key features being the notably high pH (6.78) and high moisture (76%). High pH values are attributed to the presence of large amounts of onion Peels and radish peels (seasonally consumed vegetable). The main contributors to the high moisture content were cooked and vegetable residues with more than 80% water in them. 5.2% of saw dust & dry leaves was added to provide structure and absorb moisture, reducing the moisture content finally to 76%.

It is concluded that feedstock was greenish, odorous, dark brown and compost was dark brown & odorless. The faecal coliforms was found to be 9.3 x 105 to 3.3x 103 in feedstocks and compost respectively. The heavy metals in the compost such as Cd, Mg, Cu, Ni, Fe, Al, Mn, Pb, Cr, & Zn was in the range of ND, 2095.93, 14.14, 2.89, 1451. 85, 502.04, 48.72, 10.04, 6.93, and 35.28 mg/kg are found the be below the prescribed standards of USEPA of bio-solids disposal. Moisture content, CN ratio, and TOC of the compost are 46%, 18, 30% respectively, which are key parameters to be evaluated for compost application to agricultural land. These parameters are acceptable as per prescribed compost standards. These result shows the compost is very stable and can be used for agricultural application. Adhikari et al. (2009) produced a compost with a C/N of 21 after 66 days of composting process, achieving only a 23–54% decrease, therefore, this research shows better results in a shorter period of time.

main composting compares

3.2. Lessons that can help Indian waste management

This prototype testing shows that Intensive composting can address multiple issues that Indian compost plants are facing today with respect to longer composting time, higher odor and laborious operations. This actively aerated intensive composting system not only reduce all these but also reduce capital and operation cost by 30% due to lower land foot print and higher yield when compared to conventional system. At a decentralized scale, it could further save transportation cost and bring additional savings to city governments. Since Food consumption habits in India are drastically different from that of western world, the European design of Intensive composting cannot be simply replicated for Indian waste. Therefore, necessary adaptations have been made in design and operating conditions and would also be required for the business model for Indian cities. The economic evaluation of full scale implementation is not covered in this study but the estimations based on prototype look positive. Similar technologies from Germany if adapted properly for Indian market and waste compositions could help build mature and robust technologies for waste management.

Acknowledgements

This research was supported by Nidhi Prayas Grant under Govt. of India startup India program where they funded the proof of concept (POC) for a Decentralized and automated organic waste composting technology. IIT Roorkee -TIDES supported as an incubator during this project and the chemistry department of IIT Roorkee for conducting tests.

References

Kumar, S., Smith, S. R., Fowler, G., Velis, C., Kumar, S. J., Arya, S., … Cheeseman, C. (2017). Challenges and opportunities associated with waste management in India Author for correspondence : https://doi.org/10.1098/rsos.160764

MOUD. (2016). MUNICIPAL SOLID WASTE MANAGEMENT MANUAL.

Pragati Kanaujiya , Devendra Dohare, 2020, Study of Composting for Municipal Organic Waste A Review, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) Volume 09, Issue 11 (November 2020),B.N. Effect of active and passive aeration on composting of household biodegradable wastes: a decentralized approach. *Int J Recycl Org Waste Agricult* **8,** 335–344 (2019). https://doi.org/10.1007/s40093-019-00306-7

Haug RT (1993) The practical handbook of compost engineering, 1st edn. CRC Press Lewis, Boca Raton

Christian Zurbrügg; Silke Drescher; Almitra Patel; H.C Sharatchandra (2004). Decentralised composting of urban waste – an overview of community and private initiatives in Indian cities., 24(7), 655–662. doi:10.1016/j.wasman.2004.01.003

Nair, J., Sekiozoic, V., Anda, M., 2006. Effect of pre-composting on vermicomposting of kitchen waste. Bioresour. Technol. 97, 2091–2095. https://doi.org/10.1016/j. biortech.2005.09.020.

Yang, F., Li, G.X., Yang, Q.Y., Luo, W.H., 2013. Effect of bulking agents on maturity and gaseous emissions during kitchen waste composting. Chemosphere 93, 1393–1399. https://doi. org/10.1016/j.chemosphere.2013.07.002.

Adhikari, B.K., Barrington, S., Martinez, J., King, S., 2009. Effectiveness of three bulking agents for food waste composting. Waste Manag. 29, 197–203. https:// doi.org/10.1016/j. wasman.2008.04.001.

Enlivening Many Birds by Removing Stones: Rejuvenation of Mountain Rivers

Dr. Ajit Gokhale
Natural Solutions, 302, Sudama Chhatra CHS, Near Sai Baba Mandir, Pandurang Wadi, Dombivli East, 421 201 Dist Thane Maharashtra India

Abstract

Presented here is Logical Frame Work of need, to recognize the hazards of Construction Debris, particularly of major infrastructure projects. This solid waste is benign when generated but with lapsing time and changing space it becomes violently malignant. It causes, floods, droughts, loss of farming land hence loss of livelihood for humans and loss of precious habitat for aquatic life in riverine ecosystems. We are sharing the cause-effect-mitigative actions taken by us through community mobilization.

An unexpected, unassuming, solid waste which is absolutely non-poisonous and non-biodegradable gets ignored mostly even by solid waste experts. It causes destruction of thousands of hectares of habitats, of over hundred and fifty species of birds and over 30 species of local fish, a few hundred species of mollusks, arthropods and amphibians put together.

It is infrastructure Debris. Tunnel debris, Hill cutting debris while making road taken out for ambitious Railway, Road and Hydroelectricity projects. It's quantity is over 45 Million tons. All this was generated in about a decade. Over the next three decades, it has moved to and settled in river beds. Now those river beds are dry. Even the pools, which used to retain water through out the summer, are now dry for over 7 months in a year. No fish in the dry pools, no nesting place.

These 45 million tons of debris heat up in six months of dry season. They cause huge heat island effect that brings in cloud bursts. Eventually this has started causing floods in villages and cities along the rivers. We understood this cause-effect reasoning through working with the local communities. Now we have started a people's movement and

have emptied at least about 18 kilometer length of pools in the rivers. Now those pools hold water, as they earlier did, about four decades ago. Some fish and many birds have returned.

When removed and repurposed, these 45 million tons will become construction material and make way for 15 million tons of water. This water will be there throughout the year, quenching thirst, supporting forests' fauna and last but not the least cooling the surroundings by absorbing about 33,900,000,000,000 Kilo Joules of Heat, every year… Cooling local climate. Similar 'mistakes' must have happened in other parts of the world. After correcting them, we can give much more cooling effect and restored habitats for our warming Earth.

Keywords : Flood Cause/s, Flood Prevention, Infrastructure waste, Global Cooling, Reversing of Global Warming, Alternative Building material Sources, Recycling solid waste from Infrastructure industry, Mitigating Water Scarcity, Riparian Biodiversity conservation/improvement, Habitat Restoration, River Rejuvenation,

1. Introduction

Recent news show numerous and more devastating floods as compared to news a few decades earlier [1,2,3,4]. These frequent floods and their increased severity are being attributed to global warming. With that reasoning comes a sense of helplessness. We have found that we have a way to prevent many of these floods.

I have been travelling across India in Hilly and plain regions for last four and half decades and meeting people. I have heard from middle aged people that when they were young they used to dive from trees in to the river pools. They are sad that their children and grandchildren can not enjoy the way they did. Not even in the rainy season.

As a rain water harvester and environmentalist, I know that the annual rainfall has not reduced so much that the pools in river would go dry. Same people say that the frequency and severity of flooding has increased. They also said the floods, in recent past, have started coming earlier than usual in the season.

What must have happened in these four to five decades? In my experience, the floods, in modern times, have many manmade causes. Following are the examples of such causes;

- Diverting and restricting riverine flows by making them pass through narrow culverts or diversion channels.
- Building low height bridges on forest streams. Such low height bridges often get converted to low head dams because of incoming forest material like fallen trees, branches etc. which are quite obvious part of natural flow of such streams when in flood. Such low head dams cause upstream floods.
- One more manmade cause of upstream floods is debris accumulated in the pools in rivers. Such debris comes from infrastructure projects like Roads, Railways etc. Whether they are executed on smaller or larger scale such projects often involve large earth moving. They generate a lot of debris. This debris is not considered as a solid waste in conventional meaning of the term. **But it is solid waste and it has caused and is causing severe damage to aquatic and riparian habitats.**

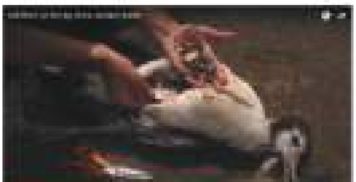
All this debris appears as just simple innocent looking stones and shingle in river beds.

Environmentalists who do not have historical perspective feel that these are just simple natural, integral part of the riverine ecosystem.

But on probing in details, one understands that these stones, earlier, never came into the stream so often. Or, if they did, they just rolled off. Leaving the pools as they were for literally hundreds of generations. Only in recent past, these pools have started accumulating the rolling stones. And the rivers have started breaking their banks and eating away the rice fields which all those generations have been tilling for their livelihood. With their rice fields washed away by rivers, the farmers and peasants dependent on them had no other choice but to take refuge in city slums and add to already swollen cities.

There are other group of villagers named as Ghorpi or Bhorpi. These people are traditional fisher folks. They used to fish in the riverine pools for local consumption. The pools, when they held water even in the peak of summer, were repositories of fish. They had the DNA stock of the river. These people had traditional repository of aquatic life. Which fish will arrive when, when will they reach appropriate stage for fishing? When are they not to be caught? When are they to be sustainably culled? They have had all the answers. They too became job less and foodless when the pools filled up with Innocent Natural Stones. They too had to look for another work, or another place to live.

Back then the word “climate refugees” was not there at all. They were indeed disaster hit people. The disaster appeared natural but actually was a result of human activities. The system, just looked at them as aspirants of city life who had come from some obscure village to the slums of urban centers. For them its loss of livelihood and breaking of family; breaking ties with the ancestral village. For city dwellers they are unwanted blot on their “Beautiful City”. Then the city dwellers use them as cheap labour.



For ‘Conservationists’ and ‘Environmentalists’ the stones which destroyed hamlets after hamlets are simple Natural Stones, they are cute pebbles with which the artists make aesthetic stuff. They are pebbles and shingles in the stream which should be kept as they are because some foreign language “Science” books state that they are integral part of the ecosystem. In recent past our whole world perspective has changed. There are people who are very well educated but do not understand the reality of life for many around them.

Simple Stones…Cute !!! ... Aren’t They?

But Reality is they are Villains…

Or … Are They?

In order to bring all of us to our senses, I call readers’ attention to the fact that we learned folks admire the skill of a person when we use the idiom "killing two birds with a stone". We take pride in killing literally and figuratively.

We all have become killers of distant birds. And we do not need bullets, arrows, traps or poison for doing that. We are killing Brown Albatrosses in central North Pacific Ocean. Brown Albatrosses are giant birds with 7 ft wing span…they have been living on far off pacific islands for millions of years.

We are causing their death remotely, even without being aware of it, with our plastic refuse[5]. and we are killing them with bottle caps. From the carcasses bottle caps can go back to the sea grow algae on themselves, get eaten by the small fish get caught by the big fish and come back to haunt the surviving birds again and again and again. These caps have become reusable bullets… So … killing Many Birds with a plastic cap should be the new age idiom.

BUT … this article is not about the plastic waste… and its not about killing the birds….

Its about … Enlivening many species of birds by removing stones from the rivers and making the rivers flow again. Many a learned scientists and ecologists too wonder that just by removing these stones aquatic and avifaunal bio-diversity could be conserved and supported. Because they do not have the historical perspective, which I have got from my travels and interactions with people.

All the above and many more kinds of birds live in the riverine habitats. Those simple cute stones which are considered 'Natural Part of the River Beds' cause food loss and habitat loss for these birds. And hence we took up a project of removing these stones from the river bed.

This project brought us close to our vision and Mission which you can see in our website www.naturalsolutions.org.in. we work, only on invitation basis, for the following types of projects;

i) Water Harvesting : Urban and Rural

ii) Flood Prevention

iii) Natural Wastewater recycling (STP/ETP)

iv) Pond and River Rejuvenation
v) Organic Farming and City Farming
vi) Environmental Literacy
vii) Biodiversity improvement

Under each of these headings we have done several different types of projects in several different types of agro-climatic zones. The general geographic spread of our work can be seen in the image on the left. where each mark is at least a few projects.

While doing all these ecofriendly projects we were brought face to face with stone filled rivers.

Such ferocious forceful flows, falling from over 100 meters into the abyss chiseled away by incessant flows. Many such flows combine to form a rivulet …

Such small but fast flowing rivulets gather great force, We are talking about such fast moving Mountain Rivers These Mountain rivers have been flowing for last 100 Million Years. Much before the dinosaurs got extinct.

On the Western Slope of the Western Ghats, the Biodiversity Hotspot, live thousands and thousands of birds of many different species and subspecies. Quite a few of them are resident while over 50 species are migratory.

Their food is mainly comprised of aquatic life forms…and insects and fruits which grow by the streams and rivers.

These aquatic life forms have been dwindling….

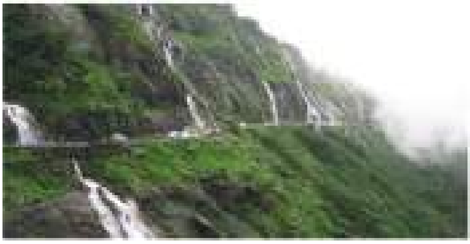
Not because of Climate Change but because of simple river stones, pebbles and Shingle.

We were invited by Mr Shridhar Kabnoorkar a local merchant and a social worker from Kondgaon Sakharpa a village in Sangameshwar Taluka of Ratnagiri District of Maharashtra in India.. He and his neighbors elder than him took us to the river and told us her story. An unprecedented landslide caused the river to silt up in 1949. Later on it started flowing through a new path on the right which caused annual flooding of the market area of the village.

2. What must have caused the landslide?

Making Roads in the Hilly regions changes several water and land forms. Above is one such Ghat Road. As can be seen a lot of hill side cutting is necessary to make this road.

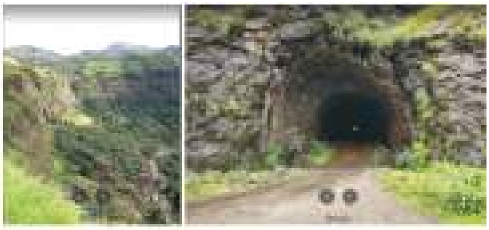
Some debris is brought into use for levelling the road but a large portion of it is just dumped by the road side, mostly on the down hill side. What happens with the debris?



several water flows which had their own paths to go down the hill, do get converged into one large stream due to the "Storm Water Drain" planned and executed by the Engineers. This pushes the road debris down hill. Soon it reaches minor streams and then the river. Enroute to the river the sharp edged dynamite-torn sharp rock fragments get polished to form nice looking rounded Pebbles and Shingles.

The fact that these do not have 'Real Natural' origin does not occur to many 'educated environmentalists'.

Then there are several low height culverts. They are good low cost alternatives to full scale bridges. But they restrict the river flow and reduce the river speed upstream of the culvert and increase the speed of the river downstream of them. Thus, upstream they aid sediment accumulation and upstream flooding while downstream they aid erosion.



After these minor road projects, the region did develop many major road projects and even so called watershed development projects which aimed at breaking the speed of running water. This developed several low height bridges, low head dams (check dams) etc. which resulted in more obstructions to river flow and more accumulation of innocent Pebbles and stones in place of water, aquatic plants, fish and crustaceans. Thus, slowly, and steadily reducing the habitat and food supply to those many birds in the whole area.

The people of the region demanded and waited five long decades to get their own railway system. It was certainly an excellent engineering feat to execute the Konkan Railway Project[7]. Building the Konkan Railway posed great challenges for the engineers tasked with the job. The rocky Sahyadri range had to be bored through, viaducts had to be built through valleys and more than 1,500 rivers had to be forded. Several tunnels opened onto viaducts and viaducts ended into tunnels. Around 2000 bridges were built and 91 tunnels were dug.

Together this resulted in Several Million Cubic meters of material movement. Only a part of it was used for leveling or back filling. Rest was dumped onto the hill sides. Daily several times the heaps got vibrations from passing by trains. Annually over 3000 mm rain battered them. And gravity kept on pulling them down slope, every second.

Train coming out of the tunnel on a bridge and proportion of tunnel and its entry path[8]

Simultaneously came other infrastructure projects like dams and hydroelectric power plants. They too dug several kilometer long tunnels and dumped their debris out on the hill slopes. Good engineering but bad disposal of the by-products.

Note the Vertical Cliffs and Tunnels Drilled Through Them.

Koyana dam, pioneering hydroelectric dam of India was lake tapped 4 times. This too generated a lot of ‘mucking’ which essentially is debris. It accumulated in the lower water ways and caused huge sedimentation there.

319,011 Cu m of mucking material came out of the Lake Tapping. Four such tapping attempts were done[10]. Over 1200,000 cu m of mucking material was deposited in River beds … **Conventionally it is not considered as solid waste But that is what it is**

To make roads and rail road ballasts we need quarried stones. To do concrete constructions, we need quarried stones, gravel, and sand. For this, people make stone quarries. They break hill sides for this and cause a lot of deforestation, tremors in the hills and cause landslides and soil slips. Which all adds to further siltation of the streams and rivers. And this causes flooding and habitat loss. So, the habitat loss happens in two places. Where mining is done and where the debris deposits.

In order to reduce flooding and re-create the habitat and water pools, we collected information of events in the past from people and developed a plan for actually removing millions of tonnes of debris from the river. The villagers who had come together decided to take action. They approached NAAM Foundation an NGO which is helping villagers who come together to take positive action on water scarcity and famine. This foundation provided the necessary earth moving equipment. The villagers fueled it and looked after the operators. The operators, in their turn worked honestly, intelligently and hard. The result was, in two months time they removed about 210,000 cu m stones. And deposited them in such a way that the banks of the river became strong. Then they got a reformed river with pools and strong banks.

The core team at ground level. They were backed by the village elders and expatriates from the village, now settled elsewhere

... River in Full Spate but not crossing the banks. In these fast moving rivers fish climb up to spawn in their hilly birth places.

The net result was, there was no flood in the village for the first time in last 72 years.

After seeing the success of this work people from other villages from near and far have come together to work on their own rivers. To clean the infrastructure debris form their water ways. In human body terms it is like unclogging the arteries and veins.

Kaal River silted up by over 4 to 6 meters. Kaal River getting unclogged. Joint efforts of people, NGO and to a great extent government as well, 'sans contractors'. So that the resources put in are fully converted in ground level action. Making real difference to the fullest extent.

3. What does it have to do with global warming?

Ever walked, barefoot, on hot stones in summer where temperature reaches 40 – 45 degrees? They do actually scorch your feet. Stones collect and reflect heat. Same volume of water on the other hand COOLs

There are 1500 river locations crossed by Konkan railway. (1,500 rivers had to be forded. Several tunnels opened onto viaducts and viaducts ended into tunnels. Around 2000 bridges were built and 91 tunnels were dug). Almost each causing several kilometers of siltation with stones. Say 5 Kilometers per bridge. That amounts to 10,000 kilometer length of water replaced by stones. Considering average width to be 25 meters and average depth of 3 meters. This amounts to

10,000,000 x 25 x 3 = 750,000,000 cu m of stones replacing equivalent volume of water. Which is 750,000,000,000 litres that many kilograms.

This water, in getting heated between 19 deg to 30 degrees would absorb

4.184 x 11 x 750,000,000,000 = 34,518,000,000,000 K Joules of heat At present all this is stone filled. Heating up quickly and giving off that heat in the night.

4. What does it do to carbon dioxide and food web?

Water absorbs 1.449 g of CO_2 per litre at NTP … The above mentioned water volume will also absorb 1.449 x 750,000,000,000 = 1,086,750,000,000 g i.e. 1,086,750 Tonnes of CO_2 every year.

So much Carbon Di Oxide will be available to aquatic food chain enlivening aquatic life forms from protozoa to mammals and the birds life depending on them…Hence removing stones form rivers helps in rejuvenating rivers and mitigating water scarcity, ensures food security, reduces poverty.

All over the world (at least the third world) the rivulets and streams have accumulated debris in similar manner. Removing it and giving the space back to water will result in regaining tremendous water reservoirs which will cool the surroundings, feed the hungry humans as well as non human life forms.

5. What does it have for the 'Development'?

750,000,000 cu m of construction material will become available to the Real Estate Industry.

The debris that has accumulated is in a way quarried from the bellies of the hills and entrails of the forests. This is quite similar to the stuff that is quarried using explosives. And milled using huge stone breaking machinery. Instead of blasting new hills and destroying forests on it, a law should be passed world over to use such obstructing debris in a manner that the pools are recreated in the paths of the rivers.

The old riverine harbors should be brought back to life and to that extent the load on the road system is reduced.

6. What does it mean for the wild life?

For countless species of aquatic flora, fauna and microfauna it will mean regaining their paradise. Their habitat. Their food and shelter. A new chance to repopulate the areas which their ancestors lived in. and that si not only for the land based organisms. It will mean rejuvenation of marine life as well, because the nursery of marine life is in the hills. All fish varieties have their nurseries in the pools of hilly streams.

It will be a win-win-win-win situation for

'Development' … Global Cooling… Human Food & Water recovery …wildlife habitat recovery.

Acknowledgements

I thank the opportunity I got to study these, development battered, rivers. My gratitude is also towards the villagers of Kondgaon Sakharpa for believing in our conceptualization and NAAM Foundation for supporting the villagers in executing our plan.

I also thank Prof. Amal Mukhopadhya for insisting that this paper be included in the proceedings of the 12th Hanseatic, critically reviewing this manuscript and for suggesting improvements.

References

https://www.nytimes.com/topic/subject/floods

https://www.sciencedaily.com/news/earth_climate/floods/

https://www.washingtonpost.com/world/interactive/2021/world-floods-climate/

https://public.wmo.int/en/media/press-release/weather-related-disasters-increase-over-past-50-years-causing-more-damage-fewer

https://www.youtube.com/watch?v=iQQIYKEY9Bw

http://www.naturalsolutions.org.in

https://www.thebetterindia.com/63760/konkan-railway-success-story/

https://www.google.com/search?q=Konkan+railway+Karbude+Tunnel+image&rlz=1C1VDKB_enIN962IN962&sxsrf=ALiCzsaeYToQyoCjSpg8qhPDkop-rXKJhg:1654854173626&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjd7LGZzKL4AhWWRmwGHdW_CK0Q_AUoAnoECAEQBA&biw=1024&bih=442&dpr=1.88#imgrc=m5Vf7jc5jF9-HM

https://www.researchgate.net/figure/Profile-of-Konkan-Railway-Bridges-Tunnels-and-Cuttings_fig4_312218410

https://prahaar.in/%E0%A4%95%E0%A5%8B%E0%A4%AF%E0%A4%A8%E0%A4%BE-%E0%A4%B2%E0%A5%87%E0%A4%95-%E0%A4%9F%E0%A5%85%E0%A4%AA%E0%A4%BF%E0%A4%82%E0%A4%97%E0%A4%9A%E0%A5%80-%E0%A4%86%E0%A4%AF%E0%A4%8F/

BIOGAS Renewable energy with many opportunities Focus on waste and biomethane

Helmut Muche
Strategic Infrastructure Business Consultancy Services GmbH

Abstract

The properties of biogas and the substrates from which biogas is produced are described. The requirements for the properties of the substrates are presented. Basics of the technology of biogas plants. Properties of waste from which biogas can be produced. Estimation of the recoverable quantities of gas that can be produced from waste to illustrate the potentials. Waste separation to separate the disruptive materials as a prerequisite for gas production. Use of the biogas as fuel for gas engines, in boiler plants and for the production of biomethane. Comparison of LPG and CBG, possible uses of CBG. Processes for the separation of carbon dioxide for the production of CBG. Future ways of using biogas. Parallel production of biohydrogen and biogas. Examples of plants for the production of biogas and biomethane.

1. What is Biogas ?

Biogas is an energy that has been known for a long time. For example, municipal sewage sludge has been treated in “digesters” for more than one hundred years. True, the main purpose is to reduce the dry matter and make the sludge easier to dewater. But the secondary benefit was also very welcome. The sewage gas obtained was also used early on to generate energy. Even before the Second World War, municipal vehicles were powered by sewage gas.

As a result of the Korean War and the associated energy shortage, the production of biogas from agricultural waste products, mainly manure and slurry from animal husbandry, became interesting. As a result, a number of small biogas plants were built. Since energy was very cheap after 1960, biogas fell into oblivion again. It was not until after the so-called energy crisis in 1973, which, significantly, was also triggered by a war, that renewable energies were rediscovered. Biogas is one of them. In the meantime, there are more than 10,000 biogas plants in Germany, which contribute to about 6.0 % of electricity generation. The three remaining nuclear power plants also generate about 5 % in comparison.

Biogas is a product of a mass conversion. Biogas is converted from complex organic substances with the aid of bacteria in a likewise complex biological-chemical process to produce biogas.

- Biogas is a gas with the main components
  - > Methane
  - > Carbon dioxide
- The methane is the desired material.

Methane is gaseous and combustible. Thus, it can simply be used to generate electricity and heat.

$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O + \text{energy}$$

Benefits Biogas

- Easy to handle
- Clean energy carrier
- Utilization of waste and residual materials
- Waste treatment in one step
- Wastewater treatment
- Versatile application

The main component of biogas is methane – CH_4

The methane is flammable and therefore an ideal energy carrier. Natural gas mainly consists of methane.

Average composition of biogas

app. 50 - 55 Vol.% methane	:	CH_4
app. 45 - 50 Vol.% carbon dioxide	:	CO_2
app. 0.1 – 0.7 Vol.% hydrogen sulphide	:	H_2S

The heating value of biogas is on average 18.7 MJ/m^3_n = 5.2 kWh/m^3_n

The low heating value is determined by the high starch content of the plants.

2. What is Biogas made from ?

Biogas can be produced from a variety of organic substances, the so-called substrates. Many substrates with high water content can be used, which are not suitable for combustion.

The classic source of biogas substrates is waste and by-products. In agriculture, it is the liquid manure and dung from animal husbandry. Sludge from wastewater treatment is another substrate. In Germany, sewage gas = biogas has been produced from sewage sludge for over a hundred years and is used to cover the energy requirements of sewage treatment plants. Many very different substrates are produced during the processing of foodstuffs. Many of these by-products are also used, for example, as animal feed. Nevertheless, food processing is a large source of suitable substrates. For example, waste from grain processing, sugar production, palm oil production and slaughterhouses can be excellently used to produce biogas. Household and restaurant waste is another substrate source.

With the introduction of the Renewable Energy Sources Act (EEG) in Germany just under twenty years ago, “renewable raw materials” are being produced on a large scale in order to obtain biogas from them. This development was possible because of the availability of free land due to the increase in agricultural output. With this land it was possible to produce biomass for energy production and to provide farmers with additional income. The most important crops are corn, grain, and grass, which are ensiled and thus transformed into a storable state. The substrates are thus available throughout the year. For tropical and subtropical regions, fast-growing Napier grass, which can be harvested several times a year, is suitable for this purpose.

2.1 Biomass - Definition

BIOMASSES are organic substances of biological origin.

A distinction is made between

- Plant biomass, the “phytomass”.

and the

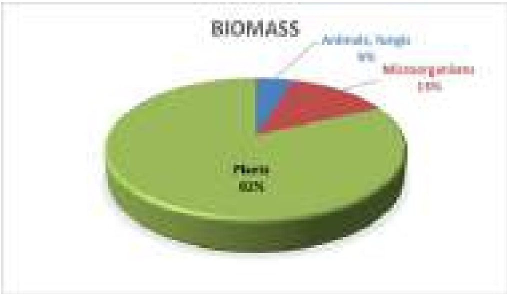
- Animal biomass, the “zoo mass”.

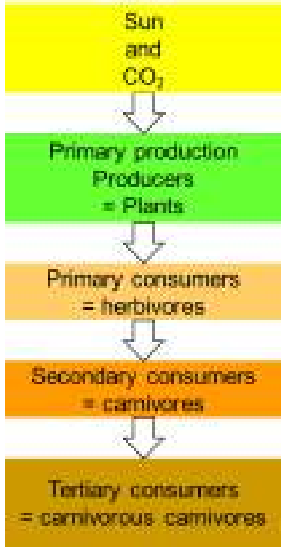
and the

- Microorganisms
- Fungi

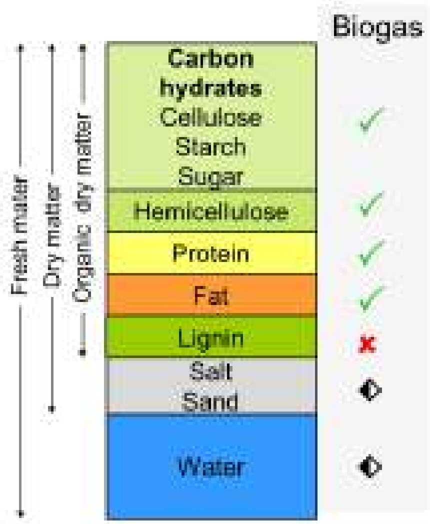
The term “biomass” is independent of whether the biomass is “alive” or already dead.

Fossil energy sources such as coal, oil and natural gas, whose origin is also of a biological nature, do not fall under the definition of “biomass”.





General composition of biomass



Carbon hydrates

Main components of the plants with up to 70 %

Cellulose largest component, polymer, must be broken down into smaller molecules in order to be able to produce biogas.

Starch, polymer, can be split into smaller molecules more easily

Sugar, small molecules that can be quickly converted into biogas

Hemicelluloses important constituents in plants, rapidly degradable

Proteins, component in plants and animals, important in the biogas process

Fat, component in plants and animals, increases methane content

Lignin, important component in plants.

Anaerobically not degradable, so that no biogas can be produced.

Inorganic molecules, no biogas but important as trace elements without which no biogas can be produced

Water, no biogas but without water no biogas can be produced

Substrates

Plants → Phytomass

Targeted cultivation for energy → energy crops

Plants with a high content of carbohydrates and low content of protein and fat

Zoo mass

Faeces and urine (manure) from livestock

Activated sludge from the wastewater treatment

Waste from processing of agriculture products

Wastes from the processing of plants

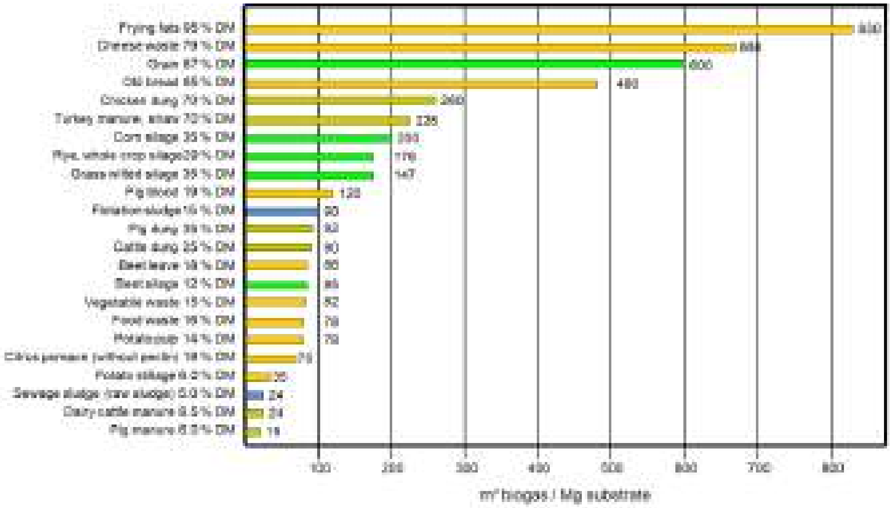
Slaughterhouse waste

Biowaste

2.2 Gas yields of different substrates

A major advantage of biological gas recovery is the use of very moist substrates. Unlike other biomass such as wood, such biomass cannot be burned to produce usable energy. However, it is possible to produce biogas via anaerobic microbiological degradation. With methane as its main component, it can be converted into usable energy by combustion in boilers or gas engines.

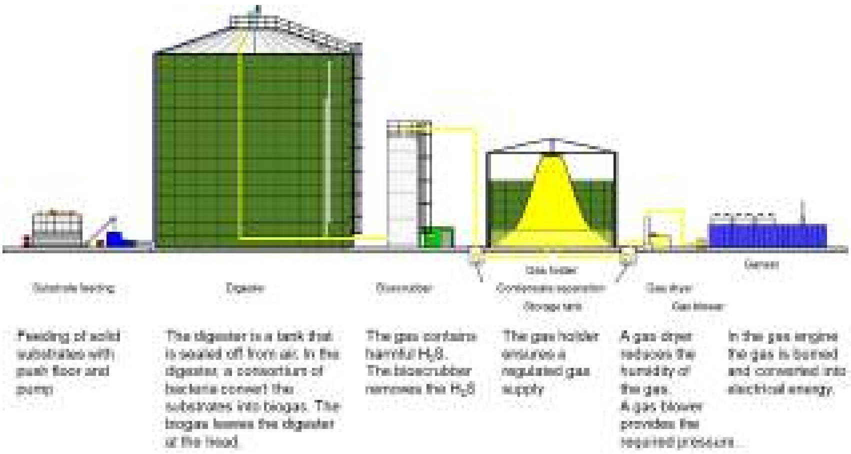
By its very nature, less energy can be produced per metric ton with a very wet biomass such as manure than, for example, from highly concentrated waste grease.



3. How is Biogas produced ?

3.1 Structure of a biogas plant

A biogas plant consists of various components. The conversion of organic substrates to biogas takes place in the digester. Liquid substrates are fed into the digester by pumps. Solid substrates are pumped into the digester from a moving floor via special feeding pumps. The digester is a tank that is tightly sealed from the air. The bacteria that "eat" the substrate are anaerobic and facultative anaerobic bacteria. They cannot exist in the presence of atmospheric oxygen. The decomposition of the complex organic biomass proceeds through several stages. The end products are methane (CH_4) and carbon dioxide (CO_2). Methane is combustible and is the desired energy source. The biogas collects at the head of the digester and is fed from there for further use.



Digester can be designed in various forms. Very important is a good mixing of the contents. Mixing or stirring ensures good heat and mass transfer. Optimum heat and mass transfer is very important for effective conversion of the substrate and to avoid sinking and floating layers. A proven design is the tall digester with a height to diameter ratio of about 1 : 1. A vertical agitator ensures complete mixing with low energy input.

Depending on the substrate, the biogas contains different concentrations of hydrogen sulphide (H_2S). Hydrogen sulphide is a pollutant for the environment and for the gas engines. It must therefore be removed, e.g., in a bioscrubber. The gas enters a gas storage facility to balance minor fluctuations between production and consumption. Before it is fed into a gas engine as fuel, the gas is cooled to condense the moisture. In the gas engine, the gas burns to produce mechanical or electrical energy. The waste heat from the engine can be used to heat buildings.

The digester is operated continuously. Every day, substrate is added to the digester and a corresponding amount of digestate is removed. The digestate contains undecomposed biomass, bacteria, and the inorganic nutrients such as nitrogen, potassium, and phosphorus. The digestate is excellent as a fertilizer in the landscape. The material cycle with the nutrients can thus be partially closed again.

4. How can waste be converted into Biogas?

4.1 Definition municipal waste

Municipal waste includes waste from private households. (Domestic waste) and the commercial waste similar to household waste.

Domestic waste contains essentially

- Food waste
- Yard waste
- Paper and cardboard
- Plastic
- Textile
- Glass
- Metals
- Wood

Separate collection of domestic waste

- The organic fraction then contains many impurities (plastic, glass, metal, pollutants).
- The contaminants impede the production of biogas and can reduce the quality of the compost.

The separate collection of the waste facilitates the recycling of the organic material.

Picture: Bauer Südlohn

The composition of domestic waste in different Indian cities.

The table above gives an overview of the results of the waste composition of several Indian cities. The share of the organic fraction is between 40 - 50 % of the total amount.

Composition and quantity of municipal solid waste in India			
Component	Bhubaneswar [1]	Allahabad [2]	Chennai[3]
	% (weight)	% (weight)	% (weight)
Biodegradable	50.7	45.3	40.3
Plastic	5.7	2.9	7.0
Paper and Cardboard	5.7	4.7	6.5
Rubber, leather	2.1	-	1.4
Glass	0.5	0.7	-
Metals	0.8	2.5	0.1
Coconut / wood	2.2	-	7.0
Rags	3.2	2.2	3.1
Inert materials	27.2	41.7	34.6
Total	98.1	100.0	100.0

DM Dry Matter

ODM Organic Dry Matter

GY Gas Yield (specific)

OFMSW Organic Fraction

Municipal Sorted Waste

Kind of waste	Source	Impurity	Range of variation
Food waste Kitchen waste	Canteen kitchens Food industry	Low plastic, cutlery	DM ≈ 20 - 30 % ODM ≈ 16 - 27 % GY ≈ 0.6 – 1.1 m³/kg ODM
Fruit and vegetable waste	Market waste	Low plastic	DM ≈ 8 - 13 % ODM ≈ 6.5 - 11 % GY ≈ 0.44 – 0.83 m³/kg ODM
OFMSW	Mixed household waste	High plastic, metal, gravel	DM ≈ 3.5 - 30 % ODM ≈ 1.7 - 20 % GY ≈ 0.39 – 0.59 m³/kg ODM

The origin of organic waste from households, markets and large-scale catering establishments can vary, so that the quantities that can be generated can differ. The composition also affects the pre-treatment of the waste.

4.2 Potential municipal waste

Estimation of the gas potential of waste from the composition and with the help of Buswell's equation and the sum formula.

Example

Food waste	275	Mg/d
Water	54.3	%
Ash	10.4	%
Organic substance	35.3	%
Organic substance	97	Mg/d

Sum formula organic substance
$C_{23.63}H_{37.52}O_{14.66}N_1S_{0.089}$

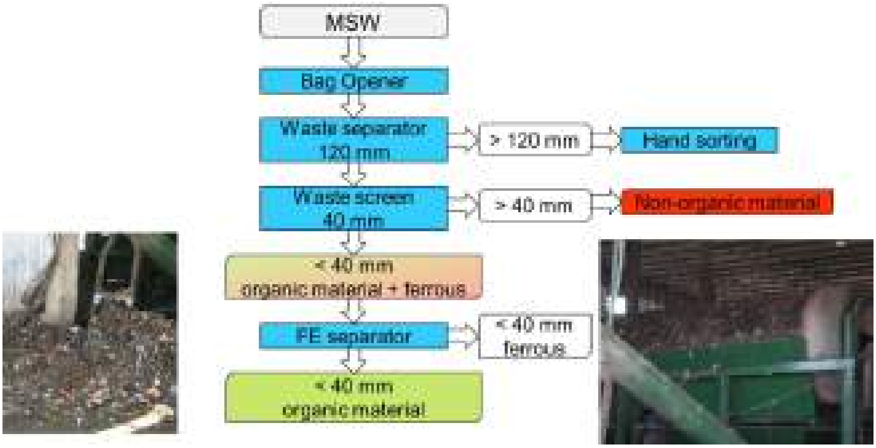
Theoretical gas yields	
1 kg organic substance = 0.882 m³ biogas = 0.486 m³ methane	
Practical gas yield ≈ 60 % of the theoretical gas yield	
1 kg organic substance	= 0.525 m³ biogas = 0.290 m³ methane = 55.2 Vol.% CH_4
97,000 kg organic substance per day = 50,925 m³ biogas per day	
50,925 m³ biogas per day = 2,120 m³ per hour = 11,660 kWh/h	
11,660 kWh/h * 40 % = 4,664 kW electric power	

Pre-treatment MSW

Unsorted municipal solid waste must be sorted before processing in the biogas plant.

All non-organic impurities must be separated.

The organic substances are crushed before they are given in the digester.



A simple way to separate the mixed waste is to screen the waste in drum screens with different screen diameters. The separation can be supplemented with magnets for metal separation.

Sorting and separation of organic waste packed in plastic bags can be done in separators. These consist of a hammer mill that crushes the material. Separation takes place via a sieve, which separates the organic mass from the foreign matter.

Picture: Huning Anlagenbau

5. What can Biogas be used for?

5.1 Applications for Biogas

Biogas can be used in various ways. The main possibilities are:

• Combustion in gas engines	• Generation of mechanical / electrical energy, heat
• Refining to highly concentrated methane > 90 %	• Substitution of natural gas Feeding into the public gas grid Fuel for motor vehicles
• Combustion in boiler plants	• Production of heat and steam

5.2 Power production with gensets

- The power plant can be designed to supply electricity for either internal consumption or for selling of electricity to the public power grid

5.3 Biomethane production

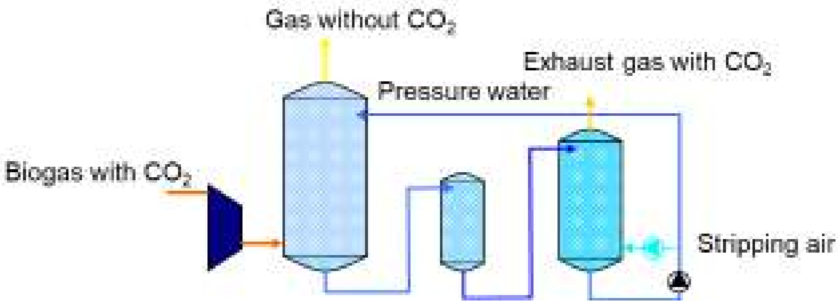
With the enrichment of the methane from the biogas, an energy-rich gas can be made available for further applications:

- Biomethane as a substitute for natural gas
- Substitute for LPG as cooking gas
- Fuel for motor vehicles

Biomethane as a substitute for natural gas requires a natural gas distribution network.

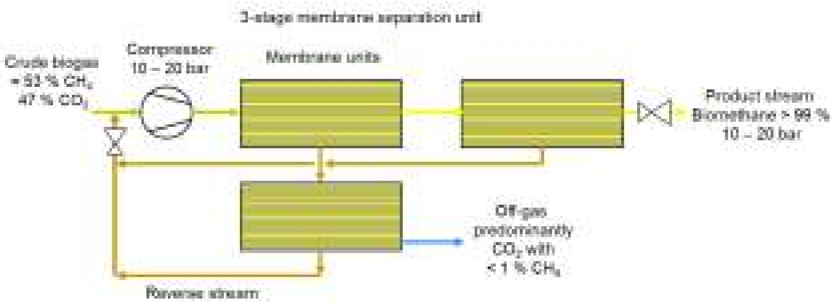
Germany has a widely distributed natural gas network at various pressure levels, so it is relatively easy to feed in.

However, the gas must be adapted to the requirements for the necessary combustion properties. For this purpose, small amounts of LPG and an odourant are added



Pressurised water scrubbing to separate the carbon dioxide from the biogas

5.4 Membrane separation



When the gas is separated with membranes, the methane molecules are "sieved" from the carbon dioxide molecules. The membranes have openings through which the smaller molecule can escape.

5.5 Comparison LPG and CBG

	CBG	LPG		
Energy content LHV	12.137	12.87	kWh/kg	
Density	0.7805	m^3_n/kg	540	m^3/kg (20 °C)
Energy content 11 kg bottle with LPG		Same energy content CBG		
Energy content	141.57	kWh	141.57	kWh/12.137 kWh/m^3 = 1.66 kg CBG
Volume bottle		20.4 l	4.95 m^3	

Pressure required to store this standard volume in a 20.4 l bottle

≈ 747.5 bar

Pressure in CBG bottles: 205 – 275 bar

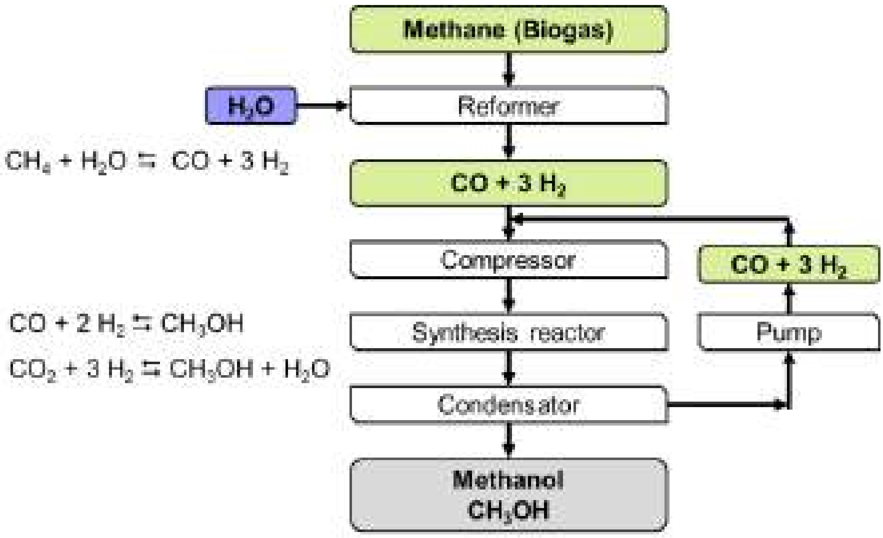
The use of CBG as cooking gas requires a different infrastructure. The energy density of compressed biomethane is lower than that of LPG. Larger gas cylinders are therefore needed.

Since the biomethane has different combustion properties than LPG, other burners are also required.

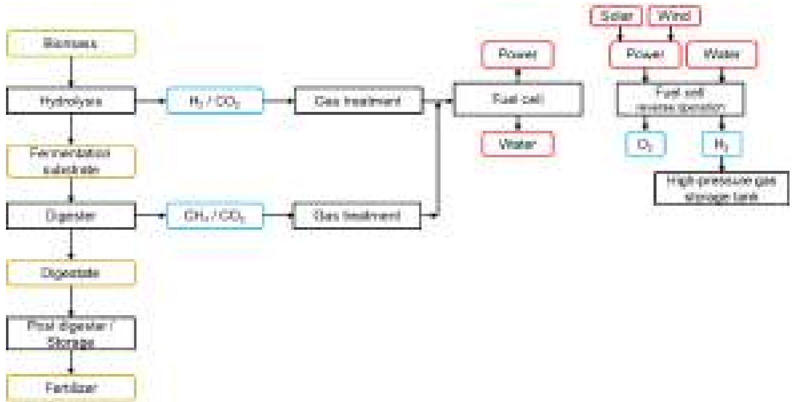
6. What developments can we expect ?

6.1 Green methanol

- Methanol is produced on an industrial scale from the methane in natural gas.
- Methanol can therefore also be produced from biogas.
- The biogas is first converted to carbon monoxide and hydrogen in a reformer
- The methanol is then produced in the synthesis reactor.



6.2 Bio-hydrogen and biogas



Hydrogen can also be produced from moist biomass by microbiological means in various ways.

The technically simplest option is the combined production of hydrogen and methane. The biomass is converted into hydrogen and methane (biogas) in a two-stage process.

Effects

1. Increase in energy yield due to better efficiency of the biological conversion
   - acidification of the liquid with a high concentration of organic fatty acids.
   - The fatty acids are quickly converted to biogas in the biogas digester.

This also allows energy production to be adapted more quickly to demand.

References

Panda etal: Present practice of Municipality Solid Waste Management in Bhubaneswar, Odisha, India

International Journal of Energy, Sustainability and Environmental Engineering 1(1) 28-34, 2014

Sharholy etal: Municipal solid waste characteristics and management in Allahabad, India Waste Management 27, 490-496, 2007

Palanichamy: A Sustainable Energy Option to the Expanding Chennai Metropolitan Area India Journal of Science and Technology, 8(22) September 2015

Riße, H.; Lenis, A.; Ooms, K.; Jagemann, Peter, Schulte, Patrick; Klein, Daniel; Gramlich, Eric; Schröder, M. Illing, F.

WaStraK NRW „Einsatz der Wasserstofftechnologie in der Abwasserbeseitigung" - Phase II

Methanolsynthese, Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes

Nordrhein-Westfalen, 2018

Pictures

Bauer GmbH, Südlohn

Huning Anlagenbau GmbH & Co. KG, Melle

Helmut Muche

27.03.2022

We, the Organizing Committee, invite you cordially to register and attend the above mentioned Conference being planned in Hamburg on the 7th April, 2022. Registration is free but mandatory to participate at the Conference. Restrictions due to Covid-19 apply, as admission to the conference hall is based on prevalent vaccination requirements and **only first fifty** registrants will be admitted.

ORGANIZERS

Two Co-Organizers, one from Germany and one from India, will be responsible to develop the Concept, Faculty, Speakers, Scientific Program, and to publish the proceedings as a book.

PD Dr.-Ing. habil. Dirk Weichgrebe
Institute for Sanitary Engineering and Waste Management
Gottfried Wilhelm Leibniz Universität Hannover
Welfengarten 1, 30167 Hannover, Germany

and

Dr. Babu Ambat, Executive Director
Centre for Environment and Development
Thozhuvancode, Vattiyoorkavu P.O., Thiruvananthapuram-695013, India
E-Mail: director@cedindia.org

OPERATIONAL MANAGEMENT OF THE CONFERENCE AND CONTACT

Hanseatic India Forum e. V., Hamburg
Contact Person:
Dr. Amal Mukhopadhyay
Chairman of the Board
Baumschulenweg 26, 22609 Hamburg, Germany
Phone: 0049 40 41161360
Mobile: 0049 163 3243522 (WhatsApp)
E-Mail: **vorstand@hif-hamburg.de**

LOCATION OF THE CONFERENCE

Auditorium of the Consulate General of India in Hamburg,
Kohlhöfen 21, 20355 Hamburg

The Conference is being planned as an „in presence" event. However, online access (Hybrid mode), will also be available. Registration is mandatory for online participants as well.

REGISTRATION

Registration to participate will be without cost but registration will be mandatory to enter the Conference hall. For Registration please send an E-Mail to **vorstand@hif-hamburg.de**.

12th Hanseatic India Colloquium

"Solid Waste Management: an Indo-German Dialogue"

Hamburg, 7th April, 2022, 9:30h – 17:00h

Consulate General of India
Hamburg

Programme Migration & Diaspora

With the friendly support of

12th Hanseatic India Colloquium "Solid Waste Management: an Indo-German Dialogue"

Hamburg, 7th April, 2022, 9:30 h – 17:00 h (CET) , 1:00 pm-8:30 pm (IST)

Both On-line and in Presence Conference (hybrid)

Auditorium, Consulate General of India, Kohlhöfen 21, 20355 Hamburg, Germany

Program

09:30 h – 10:00 h **Registration**

10:00 h – 10:30 h OPENING SESSION

Words of Greetings by **John Ruolngul**, General Consul of India, Hamburg, Germany

Welcome Address by **Julie-Ann Tai Shiraishi,** Senate Chancellery, State Office, Department International Cooperation, Hamburg

Indrajit Ghosh, Chairman, MSME Chamber of Commerce and Industry of India, New Delhi, India
MSME Role of Recycling and Waste Management Development in India and its future

10:30 h – 12:00 h PLENARY SESSION

Chair: **Dr. Amal Mukhopadhyay**, Chairman, Hanseatic India Forum e.V., Hamburg

PD Dr. Ing. habil. Dirk Weichgrebe, Associate Professor, Institute for Sanitary Engineering and Waste Management, Gottfried Wilhelm Leibniz Universität Hannover, Germany
SMART city concepts for treatment of and resource recovery from municipal organic waste - Experiences from IGSTC 2+2 projects

Dr. Babu Ambat, Director, Center for Environment and Development (CED), Thiruvananthapuram, India and **Thrikkaniyur Ananthanarayanan Jayanthi**, Scientist Biotechnology, Center for Environment and Development (CED), Thiruvananthapuram, India
Integrated solid waste management : Issues, challenges and opportunities – an Indian experience

Prof. Dr. Ing. Jörg Rainer Nönnig, Hafen City University, Hamburg, Germany
Digital Modelling of SWM for the Indian Urban Development Context

12:30 h – 13:00 h SESSION RECYCLING AND UPCYCLING OF WASTES

Chair: **Dr. Souvik Chakrabarty,** Technical University Clausthal, Clausthal-Zellerfeld, Germany

Fabian Schott, M.Sc., Assistance to the CEO at SRH, Stadtreinigung Hamburg, Germany
Challenges and perspectives for a sustainable and carbon neutral circular economy in Hamburg – Stadtreinigung Hamburg

Ronobir Roy, General Manager, Arcelormittal Recycling, Esch Sur Alzette, Luxembourg
Steel Scrap - Green with potential of Endless Recycling

Amita Deshpande, CEO and Founder, reCharkha EcoSocial, Pune, Maharashtra, India
reCharkha EcoSocial : A small drop in the Ocean! - An experiment in upcycling

13:00 h - 14:00 LUNCH BREAK

14:00 h – 15:30 h SESSION CIRCULARITY IN WASTE MANAGEMENT

Chair: **PD Dr. Ing. habil. Dirk Weichgrebe**, Hafen City University, Hamburg

Dipl.-Ing. Helmut Muche, Consultant, Strategic Infrastructure Business Consultancy Services GmbH, Lemgo, Germany
BIOGAS : Renewable energy with many opportunities, Focus on waste and biomethane

Aparna Kapoor, Cofounder and Co-Owner, SFC Environmental Technologies, Navi Mumbai, India
Bio methanation of Municipal Solid Waste at our Goa Garbage treatment facility

Dr. Souvik Chakraborty, Group Leader, Institut für Polymerwerkstoffe und Kunststofftechnik, Technical University Clausthal, Clausthal-Zellerfeld, Germany
Towards a closed loop recycling of CFRP within circularity concept processed with a novel thermoplastic matrix

Shivali Sugand, International Solid Waste Management Consultant, Center for Environment and Development, Roorkee, India
Food waste management: Experiences from Germany applicable in Indian scenario

15:30 h - 16:00 COFFEE BREAK

16:00 h – 17:00 h SESSION WATER AND ENVIRONMENT

Chair: **Fabian Schott, M.Sc.**, Stadtreinigung Hamburg

Dr. Ajit S. Gokhale, Owner, Natural Solutions, Dombivli, India
Enlivening Many Birds by Removing Stones : Rejuvenation of Mountain Rivers

Sanchita Khandelwal, Project Engineer, Aqua & Waste International GmbH, Hannover, Germany
Wastewater: Solutions from German-India Partnerships

Closing Remarks

Authors Index

Organised by

Hanseatic India Forum e.V &
Centre for Environment and Development, India

ISBN 978-81-962252-0-9