DESIGN, DEVELOPMENT, AND ANALYSIS OF HYDRO SEPARATOR FOR MIXED MUNICIPAL SOLID WASTE

A Thesis Submitted To The
University of Petroleum and Energy Studies

For the award of
Doctor of Philosophy
in
Mechanical Engineering

BY
Prashant Shukla

November 2021

SUPERVISOR
Dr. Pankaj Kumar Sharma
Dr. Shyam Pandey

UNIVERSITY WITH A PURPOSE

Department of Mechanical Engineering
School of Engineering
University of Petroleum and Energy Studies
Dehradun-248007; Uttarakhand

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DECLARATION

I declare that the thesis entitled "**Design, Development, and Analysis of Hydro Separator For Mixed Municipal Solid Waste**" has been prepared by me under the guidance of Dr. Pankaj Kumar Sharma, Professor, Department of Mechanical Engineering, University of Petroleum & Energy Studies and Dr. Shyam Pandey, Professor, Department of Mechanical Engineering, University of Petroleum & Energy Studies. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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Nov. 2021

CERTIFICATE

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ENGINEERING | COMPUTER SCIENCE | DESIGN | BUSINESS | LAW | HEALTH SCIENCES | MODERN MEDIA | SMART AGRICULTURE

ABSTRACT

The unprecedented population growth, rise in community living standards (changing lifestyle), and urbanization have left most of the Countries grappling to find viable technological solutions to their waste management problems. An improper WM is attributed to the systemic failure of policy makers and municipal authorities to identify the most sustainable approach to dealing with it so as to meet environmental and socio-economic aspirations. A sample of MSW contains waste generated from households, public places, commercial & institutional places. Such waste contains recyclable, degradable, and inert waste; hence these wastes can be treated as a resource for raw material for recycling, composting, waste to energy, etc. It is only possible when the waste contents are available in desirable for, i.e., only degradable waste for composting or methanation, dry waste for incineration, and plastic for recycling. The requirement of the mentioned form of waste is not being fulfilled due to its unsegregated form. As per the waste management rules in all the countries, MSW must be segregated at source, so that each type of waste can be utilized according to the available infrastructure. The current technological solution gives the flexibility to segregate mixed MSW after its collection, but various limitations drag the available technology a few steps back towards the inefficient performance. The existing segregation system works only with the dry form of waste, whereas the fresh amount of MSW contains around 50- 60% moisture. Hence, it requires an open land area for MSW drying process and to install machinery like conveyor, screening drum, air classifier, magnetic chamber etc. A small drying area causes the random growth of mixed MSW at the dumpsites, from where waste processing facilities consume waste as per their requirement. Hence prolonged mixed waste at dumpsites contaminates each other and the surrounding atmosphere also. Therefore a technological solution is required to be intervened in the MSWM process, which is able to segregate mixed MSW immediately after its collection. Such intervention does not require any prerequisite of the drying process, and segregated waste will be directly used by the waste processing industries. In the present work, a segregation system was designed and developed for mixed municipal solid

waste, which works on the phenomenon of density differences and the principle of sink & float.

The system is named "Hydro Separator," and its foundation lies in analyzing a few important physical properties of MSW contents such as specific density, bulk density, water absorption properties, sink/float response with respect to time. Based on the sink/float feasibility test and the existing sink & float separator in the mineral processing industries, a prototype segregator was designed and developed. The prototype segregator can segregate 5 kg mixed MSW in one batch, in which multiple segregations were performed for the detailed analytical study of the system and its process performance. The system is able to segregate the mixed MSW into three categories, i.e., plastic waste, degradable waste, and inert & metal waste. Therefore the performance/characteristic curves were plotted against the recovery of classified MSW content and analyzed for further optimization of the system. A standard operating procedure was also developed to perform MSW segregation in the future.

ACKNOWLEDGMENT

I would first like to thank my Ph.D. advisors, Dr. Pankaj Kumar Sharma and Dr. Shyam Pandey, for the past five years of great support at UPES. Their passion and persistence in science have always encouraged me during my Ph.D. study. In the first year, they spent enormous efforts guiding research and never lost their patience when the experiment was not going well. They would seek every chance to train paper writing and presenting skills that help build confidence and become a qualified researcher. Without their constant support, I would never be able to accomplish a Ph.D. study. All the knowledge and merit that they passed on, has made me today and will continue benefiting my future life.

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LIST OF SYMBOLS

Abbreviations	
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
IMSWM	Integrated municipal solid waste management
ULB	Urban local body
FCO	Fertilizer Control Order
FI	Fertilizing Index
CI	Clean Index
WTE	Waste to energy
RDF	Refuse derived fuel
TPD	Ton per day
SWMS	Solid waste management system
MRFs	Materials recovery facilities
CPCB	Central Pollution Control Board
SEC	Socio-economic conditions
SWMR	Solid Waste Management Rules
SBM	Swacch Bharat Mission
Nomenclature	
H	Height of the lab scaled segregator
D	Diameter of the lab scaled segregator
V	Volume of the lab scaled segregator
V	Volume of the waste plastic column
R	Radius of the prototype segregator
H	Desirable column height of floating waste plastic
σ_b	Bending stress in the agitator blade
M_b	Bending moment developed in agitator blade
Y	Position of neutral axis
I	Moment of inertia of agitator blade

σ_a	Allowable stress in the agitator blade
S_{yt}	Yield tensile strength of the material
F.S.	Factor of safety
d_a	Diameter of the agitator blade
w_a	Width of the agitator blade
d_s	Diameter of the agitator shaft
T	Required torque to be applied on the agitator shaft
T	Allowable torsional shear stress for agitator shaft
P	Force acting on agitator blade
A	Throat area of all welds
τ_1	Primary shear stress in the weld
T	Throat thickness of the weld
H	Leg length of the weld
N	No. of observation
B	Confidence factor
A	Precision factor
W_P	Amount of water consumed for recovery of waste plastic
S_P	Shredding size of the waste plastic
W_D	Amount of water consumed for recovery of degradable waste
A_D	Duration of agitation for degradable waste
S_D	Average shredding size of degradable waste
S_I	Average shredding size of inert waste

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Chapter 1

Introduction and organization of the thesis

1. INTRODUCTION AND ORGANIZATION OF THE THESIS

1.1 Municipal Solid waste and its generation

Municipal solid waste is a complex mixture of substances that individuals, households, and commercials discard in communal or registered locations in solid or semi-solid form. It does not encompass hazardous industrial wastes but contains treated bio-medical wastes. MSW consists of compostable, recyclable & inert waste. The components of MSW are explained in Table 1-1 (Annepu, 2012) (Sujauddin, 2008).

Table 1-1 Contents of waste materials in MSW (Annepu, 2012) (Sujauddin, 2008)

Source	Typical waste generation	Types of waste
Residential	Single and multifamily dwellings	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes (e.g., bulky items, consumer electronics, white goods, batteries, oil, tires), and household hazardous wastes
Commercial	Stores, hotels, restaurants, markets, office buildings, etc.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Institutional	Schools, hospitals, prisons, government centers	Same as commercial
Construction and demolition	New construction sites, road repair, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, etc.

Municipal services	Street cleaning, landscaping, parks, beaches, other recreational areas, water, and wastewater treatment plants	Street sweepings, landscape and tree trimmings, general wastes from parks, beaches, and other recreational areas, sludge

MSW can be classified mainly into three categories, i.e., compostable, recyclable, and inert. In which a waste that is capable of anaerobic or aerobic decomposition falls under the category of compostable waste, e.g., food waste, garden waste etc. Whereas the waste that can be reused as a useful product is considered recyclable waste such as plastic bags, glass, etc., inert waste is neither chemically nor biologically reactive and will not decompose or only very slowly, such as earth particles and dirt, sand etc.

Table 1-2 shows that MSW is generated in all the regions of India and its percentage composition in all three categories. As per the data, a sample of MSW contains an average 50% of compostable waste, 20% recyclable waste, and 30 % inert waste. The quantity of MSW varies according to the region and its population, i.e., rural areas produce lesser waste than urban areas.

Table 1-2 Composition of MSW in India and Regional Variation (Annepu, 2012)

Region/city	**MSW (TPD)**	**Compositions of MSW**		
		Compostable (%)	**Recyclables (%)**	**Inert (%)**
Metros	51402	50.89	16.28	32.82
Other cities	2723	51.91	19.23	28.86
East India	380	50.41	21.44	28.15
North India	6835	52.38	16.78	30.85
South India	2343	53.41	17.02	29.57
West India	380	50.41	21.44	28.15
Overall Urban India	130000	51.3	17.48	31.21

Waste generation is unavoidable in any habitation, large or little. Since the start of civilization, humanity has gradually drifted away from nature, culminating in a massive change in human society's lifestyle today. The type and quantity of waste generated by a community is a direct indication of this transformation. Waste can be recycled or disposed of and, with good management, can provide revenue. Indian cities, which are rapidly catching up with global economies in their pursuit of rapid economic development, have failed to efficiently manage the massive amount of waste generated. India has roughly 593 districts and approximately 5,000 towns. Around 35% of India's total population of more than 1/2 billion people reside in cities. By 2036, the estimated urban population share will be 39% (Worldbank, n.d.). The amount of waste generated in Indian towns and cities is increasing daily, owing to the country's growing population and GDP. Annual solid waste generation in Indian cities climbed from six million tonnes in 1947 to 48 million tonnes in 1997 at a pace of 4.25 percent each year and is anticipated to reach 300 million tonnes by 2047 (Agarwal, Chaudhary, & Singh, 2015).

1.2 Municipal Solid Waste Management

Solid waste management can be defined as the process of regulating the generation, storage, collection, transfer and transportation, processing, and disposal of solid wastes in a manner that is consistent with best practices in public health, economics, engineering, conservation, aesthetics, and other environmental considerations, while also being responsive to public attitudes. The first goal of solid waste management is to remove wasted materials from occupied areas in a timely manner in order to avoid disease spread, reduce the chance of fires, and minimize the visual impact of decaying organic matter.

The goals of MSWM can be summarized as follows:

- To protect environmental health.
- To promote the quality of the urban environment.
- To support the efficiency and productivity of the economy.
- To generate employment and income.

In order to achieve the above goals, it is necessary to establish a sustainable system of MSWM. The principle of sustainable waste management strategies is to:

- Minimize waste generation.
- Maximize waste recycling and reuse.

- Ensure the safe and environmentally sound disposal of waste.

1.2.1 Functional Elements of a Waste Management System:

Civilization continually creates solid materials from a variety of rural, commercial, residential, and institutional sectors as a result of its rapid growth in creation and consumption. It places an enormous burden on common resources and obliterates the possibility of productive and sustainable growth. Effective solid waste management is the only way to avert such situations. MSWM is a fundamental technique for advancement because it entails the segregation, storage, collection, relocation, processing, and disposal of solid waste to minimize its negative influence on the environment. Unmanaged MSW becomes a role in the development of chronic diseases. As a result, MSW is treated in a variety of ways, including recycling, composting, incineration, and landfilling. (Annepu, 2012)(Rajkumar & Sirajuddin, 2016). Combining all of the foregoing treatment approaches with MSWM results in an integrated MSWM (IMSWM) system (Figure 1-1) (Planning Commission, 2014), which is being adopted by the majority of developed countries. Instead of being dumped into open places, separated garbage from diverse sources (excluding industrial and medical waste) is treated using a variety of processes under the integrated MSWM system. These strategies could include WTE, composting, or recycling (Planning Commission, 2014).

The MSWM activities are grouped into the following six functional elements:

a) Waste generation.
b) On-site handling, storage, and processing.
c) Collection.
d) Transfer and transport.
e) Processing and recovery.
f) Disposal.

The interrelationship between the functional elements is shown in Figure 1-2 (Mansour, n.d.).

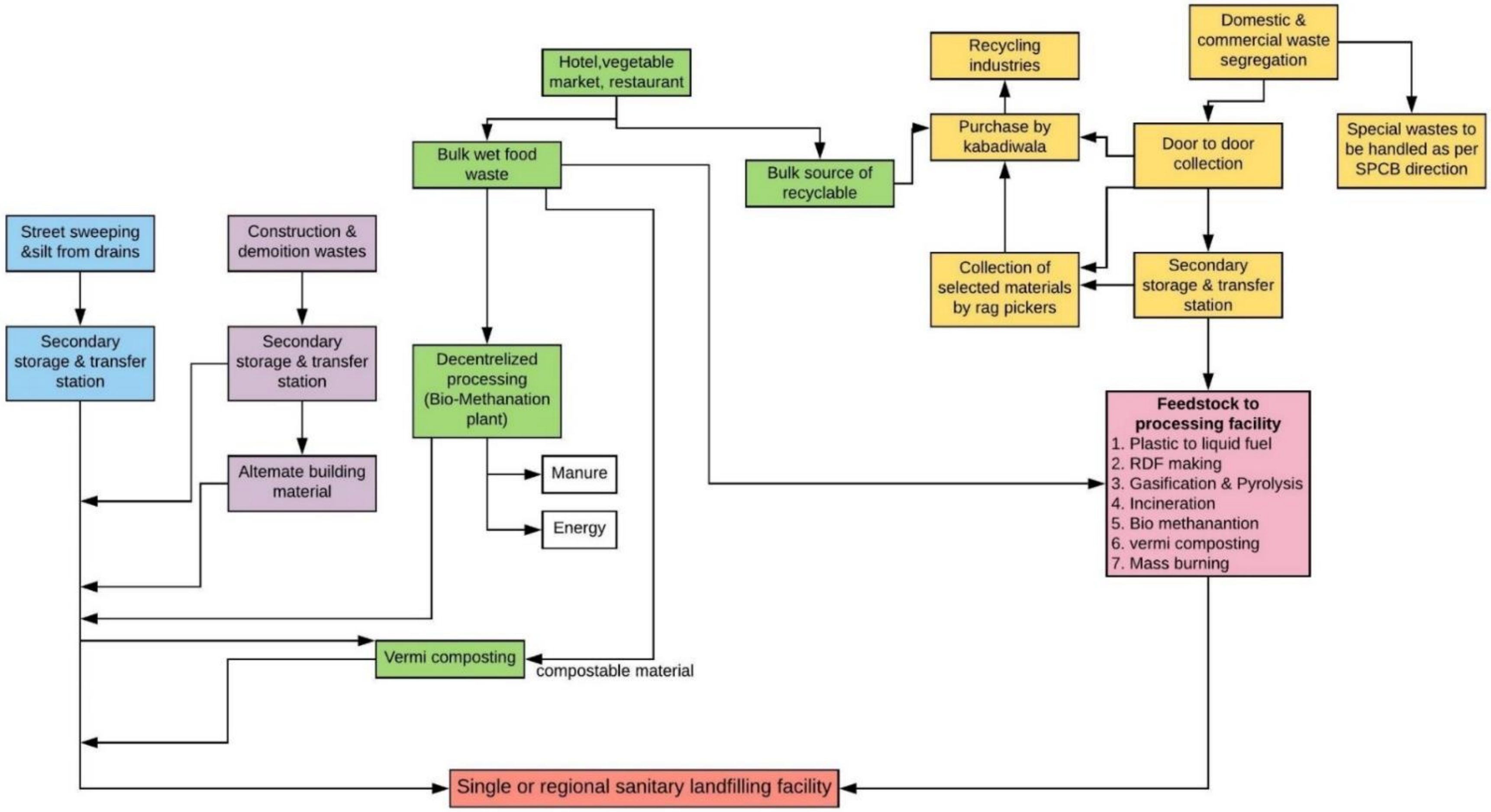


Figure 1-1 Integrated MSW Management

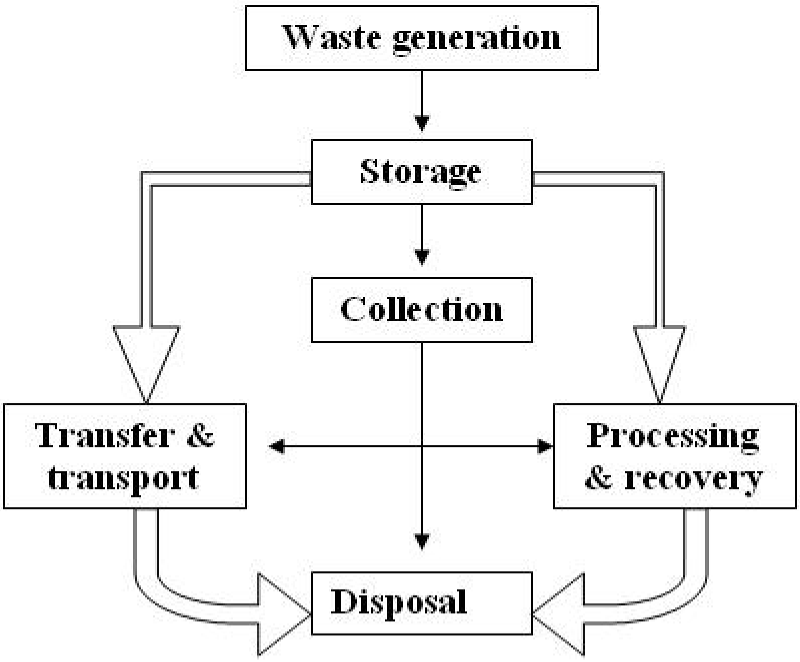


Figure 1-2 Interrelationship of functional elements comprising SWMS

a. Solid waste generation: Solid wastes are defined as any solid or semi-solid material that is no longer deemed valuable enough to maintain. MSW is generated on a daily basis in residential, commercial, and institutional places. The quantity and composition of trash generated are significant factors in the design and operation of solid waste management systems. The quantity of MSW created can be quantified in two ways:

The load-count Analysis: The quantity and composition of solid wastes are determined using this method by keeping track of the expected volume and the general composition of each load of waste transported to a landfill or transfer station during a set period. The overall mass and compositional distribution of the mass are calculated using average density statistics for each trash type.

Mass volume analysis is another technique that is similar to the previous one but includes the capability of recording the mass of each load. Unless each waste category's density is measured independently, the mass distribution by composition must be calculated using average density values.

Municipal trash creation is influenced by a variety of factors, including geographic location, season of the year, collection frequency, use of kitchen waste grinders, population characteristics, degree of salvaging and recycling, public attitude, and regulation.

b. On-site handling, storage, and processing

***Handling*:** The term "handling" refers to the procedure by which solid waste is handled until it is placed in the containers used to store it before collection. Additionally, it may be necessary to transport loaded containers to the collection point and empty containers back to the location where they are stored between collections.

Storage: The storage procedure is determined by several elements, including the container type, its location, public health and aesthetics, and the collection technique. There are numerous container types and capacities that are frequently used for on-site solid waste storage. However, as expenses continue to rise (labor, workers compensation, gasoline, and equipment), there is a significant trend toward adopting huge containers that can be mechanically emptied via an articulating joint-equipped pick-up mechanism.

Processing: Processes are used to recover useable materials from solid wastes, to reduce their volume, or to change their physical form. Manual sorting, compaction, and incineration are the most often performed on-site processing activities.

c. Collection of solid wastes:

The collection's functional component entails the collection of solid trash and recyclable products, as well as their transportation to the location where the collection truck is emptied following collection. A material processing plant, a transfer station, or a landfill may be used as this place.

Transfer and Transport: This element consists of two distinct phases. To begin, waste is transferred from a smaller collecting truck to larger transport equipment via a transfer station. After that, the trash is transported, typically over great distances, to a processing or disposal facility. Transfer stations are categorized into two groups based on the manner used to load transport vehicles:

Direct Discharge: The collection truck’s wastes are deposited straight into the vehicles, which are then transferred to the final disposal place, which is typically used in small communities.

Storage Discharge: The wastes are unloaded into a storage area from where they are loaded onto transport vehicles and transported to final disposal destinations using auxiliary equipment. It is advantageous for communities with a large population.

d. Processing and recovery

It is essential to process the collected MSW, recover the valuable contents, and let the inert part be dumped into landfill sites. In contrast, separation of MSW is the prerequisite, which can be done at the source or in the stage before it moves for any process or disposal. Chemical and biological conversion procedures are employed to limit the volume and weight of waste that must be disposed of, as it is critical to separate recyclable materials. Separation methods vary according to the type of solid waste. Such as:

Density separation: Separating materials by their densities is based on the fact that various materials have varying densities. Thus, if a combination of substances with varying densities is poured in a fluid with an intermediate density, grains with densities lesser than the fluid's density float, while grains with densities greater than the liquid sink. Similarly, air classification is a unit operation that is used to separate light materials such as paper and plastic from heavy materials such as ferrous metal based on the material's weight differential in an air stream.

Magnetic separation: magnetic separation is a unit operation that utilizes ferrous metals' magnetic characteristics to separate them from other waste elements. The following engineering factors apply to the implementation of waste separation:

a. Selection of the materials to be separated.
b. Identification of the material specifications.
c. Development of separation process flow diagrams.
d. Layout and design of the physical facilities.
e. Selection of equipment and facilities to be used.
f. Environmental control.
g. Safety and health impact.

There are many ways to process the segregated MSW and convert it into valuable product/service, such as mentioned below:

Recycling: After the source segregation, material recovery for recycling and composting is a critical component of an integrated SWM operation. Although recycling includes operations such as refilling bottles for reuse and remanufacturing products for resale to consumers, it is preferable to use the phrase to refer to materials that are collected and used as raw materials for new products. Recycling includes collecting recyclable materials, sorting them according to kind, processing them into new forms that may be sold to manufacturers, and lastly purchasing and using things manufactured from reprocessed resources.

Composting: Yard trimmings and food trash account for about 25% of all municipal solid garbage created. Before the 1990s, nearly all of that was discarded at a landfill or incinerator. However, when landfills reach the end of their useful life, it is obvious that source reduction, recycling, and composting should be done. It is a term referring to the aerobic breakdown of organic matter under controlled conditions that result in the production of a commercial soil amendment.

Energy generation*:* Municipal solid waste has the potential to be utilized to generate electricity. Numerous methods have been developed that enable processing MSW for energy generation cleaner and more cost-effective than ever before. These technologies include landfill gas capture, combustion, pyrolysis, gasification, and plasma arc gasification. (Agaton, Guno, Villanueva, & Villanueva, 2020)(Brian Glover, 2009).

Incineration is a method of waste treatment that entails the combustion of organic compounds found in waste materials. Waste-to-energy facilities are frequently used to refer to industrial waste incineration units. The term "thermal treatment" refers to incineration and other high-temperature waste treatment techniques. The combustion of waste materials produces ash, flue gas, and heat. Ash is mostly composed of inorganic waste elements and may take the form of solid lumps or fine particles carried by the flue gas. (Spence & Shi, 2004; Visvanathan, Adhikari, & Ananth, 2007; Walter, 1980).

Extraction of fuel from plastics addresses two critical environmental issues: pollution caused by the accumulation of plastic waste and the lack of an alternative fuel source. Pyrolysis is a critical step in the process of converting plastic to fuel. It is the thermal breakdown of materials in an inert atmosphere at extreme temperatures. It is a chemical process that results in a change in chemical composition and is primarily used to treat organic materials. In large-scale production, plastic waste is shredded and transferred to melt feeding, where it is pyrolyzed. The resulting fuel can be utilized in automobiles and industrial machinery. Additionally, it is frequently referred to as thermofuel from polymers or energy from plastics.

Gasification is a process that turns carbonaceous materials derived from biomass or fossil fuels into gases, the most abundant of which are nitrogen (N2), carbon monoxide (CO), hydrogen (H2), and carbon dioxide (CO2) (CO2). This is accomplished by reacting the feedstock material at elevated temperatures (usually >700 °C) without combusting it, while carefully regulating the amount of oxygen and/or steam present in the reaction. Syngas (from synthesis gas) or producer gas is the resulting gas combination and is itself a fuel due to the flammability of the H2 and CO in the gas. The subsequent combustion of the resulting gas generates electricity and is considered a renewable energy source if the gasified chemicals are generated from biomass feedstock. Thermal depolymerization (TDP) is a process using hydrous pyrolysis for the reduction of complex organic materials (usually waste products of various sorts, often biomass and plastic) into light crude oil. It mimics the natural geological processes thought to be involved in the production of fossil fuels. Under pressure and heat, long-chain polymers of hydrogen, oxygen, and carbon decompose into short-chain petroleum hydrocarbons with a maximum length of around 18 carbons.

Pyrolysis is most frequently employed to process organic compounds. It is a step in the process of charring wood. In general, pyrolysis of organic material yields volatile compounds and a carbon- and char-rich solid residue. Carbonization is a type of extreme pyrolysis that produces primarily carbon as a byproduct. Pyrolysis is the initial phase in the gasification or combustion processes. (A. D. McNaught, 2019).

Plasma gasification is a high-temperature thermal process that transforms organic matter into syngas (synthesis gas), which is primarily composed of hydrogen and carbon monoxide. A plasma torch powered by an electric arc ionizes the gas and catalyzes the conversion of organic matter to syngas, leaving slag as a byproduct. It is commercially available as a waste treatment method and has been tested for gasification of refuse-derived fuel, biomass, industrial waste, hazardous waste, and solid hydrocarbons such as coal, oil sands, petcoke, and oil shale. (Hosansky, 2016)

e. Transfer and Transport:

It refers to the infrastructure and apparatus used to transport wastes between locations. Small collection vehicles transfer waste to larger vehicles that convey it long distances to disposal facilities. Calculating the transit time between the collection places and the final disposal area is critical. Transfer stations are categorized into following groups based on the manner used to load transport vehicles:

Direct Discharge: The collection trucks' wastes are deposited straight into the vehicle, which then transports them to the final disposal area, which is typically used in small communities.

Storage Discharge: The wastes are dumped into a storage area from which ancillary machinery loads them into transport vehicles. The waste is then transported to final disposal sites. It is advantageous for communities with a large population.

f. Disposal

Today, the ultimate fate of all solid wastes is landfilling or land spreading, regardless of whether they are collected and transported directly to a landfill site, residual materials from materials recovery facilities (MRFs), residue from solid waste combustion, compost, or other substances from various solid waste processing facilities. A contemporary sanitary landfill is not a dump; it is an engineered facility used to dispose of solid wastes on land without causing inconveniences or posing risks to public health or safety, such as bug infestations or groundwater contamination.

Landfills are formed as a result of land disposal. Land dumping techniques vary; the most prevalent way is to dump waste in bulk into a defined area. After waste is deposited, it is compressed using enormous machinery. When the dumping cell is filled, it is covered with several feet of dirt and "sealed" with a plastic covering. Due to the low cost and abundance of vacant land in North America, it is the predominant method of dumping in the United States. The Environmental Protection Agency regulates landfills in the United States, enforcing regulations set forth in the Resource Conservation and Recovery Act, such as the requirement of liners and groundwater monitoring. (Marianne Horinko, Cathryn Courtin, James Berlow, Susan Bromm, 2020). Similarly, the Central Pollution Control Board (CPCB) in India has now issued recommendations requiring the establishment of buffer zones, including a green belt, around landfills and waste disposal facilities. It is suggested that "Ideally, a distance of 500 metres from the boundary of the solid waste processing and disposal facility (sanitary landfill) should be maintained,". This is because landfills are a source of pollution and have the potential to contaminate groundwater. Disposal businesses skillfully conceal pollution signals, and it is frequently difficult to identify any proof. Typically, landfills are encircled by massive walls or fences that conceal heaps of waste. Numerous chemical odor-eliminating agents are sprayed into the air surrounding landfills to mask the smell of decomposing waste inside the facility. (Rogers Heather, 2005).

1.3 Current status of MSWM system in India and other countries

With the increasing population, the management of MSW in the country has emerged as a severe problem, as environmental and aesthetic concerns and the sheer quantities are being generated every day. Not all, but many cities in India are not working efficiently according to defined norms of the MSWM plan. The government of India is driving many awareness campaigns with the help of NGOs and some agencies like Shuddhi, Vatvaran, Ruchi, etc., for the efficient performance of the MSWM system (Dash, 2017; Manohar, 2019; Rai, 2017; Subramanian, 2017). These campaigns promote various positive activities through social media, print media, and TV channels like zero or minimum waste generation, segregation of waste at source, lesser use of the non-recyclable and non-degradable substance, etc. These efforts have shown remarkable improvements in a few cities like Indore, Ambikapur, Mysuru & Tirunelveli. In these cities, residents are now showing their interest towards source segregation because either ULB (Urban local body) fines for non-segregation of waste at source or, on the positive side, new startups of recycling and composting such as Saahas Zero Waste, Hasiru Dala, Namo E-waste, GEM Enviro Management, Citizengage, Paperman, Vital Waste, Extra Carbon etc. are rewarding for segregating the recyclable and non-recyclable waste at a source point and depositing the garbage at a predefined location. This idea is helping to minimize the open dumping of MSW(Dash, 2017; Manohar, 2019; Rai, 2017; Subramanian, 2017).

Despite all these positive moves and promotions, the major portion of India is still facing many problems related to solid waste like lack of land space for dumping MSW, spilled out waste on roads, poor quality of compost due to the presence of plastic and metals. Segregation at the source, collection, transport, treatment and scientific disposal of waste are largely inadequate, which leads to a deterioration in the environment and a poor quality of life. Some key issues affect proper municipal waste management, such as: limited primary collection at the doorstep, Reluctance in public to take ownership, unavailability of adequate funds, lack of access to proper technology, and unscientific disposal of MSW at dumpsites (CPCB, 2018b; Lahiry, 2017; Ministry of Environment and Forests, 2016; Press Trust of India Ltd., 2019).

Figure 1-3 (Statista, n.d.) shows waste generation in different countries. According to the data US, China & India generate waste in larger quantities. In contrast, Figure 1-4 (The World Bank, 2018) shows the percentage of waste quantity treated by different methods in different countries. According to the data, countries like Germany, Korea, Netherland, South Africa don't let go their waste in dumping areas. Either it is recycled or goes to landfill areas, or is utilized as waste to energy. Whereas open dumping is the common practice in the countries like UAE, India, Kuwait, Sri Lanka and Oman.

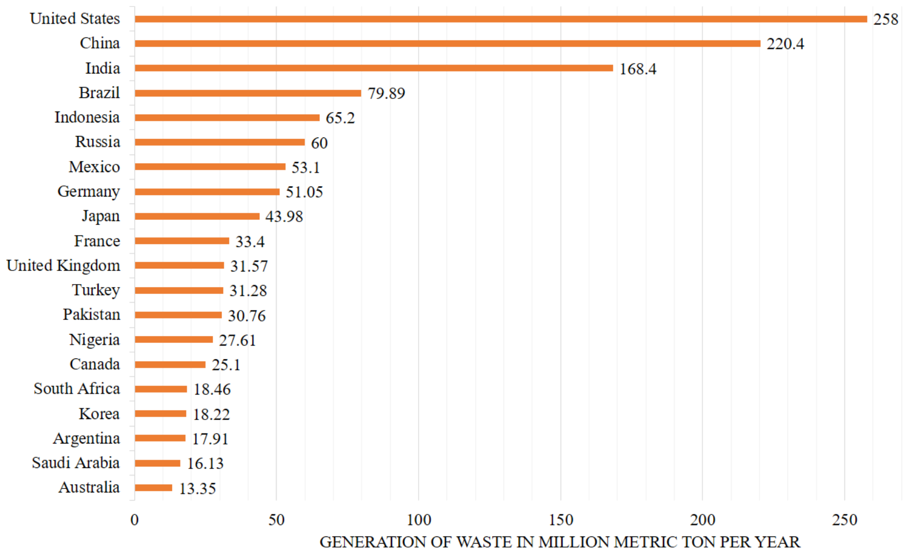


Figure 1-3 Waste generation in different countries (Statista, n.d.)

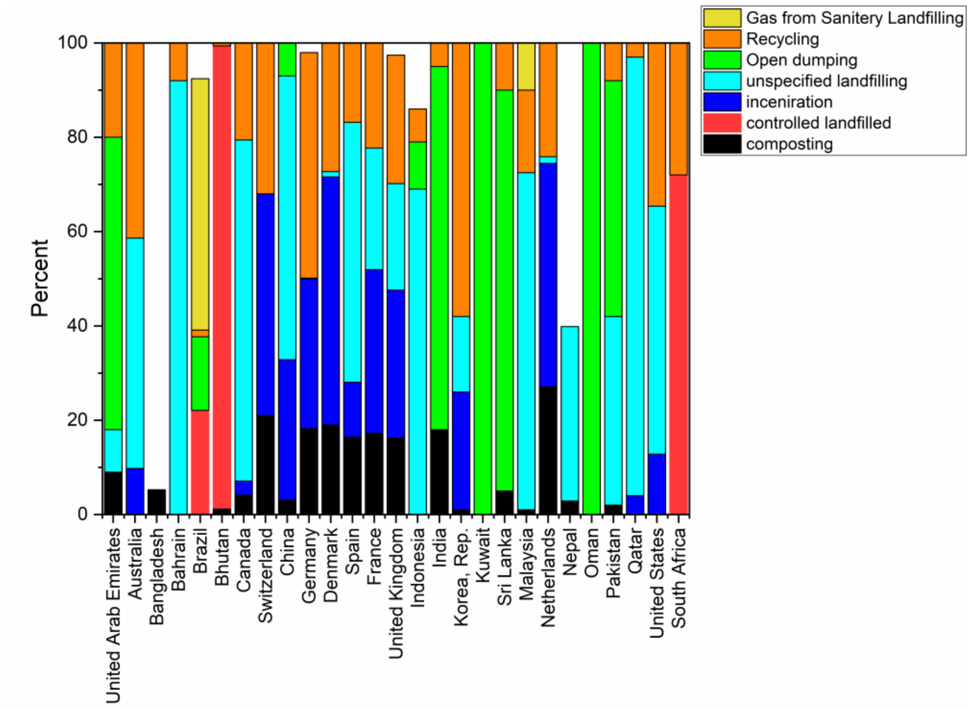


Figure 1-4 Percentage of waste treatment in different countries (The World Bank, 2018)

As per the latest report of the Central Pollution Control Board (CPCB), published in February 2018, the total quantity of waste generated in India is estimated at around 152076 tons per day. Out of which, 149748 tons are being collected, and the remaining are littered. Out of the total collected waste, only 55759 ton is being treated and remaining 50161 tons is being disposed-off

(Press Trust of India Ltd., 2019)(CPCB, 2018a). The general practice for MSWM followed by most Indian cities is shown in Figure 1-5; it reflects that source segregation is very less in practice, which also dominates the processing of MSW and raises the practice of waste disposal. Figure 1-6 shows the state-wise comparative data between MSW collection and its treatment, in which there are many states where the collection of waste and its processing is lesser than the generation, such as Orrisa, Punjab, Rajasthan, Uttarakhand. Whereas Table 1-3 shows the MSWM and related facilities available in major Indian states. All these data reflect that only 36% of India's states have treatment plants, and due to the unavailability of the desired form of waste (segregated waste), some of them, like in Maharashtra, Delhi, Gujrat Tamilnadu is not able to perform at its maximum capacity. Hence the mixed waste is being dumped in open land areas and getting stockpiled. (S. Kumar et al., 2017; Ministry of new and renewable energy, 2016).

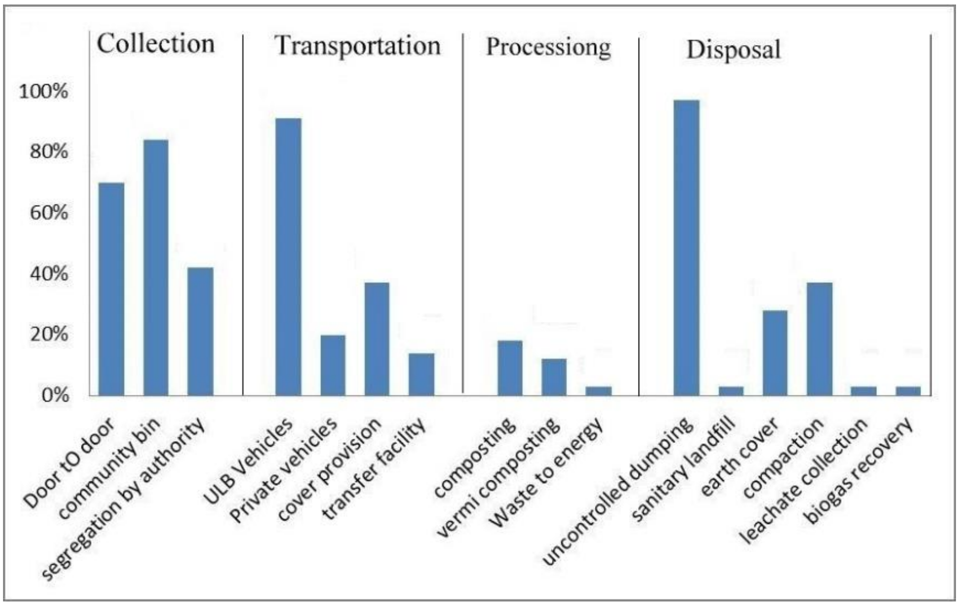


Figure 1-5 MSWM Practices in Indian Cities (S. Kumar et al., 2017)(Panwar, Nagpal, & Sharma, 2017)

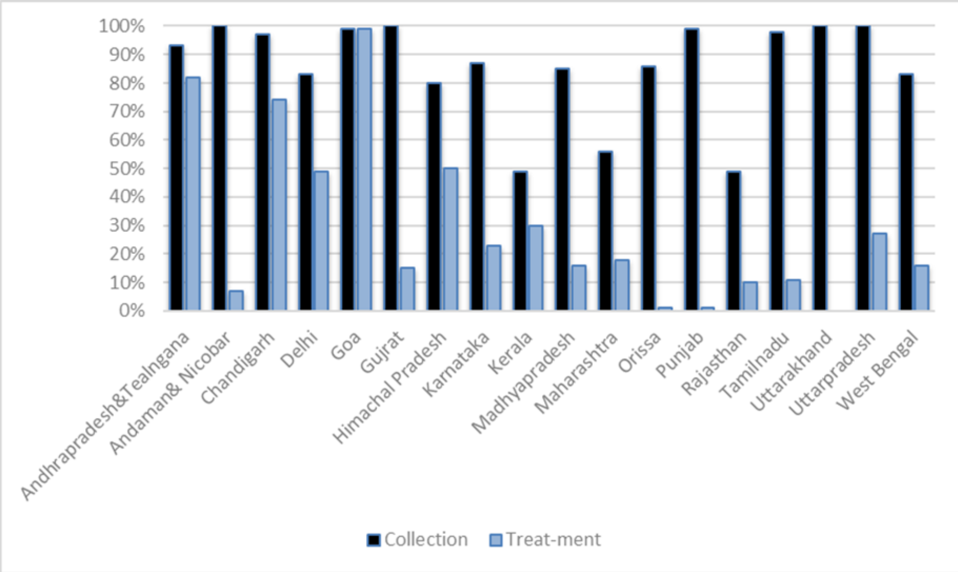


Figure 1-6 Collection Vs. Treatment in major Indian states (S. Kumar et al., 2017)(Ministry of new and renewable energy, 2016)

Table 1-3 Facilities for MSWM in major Indian states (Ministry of new and renewable energy, 2016)

		No. of Units for treatment				
S. No.	**States**	**Composting**	**Vermicomposting**	**Bio-Methenation**	**Pelletization**	**Waste to Energy**
1	Andhra Pradesh & Telangana	24	0	0	11	2
2	Andaman & Nicobar	1	0	0	0	0
3	Chandigarh	0	0	0	1	0
4	Delhi	3	0	0	0	3
5	Goa	14	0	0	0	0
6	Gujrat	3	93	0	6	0
7	Himachal Pradesh	10	0	0	0	0
8	Karnataka	0	0	0	0	0
9	Kerala	21	7	10	1	1
10	Madhya Pradesh	7	0	0	2	0
11	Maharashtra	6	2	5	5	2
12	Orissa	1	0	0	0	0
13	Punjab	1	3	0	0	0

14	Rajasthan	0	0	0	0	0
15	Tamilnadu	102	24	0	3	0
16	Uttarakhand	0	0	0	0	0
17	Uttarpradesh	0	0	0	0	0
18	West Bengal	13	7	0	0	0

1.4 Plan of thesis

The present work has been reported in a thesis comprising five chapters - Introduction, Review of literature, Research methodology, Experimental analysis, Results and discussion, Conclusions & Future work.

- Chapter 1 represents the detailed introduction to the MSW, its management system, and the current scenario that appeared in India and many other major countries.
- Chapter 2 deals with the literature review, which shows the challenging scenario associated with the MSW, its root cause, management, and research works that have previously been carried out in the mentioned area, which further helps to identify the research gap and formulate the objectives.
- Chapters 3 & 4 deal with the research outline - the experimental methodology, feasibility test, concept development, design & development of the prototype, design/selection of mechanical components, analysis of experimental results.
- Chapter 5 summarize the thesis with the conclusion and possible improvements with future work.

Chapter 2

Review of Literatures

2. REVIEW OF LITERATURE

2.1 Overview

The previous chapter described the generation and management of MSW and highlighted how the MSW management process deviates from the predefined standard procedure. Such deviations are the primary cause behind the inefficient performance of the integrated solid waste processing facilities like recycling, composting, WTE, etc. Therefore, this chapter discusses a detailed literature review on all aspects of MSW generation, storage, collection, transportation, processing, and disposal. The findings of the review will be helpful to frame the objectives, which can target the identified root cause and formulate the technological solution. Whereas, for getting into the detailed aspects and issues of MSWM process, SWM guidelines also need to be considered, through which existing elementary functions can be taken into account for further process enhancement.

The Ministry of Environment and Forests, India, has communicated the new rules for solid waste disposal from 2016 with clear responsibilities for different consumer classes. These rules have made it compulsory for an area's concerned authority to undertake responsibility for all activities related to (MSWM). The rule extends beyond municipal boundaries to urban agglomerations, census cities, registered industrial communities, areas under the control of Indian Railroad tracks, airports, airbases, embassies, and seaports, defense establishments, special economic zones, State and Central government organizations, and pilgrimage, religious, and historical sites. In Table 2-1 the characteristics of the 2016 solid waste management guidelines are highlighted and classified according to their application to the various stages of the solid waste management process (i.e., generation, storage, collection, transportation, processing, recovery, and disposal) (Central Public Health & Environmental Engineering Organisation (CPHEEO), 2016)(Central Pollution Control, 2016)(Ministry Of Environment, 2016).

Table 2-1 Solid Waste Management Rules

Categories	Rules	Responsible authority
Segregation & Storage	Residents, merchants, institutions, hotels, resorts, dining establishments, and event or gathering organizers (with more than 100 persons in each licensed / unlicensed site) are required to classify garbage at the source into biodegradable, non-biodegradable, and inert categories.	Waste Generators
	Under the Swachh Bharat mission's partnership approach, all MSW generators have been made instantly accountable for segregating and classifying trash and managing it in collaboration with local bodies.	
	MSW generators with a footprint greater than 5,000 square meters must segregate garbage at the point of collection into valuable dry waste and recyclable components.	
	MSW generators are prohibited from discarding, burning, or burying solid waste on streets, public spaces outside their premises, in the sewer system, or in bodies of water.	
	A generator has to pay ‘User Fee’ to the waste collector and ‘Spot Fine’ for Littering and Non-segregation.	
	Each street hawker is required to maintain appropriate bins for the storage of garbage created during his activity and to dump such waste at a waste storage depot, container, or vehicle as notified by the local authorities.	

	Construction and demolition waste should be stored disposed of separately.	
Collection	Segregated waste must be handed over to legal rag-pickers or waste collectors , or local bodies.	Waste generator and collector (ULB)
	Waste pickers/rag pickers must be integrated into the MSWM system.	
Transportation	The vehicle must have distinct compartments for different types of separated garbage, and it must be covered to prevent waste from spilling out onto the streets while it is being transported.	Urban Local Body (ULB)
Dumping	All the dumpsites must be sanitarily designed.	ULB
	Out of the entire segregated MSW, only inert waste must be dumped into landfills.	
	Landfill development on the mountain should be prevented. Within a 25-kilometer radius, suitable land in the plains, down the hill, must be sought for the establishment of a sanitary landfill.	
Treatment	The developers of Special Economic Zones, industrial estates, industrial parks, new townships, and cooperative housing societies are responsible for implementing in-house waste management and processing plans for biodegradable garbage.	Waste generators and ULB
	All resorts and dining establishments must install a machine to treat such food waste for composting / bio-methanation.	

	All producers of non-biodegradable items, as well as several other brand owners who launch such products into the marketplace, are required to provide local governments with the economic aid necessary to build a waste management system.	
	Organizations that market sanitary napkins and diapers should investigate the possibility of employing 100% recyclable materials in their products.	

2.2 Literature Survey

Refinement in solid waste management guidelines brought positive changes in India, like Indore and Ambikapur, but few factors like literacy, economic condition, and infrastructure capped the applicability of the guidelines. Therefore, even after the reformation in the solid waste management guidelines, a continuous struggle for managing and minimizing solid waste can be noticed. Policy failure is evident when the environment ministry reports the estimated 62 million tonnes of waste annually are not fully collected or treated. Worryingly, it could rise up to 165 million tons by 2030, and dramatic episodes of air and water pollution from piles of waste, as seen recently in Mumbai and Bengaluru, could be seen in more places (Areeba Falak, 2017; Early Times, 2019; G. Krishnakumar, 2021). Hence various challenges coming across the process of solid waste management are discussed in this chapter.

2.2.1 MSW generation and storage

Municipal waste disposal (MSW) has become a severe concern in the country as a result of the expanding population, not just for environmental and aesthetic reasons, but also due to the sheer volume created each day. Not all, but a significant number of cities in India are not operating properly in accordance with the MSWM plan's established standards. The Indian government is conducting many awareness efforts involving NGOs and government organizations to promote the efficient operation of the MSWM system. Through social media, print media, and television channels, these campaigns encourage a variety of good actions such as zero or minimal waste generation, trash segregation at the source, and reduced usage of non-recyclable and non-biodegradable chemicals. Despite these encouraging developments, India continues to face other solid waste-related challenges, including a lack of land for MSW disposal, spilled garbage on highways, and low-quality compost due to the inclusion of plastic and metals. Separation of garbage at the source, collection, transportation, treatment, and scientific disposal have all been essentially insufficient, resulting in environmental damage and a low standard of living (Glawe, Visvanathan, & Alamgir, 2005; Lahiry, 2017; Ministry of Environment and Forests, 2016; Nandan, Yadav, & Baksi, 2017).

The manner in which garbage is generated is determined by the size of the household, its educational level, and economic status (Noufal, Yuanyuan, Maalla, & Adipah, 2020). As a result, population growth has elevated municipal solid waste management (MSWM) to a critical natural issue for all urban areas in developing countries. Inadequate storage, a lack of source segregation, insufficient transportation, and an inability to access proper facilities for the treatment and disposal of a large volume of MSW all hurt the people. Additionally, according to (Pandey & Malik, 2015), only 10%–12% of trash generated in India is handled; the remaining 88–90% is either deposited into landfills without treatment or goes uncollected.

There is no systematic and empirically arranged segregation of MSW at the family unit or community level. In many locations, the unorganized sector is responsible for waste sorting. It occurs in dangerous conditions, and segregation is economically unviable since the unorganized sector recovers only the most valuable disposed-of materials from the waste stream, which can yield a larger monetary return in the recycling market. Figure 2-1 illustrates the current state of MSW management in India (Ministry of new and renewable energy, 2016).

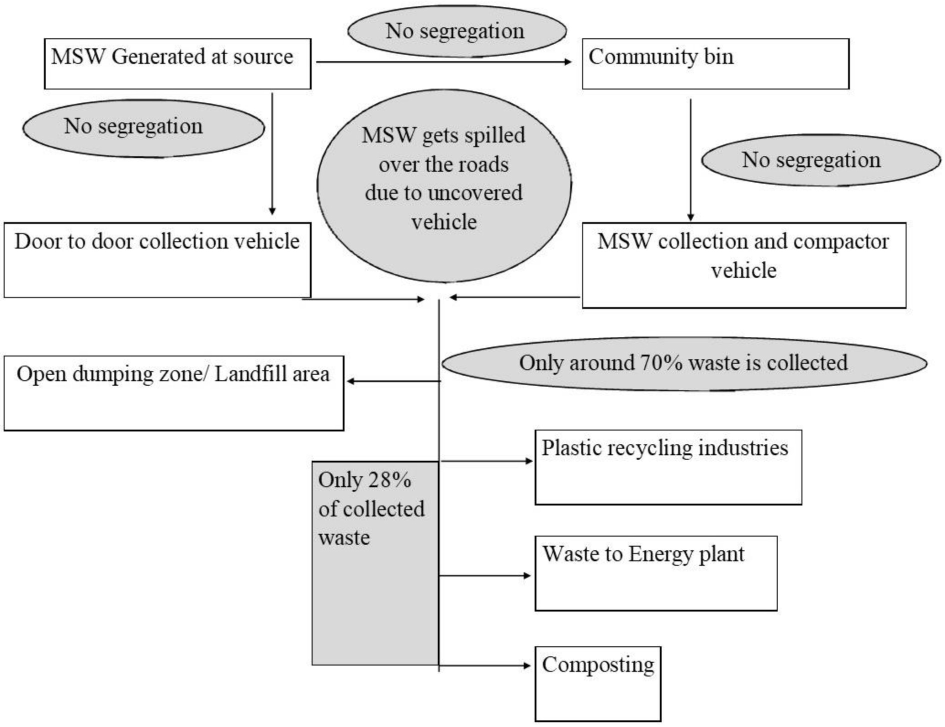


Figure 2-1 Current pattern of MSW handling in India (S. Kumar et al., 2017)(Ministry of new and renewable energy, 2016)

The Standing Committee (Ministry of new and renewable energy, 2016) has observed that the country is generating mixed waste, which is comprised of a large amount of inert material and a very high moisture level, unlike in other countries. A high level of moisture and inert in the waste make it challenging to derive power from it. The Committee found no proper public primary collection system from the source of waste generation, and municipal sanitation workers collect waste primarily through street sweeping, etc. Also, there is no practice of source segregation in a scientific way except few places like Indore (Madhyapradesh), Goa, Chandigarh, where source segregation is under regular practice.

A comparative analysis of MSWM in China and other advanced nations(Visvanathan & Trankler, 2003) aided in identifying and analyzing existing MSWM difficulties. Among all the issues, source separation is the underlying cause of them all. In most metropolitan locations, the lack of MSW storage at the source is a result of limited primary collection at the doorstep and public reluctance to accept ownership. The containers are used for both biodegradable and non-biodegradable trash (there is no segregation of waste), and the waste is disposed of at a communal disposal center. This indicates that there is currently no source separation of compostable trash from non-biodegradable or recyclable waste. Local governments have failed badly in their efforts to raise public awareness about source segregation. The responsibility for sorting biodegradable kitchen waste from non-biodegradable waste has been transferred to street sweepers hired by non-governmental organizations or self-help groups. It was found from a survey that socioeconomic conditions (SEC) have an effect on source segregation (Sharholy, Ahmad, Mahmood, & Trivedi, 2008)(Shwetmala, Chanakya, & Ramachandra, 2011)(J. Padilla & Trujillo, 2017). According to the poll, a greater SEC indicates a higher rate of source segregation, whereas a lower SECS represents the majority of a developing country's population. As a result, source segregation of MSW is a significant challenge for any developing country.

In Srinagar, India, J&K Municipal Corporation (SMC) has failed to segregate waste at the source in the summer capital (Yaqoob, 2018). Waste generating sources have also not received individual garbage dustbins; hence Solid Waste Management Rules (SWMR) are yet to be enforced. The SMC began waste separation as a pilot project in 2017 in many districts, such as Sanat Nagar, but due to lack of infrastructure, SMC used to mix the source segregated waste again after the collection. Therefore, the segregation at the source served no purpose.

The aspiring source segregation program organized by the civic bodies in Delhi (Yaqoob, 2018) has failed to achieve desired results. After the four months of this initiative, very few changes in the situation have been observed on the ground. Residents complained that the initiative was running out of the stream without adequate supervision and control by authorities. The north and east Delhi civic bodies had started the source segregation program at ten selected neighbourhoods on World Environment Day. The motive behind this project was to motivate the people to sort out their domestic trash. The initiative was designed to set up model colonies to demonstrate the introduction of the 2016 Centre's solid waste management guidelines. The agencies were expected to disseminate bins, run awareness drives, and engage vehicles with partitioned cabins for collecting bio-degradable and non-biodegradable waste.

2.2.2 Collection and Transportation

Improving the efficiency of waste collection and creating appropriate technology for waste segregation, transportation, treatment, and disposal could be a first step toward resolving the growing problem (Pandey & Malik, 2015). Because (Rajkumar & Sirajuddin, 2016) it is anticipated that India's population will reach around 1823 million by 2051, and if ULB continues to rely on landfills for MSW management, it may require approximately 1,450 km2 of land to dump MSW. No city in India can claim to have 100 percent trash segregation at the dwelling unit level, and on average, only 70% of waste gets collected, with the other 30% mixed up and lost in the urban environment. Only 12.45 percent of collected waste is technologically handled; the remainder is disposed of in open dumps. Following that, this approach encourages the development of new sanitary landfills/extensions of existing landfills in various urban locations throughout India.

It has been observed that after the launch of the source segregation campaign in north and east Delhi, (Yaqoob, 2018) local urban bodies have also been unable to acquire enough vehicles for disposal of source segregated waste. The project was initiated with a series of introductory workshops educating the public about the value of source segregation of waste. However, after two interactions, the north municipal officials became unreachable. Vehicles assigned to collect dry and wet waste became irregular too. It was also observed that the sanitation workers coming to collect garbage rarely help the residents in emptying the contents of the garbage bins into the vehicles (tippers). It is also reported that the height of the tipper is too much for any individual man or woman to reach. A major proportion of the garbage litters on the road while one tries emptying the contents onto the tippers. Once it is dumped into the tippers, the dry and wet waste gets mixed, then there is no meaning of segregating waste at the source.

In Bengaluru (Nisar, 2019), door-to-door garbage picks up from small apartments and unorganized residential areas across the city have been tangled.

Reason: collectors come for a small period, while residents have no systematic plan to keep the solid waste segregated and ready to be picked up. Many residents complained that their effort towards segregation and collection turns nothing when the garbage collection system does not meet the schedules. Even though residents keep the waste segregated, the garbage collectors dump them altogether. This results in a lack of interest among residents to segregate. The BAF (Bengaluru apartment federation) provides a solution that fits well over thousands of flats: segregate the garbage, place them at a central point from where the sanitation workers pick it at the time of their choice. In the same city, a new and innovative step has been taken to tackle the MSW. A not for a profit think tank in Bangalore named PAC (public affairs center) (Nagendra, Lakshmisha, & Agarwal, 2019) launched a mobile app, “PAC Waste Tracker,” which works on citizen science and visual mapping to find out the various issues affecting the waste collection mechanism in the city. This pilot project was implemented in the four wards, which was used to record the issues coming at every collection point. Such challenges have been reported for a total of 9 months, including non-segregation of waste, inconsistent waste collection, collection annoyance, and non-compliance.

Agra, classified as one of India's most polluted cities (Lavania, 2018), transports tons of waste in open lorries daily on city roads to the Kuberpur sites. As the trucks moves, loads of garbage spill over the side walls. Some of these even get dropped on commuters and cars alike. These trucks have only added to Agra’s pollution levels. The civic authority has not been able to ensure modern vehicles for the storage and disposal of the MSW even after strict directions have been given by the NGT (National Green Tribunal) to Agra Municipal Corporation. According to officials, the civic body trucks collect around 500 metric tonnes of garbage from various parts of the city every day and transfer it to the Kuberpur site. According to norms, these vehicles must be covered both from the rear and topsides. But around 40% of these vehicles run without covers. The back of many of these trucks is damaged, causing more spillage.

Similar issues have been identified in two major cities of Uttarakhand, i.e., Dehradun and Haridwar (Sharma, 2018), where uncovered vehicles were used for transporting waste. Out of total available vehicles, only 58% and 64% of vehicles were operational, and only 7% and 46% of vehicles were covered in Dehradun and Haridwar, respectively. Similarly, Inefficient transportation has become another reason for floating garbage in Kolkata city (Hazra & Goel, 2009). Poor route planning, lack of information about collection schedules, poor roads, and numbers of vehicles for waste collection drastically affects the process of MSWM.

Plastic trash has been observed to clog stormwater drainage systems (Figure 2-2). As per the report, dumping of garbage in water bodies has been accelerating the decay of lakes and tanks in the southern suburbs of Chennai. Residents add by discharging sewage and depositing plastic and other trash in conduits that connect bodies of water and stormwater drains (The Hindu, 2012).

Figure 2-2 Floating solid waste chokes the water bodies

Every single stormwater drain and channel that connects one lake to the next has been practically destroyed by inhabitants' non-stop waste dumping. People find it most convenient to dispose of garbage outside their dwellings, directly into these drains and water channels, through windows. Tons of floating garbage can be found in these sewers throughout Chennai's southern suburbs. (Hazra & Goel, 2009)(Moghadam, Mokhtarani, & Mokhtarani, 2009) It is also determined that bad route planning, a lack of knowledge regarding collection schedules, inadequate roads, and a shortage of waste collection vehicles all contribute to floating debris.

2.2.3 Processing of MSW

If MSW is not segregated at the source so it may become the prerequisite process for waste treatment industries so that valuable contents can be recovered and processed further such as recycling, composting, or WTE.

It is reported that in the absence of waste segregation at the source, waste processing technologies essentially handle mixed waste, which not only increases the cost of waste processing but also results in inferior products (e.g., poor quality compost due to the presence of plastic and metals) (Pandey & Malik, 2015) (Rawat, Ramanathan, & Kuriakose, 2013). Such products cannot be offered at a competitive price in the market, endangering the project's financial viability. Mixed garbage also causes wear and tear on waste handling equipment and contributes to harmful pollutant emissions when combustible waste is burned. (Sharholy et al., 2008)(Shwetmala et al., 2011) It is also concluded that the proper segregation results in a more scientific garbage disposal, while recyclables can be transferred straight to recycling units. It may result in a variety of benefits, including the ability to upgrade technology, improve product quality, conserve the country's significant raw material resources, and reduce the demand for landfill space.

The majority of MSW compost produced in Delhi does not meet FCO (Fertilizer Control Order) quality control criteria. While the FI (Fertilizing Index) values of MSW compost produced in Delhi met quality control standards, the CI (Clean Index) values were significantly lower than desired due to the presence of plastics and excess heavy metals in the compost from a variety of sources such as electronic and electrical waste (P. Mandal, Chaturvedi, Bassin, Vaidya, & Gupta, 2014). When compost factories process mixed garbage/partially segregated waste, the likelihood of plastic and heavy metals being present in compost increases. (Jank, Müller, Schneider, Gerke, & Bockreis, 2015) Even when source separation is practiced, biodegradable waste still contains pollutants that might impede the treatment process and degrade the compost quality. Contaminants may be present in separated biodegradable waste as a result of improper bio-waste segregation, such as collecting of segregated garbage in plastic bags, which results in contamination of bio-waste..

In India, waste is sorted manually by rag pickers, who collect recyclable and reusable debris from streets and dumping sites (Pandey & Malik, 2015). Segregation and sorting occur in dangerous conditions (Rajkumar & Sirajuddin, 2016); as a result, they face health risks and infection when manually sorting waste without protective equipment. Additionally, it is revealed that the viability of segregation is really poor, as the unorganized sector segregates only the most significant disposed of constituents from the waste stream, which may offer them a substantially greater financial draw near the company market. Segregation of moist waste is typically performed manually in composting plants. Further segregation of dry waste can be accomplished mechanically. There are several advanced strategies for segregating more dry trash (Lemann, 2008; Pandey & Malik, 2015; WRIGHT, 2020), which are discussed below:

- ***Manual Separation:*** Before mechanical processing begins, bulky materials such as huge pieces of wood, boulders, and long pieces of cloth are manually removed. Manual separation equipment typically consists of a sorting belt or table. Hand-picking of trash is perhaps the most common method of MSW management; it is also the only method for removing PVC plastics.

- ***Air classification:*** Fans are employed in this method to create an upward-moving column of air. Materials with a low density are blown upward, whereas those with a high-density fall. The air containing light materials such as paper and plastic bags enters a separator, where they are removed from the air stream. Air separation quality is determined by the strength of the air currents and the manner in which items are delivered into the column. Moisture content is also significant, as it can cause certain materials to weigh down or clump together.

- ***Size Reduction:*** Hammer mills and shear shredders are the two types of machines that are frequently utilized in this operation. Hammer mills (Figure 2-3) utilize revolving pairs of swinging steel hammers to shred garbage, whereas shear shredders (Figure 2-4) are employed for materials that are difficult to break apart, such as tyres, mattresses, and plastics. Hammers require frequent resurfacing or replacement; both require significant energy and upkeep. Hammer mills shatter a variety of materials, including fluorescent light bulbs, compact fluorescent lights, and batteries.

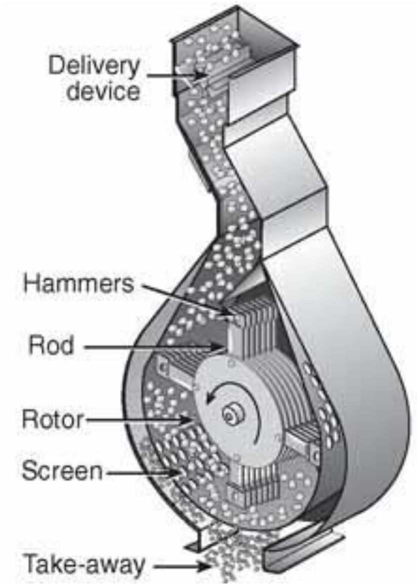


Figure 2-3 Hammer mill (Feed Mill Machinery Glossary, n.d.)

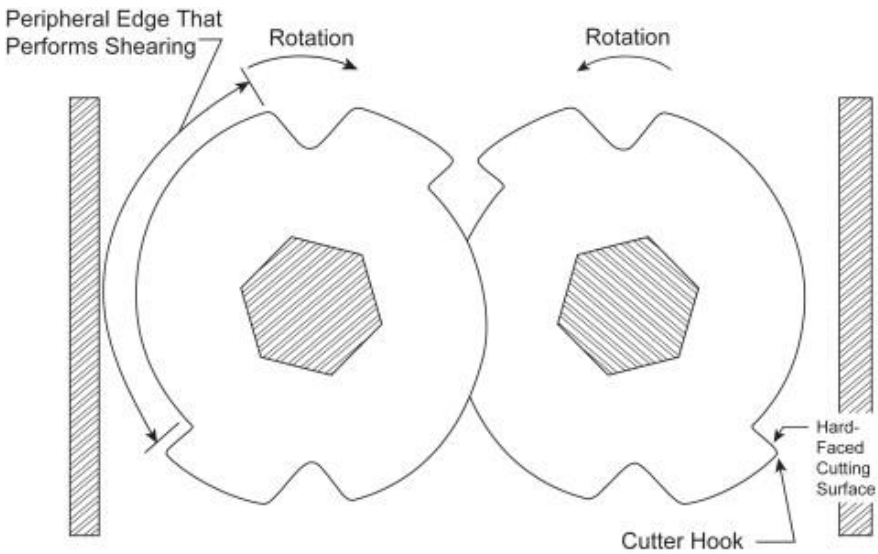


Figure 2-4 Shear Shredder (Tillman, Duong, & Harding, 2012)

- ***Trommel Screening:*** A trommel screen (Figure 2-5), alternatively called a rotary screen, is a mechanical screening machine used primarily in the solid waste processing industry to separate materials. It is made out of a perforated cylindrical drum that is typically raised at one end. To transport objects further down an inclined drum, they are raised and then dropped using lifter bars; otherwise, the objects roll down more slowly. Additionally, the lifter bars shake the objects in order to separate them. In the presence of heavy objects, lifter bars will not be considered since they risk shattering the screen.

Physical size separation occurs as the feed material spirals down the spinning drum, with the undersized material passing through the screen apertures and the bigger material exiting at the opposite end. Trommel screens are used in the municipal solid waste sector to sort the sizes of solid trash. Trommel screening improves the quality of fuel-derived solid waste by eliminating inorganic elements such as moisture and ash from the air-classified light fraction separated from shredded solid waste.

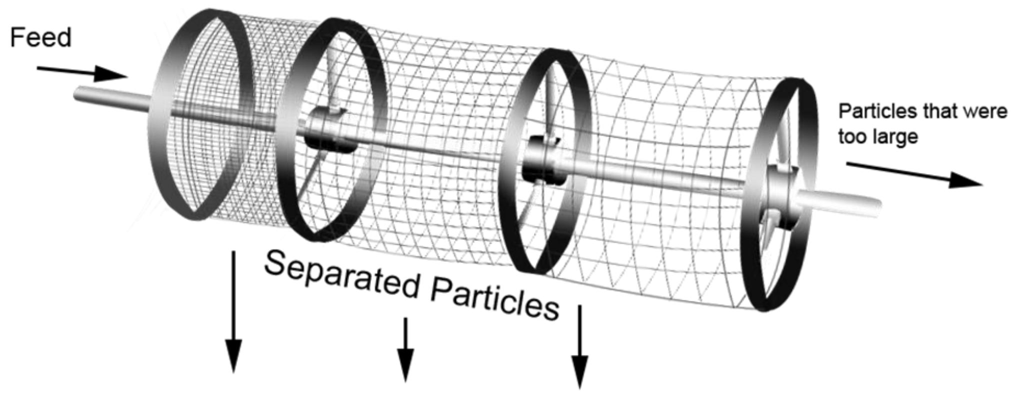


Figure 2-5 Trommel Screening (Tillman et al., 2012)

- ***Drying:*** The drying process minimizes the waste's moisture content and prevents the creation of leachate, which could leak into the water if the waste were disposed of in a landfill or stored in an open area for an extended period of time.

Dry materials are less biologically active and easier to store; this results in a homogeneous refuse-derived fuel (RDF). Any partially decaying trash should be dried either in the sun or with hot air, or preferably a combination of the twoThis critical stage of the process varies with each facility, depending on the investment or available land. Solar drying is not feasible during wet seasons, and most facilities operate at a fraction of their capacity, resulting in the majority of garbage being disposed of in landfills. Mechanical drying, on the other hand, consumes a large amount of energy, which could easily render RDF plants unprofitable without massive government subsidies.

- ***Ferrous Metal Separation (Magnetic Separation):*** This stage makes use of electromagnets that may be switched on and off to enable the removal of accumulated metals. Magnets, however, cannot be used to extract all metals. Non-ferrous metals lack iron and are hence insensitive to magnetic fields. For example, stainless steel, copper, and aluminum are either weakly magnetic or non-magnetic. Additionally, if little magnetic items are buried in non-magnetic materials, they will not be picked up, and bigger magnetic items may drag along undesired items such as paper, plastic, and food waste.
- ***Non-ferrous Metal Separation (Eddy Current Separator):*** Eddy current or non-ferrous separators separate non-magnetic metals by utilizing the current created in small swirls ("eddies") on a big conductor. When a big conductive metal plate is moved through a magnetic field that crosses the sheet perpendicularly, the magnetic field induces small "rings" of current, creating internal magnetic fields that oppose the change..

Eddy current separators can handle huge capacities since the conveyor belt constantly separates and transports non-ferrous metals. A critical component of effective separation is an even flow of material provided by a vibrating feeder or conveyor belt, for example, to create a monolayer of materials over the belt.

2.2.4 Disposal

The practise of landfilling is also not a healthy method, as it has resulted in a scarcity of landfill space in several nations (Oehlmann et al., 2009). Even a well-managed sanitary landfill has a limited negative impact on the ecosystem immediately. There is a possibility of soil and groundwater contamination as a result of certain additives and breakdown by-products in plastic. Throughout history, landfill practises have resulted in several accidents, including landfill fires in Delhi and West Bengal (Doshi, 2016; Manohar, 2017; Times of India, 2018), landfill sliding in Addis Ababa (Ethiopia) and Shenzhen (China), and many others.

Additionally, landfill fires are said to be caused by the development of methane gases and an insufficient filling of inert garbage (Lee et al., 2018). Methane is a substantial greenhouse gas; it has a pungent odour and a potential for global warming that is 28 times that of carbon dioxide. (Pulat & Yukselen-Aksoy, 2017) It is concluded that landfill sliding happens as a result of the landfill's instability, which is dependent on the engineering qualities of MSW, specifically its shear strength. It is subject to significant variation with respect to time, temperature, composition, legislative activities, leachate, drainage, and seasonal oscillations. A precise determination of the shear strength of MSW allows for the establishment of a maximum stockpile height and safer slopes. Appropriate shear strength is determined by the type of waste, its composition, decomposition rate, moisture content, unit weight, and particle size and form. Organic and fibre content, waste age, and compaction effort all have a role in determining the shear strength of MSW. Unsorted garbage at dumpsites contains food waste, which has a significant environmental impact due to the various processes involved in its life cycle (Tonini, Albizzati, & Astrup, 2018). They used a bottom-up life cycle assessment method to determine the environmental impact of food waste in the United Kingdom. They looked at food waste generated by four different sources: processing, wholesale and retail, food service, and households. The observed impacts were classified into eleven distinct areas of environmental impact, ranging from Global Warming to Water Depletion. They reported that the unavoidable food waste has a global warming impact of between 2000 and 3600 kg CO_2- eq. T^{-1}.

Ghazipur landfill can be a relatable example of such a scenario (France-Presse, 2019); this site has already taken about 40 football pitches of land on the eastern edge of New Delhi (Figure 2-6), which is widely recognized to be the world’s most polluted capital. The vast dump of waste rises by 10m every year. It is already 65m high and will be taller than the 73m Taj Mahal next year.

Figure 2-6 Trucks dumping garbage at Ghazipur Landfill site in New Delhi, India (France-Presse & Agence, 2019)

2.2.5 Quantitative analysis of the performance of Indian MSWM systems

The total quantity of waste generated in the country is estimated at around 43298.385 tons per day. Out of which, 45082.15 tons are being collected, and the remaining 18% is littered. Out of the total collected waste, only 15386.81 tons is being treated, and the remaining 22904.70 tons are being disposed of (Sambyal & Agarwal, 2018). A standard MSWM system has two primary functions, i.e., collection and segregation. The following data highlights the current scenario of collection & segregation under the Indian MSWM system.

Every state has around 84000 wards in India, and 3/4th of these wards have successfully adopted door-to-door waste collection systems. But without a proper waste disposal system, such effort is not meaningful (Jadhav, 2018). Municipal bodies in Maharashtra generate maximum garbage - 22,570 MT daily, then Tamil Nadu (15,437 MT), Uttar Pradesh (15,288 MT), Delhi (10,500 MT), Gujarat (10,145 MT) and Karnataka (10,000 MT) (Jadhav, 2018). These data reflect that the municipal bodies of the above-mentioned states are dumping such a big amount of waste onto their landfill sites, which are actually beyond their capacity to handle; hence it is polluting the surrounding land, groundwater, and air. According to the Delhi-based Centre for Science and Environment

(CSE), cities are now lacking land space to dump their waste. This scenario is leading them to throw it in the 'backyards' of smaller towns, suburbs, and villages.

It is found that only 8 out of 35 states have the practice of processing more than half the daily garbage generated in their cities; hence not one has achieved 100% processing (Jadhav, 2018). Jharkhand, Bihar, Odisha, Andhra Pradesh, Tamil Nadu, Haryana, West Bengal, Jammu & Kashmir don't process even 10% of their MSW, while Arunachal Pradesh and Dadra & Nagar Haveli don't have the practice of processing their waste (Jadhav, 2018). There are only four states that process more than 60% of municipal waste. In this list, Chhattisgarh comes first, where almost 74% of waste is processed. Then this legacy is followed by Telangana (67%), Sikkim (66%), and Goa (62%). Delhi processes 55% of its daily garbage (Jadhav, 2018).

Figure 2-7 (The World Bank, 2018) shows the comparative data between MSW collection and its treatment in major Indian cities. According to this data, the Indian MSWM system collects a major proportion of waste (i.e., around 82%) from door-to-door collection service, then half of the collected waste is being treated because the collected waste is not entirely segregated at source. Among all the major cities in India, Hyderabad, Kochi, Pimpri, Kanpur, Ahmedabad, Coimbatore & Mumbai can treat their entire collected waste. It has become possible; these cities have started maintaining all the possible ways of treatment of waste. Such as in Kanpur, there is a plant to process 1500 tonnes per day capacity of solid waste, set up with a tipping platform, a pre-segregation unit, a composting unit, an RDF (Refuse Derived Fuel) unit, a plastic segregating unit, a briquette manufacturing unit, and a secured landfill in place (Goel, 2017).

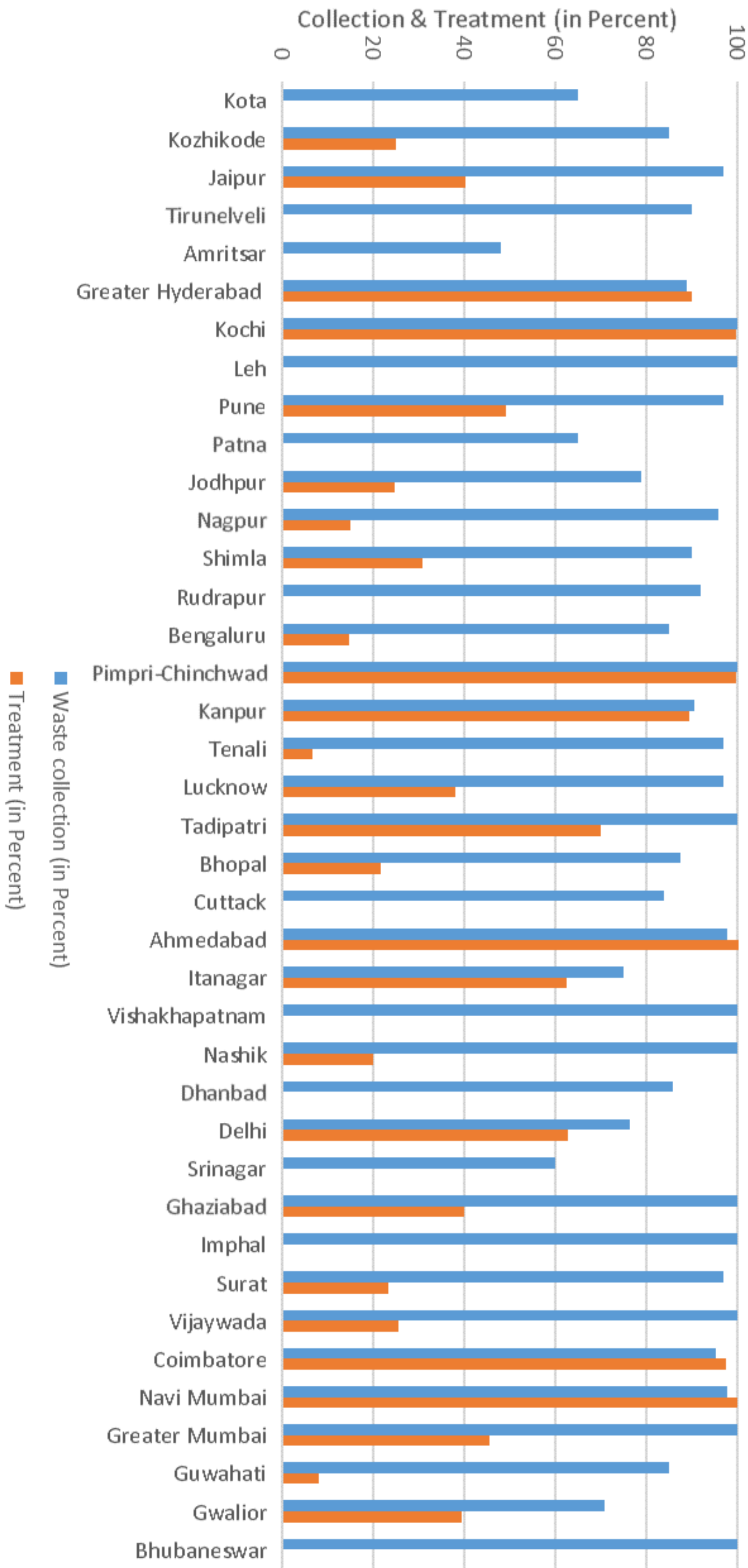


Figure 2-7 Collection Vs. Treatment in major Indian cities

Similarly, in Hyderabad, The GHMC (Greater Hyderabad Municipal Corporation) has done some excellent work in the solid management system, i.e., segregation of dry and wet waste at the source itself by involving residential welfare associations, NGOs, self-help groups, and citizens. Through this, the collection of garbage has increased from 3,000 tonnes to 4,800 tonnes daily basis. Whereas Rudrapur, Cuttack, Kota, Amritsar, Leh, Vishakhapatnam, Bhubaneshwar are failed to treat their waste. Table 2-2 Shows the MSWM and related facilities available in major Indian states. Among all the mentioned states, Tamilnadu has a higher number of waste treatment facilities, whereas Orisa and Uttarakhand don't have any facility to treat their solid waste. All these data reflects that only 36% states in India have treatment plant, and due to unavailability of the desired form of waste (segregated waste) some of them like in Maharashtra, Delhi, Gujrat, Tamilnadu is not able to perform at its maximum capacity. Hence the mixed waste is being dumped in open land areas and getting stockpiled. (S. Kumar et al., 2017; Ministry of new and renewable energy, 2016).

Table 2-2 MSW processing facilities in Indian states

S. No.	States	Collection	Treat-ment	No. of units for treatment				
				Composting	Vermi	Biomethenation	Pellatization	Waste to
1	Andhrapradesh&Tealngana	93%	82%	24	0	0	11	2
2	Andaman& Nicobar	100%	7%	1	0	0	0	0
3	Chandigarh	97%	74%	0	0	0	1	0
4	Delhi	83%	49%	3	0	0	0	3
5	Goa	99%	99%	14	0	0	0	0
6	Gujrat	100%	15%	3	93	0	6	0
7	Himachal Pradesh	80%	50%	10	0	0	0	0
8	Karnataka	87%	23%	0	0	0	0	0
9	Kerala	49%	30%	21	7	10	1	1

10	Madhyapradesh	85%	16%	7	0	0	2	0
11	Maharashtra	56%	18%	6	2	5	5	2
12	Orissa	86%	1%	1	0	0	0	0
13	Punjab	99%	1%	1	3	0	0	0
14	Rajasthan	49%	10%	0	0	0	0	0
15	Tamilnadu	98%	11%	102	24	0	3	0
16	Uttarakhand	100%	0%	0	0	0	0	0
17	Uttarpradesh	100%	27%	0	0	0	0	0
18	West Bengal	83%	16%	13	7	0	0	0

2.2.6 Problems associated with unsegregated waste

It is discussed in the previous section that unsegregated waste is not easily acceptable by the waste processing industry; therefore, it gets dumped into landfill sites. Subsequently, this practice promotes improving new sanitary landfills or the extension of an existing landfill in different urban areas in India (SINGH, 2020). Landfill practice caused many accidents in history (Doshi, 2016; Manohar, 2017; Times of India, 2018) as discussed under heading 2.2.4.. Hence, when mixed waste is ended to landfill sites, it brings out many other issues such as landfill fires (Lee et al., 2018), landfill sliding (Pulat & Yukselen-Aksoy, 2017), environmental impact due to food waste (Pulat & Yukselen-Aksoy, 2017). Apart from ecological problems, mixed waste has become the leading cause of the poor performance of waste processing industries like WTE, composting, or plastic recycling industries. Many WTE plants in the country are either combustion-based or gasification-based. Combustion based plant requires a dry form of waste and wet for gasifier-based plants. But due to the unavailability of the required form of segregated waste, most of the WTE plants are in "Not Working" condition (Pulat & Yukselen-Aksoy, 2017).

2.2.7 MSW contents

A sample of MSW contains majorly organic waste (food scraps, yard leaves, grass, brush, wood, process residues paper, etc.), paper waste (paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, paper beverage cups, etc.), plastic waste (PW) (bottles, packaging, containers, bags, lids, and cups), glass waste (bottles, broken glassware, light bulbs, colored glass, etc.), metal waste (cans, foil, tins) and other waste like textiles, dirt, earth particles etc . (Annepu, 2012)(Sujauddin, 2008)(Dev Sharma & Jain, 2020). Table 2-3 shows the composition of MSW and their classification. According to the data (Aqua-Calc, n.d.; Hauser & Miller, n.d.; Reinhart, 2004; Rittenschober, Stadlmayr, Charrondiere, Photos, & Fao, 2012; Roger Walker, 2016; Smith, 1940):

- Cardboard, paper waste is the contributor of 6 – 23 % of the total amount of MSW. It can be recycled upto 6 to 7 times before the paper fibers become too short to be used for paper, but as per their physical property, it is biodegradable because it is made from plant materials, and most plant materials are biodegradable (Protega Global, n.d.). Whereas the presence of the textile is significantly less in MSW, i.e., 4 – 6 %, it can be recycled and composted (Fibre2Fashion, 2008; Leblanc, 2020; Leigh, 2018).
- Organic waste such as kitchen waste, yard trimmings etc., falls under the category of bio-degradable waste, which can be converted into compost. Organic waste shows its highest contribution in MSW, i.e., 27 – 41 %.
- The plastic waste in MSW is generally polybags, bottles, wrappers etc., which can be recycled, and it contributes a maximum of 22 % of the total amount of MSW.
- Glass waste such as bottles and light bulbs falls under both categories, i.e., recyclable and inert (FEVE, n.d.; Gaskells, n.d.; RTS, n.d.; US EPA, 2021), its presence in MSW is comparatively lesser than the other contents, i.e., 3 – 9 %.
- Metal waste is recyclable waste, and its presence in MSW is very less, i.e., 2 - 9 %.
- Dirt and earth particles are called inert waste, and its presence varies from 2.5 – 33 %.

Table 2-3 Composition of MSW

Components of MSW	Classification	Specific Density, Kg/m³.	Composition (%)	Moisture content (%)
Cardboard	Recyclable/ Degradable	689	6 – 23	5
Paper		1201		6
Textiles		>1100	4 - 6	10
Plastics	Recyclable	950	5 - 22	2
Metal		>2000	2 – 9	3
Food waste	Degradable	180-1300	27 - 41	70
Garden wastes				60
Ash and Dirt	Inert	2850	2.5 - 33	8
Glass, Ceramic	Inert	>2400	3 - 9	2

Specific density of the MSW contents: Table 2-3 shows the specific density data of the components of MSW. According to data, earth particles, dirt, ceramic, glass, and metals are on the higher side i.e.; specific density is more than 2000 Kg/m^3. Whereas cardboard shows a lower specific density than the other MSW contents, plastic waste comes after cardboard (Aqua-Calc, n.d.; Hauser & Miller, n.d.; Roger Walker, 2016; Smith, 1940). A lab experiment was conducted to identify the specific density of food and garden waste, which is discussed below:

Moisture content: In a sample of MSW, the various waste contains moisture at a different level. Table 2-3 and Figure 2-8 shows that degradable waste such as garden waste and food waste contains a higher amount of moisture, i.e., 60 – 70%, whereas the plastic, glass, ceramics, and metal waste contains comparatively lower moisture, i.e., 2 – 3% (Reinhart, 2004). Initially, moisture is the significant content of degradable waste, but if waste is not segregated at the source, moisture spreads into other waste like papers, textiles, inert, etc. In general, a sample of mixed municipal solid waste may contain moisture ranging from 65 – 80 % (Ozcan, Guvenc, Guvenc, & Demir, 2016).

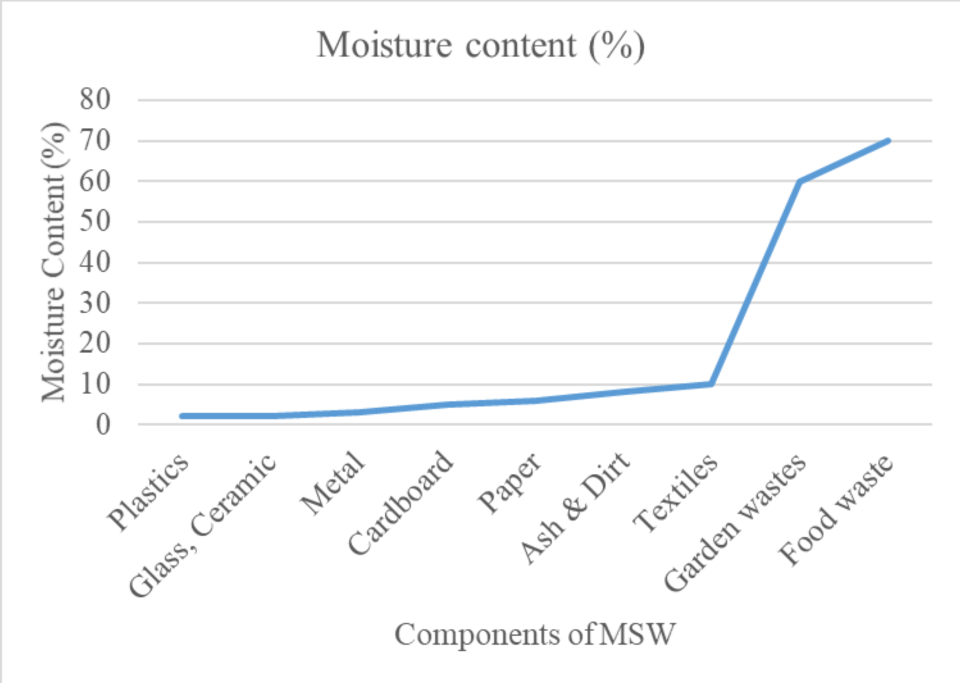


Figure 2-8 Moisture content in MSW (Reinhart, 2004)

2.2.8 Separation process based on the density difference

i. ***H. H. Sink and Float Separator:*** The separation achieved in the H. H. Sink and Float Process (Michaud, 2016) is obtained by using:

- Device that performs its necessary function of removing separated products with a minimum disruption of the medium.
- Medium of high kinetic stability.

Apparatus: The separating device is depicted in Figure 2-9. The ore is fed into the separating vessel (2) through a chute (1). The separating vessel (2) is primarily an inverted truncated pyramid. The top sides are vertical, and separation occurs within the zone bounded by these vertical sides. On top of these vertical sides are four paddles (3) with horizontal shafts that span the separation zone fully. The paddle on the right is smaller and rotates nearly twice as rapidly as the others; its purpose is to guarantee that every ore feed is completely immersed in the medium. The two middle paddles act as transporters; they dip slightly into the medium at the bottom of each cycle and slowly convey the float across the bath. The paddle on the left in the illustration is the float discharge paddle; it receives the float and pushes it over the separator's edge, along with a small amount of medium.

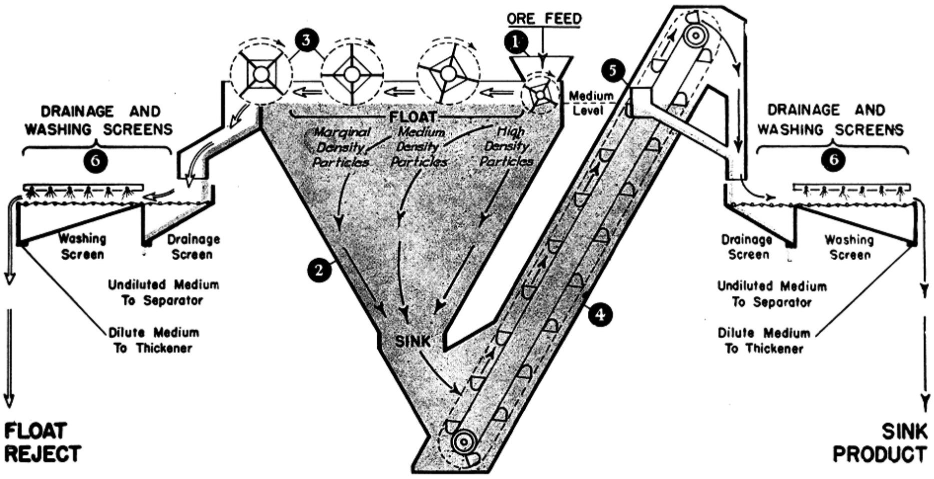


Figure 2-9 H. H. Sink and Float Separator (Michaud, 2016)

The separating vessel's bottom is connected to the bucket elevator's boot (4). Ore that descends beneath the paddles progressively sinks to the elevator's boot and is scooped up by the buckets. The perforated buckets elevate the ore a few feet above the medium level, allowing the medium in the buckets to drain off before the sink product is discharged. At the medium level, a hole is constructed in the side of the elevator casing and fitted with an adjustable weir (5) for drawing medium and controlling medium level.

ii. Eriez Hydro-Float Separator: The Hydro-Float Separator (Eriez floatation, n.d.) is a fluidized-bed (or teeter-bed) separator with an aerated fluidized bed (Figure 2-10). The synergistic effect of combining flotation with gravity concentration produces a result that neither strategy can attain alone. The fluidization mechanism disperses air bubbles, which percolates through the hindered-setting zone and attaches to the hydrophobic component, modifying its density and making it buoyant enough to float and be collected. Through improved bubble-particle interactions, the dense phase, fluidized bed avoids axial mixing, increases coarse particle residence time, and enhances flotation rate. As a result, both completely liberated and semi-liberated particles exhibit a high rate of recovery.

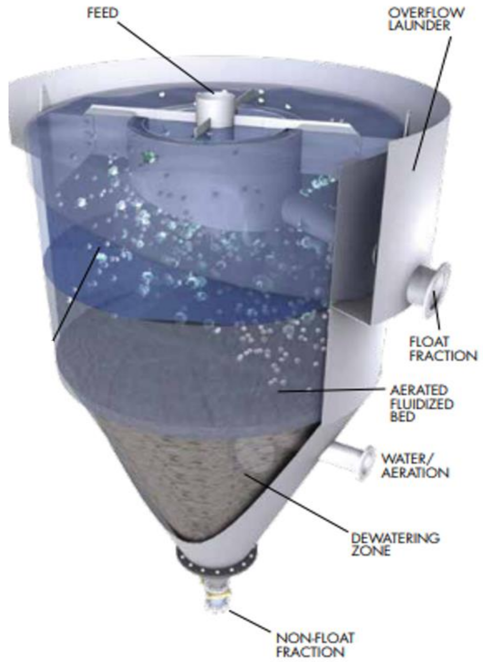


Figure 2-10 HydroFloat Separator by Eriez Flotation Division (Eriez floatation, n.d.)

iii. Sink Float Separation Tank for Recycling: Figure 2-11 and Figure 2-12 show sink and float separation tanks built for commercial purposes by the Haith group and Amster Machinery Co., Ltd, respectively. This system utilizes water as a medium for sorting co-mingled polymers according to their densities. Water has a density of 1 gram per cubic centimeter. Any plastic that has a density greater than that of water will sink as it enters the separating tank. This dense plastic stream settles at the tank's bottom and exits via a screw conveyor. Similarly, any material with a density less than that of water floats and exits the machine at the top. Additionally, activities can be introduced to enhance the separation process. (Amstar Machinery, n.d.; Haith Group, n.d.).

Figure 2-11 Sink and Float separation tank by Haith group (Haith Group, n.d.)

Figure 2-12 Sink and Float separation tank by Amster Machinery Co., Ltd. (Amstar Machinery, n.d.)

Assessment of density difference-based segregation process: A separation process can be analyzed based on the recovery of desirable contents. In mineral processing industries, the density media separation process is analyzed by using S curve (Separation curve) or partition curve (Figure 2-13).

This figure shows the ideal separation curve, according to which recovery depends upon the relative density and particle size of the contents to be separated. Both higher and lower specific gravity may show a higher recovery on sink and float streams, respectively, depending on their particle size. Smaller particles report lower recovery, as they may be lost into the streams, whereas larger particles report higher recovery. Therefore, recovery increases with the increase in particle size. The recovery also depends upon the amount of solid in separation media i.e., recovery falls with the further increase in the amount of solid contents in water (Figure 2-14) (D. Kumar & Kumar, 2018).

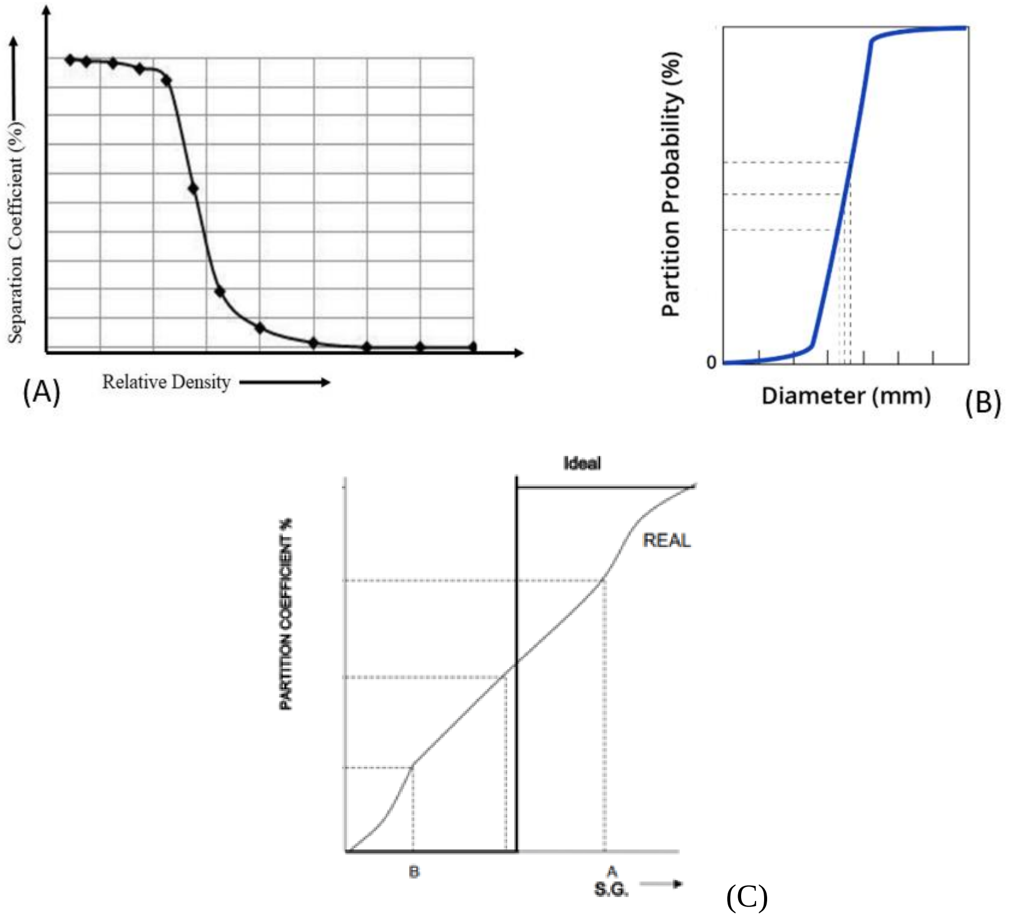


Figure 2-13 Separation Curves (David Michaud, 2015) (Dlamini, Powell, & Meyer, 2005) (Firth & Hart, 2008) (Lambert & Ryan, 2011)(Pascoe, 2006)(David Michaud, 2015)

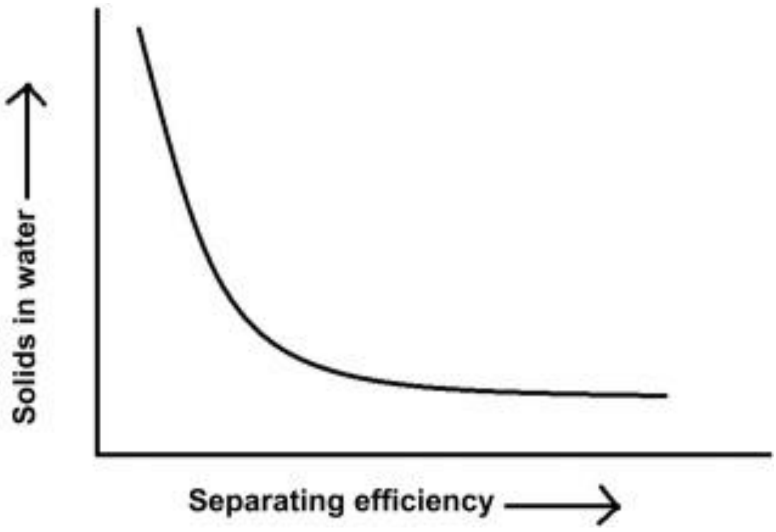


Figure 2-14 Efficiency depends on the solid content in process water (D. Kumar & Kumar, 2018)

2.3 Research Gap

In many developing countries, including India, resident's response towards segregation of waste is affected by the partial involvement of residential communities, real estate developers, other residents, and charges involved in MSWM (Agbefe, Lawson, & Yirenya-Tawiah, 2019; Basnayake et al., 2019; Speier, Nair, Mondal, & Weichgrebe, 2019). It is reported (Planning Commission, 2014)(Rawat et al., 2013) that the waste that is generated in the country is a mixed waste comprising a large amount of inert material and a very high moisture level, unlike in other countries. A high level of moisture and inert in the waste creates problems to derive power from it. The Govt. of India took the initiative to increase awareness amongst the public through SBM (Swachh Bharat Mission) (Swati Singh Sambyal, 2018), and the all-India segregation campaign was launched on June 5, 2017. The main objective of this campaign is to ensure; cities must design a mechanism through which 100 percent source segregation can be done within one year, which is a challenge and yet has been a game-changer wherever appropriately implemented. Despite such positive movements, there are few research gaps discussed below that are affecting the efficiency of the waste management system:

- According to the CPCB report, 2018, there is no proper public system of primary collection from the source of waste generation, and municipal sanitation workers collect waste primarily through street sweeping, etc. Also, there is no practice of sorting waste at the source scientifically except few places like Indore, Tirunelveli, Goa, Chandigarh, where source segregation is under regular practice (CPCB, 2018b). As per SBM August 2018 data (Swati Singh Sambyal, 2018), 43 % of the total wards in the country are segregating their waste at the source. In 2017, door-to-door collection coverage increased from 53 % to 80 %.

- As per the SWM rules 2016, waste must be segregated into different disposal bins with varying codes of color for biodegradable. However, most of the source location like slum areas, which belongs to lower socio-economic condition, does not have enough space to occupy different disposal bins. Hence, the waste collected at the source point is in the mixed form, and it moves from source to primary location, primary to a secondary location, then landfill sites as it is (J. Padilla & Trujillo, 2017). A survey reported that the source segregation is affected by SEC (socio-economic conditions). As per the survey, higher SEC gives a higher rate of source segregation, whereas lower sections are the primary representative of the population of any developing country. SEC has also affected the collection coverage of MSW; according to reports of CPHEEO (Central Public Health and Environmental Engineering Organization) and CPCB (Central Pollution Control Board) (P. K. Mandal, 2019), collection coverage in the peri-urban or slum areas is low compared to commercial or high-income group or middle-income group areas.
- Many of India's cities have a limited segregation practice (Swati Singh Sambyal, 2018) through the distribution of blue and green dustbins. At present, the majority of urban and metro housing societies/ communities are facilitated with three different bins of different colors for collecting waste like biodegradable, non-biodegradable and domestic hazardous waste; thus, it requires time and effort for segregations of waste. At the same time, there are inadequate treatment techniques and facilities for the transportation and disposal of segregated MSW. These factors affect the willingness of residents towards source segregations.

- In addition, the efficiency of a solid waste collection system depends on the type of vehicle, its capacities, and the number of staff. The collection system is classified into two categories, i.e., door-to-door collection and communal collection. The door-to-door collection system generally exists in societies that are willing to pay, whereas slums and low-income areas are covered under a communal collection system. In many cities (Swati Singh Sambyal, 2018), the collection of source segregated waste has started, but to lack of facilities, mixed waste ends up in the dumpsite. Such as, in Tirunelveli, a city in Tamil Nadu awarded by the government for achieving 100 percent source segregation, residents segregate only recyclable plastic and handover it to the collector on predefined days. Whereas mixed waste is collected daily, however SWM Rules, 2016 mandate that waste must be segregated into wet, dry, and domestic hazardous at the source itself.
- Unsorted waste forces many waste processing firms to continue their segregation process, in which waste is separated at several stages. Depending on the raw material, a variety of sorting and processing activities are used, ranging from labor-intensive hand-picking to highly automated or technically complicated processes. The technique of sorting that is chosen is determined by a number of criteria, including the nature of the waste, the ease with which it may be separated, and the quantity and quality of the resulting recyclables ("Waste Management: Sorting/Processing of waste," n.d.).
- The existing separation method is suited for use with dry MSW since its high moisture content reduces the recovery of recoverable elements, results in operational instability, and results in a low overall plant efficiency (Tun & Juchelková, 2019). Proper treatment of organic or inorganic solid wastes, such as bio-drying, is critical for economic and environmental concerns, as it allows for the recovery of value-added byproducts through resource recovery, energy recovery, and reuse (Health & safety executive, n.d.). As a result, enhancing MSW quality through drying may have a number of benefits, including facilitating the recovery of recoverable materials. The existing method of drying MSW requires open land space, which contributes to the unpleasant odour and

airborne particles in the surrounding environment. Additionally, it degrades soil and groundwater resources.

2.4 Summary

Proper segregation of waste leads to scientific disposal of waste, and on the other hand, recyclables could be directly sent to recycling units (Sharholy et al., 2008)(Pulat & Yukselen-Aksoy, 2017). It can lead to various benefits such as enabling technology up-gradation, better quality products, saving of valuable raw material resources of the country, reducing the need for landfill space. Therefore, a mechanized system with the following objectives needs to be introduced along with the existing approach, which can segregate the mixed municipal solid waste to continue its generation.

2.4.1 Objectives

I. To design a mechanical MSW segregation system.

II. To develop and testing of the performance of the MSW segregator.

III. To develop the operating curves based upon the performance parameters.

Chapter – 3

Methodology

3. METHODOLOGY

3.1 Overview

In the previous chapter, the literature review highlighted the requirement to introduce a segregation system into the MSWM process, which could segregate the mixed MSW with an immediate post-process of collection and transportation. Such intervention would be advantageous in terms of minimizing the burden of MSW from landfill sites because the segregated waste would be utilized directly by waste processing industries such as recycling and composting. Hence this chapter is projecting the detailed methodology to achieve every goal associated with the objectives. The flow chart of methodology is shown in Figure 3-1.

3.2 Analysis of MSW

A sample of MSW is a mixture of various types of waste of different physical properties. Hence such mixture can be segregated based on differences in their physical properties. Therefore an analysis was performed on MSW samples comprising paper cardboard, textile, soil, dirt & sand, ceramics & glass, food & garden waste, and metals. The MSW contents were analyzed separately in the shredded form, which disentangles the waste contents. With reference to ASTM D6683(ASTM International, n.d.-c), and ASTM D570 (ASTM International, n.d.-b), the contents were poured into distilled water and allowed it to sink or float as per their physical properties. Then referring ASTM D4442 and processed the sample through the oven drying method (ASTM International, n.d.-a) to check the water absorption capacity, specific & bulk density of shredded contents, as density is one of the most critical physical properties to execute the segregation process. It was also required to analyze the content's behavior within the water, as most of the separation processes are performed under the influence of fluid such as forced air, water, or any other dense media. The above-mentioned contents are a mixture of its different categories, as mentioned in Table 3-1. The average results of five observations are analyzed and discussed under heading 4.1.

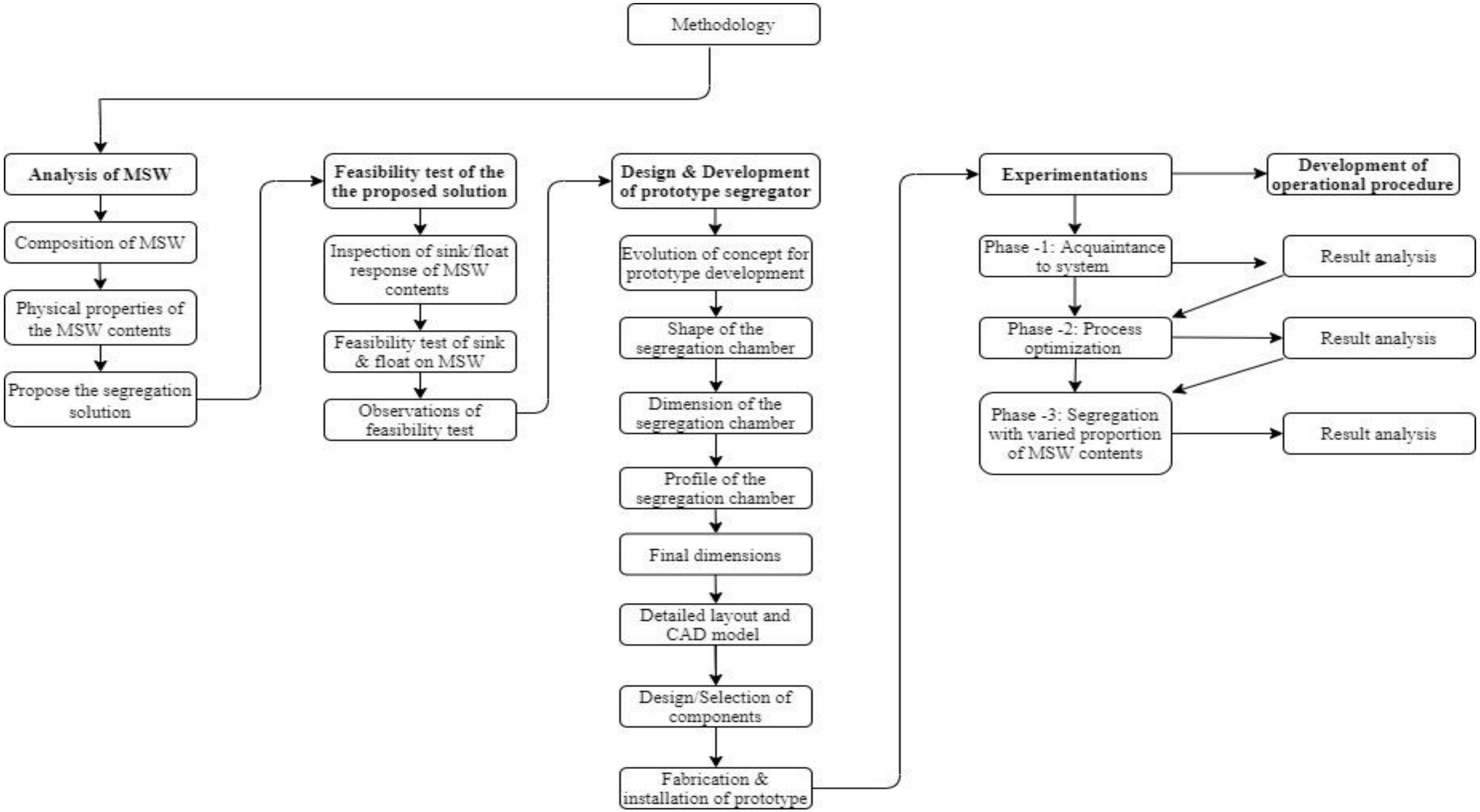


Figure 3-1 Methodology

Table 3-1 Sample MSW contents

Content	Mixture of
Paper waste	Newspaper, Repro paper, Tissue paper
Textile waste	Cotton, Silk, Linen, Wool, Jute
Plastic waste	Polybags, Food wrappers, Bottles.
Kitchen & Garden waste	Food waste, Garden trim (leaves, woods).
Glass & Ceramics	Broken glass, Cups, Jars, Light bulbs, and Tube lights.
Inert	Dust, Sand, Soil.
Metals	Nails, Cans, Wires.

3.3 Feasibility test of the proposed solution

With reference to the analysis of physical properties of MSW sample, wet density media separation technique was considered for the segregation of mixed municipal solid waste, which was required to be inspected upon its feasibility. In this section, lab-scaled experimentation was conducted on the samples of mixed MSW, which were processed through the sink and float separation technique, and experimental observations and results projected the background of feasibility.

3.3.2 Experimental setup for feasibility test

A feasibility test was performed in a transparent vessel, considering it as a segregation chamber. The transparent appearance of the vessel makes the visual observation convenient. The dimension of the vessel was :

Height, H = 30 cm

Diameter, D = 15.4 cm

Volume, V = 5585 cm^3

The feasibility test was performed on nine samples ranging from 100 g to 500 g. All the samples were prepared (Figure 3-2) with the composition of shredded 50% degradable waste, 21 % recyclable, and 29 % inert waste (Table 1-2). Each sample of mixed waste and water was taken into the vessel and permitted the sinking particle to settle down. A stirring rod was also used to stir the water so that trapped and mixed content takes the appropriate position in the water column according to their specific gravity. The observations were analyzed under heading 4.2 to predict the feasibility of the approach and design a prototype segregator.

Figure 3-2 Sample preparation

3.4 Design and development of prototype segregator

The preliminary laboratory test for the segregation of mixed MSW by sink & float reported the feasibility of the proposed method. Therefore it was required to scale up the lab setup and mechanize it for further experimentations and assessment of the process. Hence design and development of a prototype segregator encompass identifying the shape, profile, dimensions of the segregation space, and specifications of its supporting elements.

3.4.1 Evolution of prototype

Concerning the preliminary lab test setup and the articles discussed in the literature review, the prototype is evolved as a vertical cylindrical chamber, as illustrated in Figure 3-3. The cylinder's diameter and height are depicted by D and H, respectively. The segregation chamber has one water inlet and three outlets, i.e., the first outlet is located at the top of the chamber, and it is positioned tangentially to the circular profile of the chamber. Whereas inlet is also positioned tangentially, as it causes the fluid flow along the circular path, and particle in circular motion possesses linear velocity and corresponding linear speed. Therefore the tangential outlet became helpful to carry out the floating particles without any mechanical aid like rotating paddles or screw conveyors are used in the sink & float separation tank discussed in the preceding article.

The second outlet is located at the intermediate position along the verticle axis of the chamber, which is adapted for collecting the degradable waste. When the suspension is agitated at a specific RPM, degradable waste is lifted up in the water column. The third outlet is located at the bottom, from where inert sediment waste is collected through gravity.

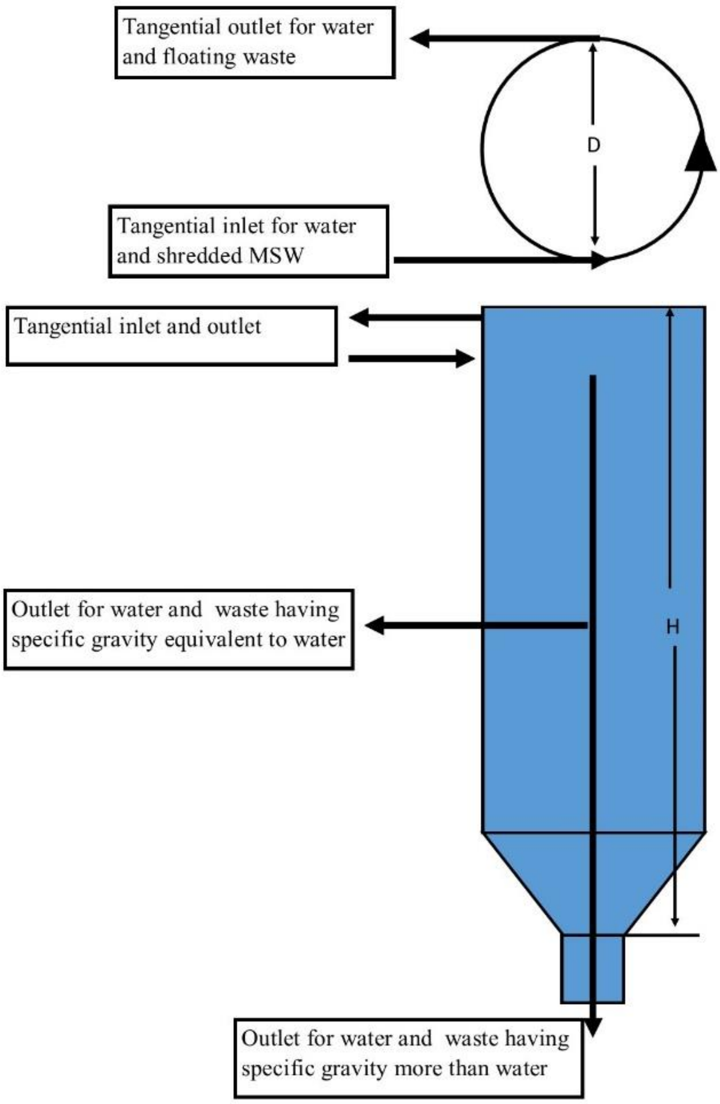


Figure 3-3 Evolution of prototype

3.4.2 Diameter and height of the cylindrical segregation chamber

The diameter of the prototype segregator was identified by assessing the column height of the preliminary lab setup, where the segregation chamber of the preliminary lab was divided into two columns, i.e., float column and sink column. The floating column contains waste plastic, and the sink column contains inert and degradable waste both. It was also observed during feasibility tests in the lab that waste plastic occupies a larger column height as the MSW quantity increases than the sinking contents, i.e., inert and degradable waste. Hence, on the underpinning of experimental observations, column height for more samples was identified through regression analysis. The projection of waste plastic column height was identified up to 5 kg of MSW sample, and it was 98 cm with the number of layers of floating plastics, as the column height of floating zone increased beyond the single layer, mixing of floating zone and sinking zone starts, which further complicates the segregation process and affects the efficiency (Figure 3-4). Therefore it is essential to maintain the single layer of floating plastic, which means column height should be kept equivalent to the average particle size, i.e., 4.5 to 5 cm. To maintain the above column height, the diameter of the cylindrical chamber was calculated using equation 3-1 and keeping the volume of the floating particles constant.

v = $\pi r^2 h$ Equation 3-1

Where v is the volume of the plastic column, cm^3

r is the radius of segregation chamber, cm and

h is the height of the plastic column, cm

Hence, according to the calculation for volume v = 17890.38 cm^3, Minimum column height h = 5 cm, and available standard fabrication facilities, the diameter of the segregation chamber was calculated as 75 cm.

With reference to the design data sheet of HydroFloat separator (Annexure I) by Eriez floatation division, the ratio of height to diameter varies between 2:1 to 4:1. Therefore as per the available fabrication facilities, the height of the segregation chamber is considered as 250 cm.

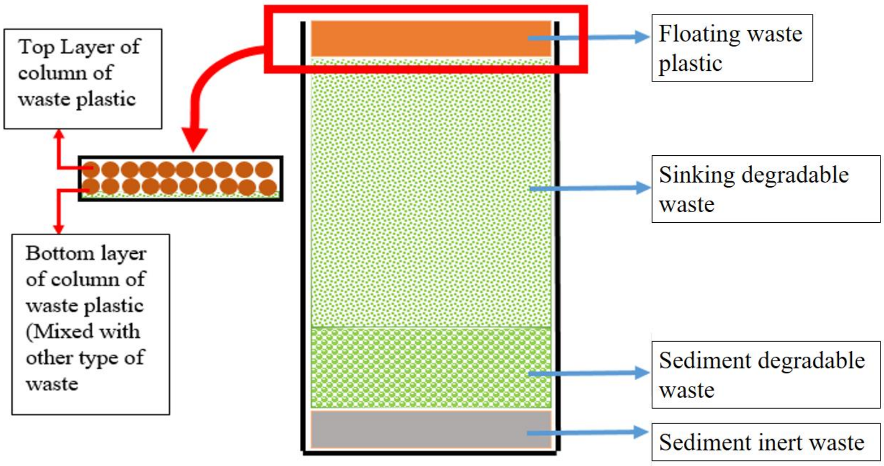


Figure 3-4 Visualization of feasibility test

3.4.3 Profile of the segregation chamber

With all the above considerations, it was essential to assess the fluid flow profile going to take place in the segregation chamber because the system was being designed to utilize the tangential inlet and outlet flow to carry out the floating plastic waste. Hence for the preferable streamline, various profiles were analyzed by CFD simulation at preliminary state. In this simulation, visuals of fluid flow patterns were analyzed against the zero velocity zone, where floating plastic waste might get stuck. Figure 3-5 shows the four-stage iterations in the segregator profile, in which the attempts were made to minimize vortex and zero velocity zone. The first and final profiles were validated experimentally and discussed under heading 4.3.

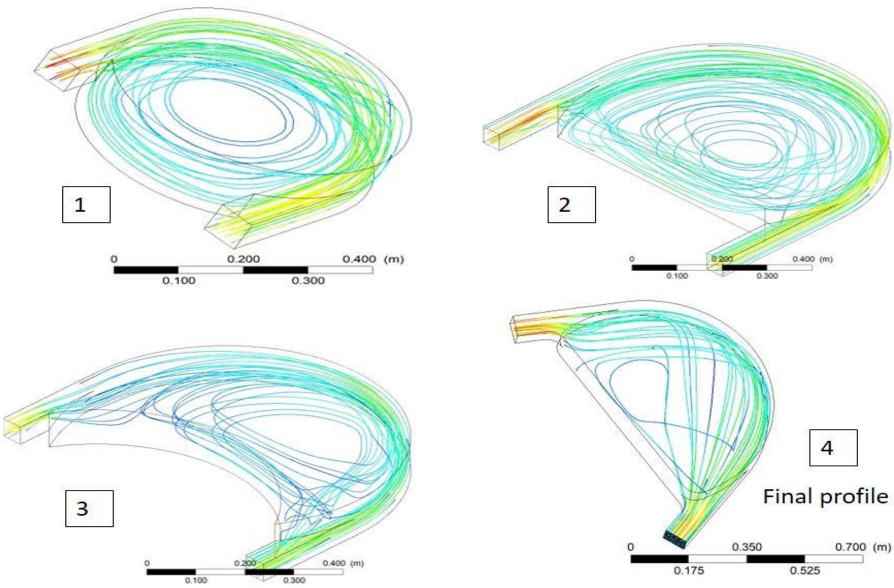


Figure 3-5 Iterated profiles of segregation chamber

Therefore, based on the literature survey and preliminary CFD analysis on iterated profiles, the 4th profile was deemed to develop a prototype segregator further. Therefore design & selection of all the elements of the prototype segregator and its fabrication are discussed under the next heading.

3.4.4 Plan of the prototype Segregator

Based on evolved dimensions, the basic profile is shown in Figure 3-6, whereas Figure 3-7 and Figure 3-8 show the complete layout and CAD model of the prototype segregator, respectively.

Based on the evolved concept in this phase, a prototype segregator was designed and developed further to analyze the sink & float-based MSW segregation process. Various other functioning elements were designed and standardized according to its market availability, such as the dimension of the segregation chamber, its profile, outlet valves, agitator, and its driving motor.

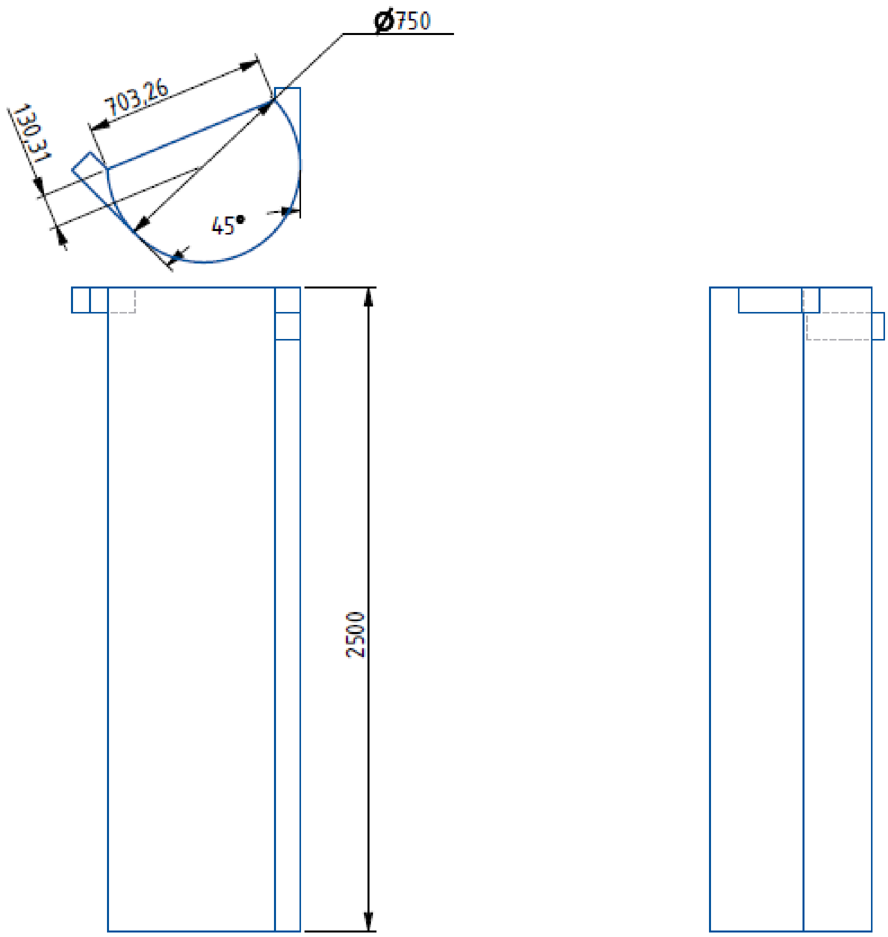


Figure 3-6 Final dimensions of the segregator profile

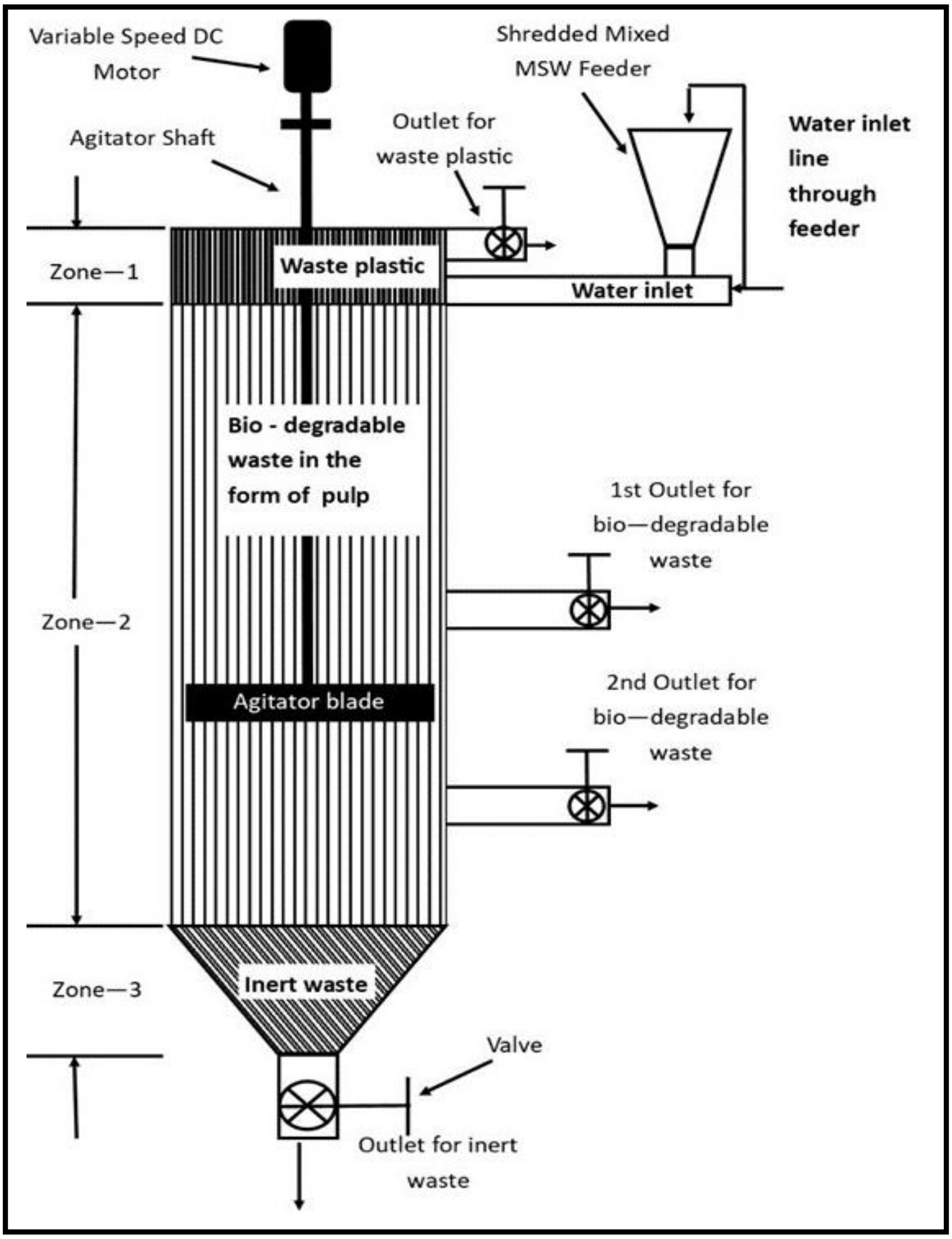


Figure 3-7 Layout of prototype segregator

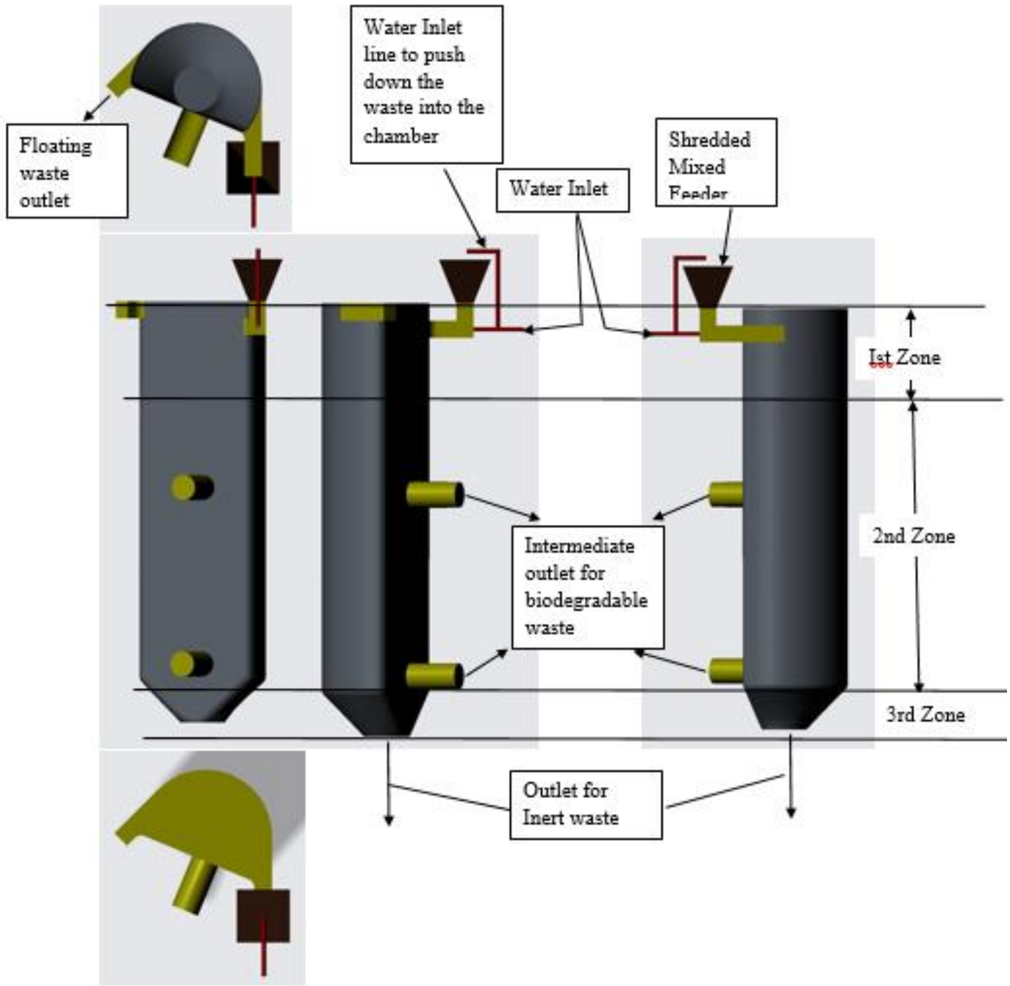


Figure 3-8 CAD model of the prototype segregator

3.4.5 Design/Selection of components

Design of Agitator: The agitator is used to agitate the suspension and also to raise the settled degradable waste into the water column for further segregation and recovery. Therefore a two-blade paddle-type agitation system was designed based on drag force acting on the agitator blade. The paddle agitator has the blade length from wall to wall of the chamber, and the width is 1/8th of the length (Abster Equipment, n.d.; CD fluid, 2020; Dynamix Agitators, n.d.; Jirout & Rieger, 2011; Shah, 2012).

Therefore in the present work, the diameter (d_a) and the width (w_a) of the paddle agitator were considered 40 cm and 5 cm, respectively. As shown in Figure 3-10 &

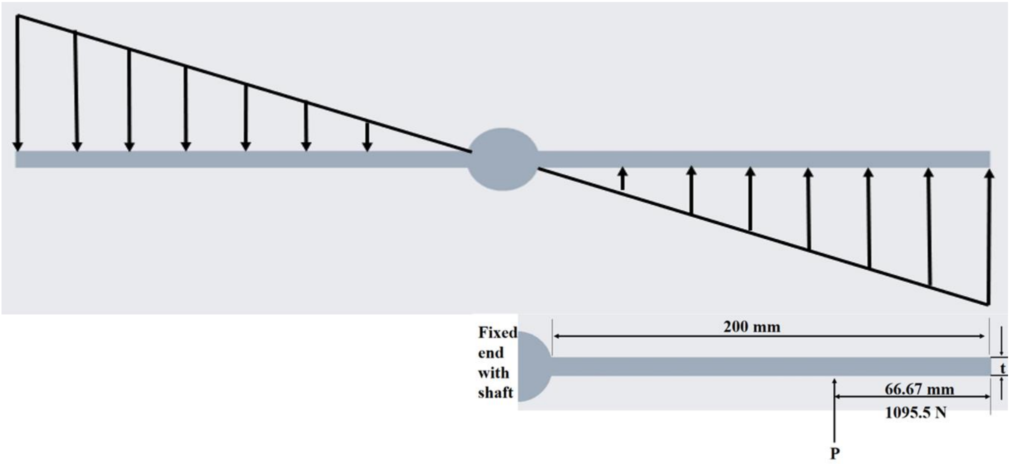


Figure 3-10, paddle blades act as a cantilever beam, and due to the loading conditions, bending stress is developed in the blades, which depends upon their thickness. Equation 3-2 is used to calculate the bending stress in the agitator blade.

Bending stress, $\sigma_b = \frac{M_b y}{I}$ Equation 3-2

Where M_b is bending moment, y is the distance of the neutral axis, and I is the moment of inertia. For safe working conditions bending stress must be lesser than the allowable stress of agitator material. Plane Carbon steel AISI 1018 was selected as agitator material with a yield strength (S_{yt}) of 370 N/mm^2. Considering the factor of safety as 6 for the gradually applied load and using equation 3-3 for the calculation of allowable stress.

Allowable stress $\sigma_a = \frac{S_{yt}}{F.S.}$ Equation 3-3

Theerfore σ_a = 61.66 N/mm^2.

Figure 3-9 Agitator

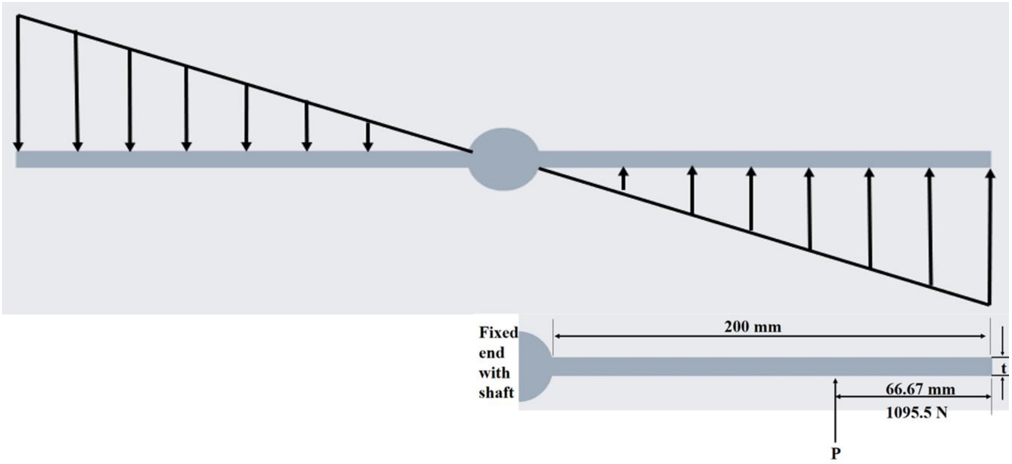


Figure 3-10 Drag force acting on agitator blade

The drag force on the agitator blade develops the torsional shear stress in the shaft, which was considered as the design criteria for agitator shaft diameter. The diameter of the shaft was calculated by using equation 3-4.

Diameter of the agitator shaft $d_s = \sqrt[3]{\frac{16T}{\pi\tau}}$ Equation 3-4

Where T is the torque required to overcome the drag force acting on the agitator blade and τ is the allowable shear stress of the shaft material, which was calculated by using equation 3-5:

$\tau = \frac{.6\ \mathrm{Syt}}{F.S.}$ Equation 3-5

Where S_{yt} is yield tensile strength of the shaft material and F.S. is a factor of safety. Therefore diameter of the agitator shaft was calculated and standardize as 30 mm.

Design of weld joint: The agitator blades are joined with the agitator shaft using a welded joint. The welded joint was designed according to the loading conditions as shown in Figure 3-11, in which force P through the plane of welds causes the primary shear stress, τ_1 and it is given by equation 3-6. W1 and W2 represent weld, which has the cross-section of a right-angle triangle. Welded joints are dimensioned in terms of throat thickness 'T', and leg length L.

Primary shear stress $\tau_1 = \frac{P}{A}$ (8.27) Equation 3-6

Where A is the throat area of all welds. The moment of fore P causes bending moment and subject the blade under bending stress, which is given by equation 3-7.

Bending stress, $\sigma_b = \frac{M_b y}{I}$ Equation 3-7

Where I is the moment of inertia of all the welds based on the throat area and y is the distance of the point in weld from the neutral axis. The bending stresses are assumed to act normal to the throat area. The resultant shear stress in the welds is given by equation 3-8.

$\tau = \sqrt{\{(\frac{\sigma_b}{2}) + \tau_1^2\}}$ Equation 3-8

Where σ_b is bending stress, τ_1 is the primary shear stress and τ is the allowable shear stress of the filler material, which is .3 times of tensile strength of filler material. Considering AWS A5.1:E6010, ASME SFA 5.1, which has a tensile strength of 550 MPa.

Therefore allowable shear stress of the filler material is 165 MPa, and the calculated value of weld throat thickness is 5.56 mm.

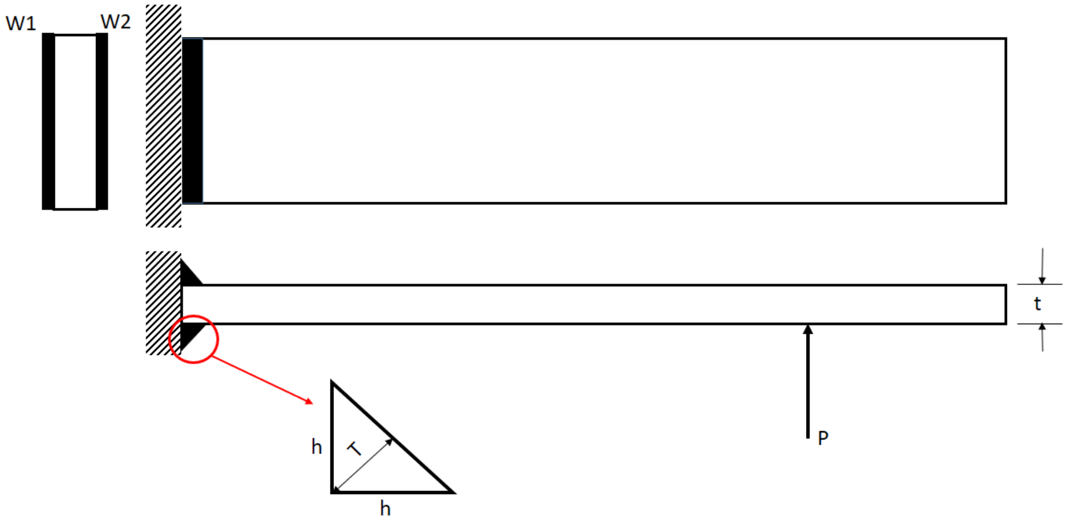


Figure 3-11 Design of welded joint for agitator blade

Selection of outlet valves: Outlet valves/lines are used to collect the floating shredded plastic waste (from the outlet located at the top of the chamber), degradable waste (from the outlet located at an intermediate position, along the verticle axis of the chamber), inert waste (from the outlet located at the bottom). The available shredder gives the average shredding size 2.5 cm and 4.5 cm as the maximum size. Therefore outlet line or valve should be able to pass the particles of maximum size. Hence concerning the catalog (Citizen Valves, n.d.), all the outlet lines are equipped with a gate valve of a standard size of 6.35 cm.

Selection of water pump: As per the working principle of the segregation process, water is the key element to execute the segregation process. Therefore to maintain the continuous water flow, a water pump is needed to be aligned with the prototype segregator. The selection of a water pump requires few important inputs, such as required flow rate and total head.

Based on the preliminary CFD analysis and its validating experiments, it was observed that, at a discharge rate of .33 – .42 LPS, floating particles show a good response of getting into the stream and recovered through the outlet line. Whereas the total head was identified as 3.5 m (Figure 3-12), concerning the catalog of CRI pumps .5 HP pump with 25 mm pipe size was found as the suitable functioning element (CRI Pumps, n.d.).

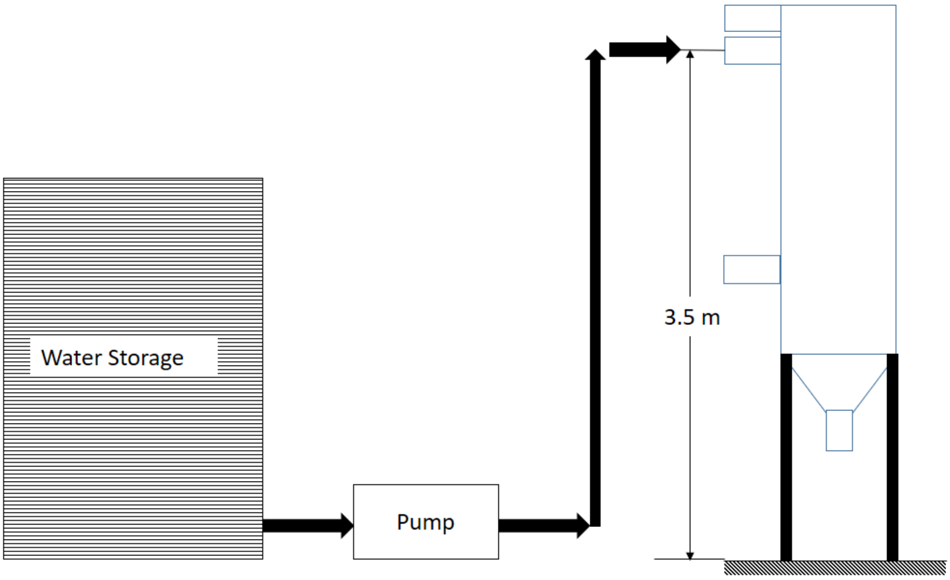


Figure 3-12 Total pump head

3.4.6 Fabrication and installation of the prototype

The designed MSW segregator was fabricated and installed in the area of 8 ft x 13 ft. The setup is equipped with a water pipe line and water storage tank of 1000 L, and the water line is made to utilize the treated STP water. The system is equipped with a water meter and rotameter to measure the water quantity and flow rate, respectively. All the MSW recovery lines (outlets) are equipped with collection bins and filters, allowing the water to pass through and let the MSW contents in the bin only. The prototype segregator is equipped with a 2.2 kW double blade agitator by AlfaTherm (Alfatherm Ltd., n.d.). The entire setup details are shown in Figure 3-13, Figure 3-14, Figure 3-15, Figure 3-16.

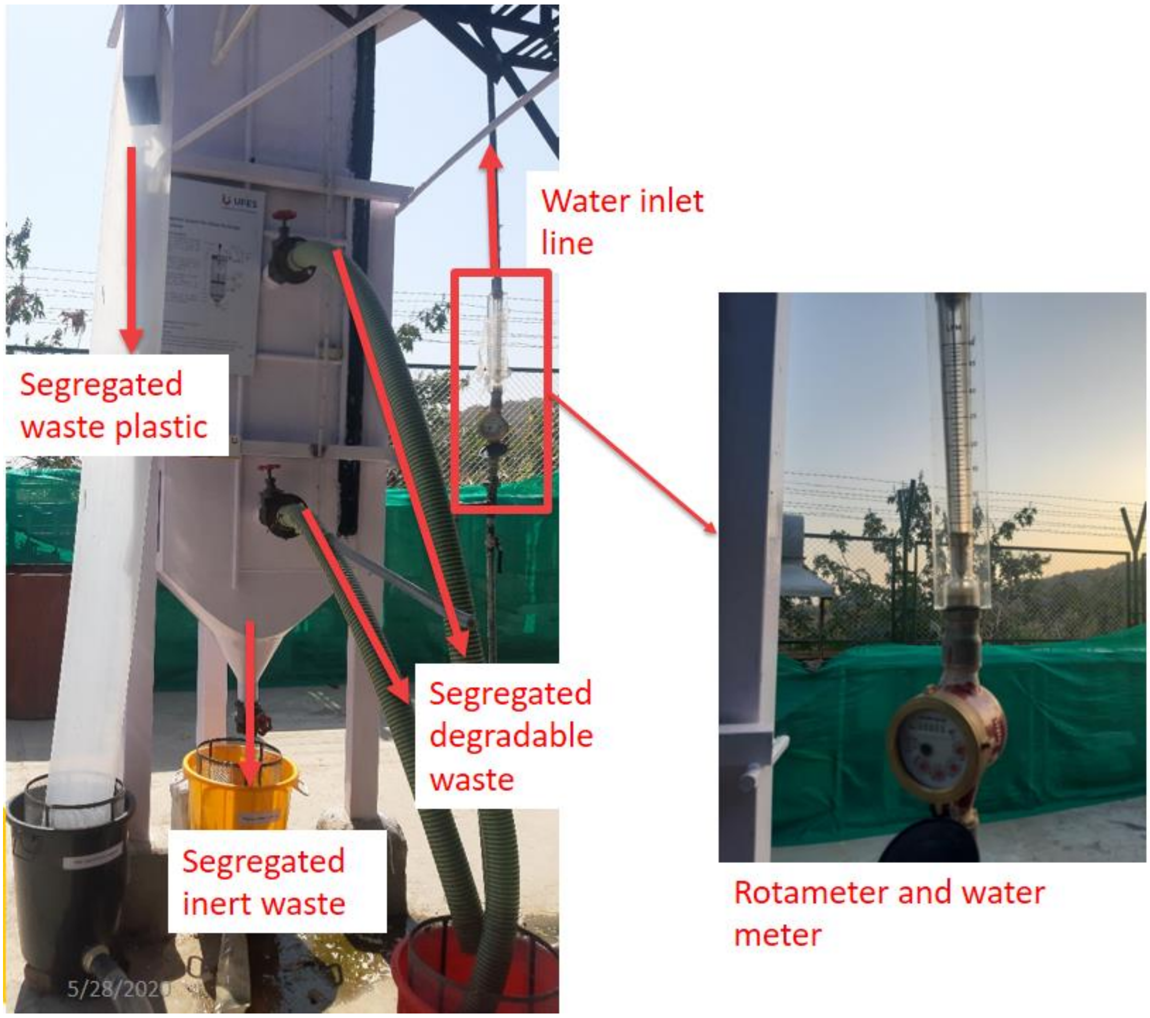


Figure 3-13 Prototype segregator and its essential fitments

Figure 3-14 Collection bins with filters

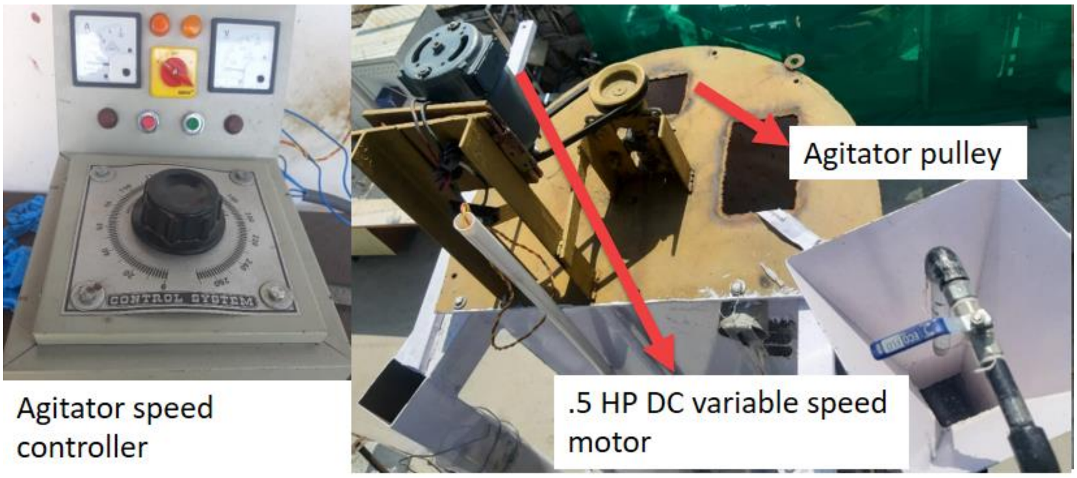


Figure 3-15 Agitator unit

Figure 3-16 Shredder

3.5 Experimentations

It is essential to evaluate the performance of the segregator and its process for establishing the correlation between input and output parameters. Therefore prototype was undergone through the various phases of experiments. In the preliminary stage of experimentations, the segregation process was evaluated to identify the wide working range of input and output parameters such as the amount of water, duration of agitation, effect of shredding size, recovery of segregated contents, power consumption, etc. The detailed analysis of the parameters was helpful to project the characteristic of the segregation process. In the secondary phase of experimentations, parameters were optimized through the design of experiments. The optimized inputs were tested against the segregation of mixed MSW samples and identified the optimum output. The segregation system was also evaluated with the MSW samples containing waste in varied proportions.

In the present work, the following operational parameters were used to perform the segregation process, its analysis, and optimization:

Input Parameters

i. ***Size of shredded waste*****:** In the process of sink & float segregation of mixed MSW, it is essential to shred the waste because MSW is collected in the form of bags or packets. Hence shredding makes the waste disentangled, and it gets washed easily inside the segregation chamber. Concerning the separation curve discussed earlier, the size of the particle is one of the most important driving factors for the sink and float separation process. The experimental processes were performed with the varied size of shredded particles, such as for degradable waste shredding size varied from 1.5 cm to 4 cm, for plastic waste size varied from 3 to 5.5 cm and for inert and metal waste range varied from 1.3 to 2 cm.

ii. ***Amount of water:*** Water is the media to carry out the segregated waste from the predefined outlets. Hence the recovery of segregated waste depends upon the sufficiency of water inside the segregation chamber. For the segregation process in the prototype, the tangential directional discharge rate on the water surface was kept constant, i.e., 20 LPM. It was identified experimentally, which carries out the floating particles through the overflow outlet without disturbing the degradable and inert waste column.

iii. ***Agitation:*** The prototype segregator is equipped with an agitator, which helps to disentangle the mixed waste while recharging the separator and also brings up the settled degradable waste and makes a difference in the column of settled inert waste and degradable waste. Degradable waste sinks in water, but particles start floating and occupy the larger water column when it is steered or agitated (as discussed earlier). Therefore the agitator speed is kept constant at 80 RPM, in which only degradable waste is lifted in the water column without disturbing the position of settled inert waste.

The process of agitation is responsible for the recovery of degradable waste only, as the agitation creates a disturbance in the bottom of the segregation chamber, due to which degradable waste is brought up in the water column and flows out from the intermediate outlet (when it is open). In contrast, additional water flow is essential to maintain the segregation of plastic and degradable waste because it carries the floating body through the outlets.

Output parameters

i. ***Percentage recovery:*** The prototype segregator is expected to segregate the 5kg mixed MSW sample into three categories, i.e., waste plastic, degradable waste, and inert waste. The sample is prepared with shredded waste in standard proportion. Therefore the percentage recovery is calculated by using the following equation:

Percentage recovery = $\frac{\text{Output quantity}}{\text{Input quantity}} \text{ X } 100$ Equation 3-9

It is one of the most important parameters to check the overall performance of the segregator. Apart from the input and out parameters, power consumption and the total time of the process are the two other measurable parameters directly associated with the process and essential to analyze.

3.5.1 Phase: 1 - Acquaintance to prototype segregator and its process

***Recovery of waste plastic**:* Experiments were performed with, 5 kg sample of shredded MSW (Containing waste in standard proportion), which was first fed into the segregation chamber. Then the chamber was filled with water till its top along with the running agitator. It was observed that degradable waste contents were also floating on the surface along with the waste plastic; therefore, agitation was stopped and allowed the degradable waste to settle down; it takes 8 -10 mins. Once no movement of degradable waste is observed through the gauging window, water flow is started again and let overflow through the outlet given on top as overflow carries the floating plastic with it (Figure 3-17). The flow was continued until the entire water surface became free from floating plastic waste. The observations are recorded in the format shown in Table 3-2, which contains the continuous observation of the recovery of plastic waste, which was used to plot the characteristic curve for waste plastic recovery. The mentioned table also contains the data related to segregation efficiency for waste plastic and all the operational inputs such as duration of agitation, amount of water utilized, shredding size.

Table 3-2 Observations: Recovery of waste plastic

Segregation cycle	**Shredding size of sampled waste plastic (cm)**	**Quantity recovered with respect to each 50 L of water**		**Overall recovery of plastic waste(%)**	**Total amount of water flown (L)**	**Total power consumption (kWh)**
N		Recovery at 50 L	____g			
		Recovery at 100 L	____g			
		Recovery at 150 L	____g			
		Recovery at 200 L	____g			
		Recovery at 250 L	____g			
		Recovery at n L (Until outlet stream gets free from recovering particles)	____g			

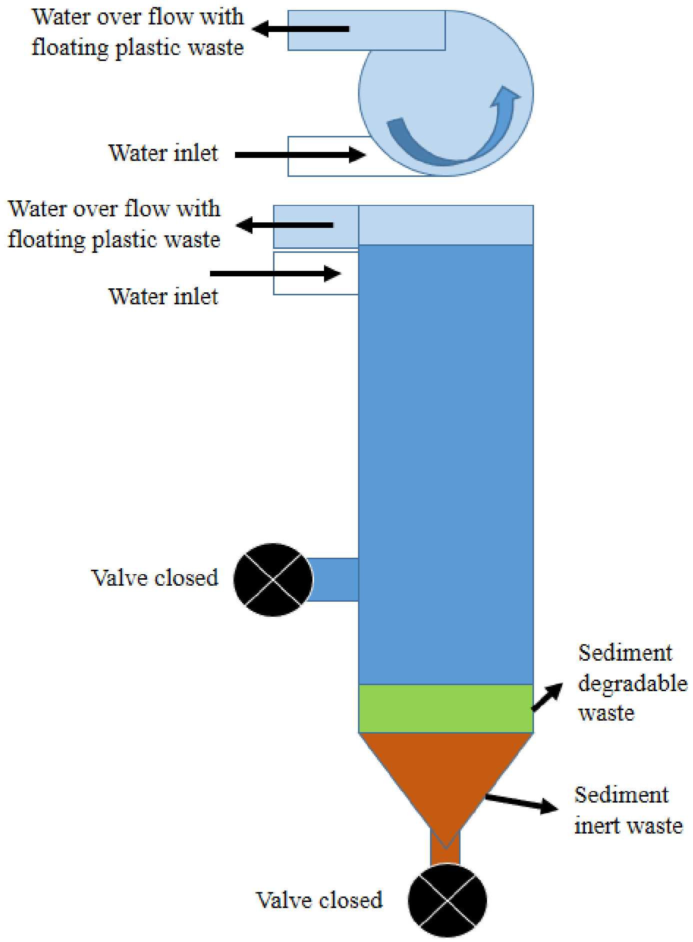


Figure 3-17 Segregation of plastic waste

Recovery of degradable waste: Once the surface became free from floating plastic, water flow was stopped, and agitation was started with the remaining water in the chamber. The agitation speed was set at a particular speed, in which only degradable waste appeared in the water column (Figure 3-18). Along with such visualization, both the intermediate valves were kept open, allowing water flow with the floating degradable waste. The first intermediate valve allows the floating degradable waste to recover; hence, it was essential to maintain the water level until the elevation of the first intermediate valve; therefore, water flow was started again for the same. The second intermediate valve allows the flow of degradable waste, which was floating within the water column. The flow of water and agitation was maintained until both the intermediate outlet streams became free from degradable waste. Observations were recorded in the format shown in Table 3-3.

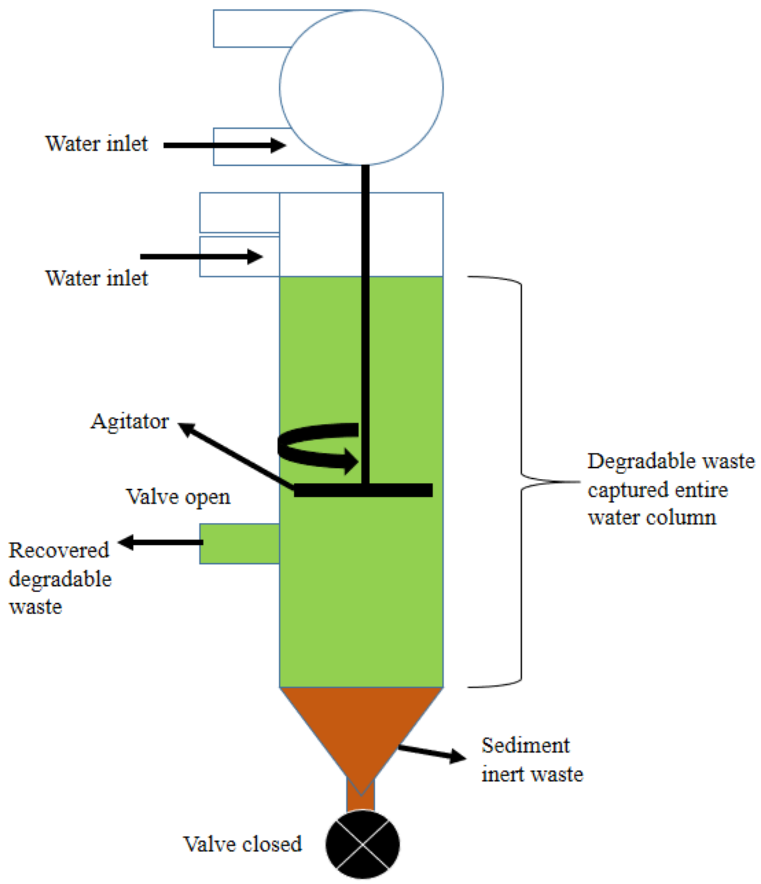


Figure 3-18 Segregation of degradable waste

Table 3-3 Observations: Recovery of degradable waste

Segregation cycle	**Shredding size of sampled degradable waste (cm)**	**Quantity recovered with respect to each 100 L of water**		**Overall recovery of degradable waste(%)**	**Total amount of water flown (L)**	**Duration of agitation (min)**	**Total power consumption (kWh)**
N		Recovery at 100 L	____g				
		Recovery at 200 L	____g				
		Recovery at 300 L	____g				
		Recovery at 400 L	____g				
		Recovery at n L (Until outlet stream gets free from recovering particles)	____g				

Recovery of inert waste: After the recovery of plastic and degradable waste, only inert waste was left in the remaining water column of the segregation chamber. Due to its higher specific density, inert waste holds its sunk position at the bottom of the chamber (Figure 3-19). Therefore it was possible to recover the entire inert waste through the outlet given at the bottom, from where waste was flushed out under the effect of gravity. All the observations related to the recovery of inert waste were recorded in the format given in Table 3-4.

Table 3-4 Observations: Recovery of inert waste

Segregation cycle	**Shredding size of sampled inert waste(cm)**	**Overall recovery of inert waste(%)**	**Total power consumption (kWh)**
N	----	----	----

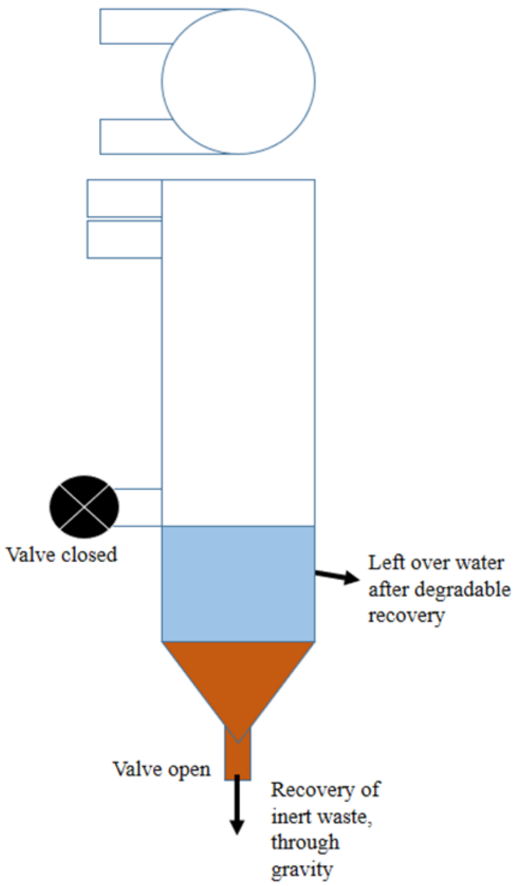


Figure 3-19 Recovery of inert waste

Along with the segregation of waste, continuous recovery monitoring against the water quantity and power consumption was also performed for the process optimization. As the separation was being executed using the sink & float separation technique, hence it was apparent that the recovered contents would absorb the water. Therefore it was essential to find the same, as to determine the exact recovered quantity. Therefore ASTM D4442 was followed, in which the sample was kept in the oven until the temperature reached 100^0C and the change in weight was measured. This process is repeated until the moisture reaches to previous (before sink & float process) value. In the present work, a moisture meter (Figure 3-20) was used for monitoring the moisture level.

Figure 3-20 Moisture meter

The experiments were aimed to segregate and recover all the three classified categories of MSW and identify the working ranges of inputs and outputs. Therefore, in this phase of experimentations, after every five observations, the further requirement of number observations were calculated by using the following equation:

No. of observations (N) = $\frac{B^2}{A^2}\left(\frac{\sqrt{n\sum X^2-(\sum X)^2}}{\sum X}\right)^2$ Equation 3-10

Where B = 2 for 95 % confidence level

= 3 for 99 % confidence level

A = .05, for $\pm$5 % desired precision and so on for other value

n = $\sum f$

$\sum X = \sum fx$

$\sum X^2 = \sum fx^2$

Where x is the value of input and f is the frequency of output readings.

3.5.2 Phase: 2 – Process Optimization through Design of experiment

Experiments conducted in phase-1reported the relationship between the recovery of MSW contents and the applicable inputs such as shredding size, water flow, Therefore for further analysis and optimization of the process, a DOE was formed with the input data ranges gathered from phase-1 experiments. With each input data set, a varied amount of waste is recovered from the segregator. In this section, outputs were analyzed further in terms of comparison with the total power consumption during the process to find out the optimum recovery. The electrical power is consumed for operating the water pump of 1 HP, agitator of .5 HP, and shredder of 3 HP for shredding the waste. Table 3-5 shows the applicable inputs for the recovery of each category of waste. All the observations were recorded in the format discussed earlier in Table 3-2, Table 3-3, and Table 3-4 .

Table 3-5 Input parameters for different waste

DOE		
Input for waste plastic segregation	**Input for degradable waste segregation**	**Inputs for inert waste segregation**
- Amount of water - Shredding size	- Amount of water - Shredding size - Duration of agitation	- Shredding size

3.5.3 Phase: 3 - Segregation of MSW with the varied proportion of waste components

Phase 1 and Phase 2 experiments were carried out on 5 kg of household waste with the standard composition of plastic, degradable and inert waste. Therefore, it was essential to check the separator's performance if the composition of any category of household waste deviates from the standard. Table 3-6 shows the different samples in which the proportions of degradable, plastic, and inert waste were varied, and their separation process was carried out with the optimal inputs identified in the phase 2 experiments. With all of these variations, the total amount of sample MSW on which segregation performance was analyzed also increases.

Table 3-6 Sample of MSW with the varied proportion of category

Composition of degradable waste	Composition of plastic waste	Composition of inert waste	Total percentage of waste	Amount of MSW (Kg)
85	50	0	135	6.75
80	45	0	125	6.25
75	40	0	115	5.75
70	35	0	105	5.25
65	30	5	100	5
60	25	15	100	5
51	21	28	100	5
40	15	45	100	5
35	10	55	100	5
30	5	65	100	5

Conclusion

As a result of the chapter, a detailed methodology projection was created in which the entire segregation system was designed, and a working prototype was also developed. The separation system has gone through the various cycles of the separation process in which a sample of mixed municipal waste is separated and classified into three classifications, i.e., Plastic, degradable, and inert waste. Whereas DOE was also applied for the optimization of input parameters, and performance evaluation was carried out through the result analysis. Such records are statistically extrapolated and discussed in the next chapter.

Chapter – 4

Result & Discussion

4. RESULTS AND DISCUSSION

In the previous chapter, observations of the feasibility test led the process to a working prototype segregator, in which different cycles of mixed MSW segregation were performed and drew quantitative observations. In the present chapter, all the design analysis and empirical observations are discussed, analyzed in detail, and summarized to compare the proposed system's separation curve and the standard principle curve.

4.1 Analysis of MSW contents

In the present work, contents of sample MSW were tested against its bulk density and individual's behavior in water such as sink or float and water absorption capacity. Table 4-1 shows the average values of bulk density of primary MSW contents identified experimentally by ASTM D6683 and water absorption capacity identified by D570. In the continuation of the above analysis, the average time taken for sinking and the percentage of water absorbed (after sinking) were also identified.

Table 4-1 Bulk density and water absorption capacity of MSW contents

MSW contents	Bulk density (Kg/m^3)	Sink/Float	Time taken to get sink, min	Water absorbed, % (During sinking)	Water absorption capacity (%)
Plastic	768	Float	NA	NA	Nil
Paper	1074	Sink	2.7	36	59.6
Cardboard	551.4	Sink	3.8	60	77.7
Textile	890	Sink	1.2	43	50.6
soil, dirt & Sand	2368	Sink	0.05	64	76
Ceramics & Glass	2178.6	Sink	0.01	Nil	Nil
Food & Garden waste	1263.1	Sink	0.1	31	79.2
Metals	1849	Sink	0.01	Nil	Nil

Cardboard & papers: Cardboard has a bulk density of 551.4 Kg/m^3 and specific density is 689 Kg/m^3; hence it was supposed to float over the water surface. But, when the shredded cardboard is poured into the water, it floats on the water surface initially, and after a short period (approx. 4 min), it starts sinking in the water (Figure 4-1). At this moment, the sample absorbed 60 % water of its total weight and the total water absorption capacity was evaluated as 77.7 %.

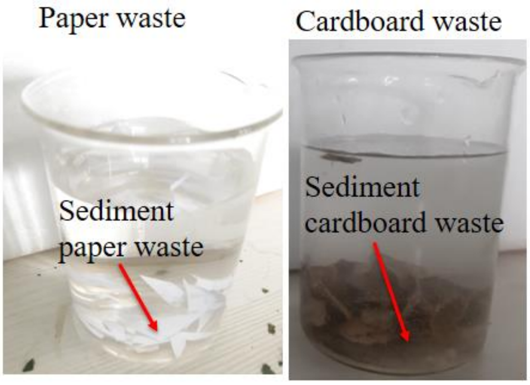


Figure 4-1 Response of cardboard and paper waste in water

Similarly, the paper has a bulk density of 1074 Kg/m^3, and a specific density is 1201 Kg/m^3 and due to its water absorptivity, it started sinking in 2.7 mins (Figure 4-1**Error! Reference source not found.**). At this moment sample absorbed 36 % water of its weight, and the overall absorption was evaluated as 59.6 %.

Food and garden waste: The bulk density of the mixture of food and garden waste is 1045 Kg/m^3, whereas specific gravity varies from 180 - 1300 Kg/m^3. Hence both the wastes sink in the water within 5 – 6 sec, as it already contains moisture ranging from 60 – 70 % (Figure 4-2).

Figure 4-2 Behavior of kitchen and garden waste in water

Textile: Textile wastes have a bulk density of 890 Kg/$m^{3,}$ whereas the specific density is more than 1100 Kg/m^3. If the textile is poured into the water, it traps air between it and the water surface, which keeps it floated for some time. Gradually the trapped air is released through the pores of the fabric or through any other passages that it can find, and the fabric becomes heavy enough to sink within 1 – 1.5 min (Figure 4-3).

Figure 4-3 Behavior of textile in water

All of the wastes, as mentioned above, show sinking behavior in water, but a minor disturbance in water through stirring, settled mass is raised and spreads throughout the water column (Figure 4-4).

Majorly found Plastic waste such as bottles and bags have a specific density ranging from 900 to 950 Kg/m^3 which is lesser than the water, and it doesn't absorb the water, therefore it floats over the water surface. The glass, ceramics, metals, and inert waste have their specific density greater than water, making them sink in the water.

Figure 4-4 Behaviour of steered kitchen & garden waste

The detailed analysis of MSW contents gives an insight into probable segregation techniques based on density differences. A mixture of MSW contains the various mass of different densities and also retains moisture. The existing separation technique works only with the dry waste (based upon density difference), i.e., air classifier, screening etc (as discussed in the literature survey).

Therefore, wet separation was also identified as an alternative solution, in which waste need not go through the time taking process of bio-drying; hence, the process can also segregate the mixed waste on the same day when it is generated. In this process, the entire shredded MSW is poured into the water as it works as separation media. Waste content of density lesser than the water is supposed to float over the water surface and heavier mass at the bottom. Hence a feasibility test was conducted further for exploring the possibilities of identified segregation approach.

4.2 Feasibility test of sink/float on mixed MSW samples

It was essential to crosscheck the feasibility of the proposed solution; hence various samples were prepared with the standard composition of MSW contents and tested its segregation through a sink/float approach under a lab environment. The segregation process was evaluated and discussed below.

4.2.1 Observations:

As per the principle of sink & float, it was observed that contents with lower specific density were floating over the water surface, such as plastic, papers, cardboards, and textile. As discussed earlier, paper, cardboard, and textile settle down after a few minutes of floating over the water surface when their pores absorb water. Settling time for the aforementioned content was observed as 4 – 5 minutes, whereas the contents with the higher specific density (glass, ceramic, dirt, sand & metal pieces) settled immediately. Contents with intermediate specific density and closer to the water settled down with the low terminal velocity (Figure 4-5 & Figure 4-6).

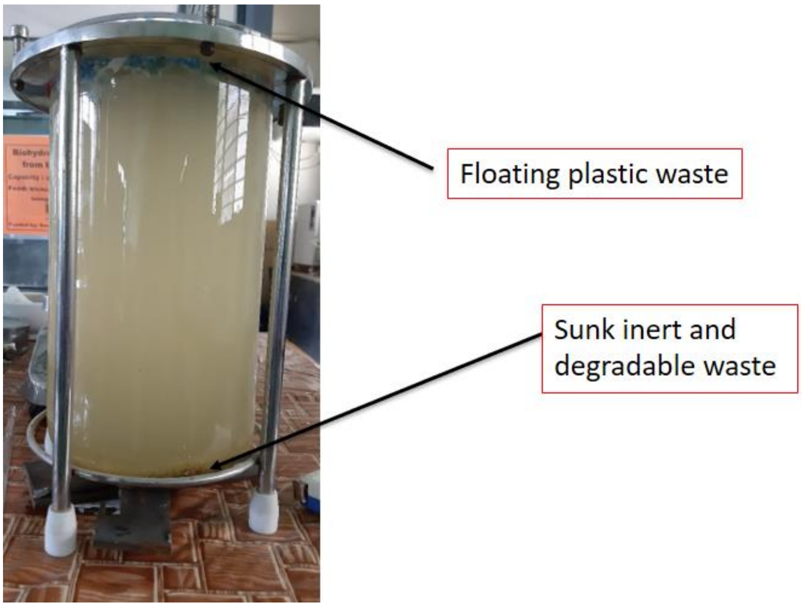


Figure 4-5 Feasibility test of sink/float separation technique on mixed MSW samples

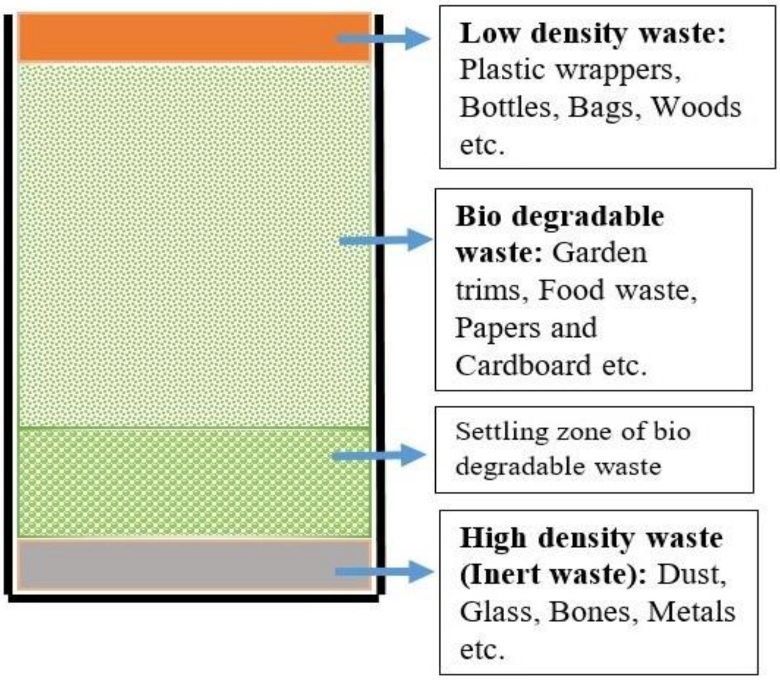


Figure 4-6 Visual of lab scaled sink & float separation on mixed MSW

As the separation was being executed by the sink & float separation technique and it is apparent that, amount of water will be added to the recovered quantity. Therefore it was essential to find the same to determine the exact amount recovered. Hence oven drying process (ASTM D4442) was considered, in which the sample was kept in the oven until the temperature reached 100^0C, which triggers the evaporation of moisture content, and therefore weight change was measured. This process is repeated until the moisture reaches the previous (before sink & float process) value, and measured weight is considered the recovered quantity. Figure 4-7 shows that the sink & float had added 13 % moisture content into the recovered plastic waste. The waste plastic sample showed a reading of .5 on the moisture meter before the sink & float process, whereas the same was 2.5 after the process. With respect to the moisture loss, weight loss of the sample was also recorded from 20 to 17.4 g.

Whereas Figure 4-8 shows that feasibility examination had added 61% moisture in the collected sample of degradable waste. The sample showed a reading of 3.6 on the moisture meter before sink & float, which moved up to 10. Therefore sample lost its weight from 30 g to 11.3 g in the process of bringing down its moisture to the initial level. Similarly, the process had added 73 % moisture in the sample of recovered inert waste (Figure 4-9).

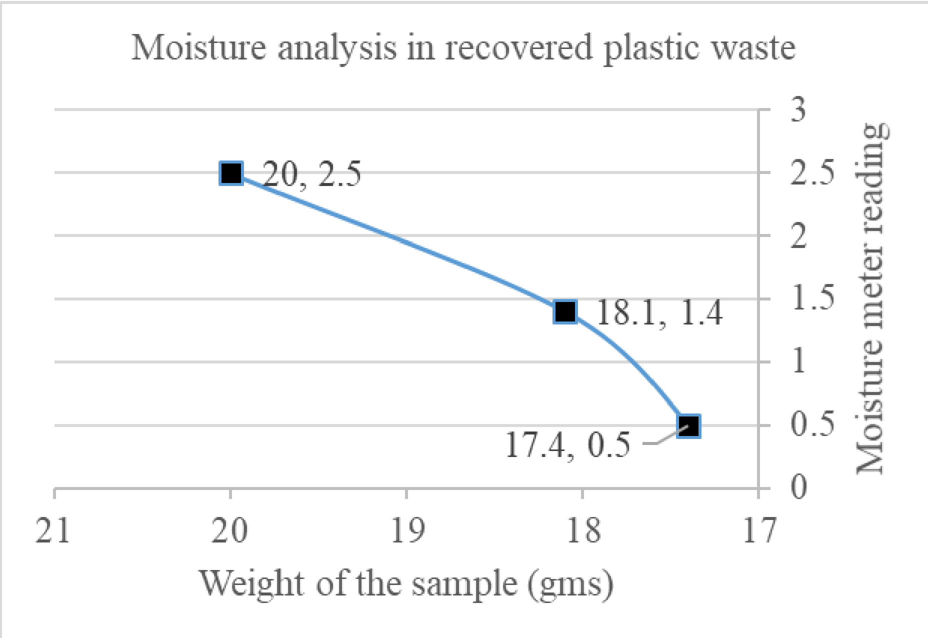


Figure 4-7 Moisture analysis of waste plastic

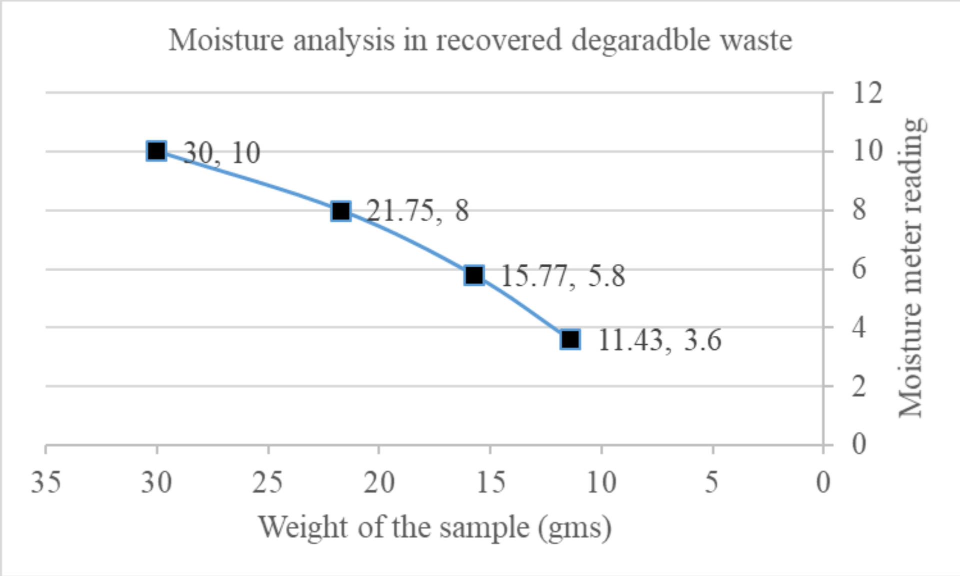


Figure 4-8 Moisture analysis of degradable waste

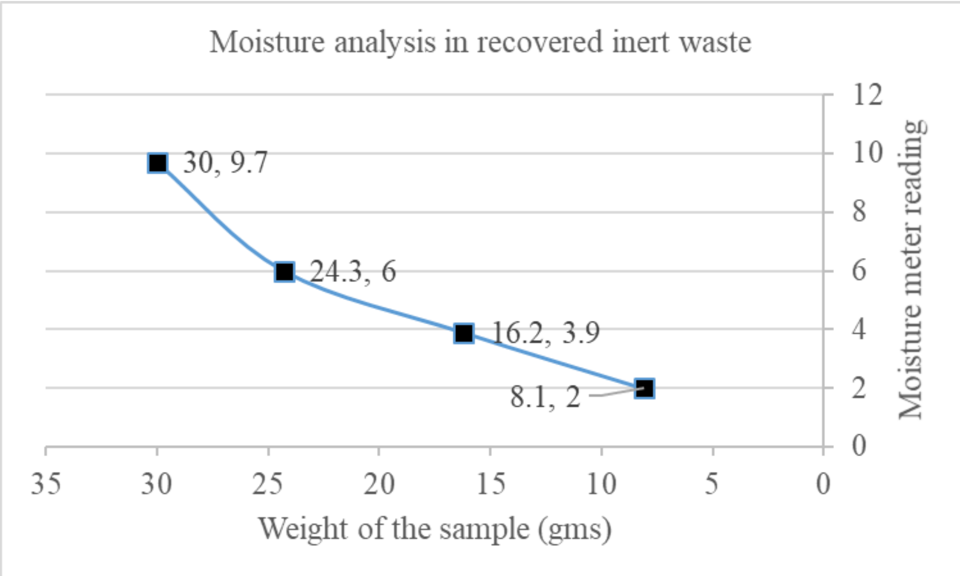


Figure 4-9 Moisture analysis of inert waste

Table 4-2 shows the observations of 9 samples of mixed MSW, ranging from 100 gm to 500 gm, tested against the sink & float separation process. Figure 4-10 shows that plastic waste (lower specific density) reports higher recovery, as it floats on the water surface, and inert waste (higher specific density) sunk at the vessel's bottom and reported lower recovery. Degradable waste has a specific density in between the other two categories. Furthermore, the inert waste contains dust particles that are smaller than any other type of shredded waste (i.e., .5 - 4.5 mm). Hence it gives lesser recovery, whereas shredded plastic waste has a larger particle size (30 – 50 mm) and reported higher recovery. Degradable waste has particle size (5 – 20 mm), and specific density lies between plastic and inert waste. Hence its recovery lies in between plastic waste and inert waste.

Table 4-2 Observation: Recovery of waste

Quantity of waste (gm)	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
Waste Plastic									
Input quantity of waste plastic (gm)	22	33	44	55	66	77	88	99	110
Recovered quantity of waste plastic (gm)	21	32	43	52	62	72	81	88	95
Recovery of plastic waste (%)	96	96	96	95	94	93	92	89	87
Food Waste									
Input quantity of food waste (gm)	50	75	100	125	150	175	200	225	250
Recovered quantity of food waste (gm)	48	71	94	116	137	158	174	191	203
Recovery of waste food (%)	95	94	94	93	91	90	87	85	81
Inert Waste									
Input quantity of inert waste (gm)	28	42	56	70	84	98	112	126	140
Recovered quantity of inert waste (gms)	26	30	50	61	71	80	87	90	96
Recovery of inert waste (%)	93	71	90	88	85	82	78	72	69

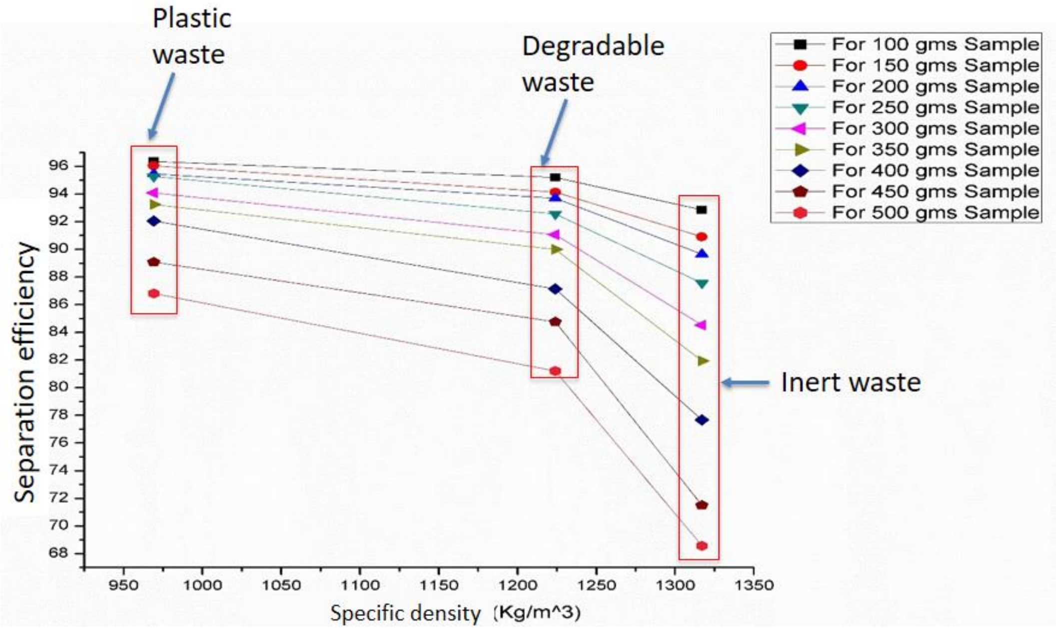


Figure 4-10 Separation curve

Whereas the combined plot of all the samples (Figure 4-11) shows the recovery of each component falls with the increasing amount of waste sample. It occurs due to the formation of a mixed zone between each column, i.e., the column of waste plastic, degradable waste, and inert waste, and also due to increasing contents of solids in water.

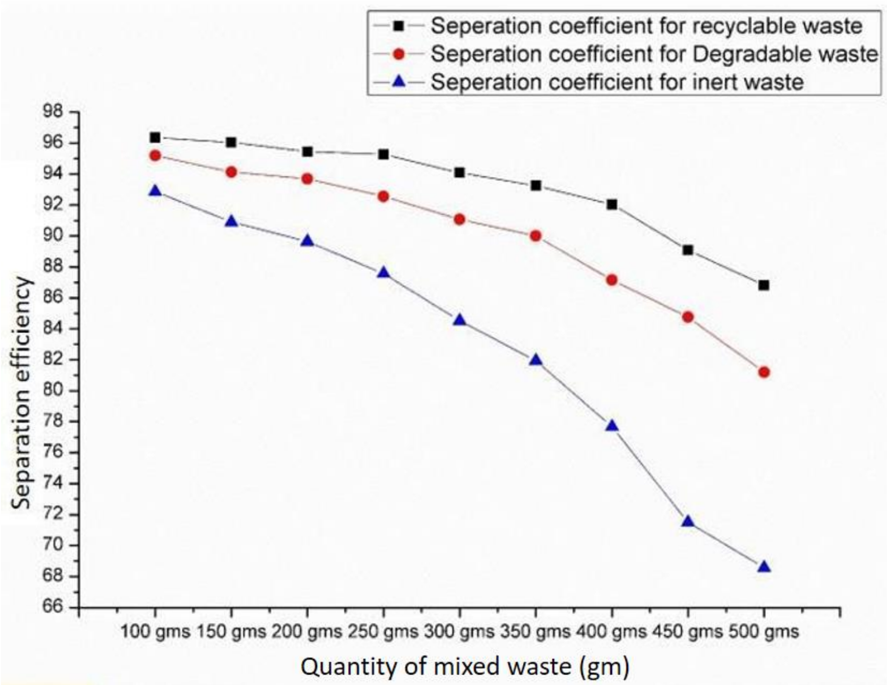


Figure 4-11 Recovery Vs Quantity of MSW

The above observations reported that the sink/float approach can segregate mixed MSW into three categories, i.e., plastic, degradable, and inert waste. In contrast, it was also observed that the segregation efficiency depends on the amount of waste and the chamber volume used for the segregation process. Therefore for the further study of the proposed method, a prototype segregator for the MSW sample of 5 kg was designed, developed, analyzed experimentally, and discussed under the upcoming headings.

4.3 Preliminary CFD streamline analysis of segregator profile

On the underpinning of the literature survey and the feasibility test, a conceptual segregator was developed. The segregator was deliberative to work on the sink & float separation principle, where water was considered the media to carry the floating and sinking particles. Therefore it was essential to analyze and optimize the segregator profile, as the fluid flow pattern may vary the recovery of floating particles.

Figure 4-12 shows the streamline analysis of the first profile, in which it was observed that the owing to vortex formation, center, and the region between inlet & outlet having zero velocity zone, which might affect the flow of floating particles and suppress the recovery rate of floating waste plastic also. Such phenomenon was also validated experimentally, as shown in Figure 4-13. In which, it could be observed that a significant amount of floating particles revolve around the axis of the cylindrical chamber, and very few particles are marked on the outlet side.

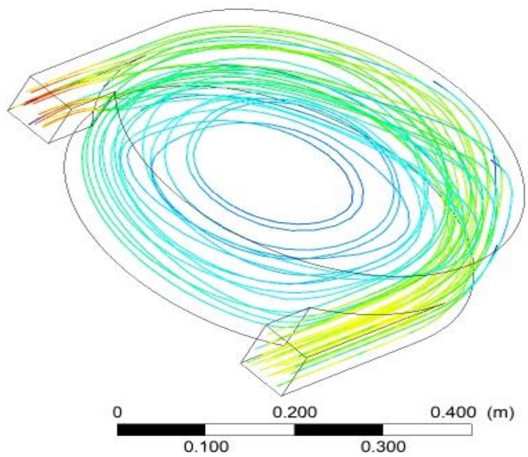


Figure 4-12 Segregator profile : 1

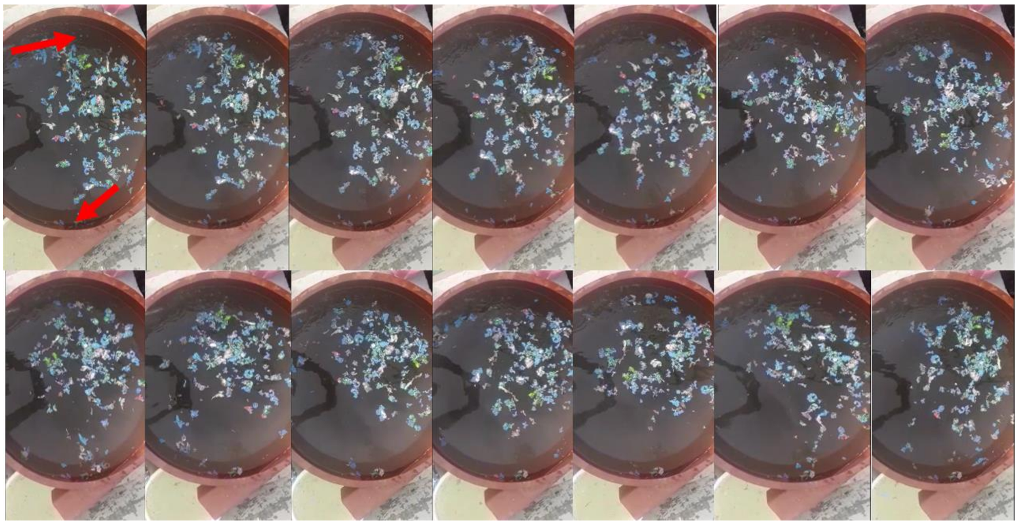


Figure 4-13 Experimental validation of first profile

The observations from 1st profile led the approach to minimize/suppress the vortex formation. Hence Figure 4-14 shows the 2nd iteration in the profile where the walls between the inlet and outlet were made flat. It was observed that the vortex was still being formed, which might cause the low-velocity zone and also affect the recovery. Similarly, Figure 4-15 shows the 3rd iteration in the profile, in which walls between inlet and outlet were made curved to suppress the vortex formation. But, results were not desirable; hence in the 4th iteration, the wall was made flat along with the 45^{0} angles between inlet and outlet lines. Simulation results reported that the vortex formation was lesser than the earlier profile, and streamlines were directly approaching from inlet to outlet. Hence the probability of recovery was also better than the earlier. For further analysis, the profile was validated experimentally also, as shown in Figure 4-17. In the initial phase, when the surface of the water was covered with floating plastic, a few particles were moving around the axis, and the rest were moving with the flow from the inlet to the outlet. Later on, particles began to disperse from the center to the wall and flow with the streamline (inlet to outlet) as voids were being formed due to the continuous extraction of floating plastic. Therefore, unlike the previous three profiles, no floating particles remained above the water surface.

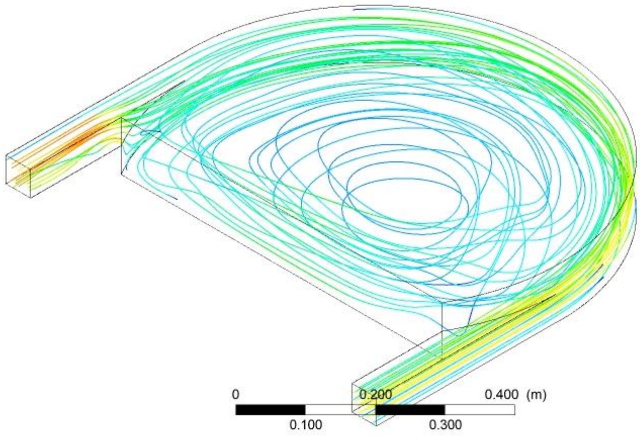


Figure 4-14 Segregator profile : 2

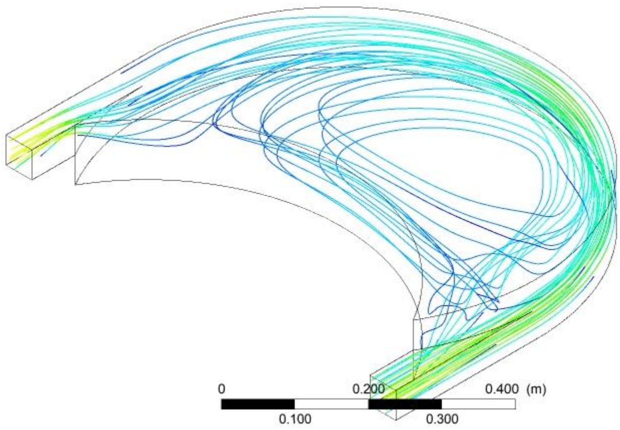


Figure 4-15 Segregator profile : 3

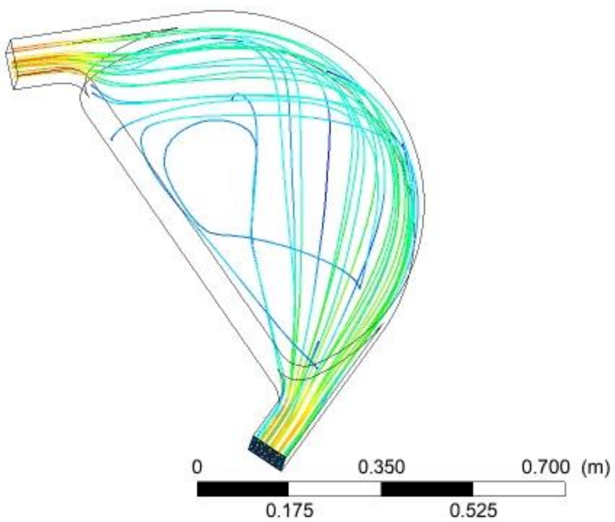


Figure 4-16 Segregator profile : 4

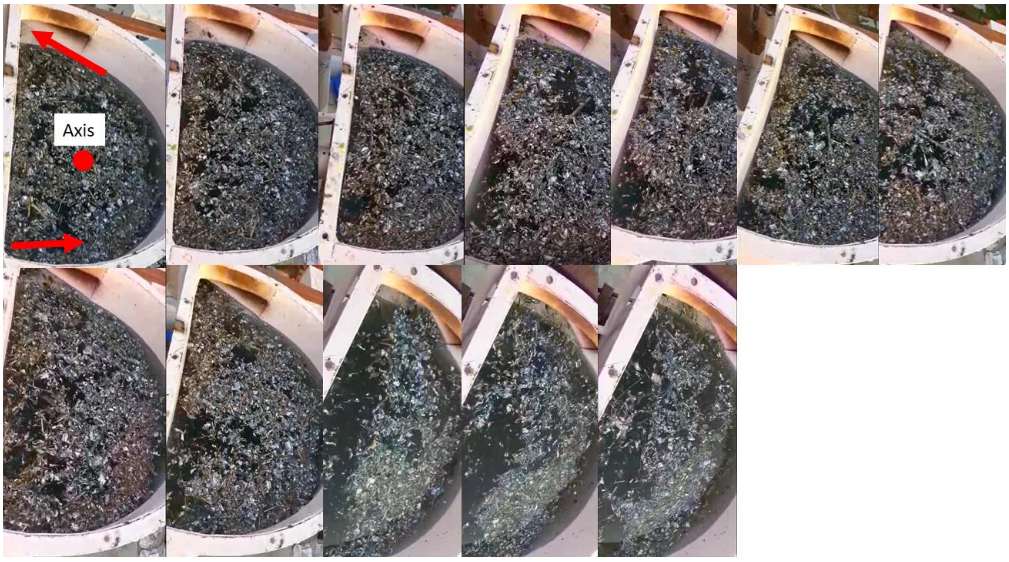


Figure 4-17 Experimental validation of 4th profile

4.4 Design of agitator

As discussed under heading 3.4.5, a double paddle agitator is used to agitate the suspension of mixed MSW into water. In the present work, plates are subjected to bending stress, for which plate thickness is the design criterion. There were three different designs tested against the developed stress under the environment of CAE and also by mathematical approach. The results are discussed below:

- Plate -1 (200 X 50 X 3): Figure 4-18 shows the CAE analysis of the agitator blade, in which equivalent stress (i.e., 1643 MPa) is more than the yield tensile strength of the material (i.e., 370 MPa), hence the dimension was considered as the failed design. Thus it was required to enhance the thickness and analyze the equivalent stress again.
- Plate -2 (200 X 50 X 5): Figure 4-19 shows the CAE analysis of equivalent stress of the plate, where the stress value (i.e., 637 MPa) was lesser than the previous design but still more than the yield limit. Hence the dimension was revised again to achieve a safe design.
- Plate -3 (200 X 50 X 8): As shown in Figure 4-20, plate thickness was revised to 8 mm, which caused the stress value (269 MPa) under the material's yield limit.

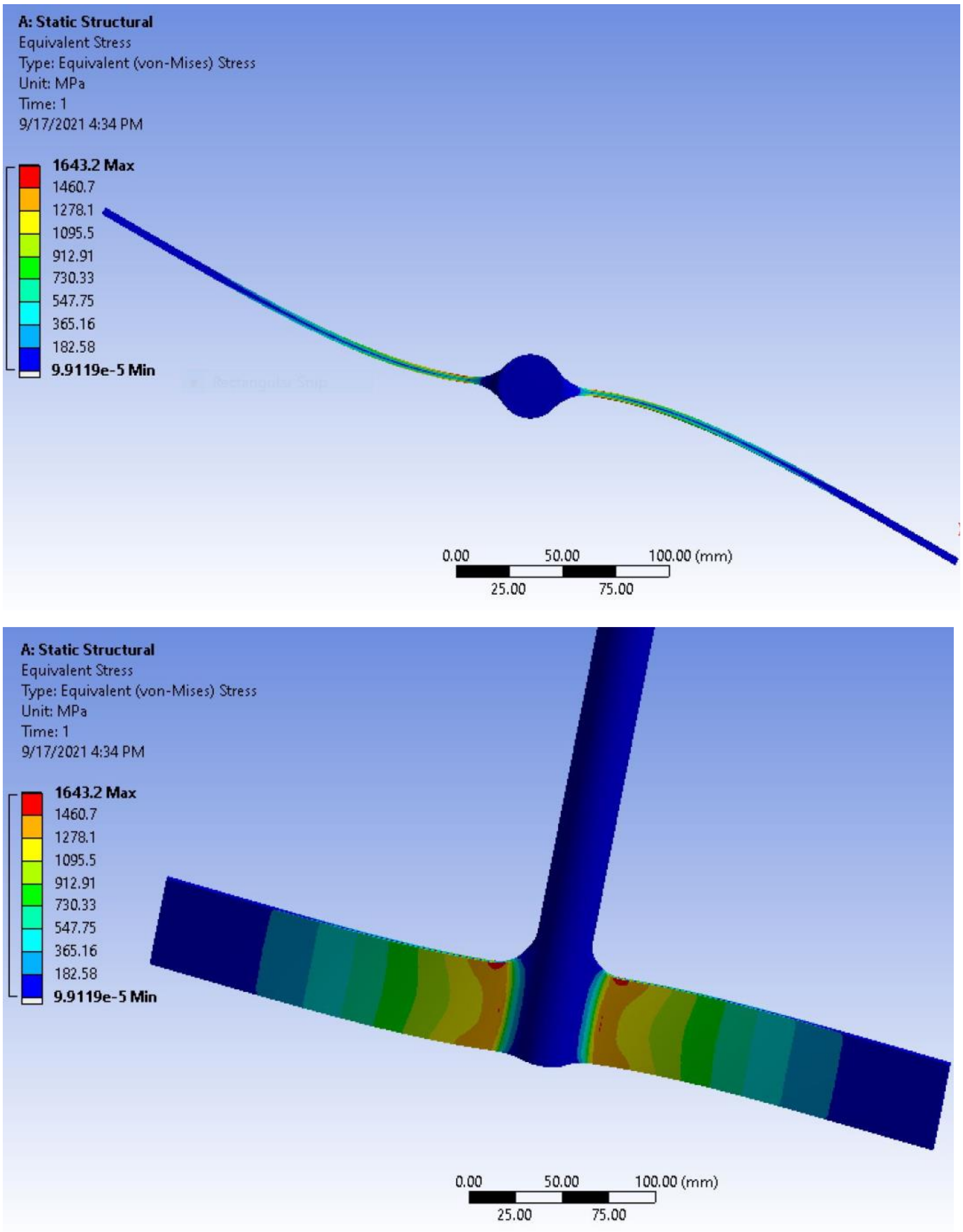


Figure 4-18 CAE analysis of plate-1 (200 cm X 50 cm X 3cm)

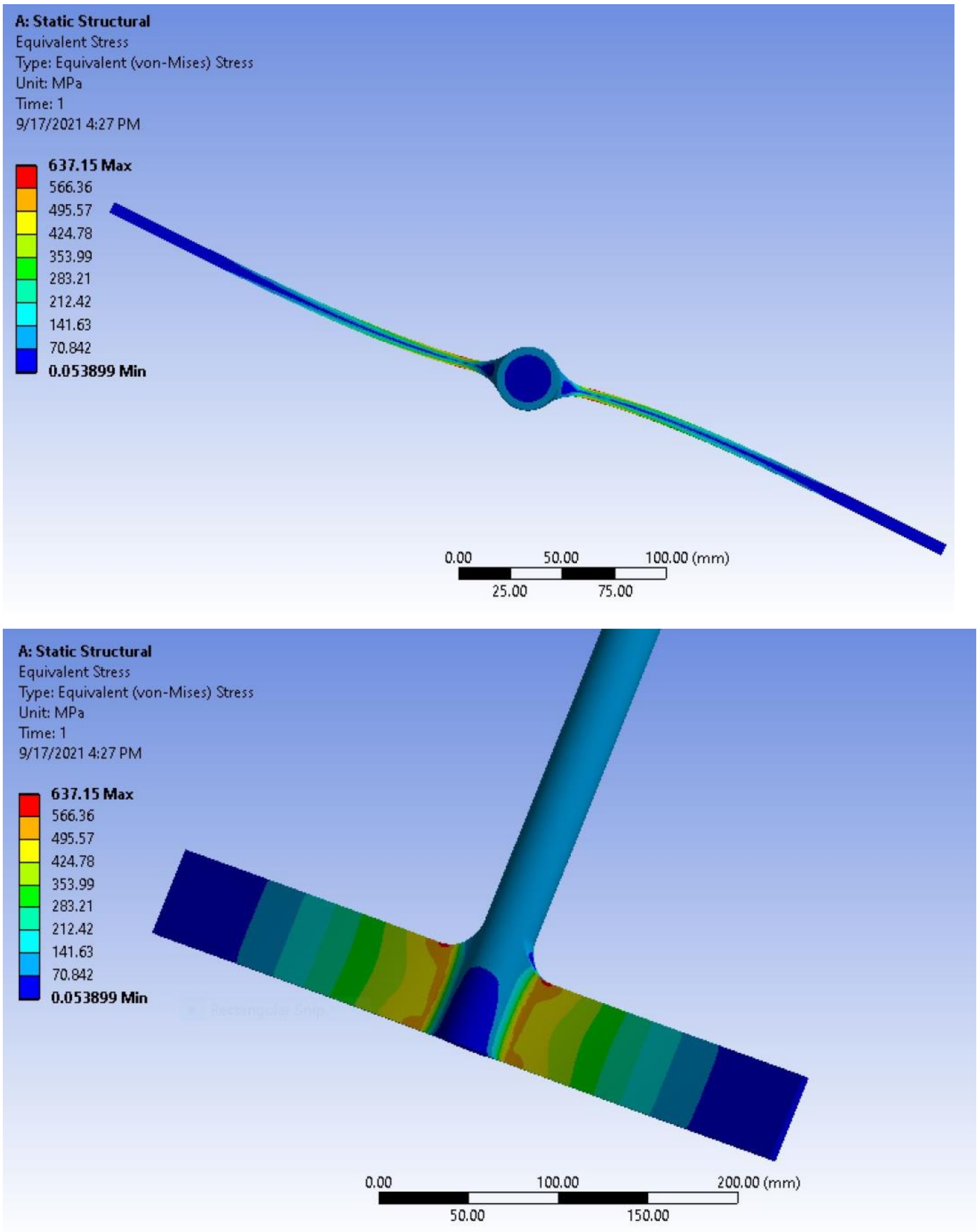


Figure 4-19 CAE analysis of plate-2 (200 cm X 50 cm X 5 cm)

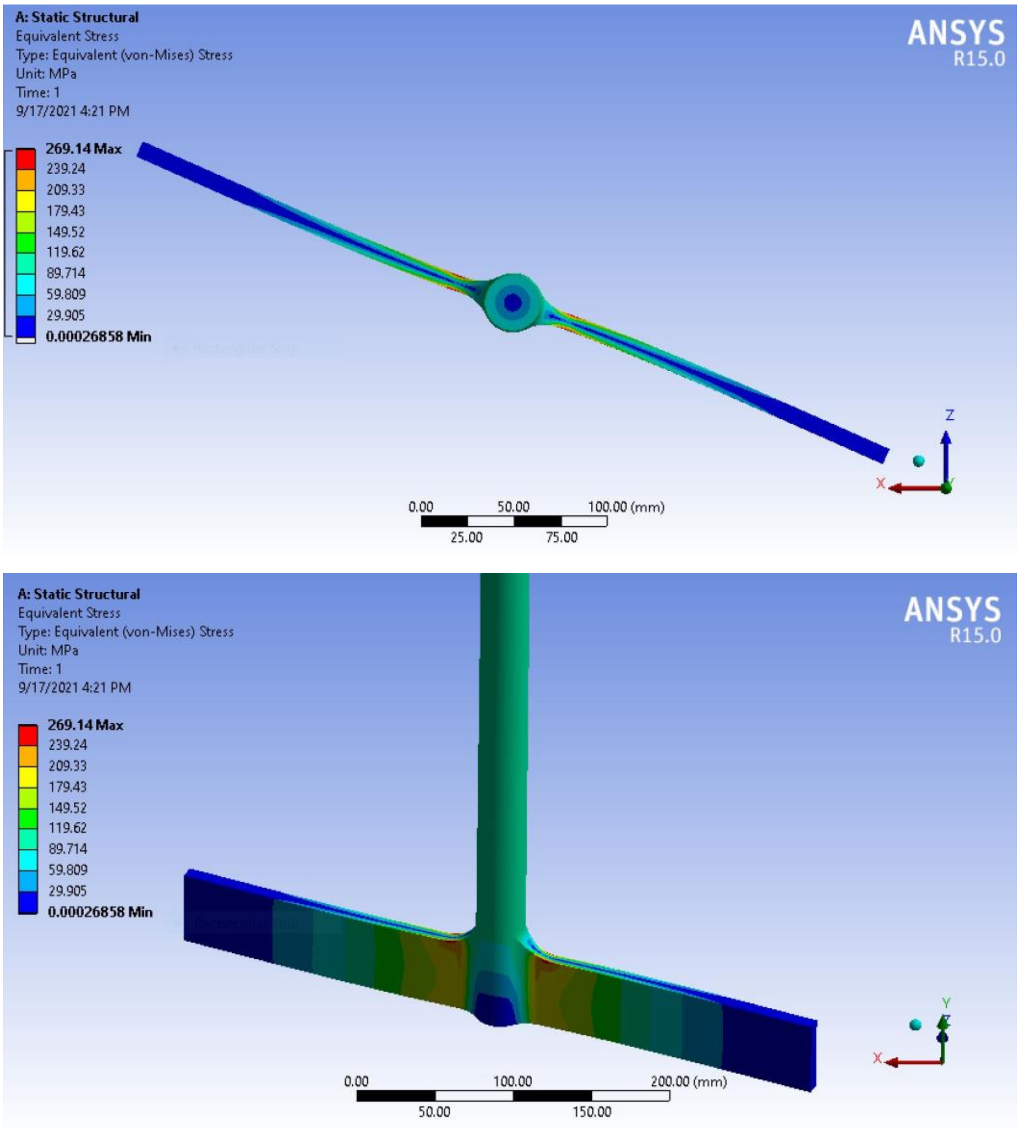


Figure 4-20 CAE analysis of plate -2 (200 cm X 50 cm X 8 cm)

All three thickness was analyzed mathematically against the bending stress. The calculated stress values were compared with the allowable stress (i.e., 61.66 N/mm^2) and discussed below:

- For agitator plate 200 X 50 X 3, σ_b = 137 N/mm^2, which is greater than the allowable limit.
- For agitator plate 200 X 50 X 5, σ_b = 87 N/mm^2, which is greater than the allowable limit.

For agitator plate 200 X 50 X 8, σ_b = 34 N/mm^2, which is under the allowable limit.

All the equivalent stress and bending stress values are plotted on a curve as shown in Figure 4-21, which reflects that the agitator blade with thickness 8 mm was found safe to use for the segregator.

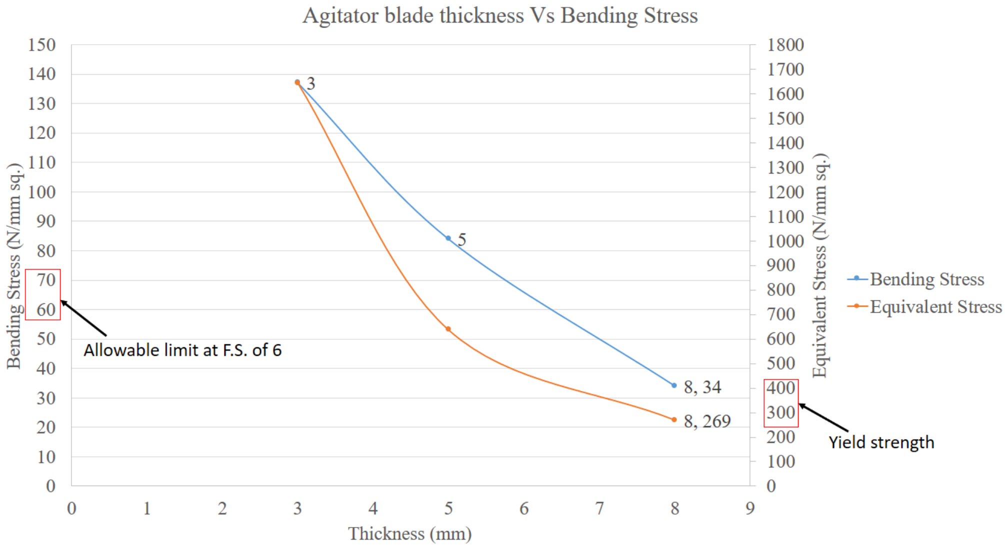


Figure 4-21 Stress analysis of agitator blades

4.5 Performance evaluation and optimization of prototype segregator

Based on a preliminary lab test of sink & float separation approach on mixed MSW, a prototype segregator was developed for the capacity of 5 kg waste. Therefore, it was essential to examine the performance, working range of inputs and outputs, and its optimization. These data are useful to develop the operational procedure for future application. Various phases of experimentations are discussed below:

4.5.1 Phase: 1 - Acquaintance to prototype segregator and its process

Segregation of plastic waste: The segregation process starts with the recovery of waste plastic as it floats over the water surface. The extra amount of water causes the overflow, which carries the floating plastic waste also. The detailed analysis of recovery starts with the assessment of moisture content by using the oven drying method.

Assessment of moisture in the recovered plastic waste: To determine the moisture content added in the recovered quantity of waste, a fresh sample of 100 gms of shredded waste plastic has been checked for its moisture content by using a moisture meter), which shows the reading of .5 initially (before sink & float process). Sample of 100 gms segregated waste plastic was captured post sink & float separation process again, for which moisture meter reading was 2.5. The sample was kept under the oven drying process until moisture reached its previous value, i.e., .5. Figure 4-22 shows that the weight of the sample comes down from 100 gms to 98 gms. Hence segregation process adds 2 % moisture to waste plastic.

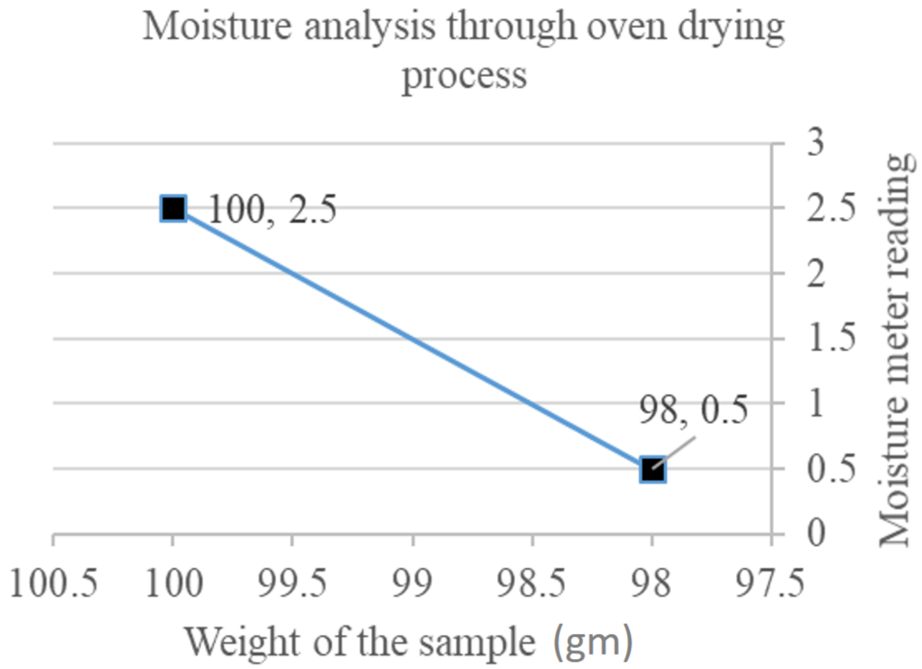


Figure 4-22 Analysis of moisture in recovered waste plastic through the oven drying process

Recovery analysis of plastic waste: During the recovery cycles, it is observed that the larger particles show it's accumulation (Figure 4-23) in the vicinity of the overflow line and affect the movement of remaining floating contents along with the water. Hence, the further amount of water carries away the floating content in bulk, reflecting that the recovery rate of large particles is higher than the small particles, as the small size particles don't get accumulated and move freely over the water surface.

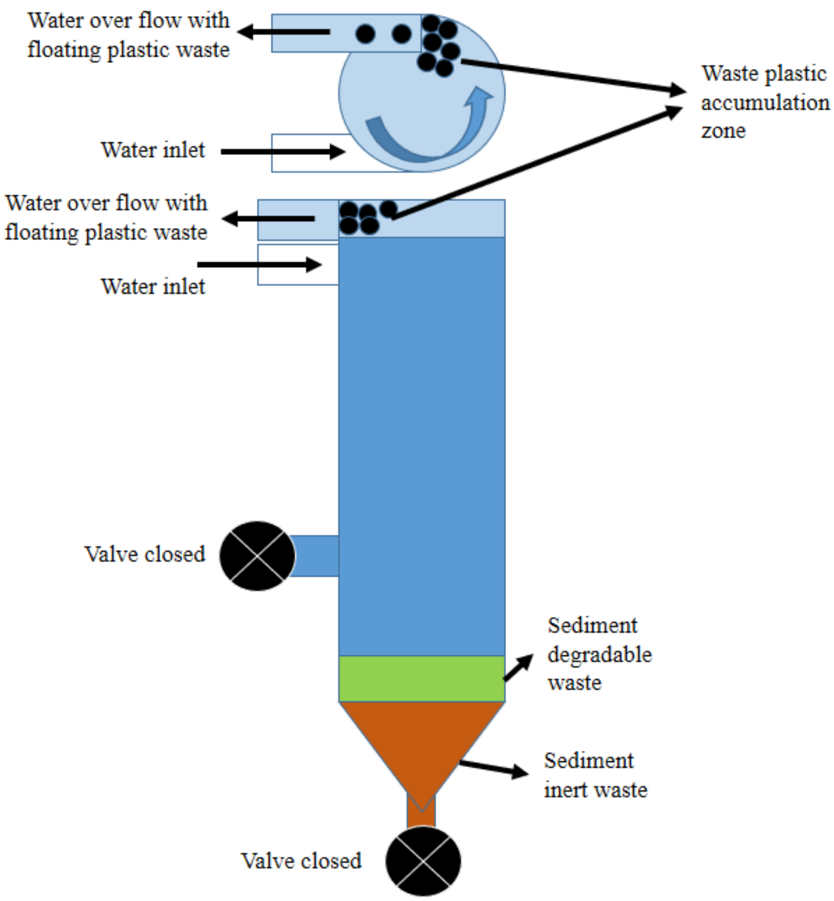


Figure 4-23 Segregation and recovery of waste plastic

Figure 4-24 & Figure 4-25 shows that the recovery of plastic waste depends on the size of the shredded particles and the amount of overflow water, which removes the floating content. The sample of larger particle size (5.5 cm) shows higher recovery than the sample of the smaller particle (3 cm) because smaller particles are generally lost into the stream or trapped into mass of other waste, i.e., degradable or inert. Due to the nature of accumulation, the sample of particle size of 5.5 cm shows the recovery of 81 % with the utilization of 453 L, whereas the waste plastic sample of 3 cm shows the recovery of 66 % with the utilization of 418 L of water (Figure 4-25), as a smaller particle has the lower tendency to get accumulated. Hence due to the same, a sample of 5.5 cm particle size shows the higher recovery rate, i.e., 2.3 g/L in the initial stage of the segregation process where the amount of water utilized was recorded as 100 L (Figure 4-25), then it falls with the further flow of water because particles accumulate near the outlet line. Such accumulation causes a surge in recovery, and particles are recovered at a higher rate, i.e., 2.8 gm/L.

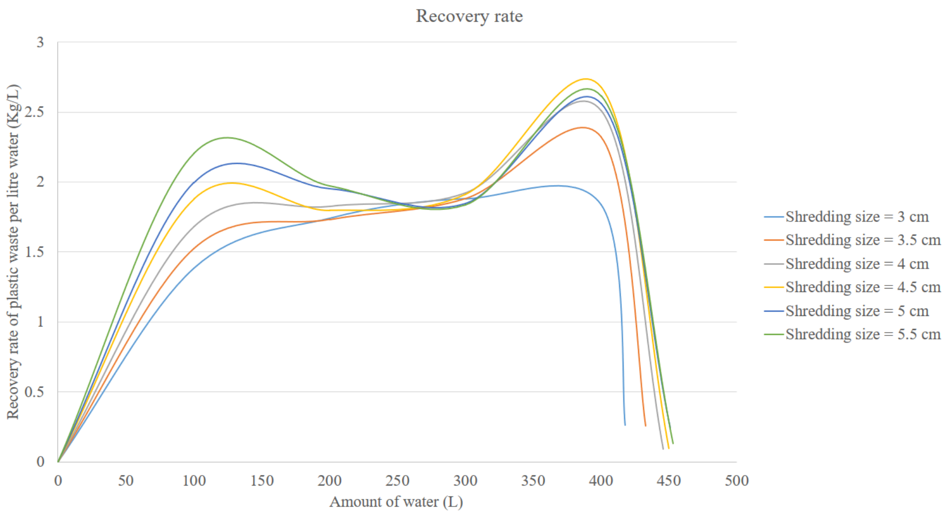


Figure 4-24 Recovery rate of plastic waste Vs Amount of water

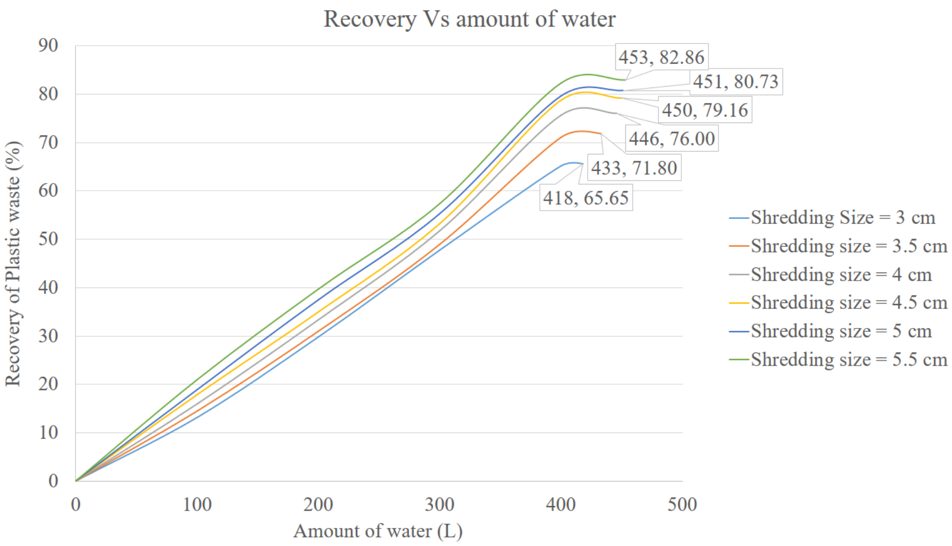


Figure 4-25 Percentage recovery Vs Amount of water

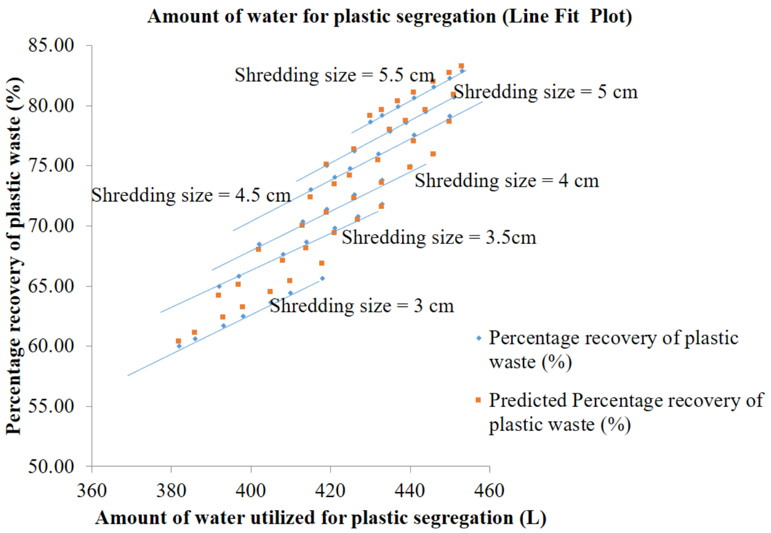
Based on all the observations, a correlation equation has been developed (Equation 4-1) through regression analysis and projected the line fit plot against the recovery with the amount of water and shredding size (Figure 4-26 & Figure 4-27), which reflects that increase in particle size along with the additional amount of water, improves the recovery. Sample of waste plastic containing particles of 3 cm reported the recovery between 60 to 65 % with water utilization ranging from 380 to 420 L. In comparison, a sample of 5 cm particles reported the enhanced recovery in-between 80 to 85 %, with water utilization varied from 430 to 450 L.

Recovery of plastic waste :

$R_P (\%) = .179858W_P + 4.042951S_P – 20.468$ Equation 4-1

Where W_P is the amount of water consumed for the recovery of waste plastic and S_P is the shredding size of the waste plastic.

The residual values are the difference between the predicted and actual value of the percentage recovery of plastic waste, which varies from -1.5 to +1. Analysis of residual values shows that the variation can be minimized with the further increase of particle size and also the amount of water. Such residual values are the effect of the accumulation of shredded plastic (as an external factor) around the vicinity of the overflow line, which cannot be controlled during the operation.



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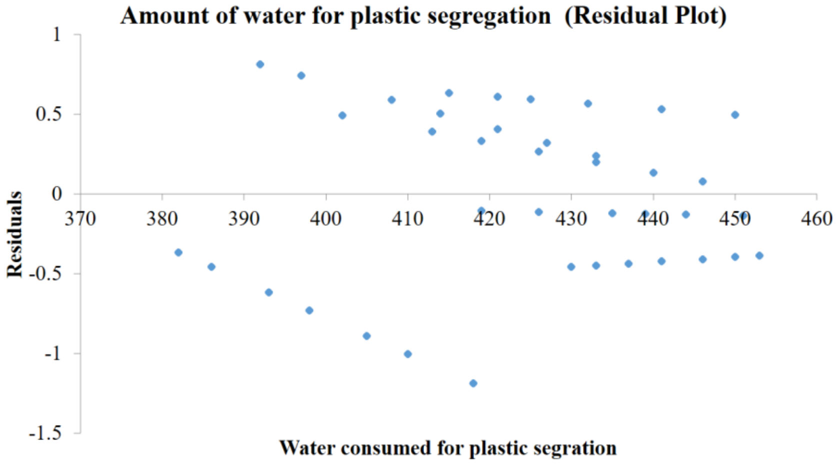
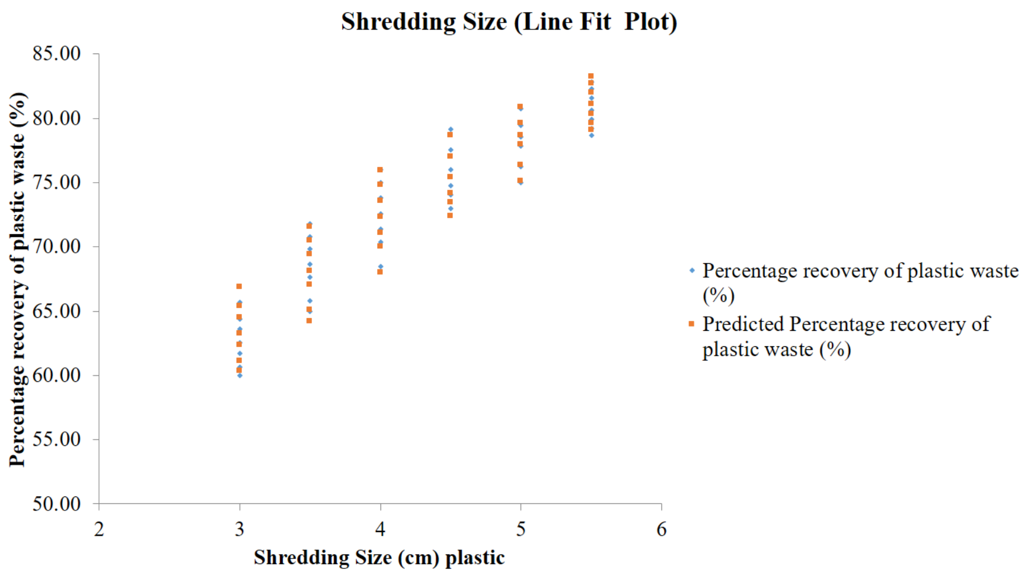
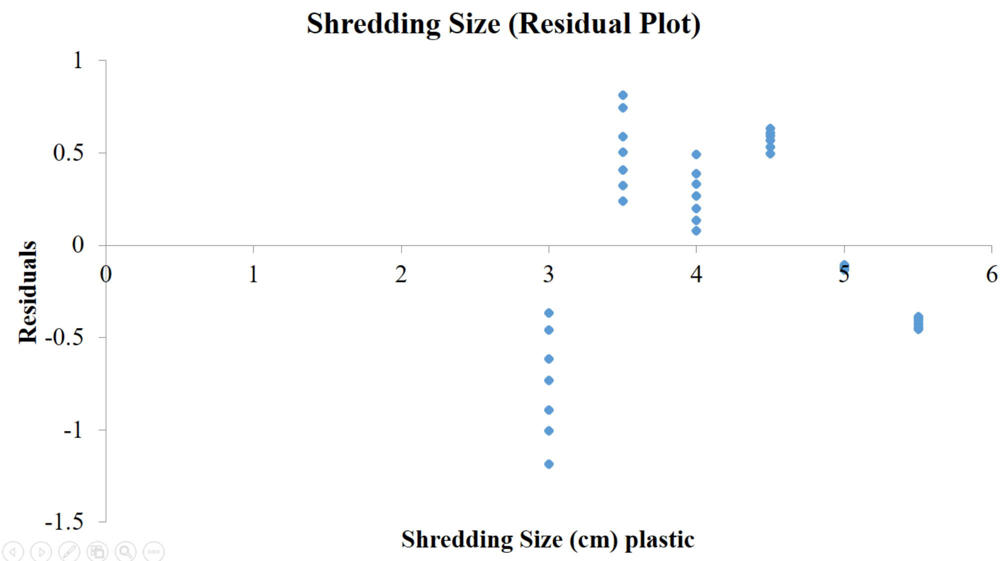


(B)

Figure 4-26 Recovery Vs Amount of water (A) Line fit & (B) Residual plot through regression analysis



(A)



(B)

Figure 4-27 Recovery Vs Shredding size (A) Line fit & (B) Residual plot through regression analysis

Segregation of degradable waste: Once the floating particles (i.e., plastic waste) get recovered, degradable and inert wastes were the remaining content in the chamber. Agitation causes disturbance in the water column and brings the degradable waste up in the water column.

When the outlet valve (gate valve) is opened gradually, the flow rate is also increased in a gradual manner. Therefore waste gets accumulate around the opening of valves (Figure 4-28). Hence, the system shows higher recovery at the initial stage; it falls afterward due to increased accumulation around the outlet, which also blocks the flow of degradable waste. The amount of accumulation depends upon the particle size, i.e., larger particles accumulate more than the smaller particle. Large accumulation demands more water to clear, which carries out the bulk amount of degradable waste. Therefore the sample with larger particles shows higher recovery with the larger quantity of water.

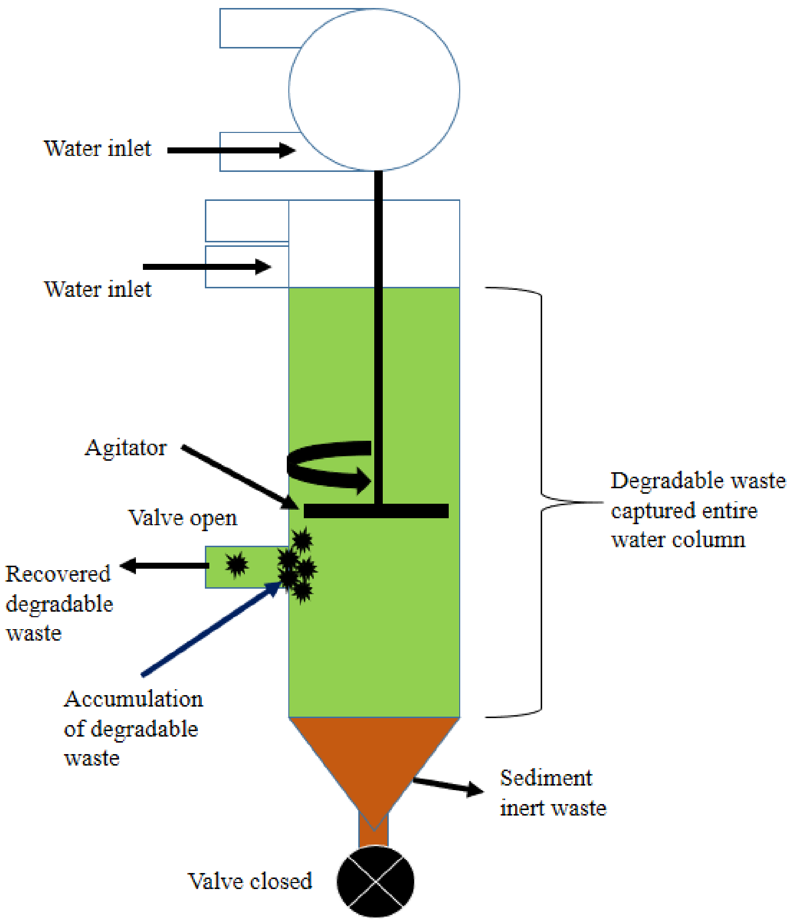


Figure 4-28 Segregation and recovery of degradable waste

Due to the larger area, larger particles face more drag than smaller particles inside the water; the larger particles have a higher area moment of inertia than the smaller particles. Therefore sample with larger particles requires agitation for a duration longer than the same for a smaller particle to overcome the inertia and bring them up in the water column.

Moisture analysis of recovered degradable waste: Recovered degradable waste contains water in it; therefore, a sample of 400 gm was analyzed before and after the segregation. The sample has was inspected through a moisture meter, which shows the reading of 4.2 and 10 pre and post-segregation activity, respectively. Hence the recovered sample was kept in the oven until the temperature reached 100^0C and moisture reached its previous value, i.e., 4.2. Figure 4-29 shows that sample has lost weight from 400 gm to 144. It means the segregation process adds 36 % additional moisture to the recovered degradable waste.

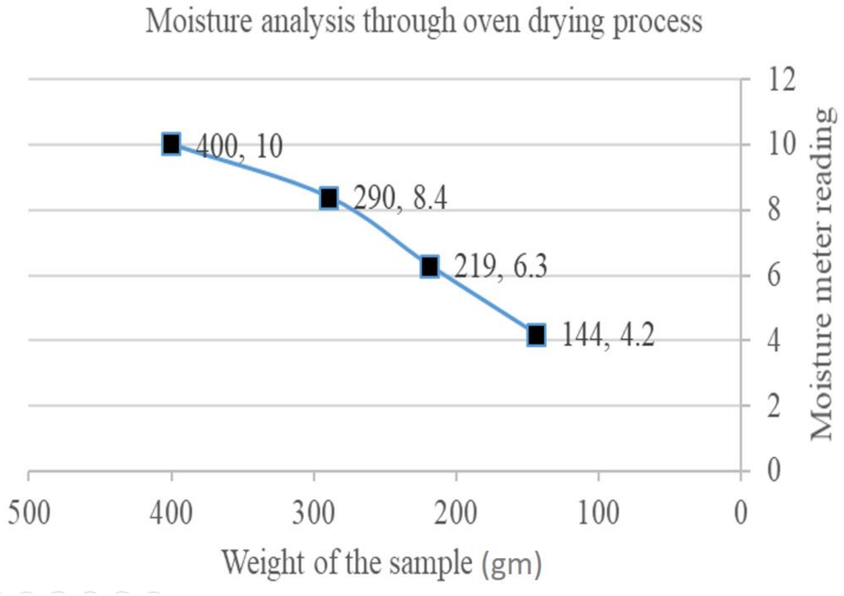


Figure 4-29 Moisture analysis in segregated degradable waste through the oven drying process

Recovery analysis of degradable waste: Figure 4-30 & Figure 4-31 shows that the percentage recovery depends upon the amount of water, the particle size of shredded waste, and the duration of agitation. Degradable waste with a particle size of 1.5 cm reports the recovery as 55 %, carried out by 504 L wate, which is lesser than the same for a waste sample with the particle size of 4 cm. i.e., 72 % recovery with 575 L water. Whereas Figure 4-32 shows that, at the initial stage, the recovery rate was higher between 0 to 100 L, as degradable waste accumulates at the vicinity of the outlet line and gives the bulk recovery. This recovery falls further then rises again due to the phenomenon of accumulation. The sample of smaller particles reports the peak recovery rate as 2.4 gm/L, which is lesser than the peak recovery rate of larger particles, i.e., 4.2 gm/L.

Along with the flow of additional water, agitation helps to prevent the settling of degradable and maintain their presence in the water column. As discussed in the previous paragraph, a waste sample with the particle size of 4 cm was agitated for 47 minutes (Figure 4-31) (agitation started 21 minutes prior to starting the flow of additional water and continued for 26 minutes along with the additional water flow) to recover its maximum possible proportion, i.e., 72 %. In comparison, the sample with a particle size of 1.5 cm was agitated for a comparatively shorter duration, i.e., 35 minutes, as smaller particles face lower drag force and possess a lower moment of inertia.

Agitation and flow of additional water both the inputs that consume electrical power to run a motor; therefore, such inputs are also need to be overlooked from the economic point of view. In Figure 4-32, it is observed that the percentage recovery of degradable waste (in each group of particle size) is noticeable till the system gets 500 L of water, then further flow of water brings out the recovery lesser than 1 %, which is negligible. Hence such an amount of water can be considered as the optimum input to recover the degradable waste. Similarly, in Figure 4-31, agitation of larger particle sample gives the optimum recovery in the initial duration of 43.5 minutes, then it doesn't work at the same rate afterward. Hence such duration can be considered as the optimum input.

Based on all the observations, a correlation equation has been developed (Equation 4-2) through regression analysis.

Percentage recovery of degradable waste

R_D (%) $=0.0304W_D + 0.3106A_D + 5.234S_D + 19.962$ Equation 4-2

Where W_D is the amount of water utilized for the recovery of degradable waste, A_D is the duration of agitation and S_D is the average shredding size of degradable waste.

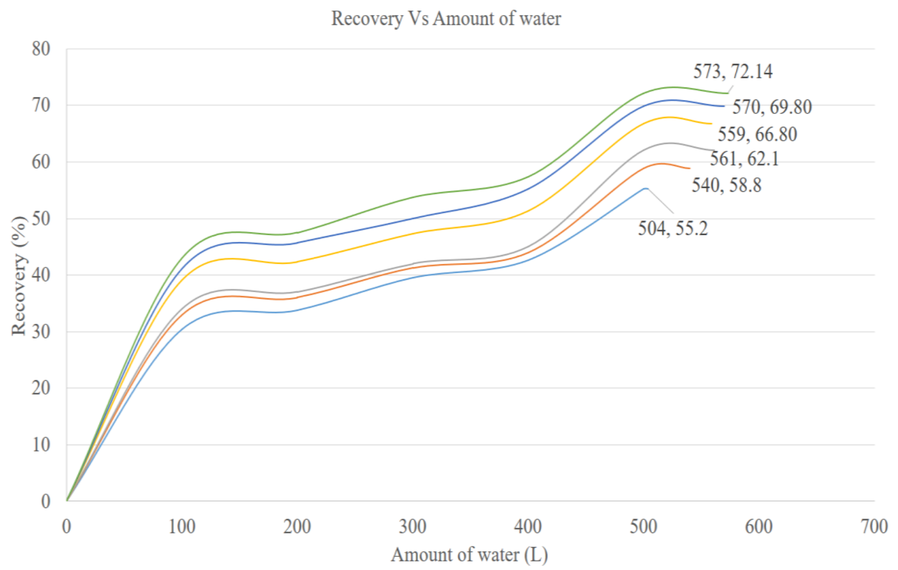


Figure 4-30 Percentage recovery of degradable waste Vs Amount of water

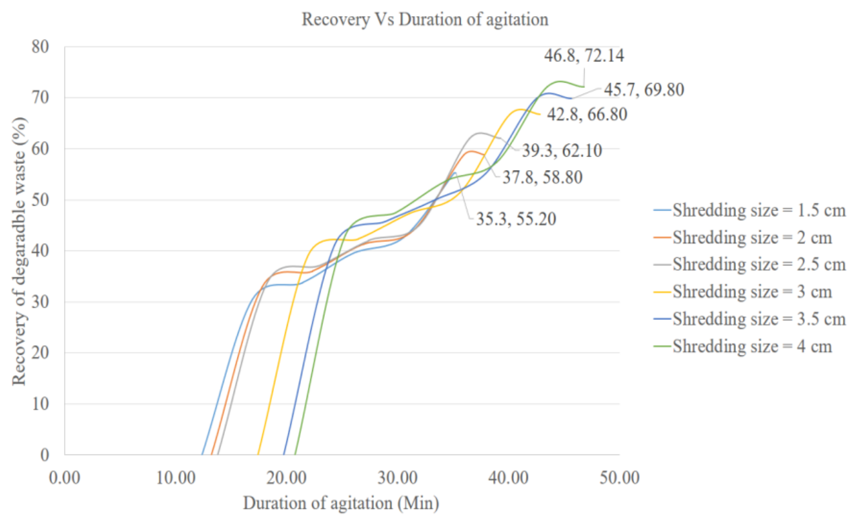


Figure 4-31 Percentage recovery of degradable waste Vs Duration of agitation

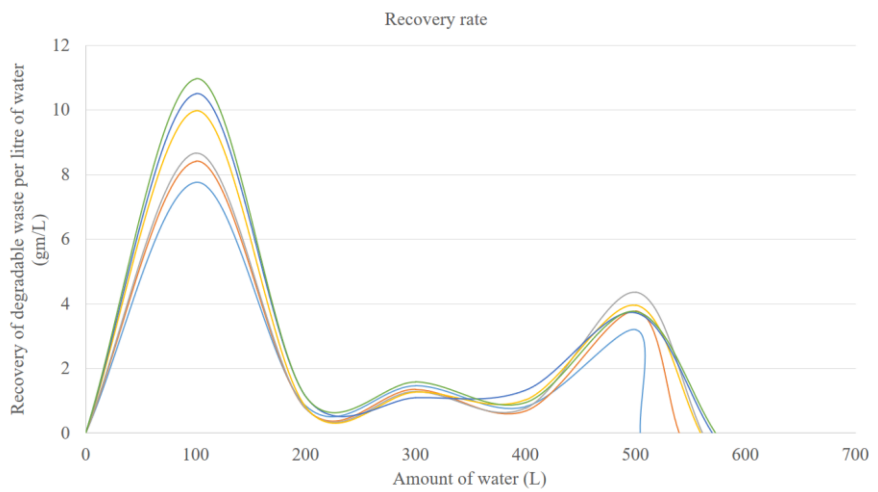
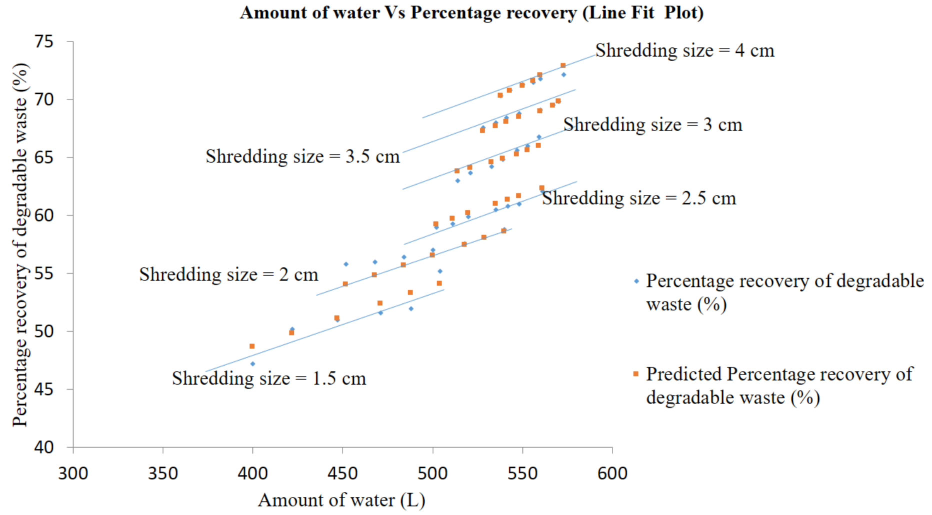


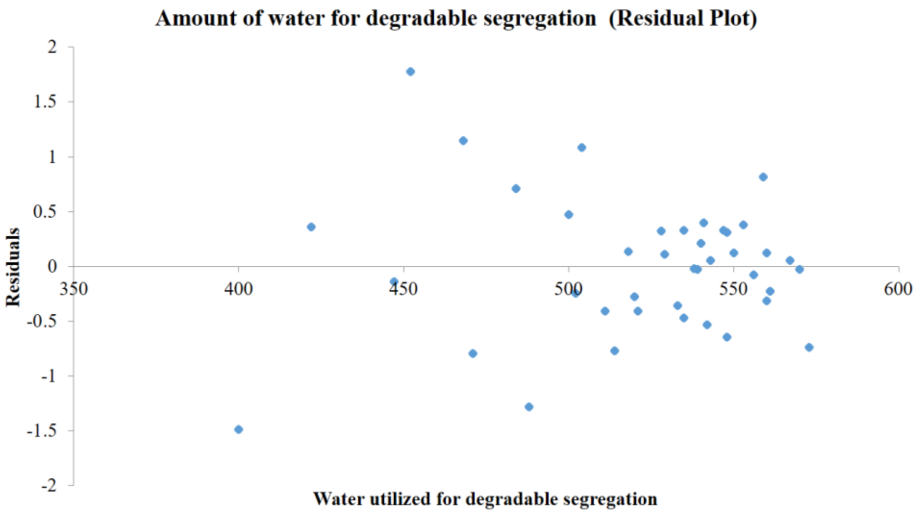
Figure 4-32 Recovery rate of degradable waste Vs Amount of water

The line fit plot (

Figure 4-33) shows that in each group of observations (grouped according to the shredding size), recovery increases linearly with the increase in the amount of water and duration of agitation (Figure 4-34). The residual values are the difference between the predicted and actual value of the percentage recovery of degradable waste, which varies from -2 to +2. Analysis of residual values shows that the variation is being minimized with the further increase in the value of inputs, i.e., amount of water, duration of agitation, and shredding size (Figure 4-35).

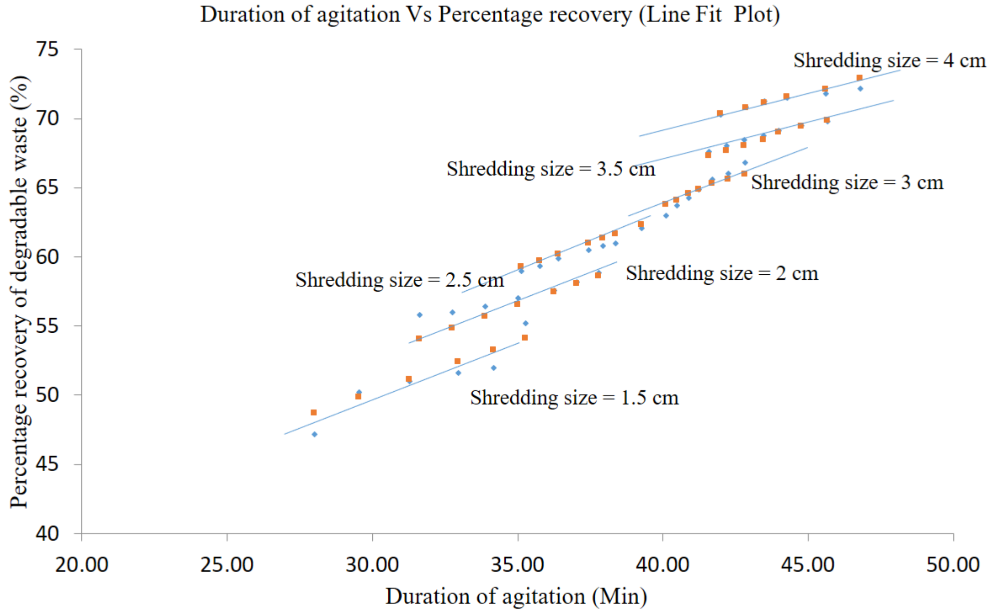


(A)



(B)

Figure 4-33 Recovery of degradable waste Vs amount of water (A. Line fit & B. Residual plot, through regression analysis)



(A)

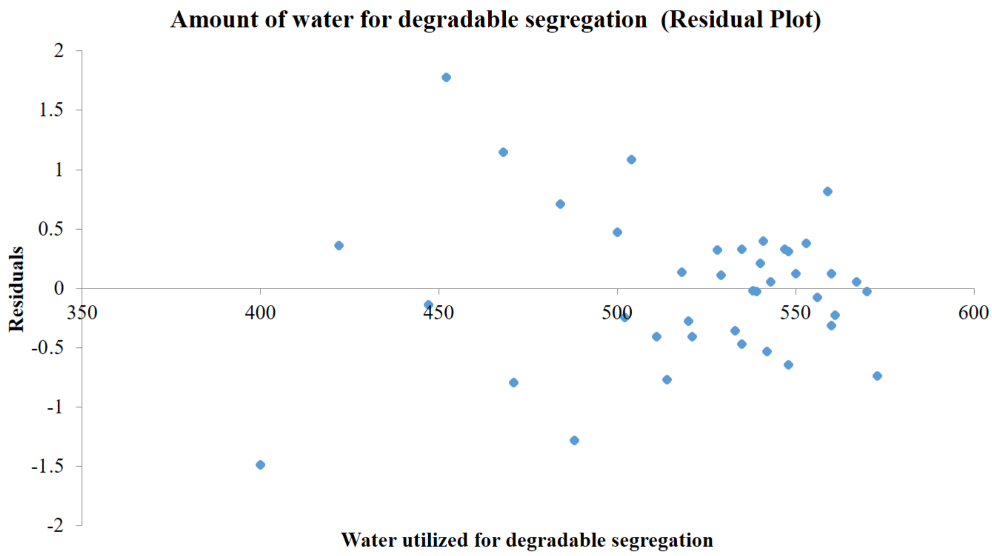


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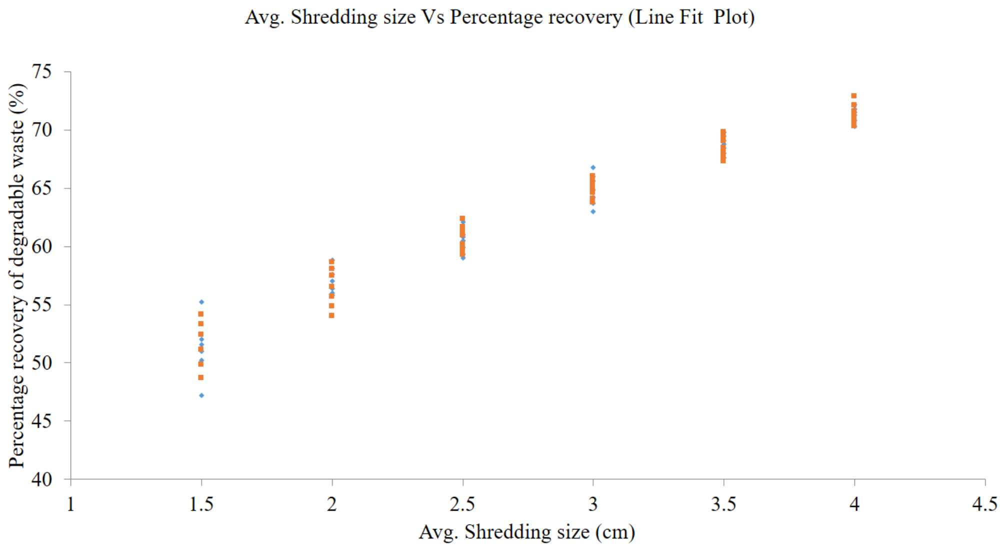
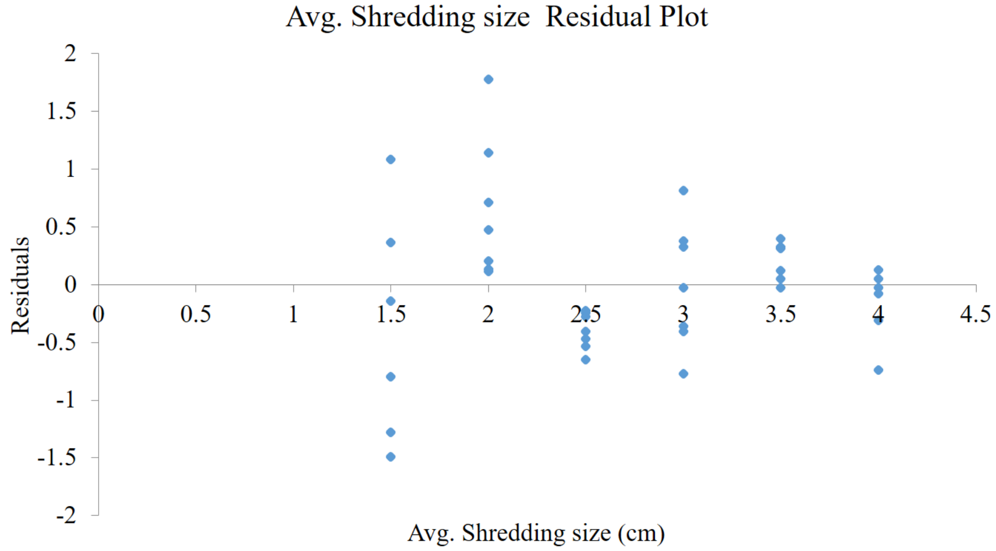
Figure 4-34 Recovery of degradable waste Vs Duration of agitation (A. Line fit & B. Residual plot through regression analysis)



(A)



(B)

Figure 4-35 Recovery of degradable waste Vs Shredding size (A) Line fit & (B) Residual plot through regression analysis

Recovery of inert waste : After the recovery of plastic and degradable waste, inert waste is the only leftover in the water column. Due to higher specific density, inert waste gets settle at the bottom of the chamber, which can be recovered from the outlet given at the bottom of the chamber. Prior to recovery analysis, moisture assessment is done through the oven drying process. A sample of inert waste shows a 2.2 unit reading on the moisture meter before it is processed for sink & float. Figure 4-36 shows a sample of 400 g of sink & float processed inert waste shows a 9 unit reading on a moisture meter. It lost

360 g of moisture to get back to previous moisture content status, i.e., 2.2 units on the moisture meter.

A regression analysis was performed on all observations, which established a correlation equation, line fit plot between shredding size and recovery, and residual plot.

The percentage recovery of inert waste, $R_I = 20.15S_I + 4.064$ Equation 4-3

Where S_I is the average shredding size of the inert waste.

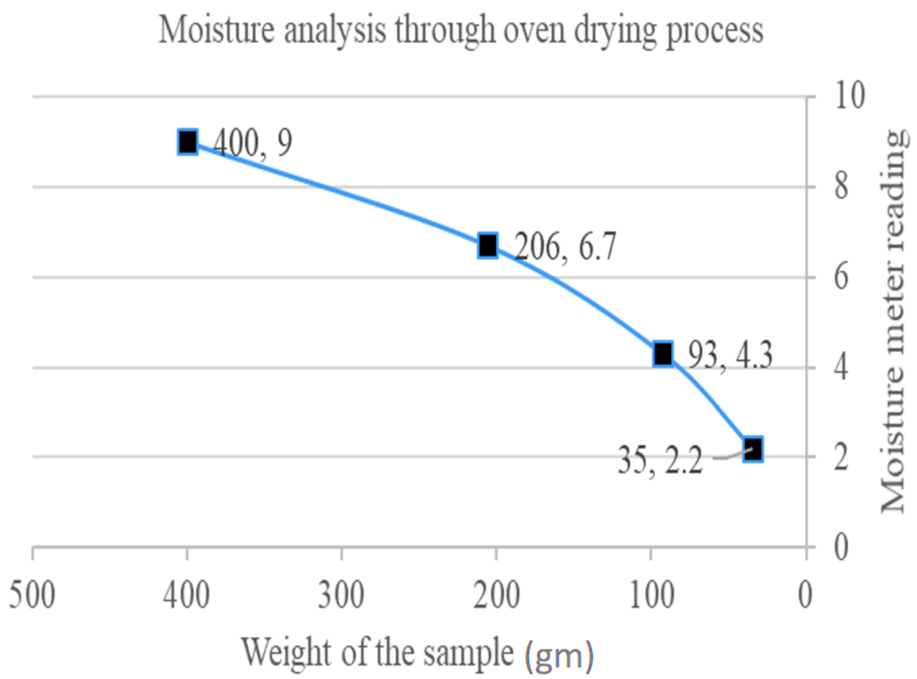
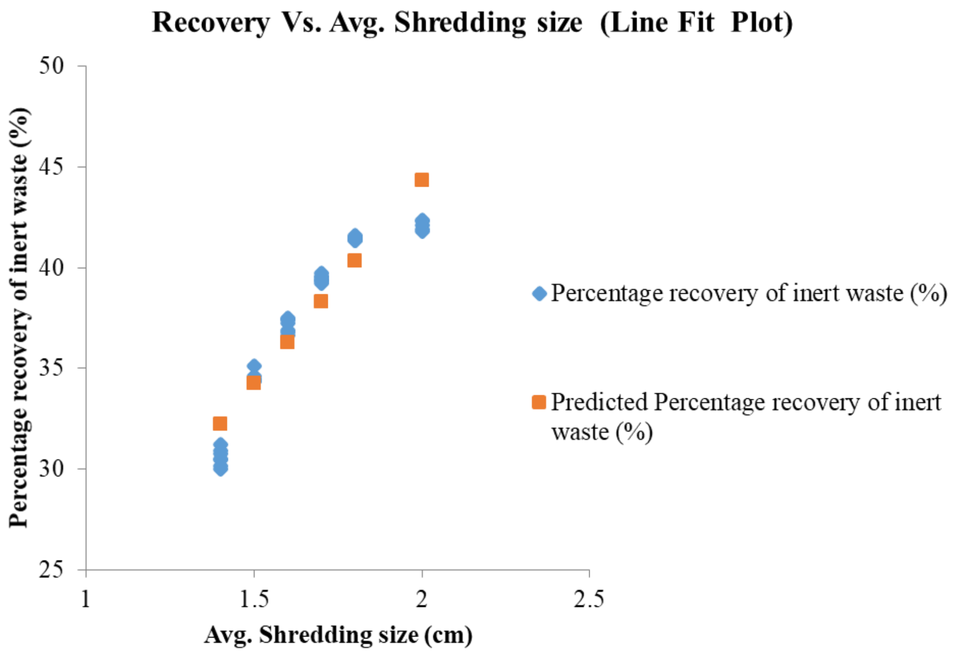


Figure 4-36 Post sink & float moisture analysis of inert waste

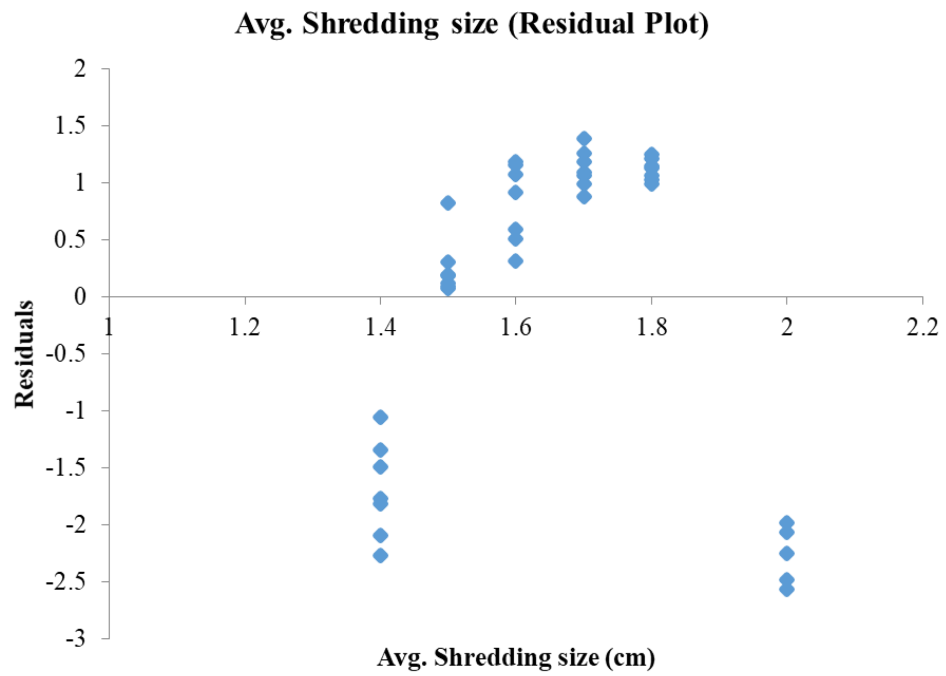
Figure 4-37 shows that the percentage recovery of inert waste is directly proportional to the size of shredded particles. The six-stage shredding reduces the size from 2 to 1.5 cm. The sample of larger particles shows a higher recovery (i.e., 42 % average) than the sample of smaller particles (i.e., 30.5 % average). The residual plot shows the variation between the experimental model and the predicted model. In that plot, residuals vary from 1.5 to -3, and such variations are due to the presence of dust particles even if the sample is classified under the range of larger particles; hence it cannot be controlled.

For further investigation, one more sample has been tested, in which only ceramic and glasses are considered in single-stage shredded form, and particle size was 2 cm. Figure 4-38 shows that the additional sample reported a rapid hike in the recovery (90%), as there were no dust and sand particles;

therefore, the loss was less. The single-stage shredding of ceramic and glass causes the formation of dust particles (6 – 9 % of the total weight of sample) of smaller sizes, which also gets lost during the segregation process.



(A)



(B)

Figure 4-37 Recovery of inert waste (A. Line fit plot & B. Residual curve, through regression analysis)

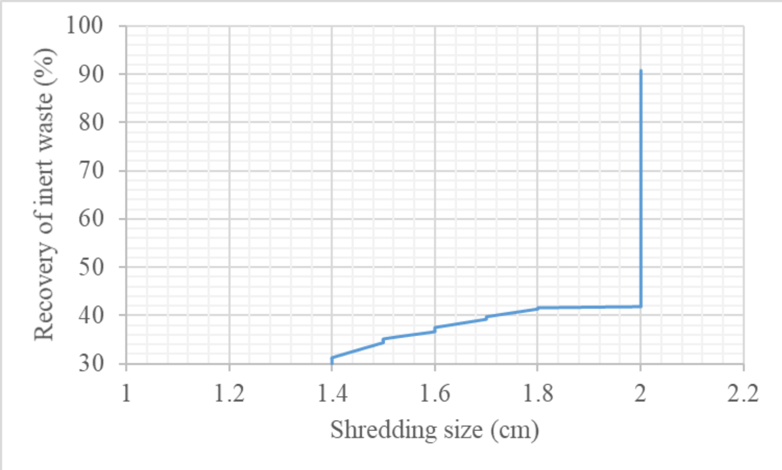


Figure 4-38 Recovery of inert waste sample containing only shredded glass and ceramics

4.1.2 Phase: 2 – Process Optimization

Design of experiment for plastic waste: A 5 level data set was prepared (Table 4-3) through the design of the experiment, for which the range of inputs was considered from the phase 1 experiments. With each input data set, a varied amount of waste plastic was recovered from the segregator. To find out the optimum recovery, outputs were further analyzed in terms of comparison with the total power consumption during the process. In the process of waste plastic recovery, electrical power is consumed in the pump (1 HP) for water supply and for shredding the waste (3 HP).

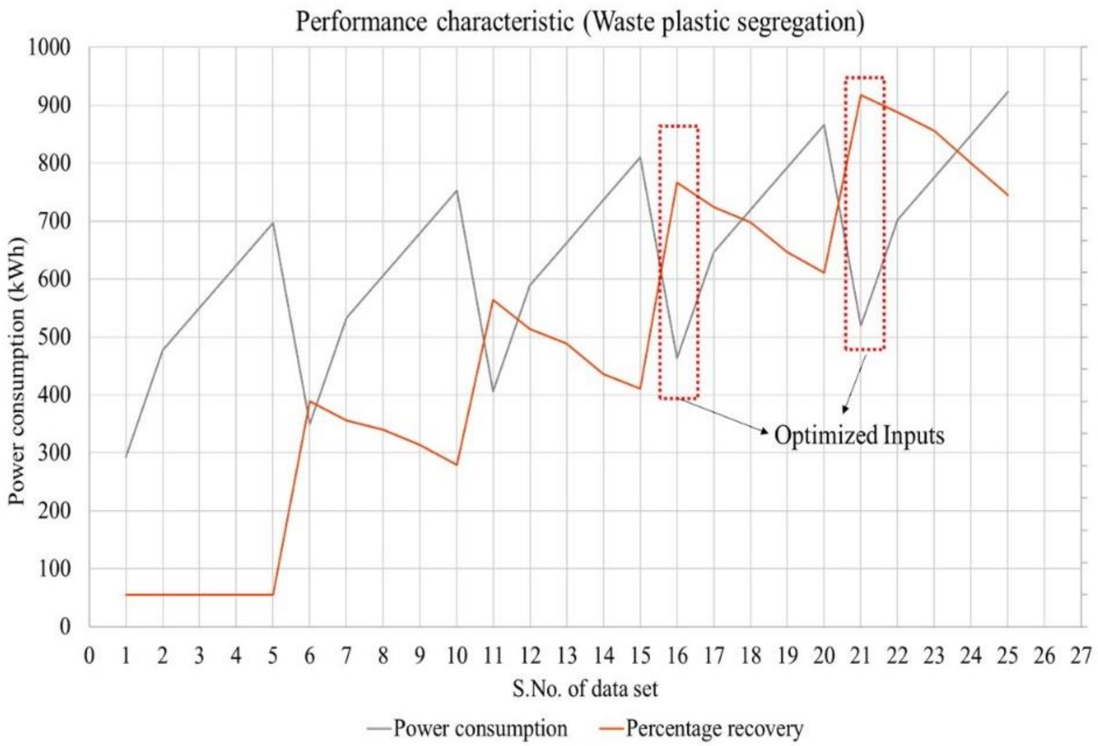
Table 4-3 DOE for plastic waste

Level	Amount of water (L)	Shredding Size (cm)
Level 1	0	3
Level 2	100	3.5
Level 3	200	4.5
Level 4	300	5
Level 5	400	5.5

Figure 4-39 shows the plot of:

- Percentage recovery and
- Input power

The plot is analyzed to find the optimum point where recovery is high with reference to input power. On data set no. 21, recovery of waste plastic is 78 %, with a total power input of 519 kWh. Therefore sample of 5.5 cm particle size shows maximum recovery with the input of 400 L water.



S. No.	Amount of water (L)	Shredding Size (cm)
1	0	5.5
2	0	5
3	0	4.5
4	0	3.5
5	0	3
6	100	5.5
7	100	5
8	100	4.5
9	100	3.5
10	100	3
11	200	5.5
12	200	5
13	200	4.5
14	200	3.5
15	200	3
16	300	5.5
17	300	5
18	300	4.5
19	300	3.5
20	300	3
21	400	5.5
22	400	5
23	400	4.5
24	400	3.5
25	400	3

Figure 4-39 Power input Vs Recovery of plastic waste

Design of experiments for degradable waste: On the basis of input ranges opted from the phase one experimentations, a 5 level of design of experiment has been prepared as shown in Table 4-4. With each input data set, varied amount of degradable waste has been recovered from the segregator. To find out the optimum recovery, outputs are further analyzed in terms of comparison with the total power consumption during the process. The electrical power is consumed in the pump (1 HP) for water supply, .5 HP DC motor for agitation, and for shredding the waste.

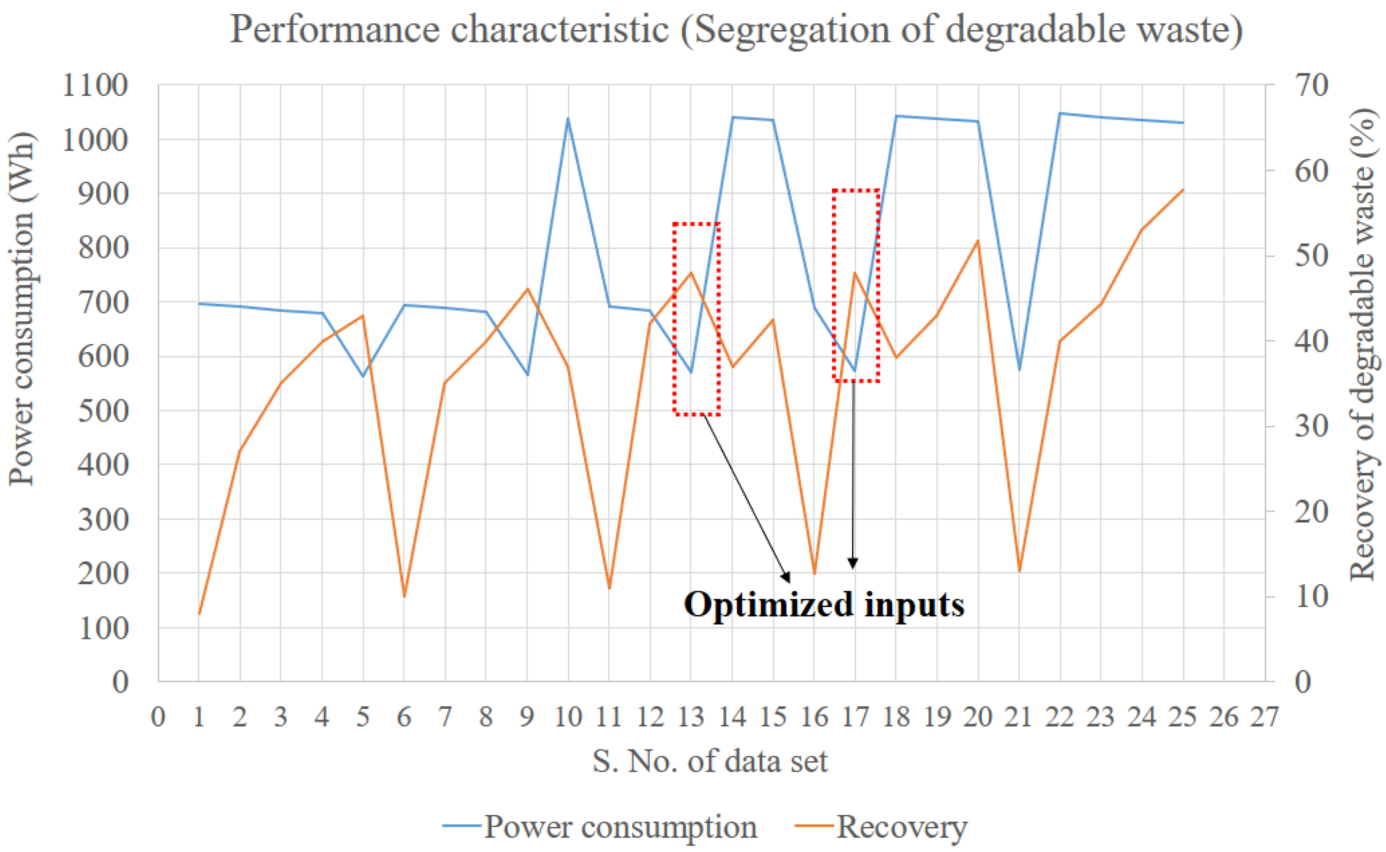
Table 4-4 DOE for degradable waste

Level	Amount of water	Duration of agitation	Shredding size
Level 1	0	0	1.5
Level 2	125	10.9	2
Level 3	250	21.8	3
Level 4	375	32.6	3.5
Level 5	500	43.5	4.0

Figure 4-40 shows the comparative plot among the following parameters:

- Percentage recovery and
- Input power

The plot was analyzed to find the optimum point where recovery is high with reference to input power. On dataset no. 17, recovery of degradable waste is 48 % with a total power input of 573 kWh; hence their ratio is 8.37. Whereas on dataset no. 13, recovery of degradable waste is 48 % with a total power input of 569 kWh and their ratio is 8.43. Therefore sample of 4 cm particle size shows optimum recovery with the input of 250 L water and 21.8 minutes of agitation (agitation needs to start 10.5 minutes prior to the start of water flow).



S. No.	Amount of water (L)	Duration of agitation (min)	Shredding size (cm)
1	0	0	1.5
2	0	10.9	2
3	0	21.8	3
4	0	32.6	3.5
5	0	43.5	4
6	125	0	2
7	125	10.9	3
8	125	21.8	3.5
9	125	32.6	4
10	125	43.5	1.5
11	250	0	3
12	250	10.9	3.5
13	250	21.8	4
14	250	32.6	1.5
15	250	43.5	2
16	375	0	3.5
17	375	10.9	4
18	375	21.8	1.5
19	375	32.6	2
20	375	43.5	3
21	500	0	4
22	500	10.9	1.5
23	500	21.8	2
24	500	32.6	3
25	500	43.5	3.5

Figure 4-40 Power input Vs Recovery of degradable waste

4.1.3 Phase: 3 - Segregation of MSW with a varied proportion of waste components:

Table 4-5 shows the various samples in which proportions of degradable, plastic, and inert waste have been varied, and their segregation process is performed with the optimum inputs identified in the previous experiments, and the performance of the segregation is analyzed further.

Table 4-5 Sample of MSW with the varied proportion of category

Composition of degradable waste	Composition of plastic waste	Composition of inert waste	Total percentage of waste	Amount of MSW (Kg)
85	50	0	135	6.75
80	45	0	125	6.25
75	40	0	115	5.75
70	35	0	105	5.25
65	30	5	100	5
60	25	15	100	5
51	21	28	100	5
40	15	45	100	5
35	10	55	100	5
30	5	65	100	5

Plastic waste reported 78 % recovery with the optimum inputs when its proportion was according to the standards, i.e., 21%. Figure 4-41 shows that recovery of plastic waste falls with the further increase in the percentage proportion. Due to the higher amount of floating plastic over the water surface, the tangential flow of water is obstructed (the water inlet is located on the top of the chamber), which slows down the movement of floating particles. Figure 4-42 shows that the water flow rate falls down with the increase in percentage proportion of waste plastic.

Figure 4-41 shows that recovery of degradable waste also falls with the increase in its percentage proportion. It occurs due to the increasing amount of degradable waste in the water column, which slows down the speed of the agitator; hence very less amount of degradable waste reaches the elevation of the outlet. Figure 4-43 shows that in each observation, the RPM of the agitator falls with the increase in percentage proportion of degradable waste.

Similarly, Figure 4-41 also shows that the percentage recovery of inert waste falls with an increase in its percentage composition, as more inert gets accumulated over the vertically aligned drain line, which obstructs the flow of water and carries out the lesser amount of inert waste.

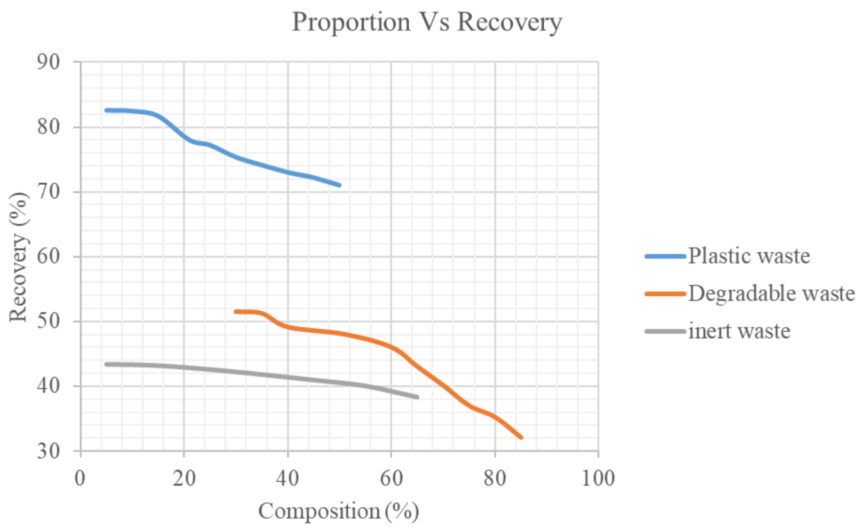


Figure 4-41 Segregation performance with the varied proportion of waste components

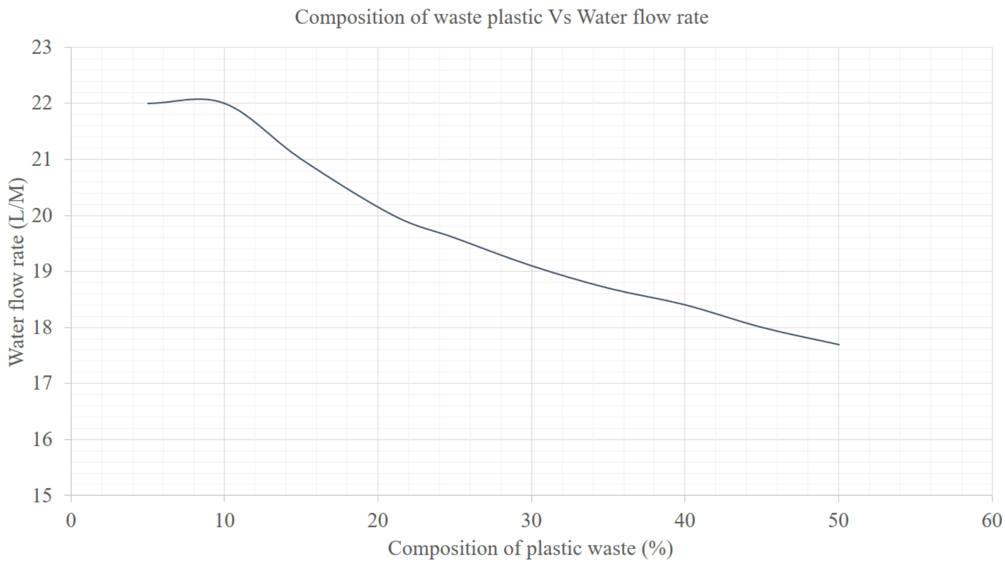


Figure 4-42 Water flow rate Vs Composition of plastic waste

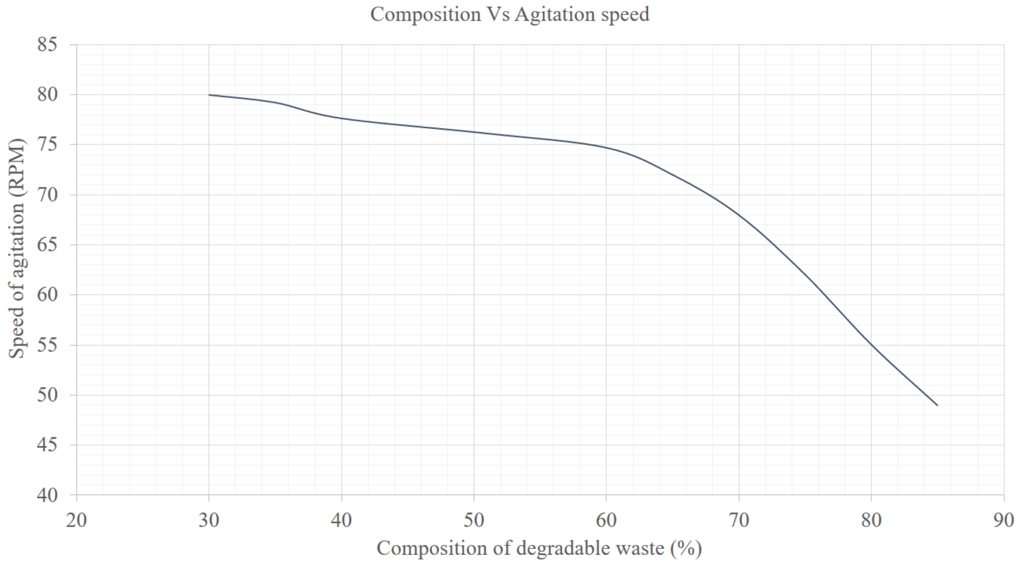


Figure 4-43 Speed of agitation Vs. Composition of degradable waste

4.4 Overall segregation performance

The overall segregation performance of a density difference-based separation process was evaluated using the separation/partition curve. In the literature review, Figure 2-13 shows the ideal separation curve, according to which recovery depends upon the relative density and particle size of the contents to be separated. Higher or lower specific gravity may show higher recovery on sink and float streams, respectively; it depends on their particle size. Smaller particles report lower recovery, as they may be lost into the streams, whereas larger particles report higher recovery. Therefore recovery increases with the increase in particle size.

The overall performance of the segregation process with the optimized input parameters is evaluated through the separation curve shown in

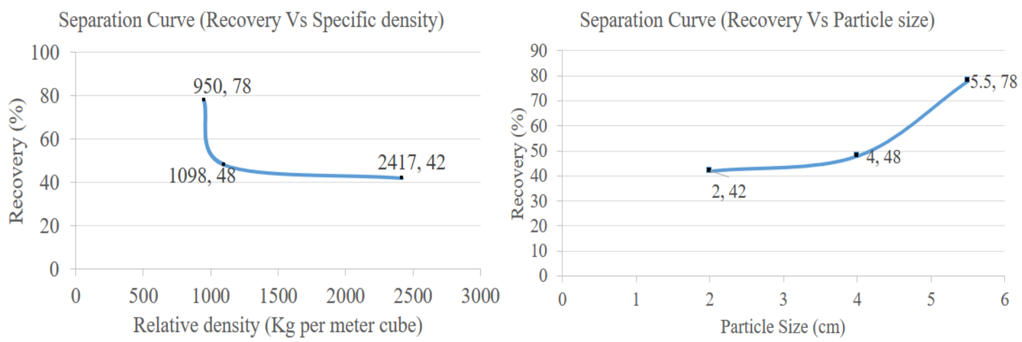


Figure 4-44. Inert waste has higher specific gravity contains sand and dust particles of smaller size; therefore, it shows the recovery lesser than the other two components, i.e., plastic and degradable waste. Plastic waste shows higher recovery as its specific density is lower and particle size is larger than the other two waste components. Similarly, degradable waste holds the intermediate position in the separation curve.

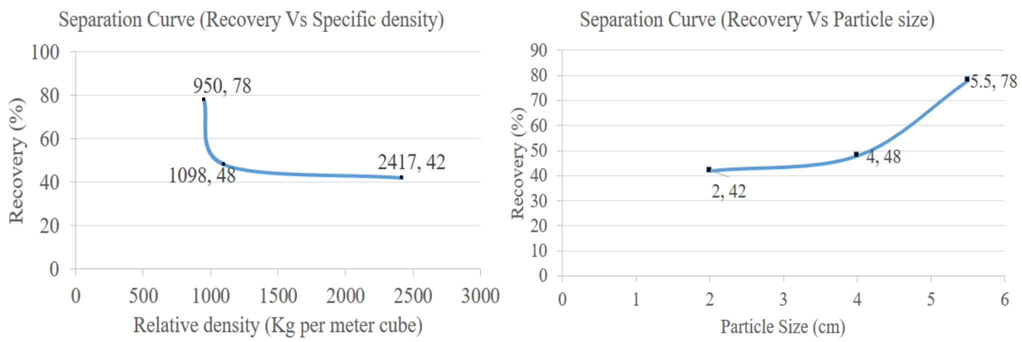


Figure 4-44 Separation curve

Chapter – 5

Conclusion

5. CONCLUSION

Municipal solid waste is the result of the continuous population growth and development of associated infrastructure. The entire management of municipal solid waste runs on mutual coordination between the MSW generator and the local urban body. The performance of the MSW management depends upon the response towards source segregation, which needs to be performed by the generator only. It is observed in the literature review that in many developing countries, lack of source segregation deviates the MSW management from its standard procedure. Literacy, awareness, availability of infrastructure and advanced technologies are the main factors that affect the efficiency of source segregation. For example, door-to-door collection vehicles have three compartments for three different classifications of MSW, but it is applicable only when it gets 100% source-segregated waste. Therefore mixed waste causes an additional task (segregation of useful content) for the waste processing industries. Hence, handling mixed municipal waste becomes a daily challenge since it is disposed of in landfills and remains there until it is used by waste processing industries such as WTE, Composting, recycling, etc. These landfills pollute the environment and make it hazardous for the surrounding inhabitants. The existing MSW segregation system can only process dry waste, for which mixed MSW is left in the open for 20 to 25 days for the bio drying process. This process also causes adverse effects on the surrounding environment. Therefore the overall scenario appeared to be a prerequisite for an innovative solution that can separate mixed MSW in its actual form and enables the approach as a mechanized segregation node for collected mixed MSW. Hence, the solution can intervene in the process flow of integrated MSW management, where mixed MSW can be segregated into the predefined categories, i.e., plastic, degradable, and inert waste. Such intervention can enable the waste processing industries to use segregated plastic and degradable waste directly, and only inert will be dumped into the landfill sites.

A detailed analysis of the physical properties of MSW contents revealed that each type of waste has a different specific gravity, so a sink & float-based approach was found to be a viable solution, which works on the principle of density difference. In contrast, the water doesn't affect the desirable properties of waste contents, as MSW already contains moisture. Therefore a feasibility study was carried out in the laboratory, and the results were compared with the standard separation curve. The overall analysis of the feasibility test has proven that the mixed municipal solid waste can be segregated by sink & float approach; hence a concept is adopted for the design & development of a prototype segregator for 5 kg of mixed MSW.

The developed setup was tested against all the input variables such as the amount of separation media (i.e., water), duration of agitation, shredding size, and proportion of different types of waste. Outputs are measured in terms of the recovered quantity of segregated waste (i.e., plastic, degradable, and inert waste) and the segregation efficiency. The overall segregation process was optimized to get higher recovery with lower power input. Hence the complete operational procedure is shown in Annexure-II, and the following observations are concluded to summarize the performance of the prototype segregator:

- Plastic waste has reported the optimum recovery of 78 % (with shredding size of 5.5 cm), for which the process has utilized 400 L of water and the total power consumption was 519 kWh.

- Degradable waste has reported the optimum recovery of 48 % (with shredding size of4 cm), for which the process has utilized 250 L of water and the total power consumption was 569 kWh.

- Inert wastes have reported recovery of 42 % (with the shredding size of 2 cm), and there is no power consumption in the process as inert wastes were the high specific density sediment recovered by gravity flushing. When the MSW sample did not contain fine inert particles such as grit or sand, inert waste recovery was observed to be higher, i.e., 90% (contains only crushed glass and ceramics).

- The overall performance of the prototype segregator was evaluated through a partition/separation curve, in which lower specific density contents, i.e., plastic waste, show higher recovery and higher specific density content, i.e., inert waste, shows lower recovery. The recovery of degradable waste was intermediate as its specific density was also somewhere between plastic and inert waste.

Therefore the proposed system is a novel solution in the field of MSW management technology. The system is able to segregate the mixed MSW on the same day when it is generated. Hence it does not require a land space for drying the waste; hence it saves the real estate resource. Further, it saves the environment in terms of no unpleasant smell, no groundwater contamination, no soil contamination etc.

The developed system has some scope of improvement in the upcoming future, such as:

- The collection bin can be equipped with a centrifugal dryer for quick extraction of water.
- Setup can be designed for continuous operation.
- Setup can be integrated with composting machine and waste plastic gasifier.
- The Shredder bin can be equipped with a magnet (for the separation of ferrous waste).
- The outlet valve (gate valve) can be replaced/redesigned with a flap valve or pinched bellows (to avoid choking).

REFERENCES

A. D. McNaught, A. W. (2019). *IUPAC. Compendium of Chemical Terminology, 2nd ed. (the "Gold Book")*. Retrieved from https://doi.org/10.1351/goldbook

Abster Equipment. (n.d.). Types of Agitators, Agitators Design and Usages for Mixing. Retrieved July 23, 2021, from http://www.sigmamixerkneader.com/types-of-agitators-design-and-usage/

Agarwal, R., Chaudhary, M., & Singh, J. (2015). WASTE MANAGEMENT INITIATIVES IN INDIA FOR HUMAN WELL BEING. *European Scientific Journal June*, (Special Edition), 1857–7881. Retrieved from http://home.iitk.ac.in/~anubha/H16.pdf

Agaton, C. B., Guno, C. S., Villanueva, R. O., & Villanueva, R. O. (2020). Economic analysis of waste-to-energy investment in the Philippines: A real options approach. *Applied Energy*, *275*, 115265. https://doi.org/10.1016/j.apenergy.2020.115265

Agbefe, L. E., Lawson, E. T., & Yirenya-Tawiah, D. (2019). Awareness on waste segregation at source and willingness to pay for collection service in selected markets in Ga West Municipality, Accra, Ghana. *Journal of Material Cycles and Waste Management*, *21*(4), 905–914. https://doi.org/10.1007/s10163-019-00849-x

Alfatherm Ltd. (n.d.). Medical Waste Shredder | Tyre Shredder | E Waste Shredder Machine. Retrieved September 29, 2021, from https://www.alfathermltd.com/product/twin-shaft-shredder

Amstar Machinery. (n.d.). Plastic Recycling Machines - Plastic Pelletizers, Shredders & Granulators. Retrieved June 30, 2021, from https://www.plasticrecyclingmachine.net/

Annepu, R. K. (2012). Sustainable Solid Waste Management in India.

Aqua-Calc. (n.d.). Density of Cardboard in 285 units of density. Retrieved March 15, 2021, from Aqua-Calc website: https://www.aqua-calc.com/page/density-table/substance/cardboard

Areeba Falak. (2017). Solid waste management rules not being implemented properly. Retrieved April 18, 2021, from The Sunday Guardian Live website: https://www.sundayguardianlive.com/news/10802-solid-waste-management-rules-not-being-implemented-properly

ASTM International. (n.d.-a). ASTM D4442 - 20 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials. Retrieved August 30, 2021, from https://www.astm.org/Standards/D4442.htm

ASTM International. (n.d.-b). ASTM D570 - 98(2018) Standard Test Method for Water Absorption of Plastics. Retrieved August 19, 2021, from https://www.astm.org/Standards/D570

ASTM International. (n.d.-c). ASTM D6683 - 19 Standard Test Method for Measuring Bulk Density Values of Powders and Other Bulk Solids as Function of Compressive Stress. Retrieved August 22, 2021, from https://www.astm.org/Standards/D6683.htm

Basnayake, B. F. A., Popuri, S., Visvanathan, C., Jayatilake, A., Weerasoori, I., & Ariyawansha, R. T. K. (2019). Concerted initiative for planned management of municipal solid waste in target provinces in Sri Lanka. *Journal of Material Cycles and Waste Management*, *21*(3), 691–704. https://doi.org/10.1007/s10163-018-0815-5

Brian Glover, J. M. (2009). *Reconsidering Municipal Solid Waste as a Renewable Energy Feedstock*.

CD fluid. (2020). Agitator impeller types - Tank Agitator Mixer Manufacturer of China. Retrieved July 23, 2021, from http://cdfluid.com/agitator-impeller-types/

Central Pollution Control. (2016). Municipal Solid waste Rules. Retrieved April 17, 2021, from Ministry of Environment, Forest and Climate Change, Govt. of India website: https://cpcb.nic.in/municipal-solid-waste-rules/

Central Public Health & Environmental Engineering Organisation (CPHEEO). (2016). Manual on Municipal Solid Waste Management. Retrieved April 17, 2021, from Ministry of Housing and Urban Affairs, Goverment of India website: http://cpheeo.gov.in/cms/manual-on-municipal-solid-waste-management-2016.php

Citizen Valves. (n.d.). Gate Valves with World Wide Shipping - Citizen Metals. Retrieved July 8, 2021, from https://www.citizenvalves.com/gate-valvesuppliers-dealers-manufacturers.html

CPCB. (2018a). *Annual Report on Implementation of Solid Waste Management Rules*.

CPCB. (2018b). *CPCB annual report as per MSW rules,2016*.

CRI Pumps. (n.d.). PERIPHERAL CENTRIFUGAL PUMPS 50 HZ - C.R.I. Pumps - PDF Catalogs | Technical Documentation | Brochure. Retrieved July 9, 2021, from https://pdf.directindustry.com/pdf/cri-pumps/peripheral-centrifugal-pumps-50-hz/61545-331855.html

Dash, D. K. (2017). solid waste management: Tirunelveli first to have 100% waste segregation | India News - Times of India. Retrieved May 21, 2019, from times of india website: https://timesofindia.indiatimes.com/india/tirunelveli-first-to-have-100-waste-segregation/articleshow/57485885.cms

David Michaud. (2015). Tromp Curve - Example of Partition Curve. Retrieved May 12, 2021, from 911metallurgist website: https://www.911metallurgist.com/blog/tromp-curve-example-partition-curve

Dev Sharma, K., & Jain, S. (2020). Municipal solid waste generation, composition, and management: the global scenario. *SOCIAL RESPONSIBILITY JOURNAL*, *16*(6), 917–948. https://doi.org/10.1108/SRJ-06-2019-0210

Dlamini, M. F., Powell, M. S., & Meyer, C. J. (2005). *A CFD simulation of a single phase hydrocyclone flow field*. (November), 711–718.

Doshi, V. (2016). The Kolkata dump that’s permanently on fire: “Most people die by 50” | Cities | The Guardian. Retrieved September 27, 2018, from The gaurdian website: https://www.theguardian.com/cities/2016/oct/24/difficult-breathe-inside-kolkata-india-rubbish-dump-permanently-fire

Dynamix Agitators. (n.d.). Mixing 101: Flow Patterns & Impellers | Dynamix Agitators. Retrieved July 23, 2021, from 2013 website: https://dynamixinc.com/mixing-101-the-basic-principles-of-mixing-and-impellers/

Early Times. (2019). PCB miserably fails to implement SWM rules. *Early*

Times Newspaper Jammu Kashmir. Retrieved from http://www.earlytimes.in/newsdet.aspx?q=263986

Eriez floatation. (n.d.). HYDROFLOAT SEPARATOR. Retrieved March 4, 2021, from Eriezfloatation website: https://www.eriezflotation.com/pdfs/FGB105Hydrofloat.pdf

Feed Mill Machinery Glossary. (n.d.). Hammer mills. Retrieved September 26, 2021, from Feed Mill Machinery Glossary website: https://www.feedmachinery.com/glossary/equipment/hammer_mill/

FEVE. (n.d.). Why choose Glass? - FEVE. Retrieved September 29, 2021, from FEVE website: https://feve.org/about-glass/

Fibre2Fashion. (2008). Textile recycling, Fabric Recycling Process, Advantage of Textile Recycling. Retrieved May 2, 2021, from Fibre2Fashion website: https://www.fibre2fashion.com/industry-article/3197/textile-recycling

Firth, B., & Hart, G. (2008). Some aspects of modeling partition curves for size classification. *International Journal of Coal Preparation and Utilization*, *28*(3), 174–187. https://doi.org/10.1080/19392690802274740

France-Presse, A. (2019). Garbage mountain at Delhi's Ghazipur landfill to rise higher than Taj Mahal by 2020.

G. Krishnakumar. (2021). NGT pulls up Kerala for failure to comply with Solid Waste Management Rules, 2016. Retrieved April 18, 2021, from The Hindu website: https://www.thehindu.com/news/national/kerala/ngt-pulls-up-kerala-for-failure-to-comply-with-solid-waste-management-rules-2016/article33665880.ece

Gaskells. (n.d.). The Glass Recycling Process. Retrieved September 29, 2021, from Gaskells website: https://gaskellswaste.co.uk/recycling/glass-reprocessor/

Glawe, U., Visvanathan, C., & Alamgir, M. (2005). Solid Waste Management in Least Developed Asian Countries – A Comparative Analysis. *International Conference on Integrated Solid Waste Management in Southeast Asian Countries*, (November).

Goel, S. (2017). Solid and Hazardous Waste Management : An Introduction. In *Advances in Solid and Hazardous Waste Management* (pp. 1–27). https://doi.org/10.1007/978-3-319-57076-1

Haith Group. (n.d.). Sink Float Tanks / Floatation Tanks and De-stoning Equipment from The Haith Group. Retrieved June 30, 2021, from https://www.haith-recycling.com/sink_float_tank_stone_separation_de-stoning.html

Hauser & Miller. (n.d.). Specific Gravity & Melting Point. Retrieved March 15, 2021, from Hauser & Miller website: http://www.hauserandmiller.com/reference/melting.html

Hazra, T., & Goel, S. (2009). Solid waste management in Kolkata, India: Practices and challenges. *Waste Management*, *29*(1), 470–478. https://doi.org/10.1016/j.wasman.2008.01.023

Health & safety executive. (n.d.). Waste Management: Sorting/Processing of waste. Retrieved July 18, 2021, from Health & safety executive website: https://www.hse.gov.uk/waste/processing.htm

Hosansky, D. (2016). Plasma arc gasification. Retrieved September 25, 2021, from Encyclopedia Britannica website: https://www.britannica.com/technology/plasma-arc-gasification

J. Padilla, A., & Trujillo, J. C. (2017). Waste disposal and households' Heterogeneity. Identifying factors shaping attitudes towards source-separated recycling in Bogotá, Colombia. *Waste Management*. https://doi.org/10.1016/j.wasman.2017.11.052

Jadhav, R. (2018). 75% of municipal garbage in India dumped without processing | India News - Times of India. Retrieved June 20, 2019, from times of india website: https://timesofindia.indiatimes.com/india/75-of-municipal-garbage-in-india-dumped-without-processing/articleshow/65190477.cms

Jank, A., Müller, W., Schneider, I., Gerke, F., & Bockreis, A. (2015). Waste Separation Press (WSP): A mechanical pretreatment option for organic waste from source separation. *Waste Management*, *39*, 71–77. https://doi.org/10.1016/j.wasman.2015.02.024

Jirout, T., & Rieger, F. (2011). Impeller design for mixing of suspensions. *Chemical Engineering Research and Design*, *89*(7), 1144–1151. https://doi.org/10.1016/j.cherd.2010.12.005

Kumar, D., & Kumar, D. (2018). Coking Coal Washing. In *Sustainable*

Management of Coal Preparation. https://doi.org/10.1016/b978-0-12-812632-5.00007-0

Kumar, S., Smith, S. R., Fowler, G., Velis, C., Kumar, S. J., Arya, S., … Cheeseman. (2017). Challenges and opportunities associated with waste management in India. *Royal Society Open Science*, *4*(3). https://doi.org/10.1098/rsos.160764

Lahiry, S. (2017). India’s challenges in waste management. Retrieved from http://www.downtoearth.org.in/blog/india-s-challenges-in-waste-management-56753

Lambert, N., & Ryan, G. (2011). Multiple partition curve analysis to estimate sampling induced uncertainty. *5th World Conference on Smapling and Blending, Santiago, Chile,*.

Lavania, D. (2018). Open garbage trucks litter Agra roads every day | Agra News - Times of India. *Times of India*. Retrieved from https://timesofindia.indiatimes.com/city/agra/open-garbage-trucks-litter-city-roads-every-day/articleshow/62449605.cms

Leblanc, R. (2020). The Basics of Textile Recycling. Retrieved May 2, 2021, from Balance Small Business website: https://www.thebalancesmb.com/the-basics-of-recycling-clothing-and-other-textiles-2877780

Lee, Y. Y., Jung, H., Ryu, H. W., Oh, K. C., Jeon, J. M., & Cho, K. S. (2018). Seasonal characteristics of odor and methane mitigation and the bacterial community dynamics in an on-site biocover at a sanitary landfill. *Waste Management*, *71*, 277–286. https://doi.org/10.1016/j.wasman.2017.10.037

Leigh, E. (2018). Fabric Composting : An Experiment in Recycling. Retrieved May 2, 2021, from Suncoast Compost website: https://www.suncoastcompost.com/blog/2018/7/20/fabric-composting-an-experiment-in-recycling

Lemann, M. F. (2008). *Waste management*. Retrieved from https://books.google.com/books/about/Waste_Management.html?id=bjhC3fKkGbgC

Mandal, P., Chaturvedi, M. K., Bassin, J. K., Vaidya, A. N., & Gupta, R. K. (2014). Qualitative assessment of municipal solid waste compost by indexing method. *International Journal of Recycling of Organic Waste in Agriculture*, *3*(4), 133–139. https://doi.org/10.1007/s40093-014-0075-x

Mandal, P. K. (2019). Review on evolution of municipal solid waste management in India : practices , challenges and policy implications. *Journal of Material Cycles and Waste Management*, (0123456789). https://doi.org/10.1007/s10163-019-00880-y

Manohar, M. (2017). Bhalswa landfill: Bhalswa landfill fire rages on as city chokes | Delhi News - Times of India. Retrieved September 27, 2018, from times of india website: https://timesofindia.indiatimes.com/city/delhi/delhi-pollution-bhalswa-landfill-fire-rages-on-as-city-chokes/articleshow/61656243.cms

Manohar, M. (2019). Segregate waste at source or face Delhi corporation fines of up to Rs 1L. *Times of India*. Retrieved from https://timesofindia.indiatimes.com/city/delhi/segregate-waste-at-source-or-face-delhi-corporation-fines-of-up-to-rs-1-lakh/articleshow/66278957.cms

Mansour, D. S. A. (n.d.). Solid Waste Management. Retrieved April 12, 2021, from http://osp.mans.edu.eg/environmental/ch6f.htm

Marianne Horinko, Cathryn Courtin, James Berlow, Susan Bromm, A. F. (2020). *Waste Managment: A Half Century of Progress Waste Management*.

Michaud, D. (2016). Sink and Float Separation Process. Retrieved April 28, 2021, from 911Metallurgy Corp's private library website: https://www.911metallurgist.com/blog/sink-float-separation-process

Ministry Of Environment. (2016). Solid Waste Management Rules, 2016. Retrieved April 17, 2021, from India Environment Portal website: http://www.indiaenvironmentportal.org.in/content/427824/solid-waste-management-rules-2016/

Ministry of Environment and Forests. (2016). *Solid Waste Management Rules Revised After 16 Years; Rules Now Extend to Urban and Industrial Areas, Press Information Bureau, Government of India,.*

Ministry of new and renewable energy. (2016). *Standing committee on energy (2015-16)* (Vol. 20).

Moghadam, M. R. A., Mokhtarani, N., & Mokhtarani, B. (2009). Municipal solid waste management in Rasht City , Iran. *Waste Management*, *29*(1), 485–489. https://doi.org/10.1016/j.wasman.2008.02.029

Nagendra, B., Lakshmisha, A., & Agarwal, P. (2019). Mobile application in municipal waste tracking: a pilot study of “PAC waste tracker” in Bangalore city, India. *Journal of Material Cycles and Waste Management*, *21*(3), 705–712. https://doi.org/10.1007/s10163-018-00819-9

Nandan, A., Yadav, B. P., & Baksi, S. (2017). *Recent Scenario of Solid Waste Management in India*. *66*, 56–74.

Nisar, H. V. & M. (2019). Door-to-door collection of garbage in a mess | Deccan Herald. Retrieved June 19, 2019, from Deccan Herald website: https://www.deccanherald.com/city/bengaluru-infrastructure/door-to-door-collection-of-garbage-in-a-mess-739969.html

Noufal, M., Yuanyuan, L., Maalla, Z., & Adipah, S. (2020). Determinants of household solid waste generation and composition in Homs city, Syria. *Journal of Environmental and Public Health*, *2020*. https://doi.org/10.1155/2020/7460356

Oehlmann, J., Schulte-oehlmann, U., Kloas, W., Jagnytsch, O., Lutz, I., Kresten, O., … Tyler, C. R. (2009). *A critical analysis of the biological impacts of plasticizers on wildlife A critical analysis of the biological impacts of plasticizers on wildlife*. https://doi.org/10.1098/rstb.2008.0242

Ozcan, H. K., Guvenc, S. Y., Guvenc, L., & Demir, G. (2016). Municipal solid waste characterization according to different income levels: A case study. *Sustainability (Switzerland)*, *8*(10). https://doi.org/10.3390/su8101044

Pandey, S., & Malik, J. K. (2015). *Industrial and Urban Waste Management in India*.

Panwar, S. P., Nagpal, S., & Sharma, M. (2017). *A Review on Present Practices, Issues and Challenges of Municipal Solid Waste Management in India*. *8*(1), 647–651.

Pascoe, R. D. (2006). *Investigation of hydrocyclones for the separation of shredded fridge plastics*. *26*, 1126–1132. https://doi.org/10.1016/j.wasman.2005.06.017

Planning Commission. (2014). Report of the Task Force on Waste to Energy (

Volume I): In the context of Integrated Municipal Solid Waste Management. In *Task Force on Waste to Energy*. Retrieved from http://planningcommission.nic.in/reports/genrep/rep_wte1205.pdf

Press Trust of India Ltd. (2019). Lack of waste management in Bihar can lead to emergency-like situation: NGT | Delhi News - Times of India. *Times of India*. Retrieved from https://timesofindia.indiatimes.com/city/delhi/lack-of-waste-management-in-bihar-can-lead-to-emergency-like-situation-ngt/articleshow/68524020.cms

Protega Global. (n.d.). Which is more eco-friendly...paper, or biodegradable plastic? Retrieved May 1, 2021, from Protega Global website: https://protega-global.com/2021/01/05/which-is-more-eco-friendly-paper-or-biodegradable-plastic/

Pulat, H. F., & Yukselen-Aksoy, Y. (2017). Factors affecting the shear strength behavior of municipal solid wastes. *Waste Management*. https://doi.org/10.1016/j.wasman.2017.08.030

Rai, S. (2017). Making the best out of waste: These 8 startups are helping Indian cities manage trash. Retrieved July 16, 2019, from Your Story website: https://yourstory.com/2017/11/waste-management-startups

Rajkumar, J., & Sirajuddin, A. (2016). Status and challenges of municipal solid waste management in India : A review. *Cogent Environmental Science*, *2*(1), 1–18. https://doi.org/10.1080/23311843.2016.1139434

Rawat, M., Ramanathan, a L., & Kuriakose, T. (2013). Characterisation of Municipal Solid Waste Compost (MSWC) from Selected Indian Cities — A Case Study for Its Sustainable Utilisation. *Journal of Environmental Protection*, *4*(February), 163–171. https://doi.org/10.4236/jep.2013.42019

Reinhart, D. (2004). Estimation of the Moisture Content in Typical MSW.

Rittenschober, D., Stadlmayr, B., Charrondiere, U. R., Photos, V. N., & Fao, : ©. (2012). Density Database Version 2.0. In *FAO / INFOODS Databases*.

Roger Walker. (2016). Mass, Weight, Density or Specific Gravity of Bulk Materials. Retrieved March 15, 2021, from simetric website: https://www.simetric.co.uk/si_materials.htm

Rogers Heather. (2005). Gone tomorrow : the hidden life of garbage. Retrieved April 12, 2021, from New York ; London : New Press website:

https://archive.org/details/gonetomorrow00heat

RTS. (n.d.). Complete Glass Recycling Process. Retrieved September 29, 2021, from RTS website: https://www.rts.com/blog/the-complete-glass-recycling-process/

Sambyal, S. S., & Agarwal, R. (2018). Forum of Cities That Segregate. In *Assessment Report 2017-18*. Retrieved from https://www.cseindia.org/model-framework-for-segregation-8603

Shah, M. (2012). *Course Material Process Engineering: Agitation & Mixing*. Retrieved from http://www.dduanchor.org/site/wp-content/uploads/2014/11/Process-Engineering-Agitation-Mixing.pdf

Sharholy, M., Ahmad, K., Mahmood, G., & Trivedi, R. C. (2008). Municipal solid waste management in Indian cities - A review. *Waste Management*, *28*(2), 459–467. https://doi.org/10.1016/j.wasman.2007.02.008

Sharma, N. (2018). Dehradun, Haridwar ULBs flout waste disposal rules, says CAG | dehradun | Hindustan Times. Retrieved June 18, 2019, from Hindustan Times website: https://www.hindustantimes.com/dehradun/dehradun-haridwar-ulbs-flout-waste-disposal-rules-says-cag/story-Dqfbt0GkL42Ogpjg7HG46J.html

Shwetmala, Chanakya, H., & Ramachandra, T. (2011). *ICON SWM 2011 2 nd International conference on solid waste management and exhibition Assessment of solid wastes choking open sewers and vulnerability to urban flooding*. Retrieved from http://wgbis.ces.iisc.ernet.in/energy/paper/iconswm_urban_flooding/ufsw.pdf

SINGH, S. (2020). *Solid Waste Management in Urban India: Imperatives for Improvement | ORF*. Retrieved from https://www.orfonline.org/research/solid-waste-management-in-urban-india-imperatives-for-improvement-77129/

Smith, H. F. (1940). Specific Gravity of Latex and of Rubber. *Rubber Chemistry and Technology*, *13*(3), 485–504. https://doi.org/10.5254/1.3546528

Speier, C. J., Nair, R. R., Mondal, M. M., & Weichgrebe, D. (2019). Multi-sector evaluation of generation, composition and sustainable treatment systems for commercial waste streams in India. *Journal of Material Cycles and Waste Management*, (0123456789). https://doi.org/10.1007/s10163-019-00869-7

Spence, R. D., & Shi, C. (2004). Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes. *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes*, 1–379. https://doi.org/10.1201/9781420032789

Statista. (n.d.). Municipal solid waste generation globally by select country 2017 |. Retrieved September 30, 2021, from Statista website: https://www.statista.com/statistics/916749/global-generation-of-municipal-solid-waste-by-country/

Subramanian, A. (2017). At This ATM, Deposit Garbage to Withdraw Rewards - The Better India. Retrieved May 21, 2019, from The better india website: https://www.thebetterindia.com/95751/garbage-waste-segregation-atm/

Sujauddin, M. (2008). Household solid waste characteristics and management in Chittagong , Bangladesh. *Waste Management*, *28*, 1688–1695. https://doi.org/10.1016/j.wasman.2007.06.013

Swati Singh Sambyal, R. A. (2018). Is Swachh Bharat Mission ensuring waste segregation systems? Retrieved June 15, 2019, from Down to Earth website: https://www.downtoearth.org.in/blog/waste/is-swachh-bharat-mission-ensuring-waste-segregation-systems--61885

The Hindu. (2012, July 7). Plastic waste chokes storm water drains. *The Hindu*. Retrieved from https://www.thehindu.com/news/plastic-waste-chokes-storm-water-drains/article3613373.ece

The World Bank. (2018). Data Catalog. Retrieved June 27, 2019, from The World Bank website: https://datacatalog.worldbank.org/dataset/what-waste-global-database

Tillman, D. A., Duong, D. N. B., & Harding, N. S. (2012). Waste Fuel–Coal Blending. *Solid Fuel Blending*, 201–248. https://doi.org/10.1016/B978-0-12-380932-2.00005-2

Times of India. (2018). Ghazipur: Fire at Ghazipur landfill, more expected as mercury rises Times of India. Retrieved September 27, 2018, from times of india website: https://timesofindia.indiatimes.com/city/delhi/fire-at-

ghazipur-landfill-more-expected-as-mercury-rises/articleshow/63372938.cms
Tonini, D., Albizzati, P. F., & Astrup, T. F. (2018). Environmental impacts of food waste: Learnings and challenges from a case study on UK. *Waste Management*, *76*, 744–766. https://doi.org/10.1016/j.wasman.2018.03.032
Tun, M. M., & Juchelková, D. (2019). Drying methods for municipal solid waste quality improvement in the developed and developing countries: A review. *Environmental Engineering Research*, Vol. 24, pp. 529–542. https://doi.org/10.4491/eer.2018.327
US EPA. (2021). Frequent Questions on Recycling. Retrieved September 29, 2021, from Environmental Protection Agency, United States website: https://www.epa.gov/recycle/frequent-questions-recycling
Visvanathan, C., Adhikari, R., & Ananth, A. P. (2007). 3R PRACTICES FOR MUNICIPAL SOLID WASTE MANAGEMENT IN ASIA. *Kalmar ECO-TECH*. https://doi.org/10.15626/Eco-Tech.2007.002
Visvanathan, C., & Trankler, J. (2003). Municipal solid waste management in Asia: a comparative analysis. *Workshop on Sustainable Landfill Management*, 3–5. https://doi.org/10.1007/s10163-016-0509-9
Walter, D. K. (1980). *Thermal Conversion of Solid Wastes and Biomass*. *130*, 42. https://doi.org/10.1021/BK-1980-0130
Waste Management: Sorting/Processing of waste. (n.d.). Retrieved April 22, 2021, from https://www.hse.gov.uk/waste/processing.htm
Worldbank. (n.d.). Urban population (% of total population) - India | Data. Retrieved September 30, 2021, from Worldbank website: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=IN
WRIGHT, S. (2020). PART 3: Different Methods of Sorting & Preparing Waste | Waste Management. Retrieved July 18, 2021, from INCINER8 LIMITED website: https://www.inciner8.com/blog/waste-management/part-3-different-methods-of-sorting-preparing-waste/
Yaqoob, M. (2018). Much-hyped waste segregation at source non-starter | Greater Kashmir. Retrieved June 15, 2019, from Greaterkasmir.com website: https://www.greaterkashmir.com/news/srinagar/much-hyped-waste-segregation-at-source-non-starter/

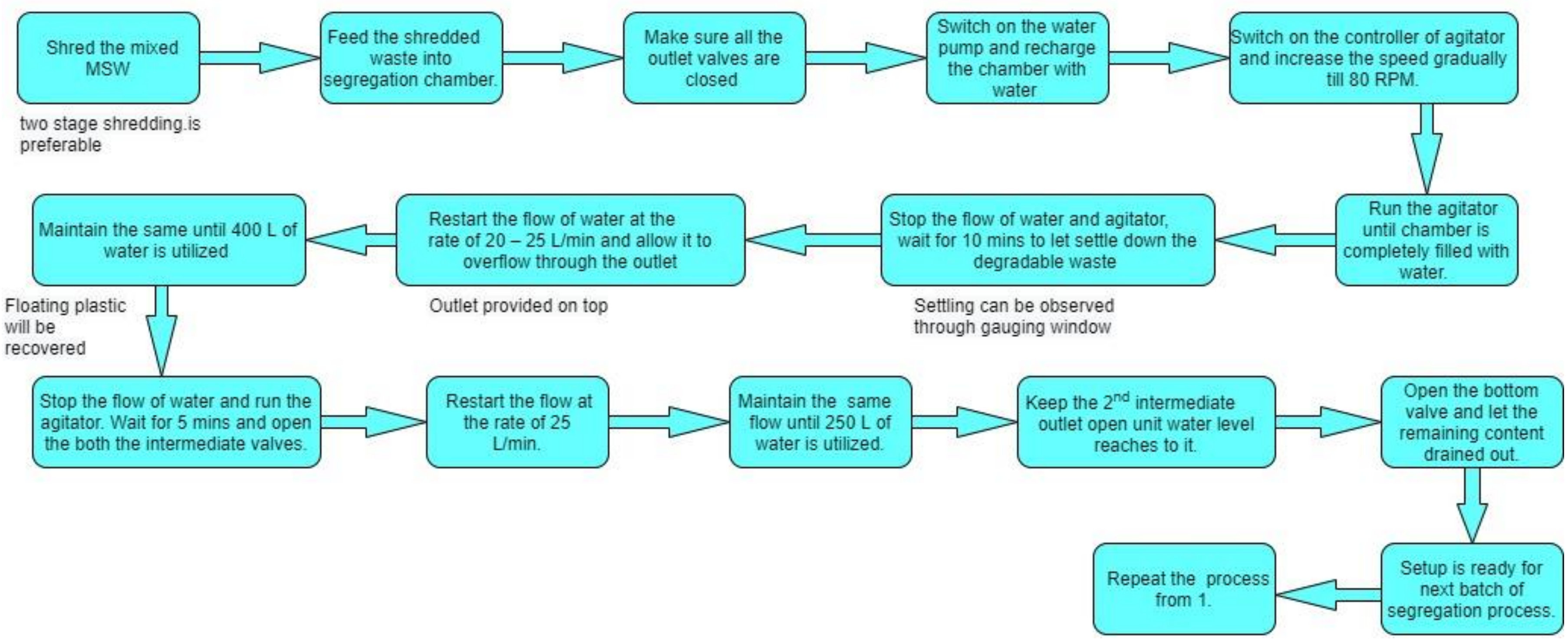
ANNEXURE-I

Specification of Hydrofloat separator by Eriez flotation division:

MODEL NUMBER	DESCRIPTION	DIMENSIONS (DxH)	
		MM	IN
HF-150	Laboratory Unit	140 x 600	5.5 x 23.5
HF-400	Pilot Unit	410 x 1350	16 x 53
HF-450	Pilot Unit	460 x 1380	18 x 54.5
HF-600	Pilot/Industrial	610 x 1380	24 x 54.5
HF-900	Pilot/Industrial	910 x 2080	36 x 82
HF-1200	Industrial	1220 x 2790	48 x 110
HF-1500	Industrial	1520 x 3400	60 x 134
HF-1800	Industrial	1830 x 3990	72 x 157
HF-2100	Industrial	2140 x 4320	84 x 170
HF-2400	Industrial	2440 x 4620	96 x 182
HF-2700	Industrial	2740 x 4950	108 x 195
HF-3050	Industrial	3050 x 5740	120 x 226
HF-3350	Industrial	3350 x 6220	132 x 245
HF-3650	Industrial	3660 x 7160	144 x 282
HF-4250	Industrial	4270 x 8590	168 x 338

ANNEXURE-II

Operational procedure flow chart of prototype MSW Segregator:



Urkund Plagiarism Report

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PROFESSIONAL WORK EXPERIENCE

S.No	Designation	Detail	Organization	Work experience
1	Asst. Professor	Mechanical Engineering Deptt.	University of Petroleum & Energy Studies, Dehradun	Feb 2014 to till date
2	Online Instructor	**Name of the Course**: Design Thinking(running by NSDA, San Diego)	NSDA, San Diego (Course was offered for UPES 1st Yr student)	Jan 2016 to Dec 2018
3	Asst. Professor	Mechanical Engineering Deptt.	Uttaranchal University, Dehradun	1.5 Yrs
4	Project Trainee	Design & Fabrication Deptt.	Heavy Engineering Workshop (A unit of Jaiprakash Associates Ltd.), Rewa (MP)	8 Months

FORMAL METRICS

Examination	University/Board	Passing out year	CPI/Percent
PhD (Persuing)	UPES, Dehradun	--	--
M.Tech. (Design Engineering	Karunya University,coimbatore	June 2012	70%
B. E. (Mechanical Engineerng)	CSVTU, Bhilai	May 2010	7.404*10
12th	CGBSE	April 2005	75%
10th	CGBSE	April 2003	84%

AREA OF INTREST

- **Machine Design**
- **Ergonomics**
- **Engg. Mechanics**
- **Work Study**
- **Solid Waste Mgmt.**

PATENTS

S.No.	Year	Title	Status	Patent No.
1	2014	A system for monitoring and maintaining air pressure in vehicles	Published	(March 2014) (#1205/DEL/2014)
2	2018	Active Safety system for the vehicle passing through stagnant and flowing water there of	Published	201811008888 A
3	2018	An implementation of On-board diagnostics of Pre-failure in Clutch and Brake wires	Published	201811009448 A
4	2018	Implementing of wheel alignment monitoring system and there of	Published	201811009447 A
5	2018	Numeric Fuel Indicator	Published	201811007957 A

6	2018	System and Method to prevent an Accident from a sudden Door opening of Vehicle	Published	201811008146 A
7	2018	Retrofit system to convert a sequential manual transmission into a semiautomatic transmission	Published	201811010769 A
8	2018	On-board diagnostic system to detect adulterants in gasoline and provide a quantified value of adulterants	Published	201811010929 A
9	2019	A vehicle collision avoidance system	Published	201911030146 A
10	2020	A mixed municipal waste segregation system	Published	202011025038 A
11	2020	A caliper disc brake assembly	Published	202011028915 A
12	2020	An accident detection system and method	Published	202011031956 A
13	2021	A mixed municipal waste segregation system (Design)	Granted	331395-001
14	2021	Beverage cup with filter (Design)	Granted	348986-001
15	2021	System for generation of electricity from the rotating wheel assembly of an automotive vehicle	Granted	201811009532
16	2021	Windshield Defogger for heavy duty vehicles (Design)	Accepted	351876-001
17	2021	System and method for contact less disinfection of public places	Published	202111039747

PUBLICATIONS

- "Experimental investigation of lab scaled sink & float based segregation process for mixed municipal solid waste" accepted in Int. Journal of Environment and Waste Management

- “Unsegregated Municipal Solid Waste in India – Current Scenario, Challenges and Way-forward” accepted to be published in Nature Environment and Pollution Technology.
- “Design Optimization of an Automotive Fuel Tank for the Minimization of Evaporative Losses of Gasoline Due to Thermal Conduction: Experimental & Analytical Approach” Chemical Engineering Transaction, 2018 Dec, Italian Association of Chemical Engineering – AIDIC
- “Magnetization of Diesel fuel for Compression Ignition Engine to Enhance Efficiency and Emissions” International Journal of Applied Engineering Research, 2018July, Research India publication.
- “Noise and Acoustic Emission Monitoring of Gear” International Journal of Applied Engineering Research, 2018July, Research India publication.
- “Comparative study of factors affecting man & material flow generated due to non-ergonomically designed manual material handling systems in industries” in International Journal of Innovative Research and Studies (ISSN: 2319 – 9725), Vol. 2 Issue 9.

RESEARCH & PROJECTS

- Waste Mgmt Technology: Compact mechanized segregation system for MSW
- Retrofit side view camera assisted driving aid : KPIT, Sparkle, 2020
- Energy audit of a village under Rudrapur Distt. Supported by UREDA.
- Design and fabrication of components of belt conveyor for bulk material handling facility (HEW, Jaypee Rewa)

Declaration

The above statements are true to the best of my knowledge and belief.

Date :17/11/2021

Prashant Shukla

Place :Dehradun