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EFFICIENT ENGINEERING TECHNIQUES FOR SEGREGATION AND MANAGEMENT OF NON-BIODEGRADABLE WASTES: SAVING THE EARTH BY REPLENISHING ITS DEARTH

Tamojit Poddar[1+]
Nirnimesh De[2]
Sagnik Sarkar[3]

[1,2,3]*Department of Mechanical Engineering, Jadavpur University, Kolkata, India.*
[1]*Email: tamojitpoddar@gmail.com Tel: +916291188128*
[2]*Email: nirnimeshde2000@gmail.com Tel: +916296876646*
[3]*Email: sagniksarkar17@gmail.com Tel: +917427994983*

(+ Corresponding author)

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ABSTRACT

The climatic conditions of the Earth seem to be deteriorating every single moment and mankind is receiving the signals of an upcoming environmental catastrophe in the forms of Global Warming, Ozone holes and Environmental Pollution. The Segregation and Management of wastes are two vital issues in the 21st century globalized world. The waste generation rates are on a sharp rise throughout the world. In 2016, the quantity of solid wastes generated globally summed up to a figure of 6.3 billion metric tonnes. With a swift population growth and rapid urbanization, scientists are expecting a rise of about 70% in the production of wastes as compared to 2016 amounting to nearly 26 billion metric tonnes of in 2050. Plastics, MPW etc. constitute a major portion of these wastes having secured an irreplaceable role in human life today. This paper majorly gives an insight to the Recycling of the globally produced wastes (after their Segregation by an IoT/GLCM/PLC based Segregator) by utilizing them in Road/ Pavement Construction, RDF, Mortar Aggregates and Toilet Blocks (Plastones) in some innovative, cost-efficient and easy-to-implement novel methods viz. Cold Plasma Pyrolysis, CMP, Injection Molding etc. for the Management of wastes to frame a greener and sustainable future. Also, certain high potential techniques for the Re-usage and Reduction of waste products have been incorporated for the Environmental amelioration.

Contribution/Originality: The paper's primary contribution is finding some novel, scientifically appropriate and pertinent methodologies in the procedure of Waste Segregation and Management. It also proffers a unique, well-conceptualized schematic for the attainment of Circular Economy across nations.

1. INTRODUCTION

Rapid increase in volume and types of solid and hazardous waste due to continuous economic growth, urbanization and industrialization, is becoming a burgeoning problem for national and local governments to ensure effective and sustainable management of wastes. The residents of developing countries, especially the urban poor, are more severely impacted by unsustainably managed waste, in comparison to those in the developed ones. In low-income countries, over 90% of waste is often disposed in unregulated dumps or openly burned, the consequences being grave health, safety, and environmental problems. Poorly managed waste serves as a breeding ground for disease vectors, contributes to global climatic changes through methane generation, and can even promote urban violence. Managing wastes properly is essential for building sustainable and inhabitable cities, but it remains a challenge for many underdeveloped as well as developing countries and cities. Effective waste management is expensive, often comprising 20%–50% of municipal budgets. Plastic wastes are one of the major harbingers of Environmental Pollution. Approximately, 70 per cent of the plastic packaging products are transformed into plastic wastes within a short span. According to studies, plastic consumption might lead to cancer, adverse effects on hormone levels and severe heart damage. It has been estimated that about 84% of seawater contains plastic and if pollution continues at this level, then in the next 30 years there are going to be more plastic wastes than fish in the oceans! If we don't check the extent of plastic use immediately, then there is going to be an unmitigated destruction of the environment and the ecological balance in the very near future. The segregation, handling, transport, management and disposal of the wastes need to be properly managed to minimize the risk of the health and safety of patients, public and the environment. Modern solid-waste management plants in most developed countries now emphasize the practice of segregation and waste management at the source rather than incineration and land disposal. In Figure 1, the graphical representation shows the estimated amounts of primary wastes going to be produced and the quantity of wastes expected to be discarded, incinerated or recycled in the upcoming years.

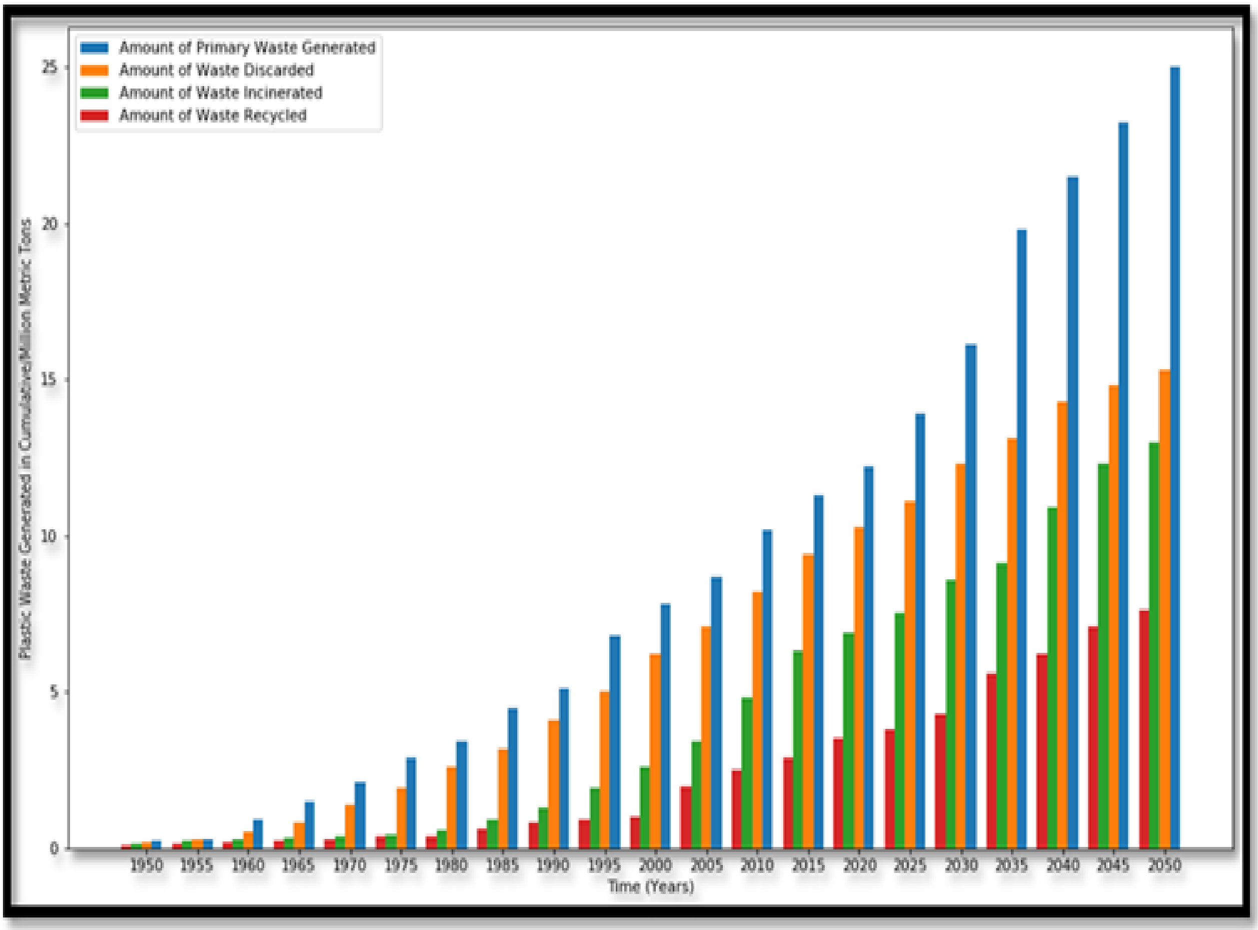

Figure-1. Predicted Global Plastic Waste generation in the upcoming years.

This paper proposes three innovative and efficient techniques of waste segregation with the aid of an Automated Waste Segregator (AWS) which is a cheap, easy to use solution for a segregation system for household as well as industrial use. This is achieved by tapping the potential of either a GLCM or a PLC or an IoT based segregator. Its design is so made, that it can easily sort the refuse into MPW, plastic wastes, metallic wastes, wet wastes and dry wastes. Now, the metalized plastic wastes (MPW) can be reutilized as a partial substitute for the aggregate in concrete composites. The plastic wastes can be used as Road construction materials by properly mixing the wastes in bituminous, thereby enhancing the property of the mix. The plastic craps can be also used to produce RDF (refuse derived fuel), roadside pavements, mortar aggregates or toilet blocks. They can be used to replenish the fuel reserve of the Earth by the processes like Catalytic Pyrolysis (Poddar & De, 2020) or Cold Plasma Pyrolysis. Other than the previously stated waste plastic management techniques, we can also reuse plastics or reduce its use in household or industrial needs to ensure a safe, healthy and secured future for Mother Earth.

2. MATERIALS AND METHODS

2.1. Waste Segregation

2.1.1. GLCM

The GLCM (Grey Level Co-occurrence Matrix) technique is used for plastic segregation where the variation of the intensity levels of the reflected light from the plastic wastes that is segregated. This unique novel of Waste management process makes a revolution in the recent days due to enormous production of the wastes generated. This Gray Level Co-occurrence Matrix (GLCM) is one of the primarily image analysis techniques when it is associated *texture feature calculations* are. Given an image (formed out of the reflection of light rays of different intensities from the object, the objects here being *the wastes*) composed of pixels each with an intensity (a specific gray level), the GLCM is a tabulation of how often different combinations of gray levels co-occur in an image or image section of the object (here, the wastes). *Texture feature calculations* use the contents of the GLCM to give a measure of the variation in intensity at the pixel of interest, and on comparing the obtained values with the predefined values, the category-wise classification and segregation of wastes occur via the sending of appropriate signals to the *robotic arm.*

The GLCM property of contrast is calculated for the given sample and it is compared with the stored predefined value. In the next step of the process, if the comparison for the given condition is successful, then the system sends a signal through the serial port to the 8051 microcontroller using the USART (Universal Synchronous Asynchronous Receiver Transmitter) feature. After the signal is received, the microcontroller is set to provide the signal for the movement to the robotic arm by controlling the servo motors. The last and final part of this process is to calculate the 2D image texture that is originally developed for two dimensional images for the seismic texture analysis. Mohebian, Riahi, and Yousefi (2018) The GLCM matrix is an image texture measurement which often describes the combined difference between a pixel's brightness and its surrounding objects especially. This matrix is filled by comparing the every entry amplitude with its direct neighboring particle and increasing the event corresponding to the cells of the matrix. This is performed for all the paired amplitudes in the entrance level and is then converted into possibilities and redone. Basically, The GLCM matrix determines the possibility of finding two neighboring amplitudes in the level surrounding the point in the calculation. An example to illustrate the working:-

a) GLCM Matrix:

The pixels of the input image of the waste objects have been assumed, as described in Table 1.

Table-1. Pixelated Image of Waste Objects

1	1	5	6	8
2	3	5	7	1
4	5	7	1	2
8	5	1	2	5

Source: Tirumazhisai (2012).

Now the *graycomatrix function* creates a *gray-level co-occurrence matrix (GLCM)* by calculating how often a pixel with the intensity (gray-level) value *"i" in the image of the waste (obtained by reflected light rays)* occurs in a specific spatial relationship to a pixel with the value *"j"*. The Table 2 below is the matrix output of the input matrix which has been demonstrated above, in Table 1.

Table-2. The Gray-Level Co-occurrence Matrix (GLCM)

Pixels → Pixels↓	1	2	3	4	5	6	7	8
1	1	2	0	0	1	0	0	0
2	0	0	1	0	1	0	0	0
3	0	0	0	0	1	0	0	0
4	0	0	0	0	1	0	0	0
5	1	0	0	0	0	1	2	0
6	0	0	0	0	0	0	0	1
7	2	0	0	0	0	0	0	0
9	0	0	0	0	1	0	0	0

Source: Tirumazhisai (2012).

In the output section of the GLCM, the element (1, 1) contains the value 1 as there is only one instance in the input image of the waste inserted where two horizontally adjacent pixels have the values 1 & 1, respectively. The proposed GLCM (1, 2) contains the value 2 because there are two instances where the two horizontally adjacent pixels have the values 1 and 2. The Element (1, 3) in the GLCM has the value 0 as there are no instances of the two horizontally adjacent pixels with the values 1 and 3. In this process the further analysis and calculation are done like the same that is mentioned and described in the above. The Figure 2 shows the texture analysis of GLCM based segregation.

b) Processing GLCM matrix for Segregation

2.2. Technique

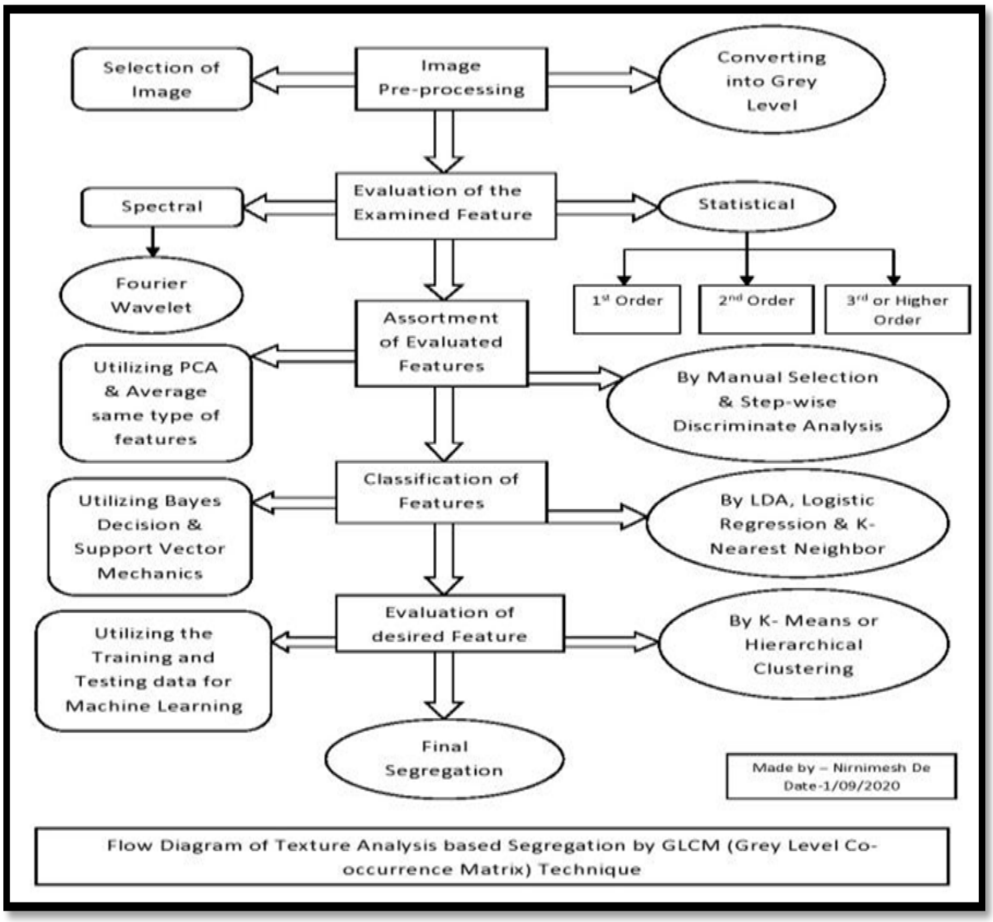

Figure-2. Flowchart of the proposed Texture Analysis based GLCM Segregation.

2.2.1. PLC Based Automatic Waste Segregator

The main advantage of the Waste separation systems lies in the modular design, which delivers any required short-term adjustments and replacements to maintain constant the capacity level. The attributes "Affordable and High Quality" are the important characteristic for waste sorting systems and waste separation systems. Every waste separation system can be used flexibly but the main stress of the competition forces companies is to produce economically and rationally stable that proposed system. A higher level of automation demands more and more programmable logic controllers (PLC). The advantage of PLC is the automation with a relatively small amount of cabling and a low error rate (Mohebian et al., 2018). The efficiency, productivity and flexibility are the only a few contactors (heavy duty relay) that specifies the controller system. The system is completed by modifications and extensions of functions (without mechanical intervention) as well as by communication with other devices via analog, digital and serial interfaces. With programmable logic controllers, the overall processes can be monitored and operated via a PC. But this paper delivers a advance automated PLC Segregator which is designed by IR, moisture (Measuring the moisture contents into the waste inputs), photo-electric (For detecting every kind of inputs), inductive Proximity Sensor (For metal waste detection) and Capacitive Proximity sensors (For Detecting both metallic & non-metallic Wastes) are interconnected with PLC in such a manner so that they function in a proper sequence to detect the materials moving continuously on the conveyor belt. Priya and Kavipriya (2019) Hydraulic cylinder will push the waste to different collecting bins which are placed exactly opposite to sensor position so as collect the wastes which can be further used as organic powder or recycled. The overall system is maintained by a supervisory control and data acquisition (SCADA) server or gateway which allows to remotely monitor & to control the main apparatus and machines used in waste collection and management process. Kittali and Sutagundar (2016) The below Figure 3 flowchart describes the advance process of segregation:

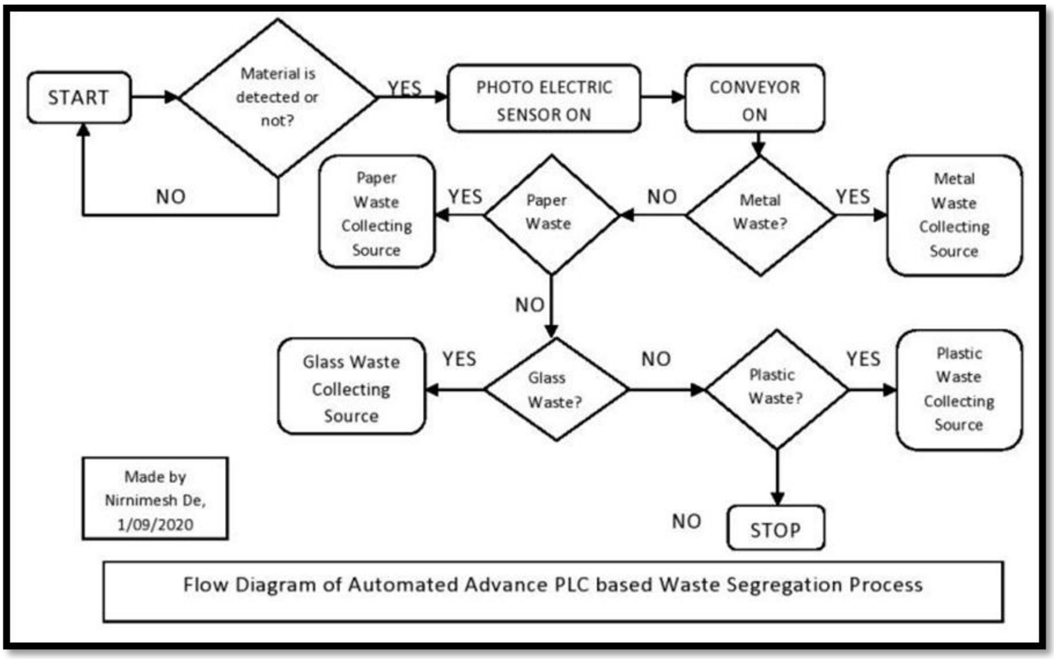

Figure-3. Flowchart of proposed Automated Advance PLC Based Waste Segregation.

2.2.2. IoT Based Segregation Techniques

For sorting the waste into three major classes, namely metallic, wet and dry and further separating dry into paper and plastic the IoT based segregator is the most innovative process. The most important feature of this work is that it is not only cost-efficient but also compact with a simpler design thereby making the waste management system more persuasive. In this paper, authors have used Arduino UNO which makes the working of the system to be smooth and convenient making the design less complicated. Each of these wastes is detected by the respective sensors and disposed into the bins assigned to them wherein these wastes can be taken for recycling or reusing directly. Once it is detected it is moved to the next sensor that is the Moisture sensor which indicates if the trash which is present is a wet or dry waste. After being detected as dry waste it moves to the next sensor which is an Inductive Proximity sensor that shows if the trash is metallic or not. Next sensor is the laser LDR Module where if the laser falls on the LDR it is recognized as plastic if it fails to pass then the material is decided as paper. Few of the limitations of this model include, that size of the trash should fit the slot size i.e. 100mm X 85mm and the width of the trash should be minimum of 30mm. This proposed system are designed in such a way that it can very easily separate only one specific type of waste at a time with an allocated priority for wet, metal and dry waste. The segregation of non-transparent plastic is not possible due to the low intensity of laser light. After detailed study of various techniques used for automating the segregation process ,we can say that IoT based technique is used more than deep learning technique or image processing technique and the advantages IoT based system has been that it collects accurate data on real-time and Load cell calibration approach simplifies the calibration process. In the cloud, the real time analysis can be carried out to generate various reports like- area generating maximum waste, seasonal or functional reports on waste, segregation reports etc. Also this proposed architecture process in this paper provides a backup server that can be utilized by the local cloud service provider for any need. So, this automated system provides the real time analysis of the data gained, also can optimize the route for collecting the garbage that can be found using Google maps and assisted by Google service. So that this innovative smart technique can save fuel cost as well as can improve the environment also. Web based applications could be hosted using cloud. The authority at the central office would view all the reports, optimized routes and all the data related to the garbage production and damping also. Here Table 3 which shows the comparison of different methods and algorithm used in IoT Waste Segregation and Management Systems.

Table-3. Methods and Algorithm used in IoT based Waste Segregator.

Method	Algorithm	Merits	Remarks
Traditional Method and dynamic on demand solution	Optimization algorithm, Artificial Intelligence (AI), Shortest Plan Spanning Tree Algorithm (SPST)	Travelling distance between two location is accurate and speed up the route optimization process	Demerits: As this uses traditional method, this becomes semi-static so problem of segregating different kinds of waste is not possible.
Top-K query Dynamic Scheduling	Dynamic Scheduling Algorithm (DSA)	More Accuracy is achieved than static scheduling	Demerits: Cost of CPU overhead is high
Dynamic Scheduling Method	Optimal Vehicle Routing Algorithm (OVRA)	Routing cost is managed	Only 80 % accuracy is achieved for five iterations.
Dynamic Routing Protocol	Genetic Algorithm (GA)	Effective tool to deal with TSP of various implementation	Optimization can be improved.
Heuristic Approach	Ant Colony Algorithm (ACA)	Travelling Salesman Combinatorial optimization problem is solved.	Vehicle Routing Problem (VRP)

Source: Modified from Sangeetha, Kayalvizhi, and Devi Kalpana (2018).

Deep learning and Image Processing techniques can be used for their high accuracy and reliable results. For high-speed deep learning, the technique can be used whereas for low-cost image processing technique can be used. The disadvantage of deep learning technique is that it requires a lot of data to be trained on the other hand image processing has also certain disadvantages like it cannot segregate the ceramic waste from the dry waste and it can segregate only one type of waste at a time. To increase its efficiency and low cost implementation basically for hardware, we have to use modern high frequency transmission module to store and send the data to server with low latency, mobility support, multilayer battery life and high speed data transfer for data processing, saving, and forwarding to the cloud for further study. Using the Dijkstra's algorithm, we can optimize the specific sequences for this type of a combinatorial optimization process to lower the cost for hardware efficiency as well as low power consumption. Sangeetha et al. (2018) The below Figure 4 shows our proposed circuit diagram system for the IoT based waste segregation process where this system makes use of general purpose board of ATMega16 microcontroller, SIM800 (GPRS/GSM) module and ultrasonic sensor. It is powered by a 12V DC adapter with a 16*2 LCD display to show the working mode of the device. An ultrasonic sensor has been used to detect the level of dustbin. Along with this system can use a website that has to be built so that this website can show the status to the users, their positions in the Google map so that the Municipal authority can also monitor it for their service and authentication purpose.

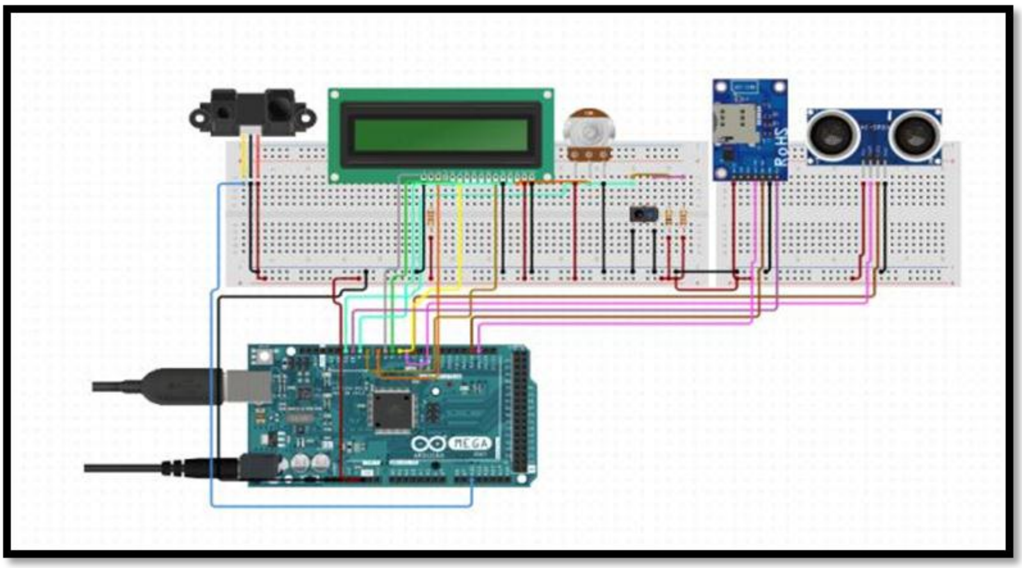

Figure-4. Circuit Diagram of the proposed IoT based Waste Segregator.

3. ADVANTAGES OF THE METHOD OF SEGREGATION

After collection of the disposed waste products from various sources, they are segregated prior to their convenient management. There are different merits of this process of Segregation. Firstly, sorting of the collected trash at the primary stage will make the waste management more fruitful and effective. Secondly, the segregation technique paves the way for a cleaner, better environment reducing its pollution level to a great extent. Next, the involved procedures the completely eco-friendly and last but not the least, the initial input in terms of capital investment are much lower compared to other methods, thereby making this method of segregation much more effective and efficient.

4. DISCUSSION AND RESULTS

4.1. Waste Management Techniques

After successfully segregating the collected wastes, they need to be managed properly in order to secure an effective and efficient fate. The segregated wastes can be broadly classified as Plastic wastes, MPW, Metal wastes, Wet wastes and Dry wastes. From the Figure 3 above, we can find out the major and dominant waste management procedures. They follow the "3-R" principle- ***Recycle, Reduce and Reuse***. Among the 3-Rs, Recycling is the most important and fruitful one. Tapping this potential, it becomes possible to turn up with some newer, highly useful and efficient products at the expense of the useless trash which are available after the segregation of the collected wastes.

4.1.1. Recycle

A. Recycling of Plastic Wastes

1. Plastic wastes in Road Construction: The use of plastic wastes in road construction opens a completely new domain for the successful implementation of recycled plastic trash. The plastic materials to be utilized for this purpose include Polystyrene (PS) (found in cartons, plates, hard packagings, cups etc.); Polypropylene (PP) (ketchup bottles, yoghurt cups etc.) and Polyethylene (both LDPE and HDPE) (plastic bags, water bottles, shampoo bottles etc.) wastes. Polyvinyl chloride (PVC) or flux sheets shouldn't be used for this construction procedure.

a) *Methodology:* The waste plastic has to be collected, segregated, cleaned and then shredded in convenient shape and size. Then, the shredded waste plastic should be passed through a sieve and it is to be retained at the required size for better spread and effective coating of the aggregate.

b) *Types of Bitumen:* The three main types of bitumen that can be used in the construction of roads are mentioned below:

i. *Bitumen 80/100:* This is a sort of mushy bitumen. The features of this grade match with those of the S90 grade of IS-73-1992. This is best fit in the case of low volume roads and might be widely used throughout.

ii. *Bitumen 60/70:* This is tougher than the 80/100 type and has the capability of coping up with higher traffic loads. The characteristics of this grade are similar to that of S65 grade of IS-73-1992. It can be used mainly in the construction of long Highways.

iii. *Bitumen 30/40:* This is the hardest type of all the grades and might withstand very heavy traffic loads. The attributes of this grade approve to that of the S35 grade of IS-73-1992 and it might be employed in specialized application fields like Airport Runways and also in very heavy traffic volume roads.

Note: The Bitumen to Plastic ratio shall be 10:1.

c) *Discussion:* It is must be taken into account that the size of the shredded plastic should be less than the surface area of the aggregate to get a uniform coating. Otherwise, the binding will not be efficacious. The waste plastic, if heated to a temperature above 250 °C, may decompose producing gaseous products which will result in Environmental pollution. Hence, the temperature during heating shall be maintained between (150-170) °C. ***Our sole aim here is to boil the plastic, not burn it.***

d) *Interaction between Plastic aggregate and Bitumen:* When the aggregate temperature is around (150-170) °C, the plastic coating is in a molten state and over this, hot bitumen at 160 °C is being added. The added bitumen gradually spreads over the aggregate. At this temperature, both the coated plastic and bitumen are in the liquid state, capable of easy diffusion at the interface. This process is further helped by the increment in the contact area. Waste polymers like PE, PP and PS are long chains hydrocarbons. The bitumen is a complex mixture of asphaltenes and maltenes which are also long chain hydrocarbons. Now, after mixing the bitumen in the plastic coated aggregate, a part of bitumen diffuses through the layer of plastic and combines with the aggregate. Meanwhile, the plastic layer also makes a strong bond with the aggregate. During this process, 3-D internal cross linked network structure results in between the polymer molecules and bitumen constitutes. This adds to the strength of the bonded structure and the removal of the bonded bitumen becomes difficult. The Figure 5 provided below demonstrates the plastic-aggregate-bitumen interaction for the waste plastic coated aggregate-bitumen mix.

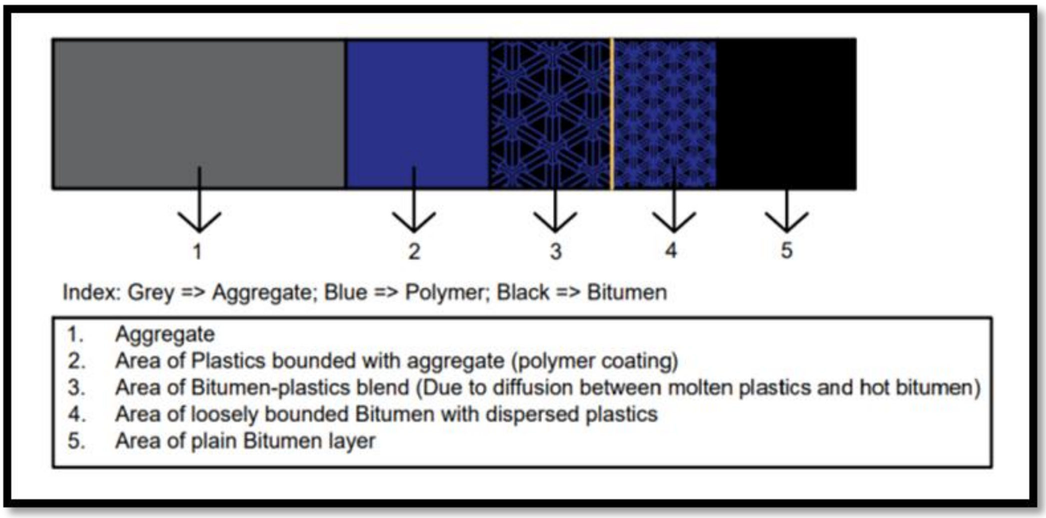

Figure-5. Illustration for the plastic-aggregate-bitumen interaction during Road Construction.
Source: Modified from www.mohua.gov.in , Ministry of Housing and Urban Affairs, Govt. of India (2019)

e) *Types of involved process:* The two major processes for manufacturing bituminous mixes using waste plastic are Dry and Wet process. In the Dry process, the processed waste plastic is added after shredding into the hot aggregates and is recommended for isolated works; while in the Wet process, processed waste plastic (in powdered form) is added in the hot bitumen. The mixing can be mainly done in two types of plants: *Mini Hot Mix Plant* and *Central Mixing Plant (CMP).*

In the *Mini Hot Mix Plant*, initially the stone aggregate mix is heated at 165 °C and then, it is transferred to the mixing pool. Calculated amount of shredded plastic is being sprayed over hot aggregate within a stipulated time when the hot aggregate is transferred into the pool. The melted plastic forms an oily coating over the aggregate. Meanwhile, bitumen is kept heated (to a maximum of 160°C) which is thoroughly analyzed and deeply monitored to secure a good bonding. The hot bitumen is then added over the plastic coated aggregate at the mixing pool and the mixture obtained as a result, is used for Road Construction activities.

The *Central Mixing Plant (CMP) technique* consists of three material types: Materials-I, II and III. Material-I consists of hoppers filled with necessary aggregates as per the formula of the mix. Material-II consists of plastic films of thicknesses within 60 microns which should not exceed the size of 4×4 mm^2. For Material-III, bitumen of type 60/70 or 80/100 should be used. Here, the stone is heated and at the same time the plastics films get melted and coated over the heated stone. Gradually, the plastic coated aggregate moves forward and gets mixed with the bitumen. Firstly, the aggregate materials are transferred to the cylinder through the conveyer belt. Then, the shredded plastic is manually sprayed over the aggregate while it is moving in the conveyer belt. The amount of plastic to be added can be calculated as follows:

For example, if the quantity of bitumen per minute is 10Kg, then the amount of plastic required to be added is 1Kg. Hence, the shredded plastics are needed to be sprayed with a speed of 1Kg/min in that case.

f) *Merits of the process:* Using plastic craps for road construction activities has several benefits. Firstly and above all, it reduces the amount of plastic wastes (one of the major harbingers of Environmental Pollution) and utilizes it efficiently for a very necessary betterment of transportation facility without the evolution of any toxic gases (like 'dioxin'). Secondly, presence of plastic lifts up the binding capacity of the aggregate mixture, thereby making the roads more corrosion resistant. Next, the plastic coating gives the aggregate a non-hygroscopic nature and thus, reduces its affinity for water. This brings down the chances of pothole formation increasing the longevity of the road structure. Also by this method, the cost and frequency of maintenance is reduced. This method helps in the reduction of the construction cost of the roads too, along with the prevention of the salt deposition in the stone pores. Last but not the least, the consumption of bitumen can be significantly reduced (e.g.- For a 1 Km×3.75 m road, if 1 tonne of plastic is used, then we can save 1 tonne of bitumen in the process).

1. ***Plastic wastes in Pavement Construction:*** Not just roads, the method elucidated above can be similarly used for the creation of pavements alongside main roads. The aggregate-plastic-bitumen mix as suggested above can be used to design asphalt pavements. Not only would this reduce the need of bitumen by 10% but also develop an eco-friendly methodology of construction of pavements. The procedure remains more or less the same, just that in the bituminous mix production, in this case, both the dry and wet processes can be carried out in the *Central mixing plant (CMP)*. CMP helps to have better grasp on controlling temperature and mixing of this material thus allocating a uniform coating. The use of plastic craps enhances the scraping and slip resistance of asphalt pavements. A coating of Titanium dioxide is often used on the bituminous mix to improve the strength and corrosion resistance of the pavement and also to absorb the smoke discharged by the adjacent vehicles. Figure 6 below shows a pavement made by employing plastic trash.

Figure-6. Pavement made by the utilization of plastic wastes.
Source: www.mohua.gov.in , Ministry of Housing and Urban Affairs, Govt. of India (2019).

2. ***Plastic wastes in Refuse Derived Fuel (RDF):*** Plastic trash can be effectively to derive aviation or Jet propulsion fuel as shown in the article by Poddar and De (2020). The process used by them to prepare the fuel is catalytic Pyrolysis method. In our case, we apply the Cold Plasma Pyrolysis methodology which is also available option. The schematic of the Cold Plasma Pyrolysis setup has been provided below in Figure 7.

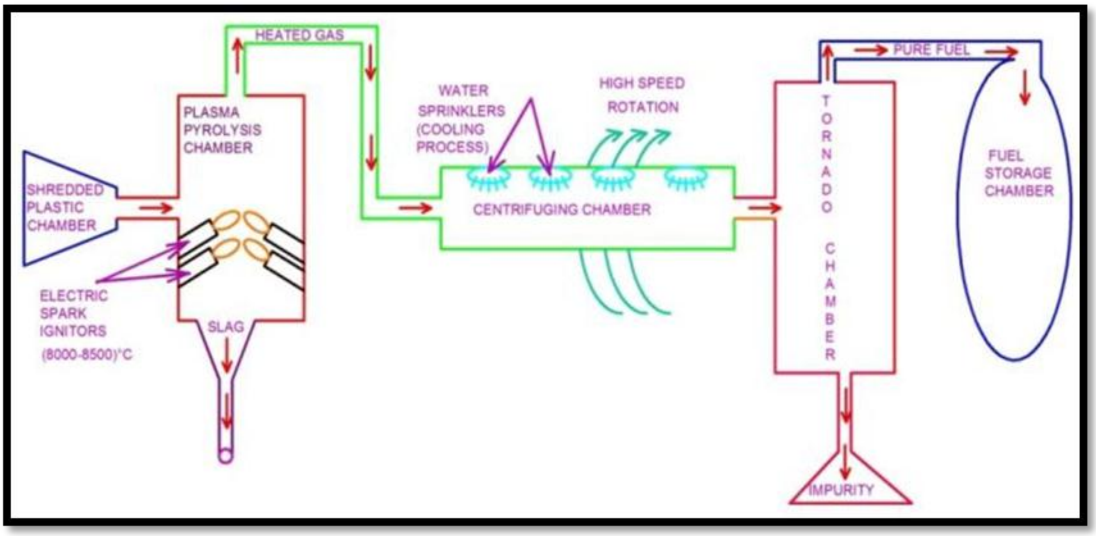

Figure-7. Schematic of the cold plasma pyrolysis setup.

a) *Pyrolysis setup and Fuel preparation:* The Pyrolysis setup consists of several chambers. In the first chamber, the properly shredded washed plastic scraps are collected. From there, they are passed into the spark ignition chamber where the plastic is heated by electric spark igniters at very high temperature reaching up to (8000-8500) °C. Thus, the solid plastic gets converted to gas and the impurity or the slag is eliminated. The vaporized plastic is then passed onto the cooling chamber where the heated gas is cooled by water sprinklers. Next, it enters the Tornado chamber where, due to high centrifugal action, the dirt and the impurities get removed from the periphery. Finally, the purified gaseous fuel is obtained and collected in a Storage chamber for future use.

b) *Application fields:* The obtained RDF (Refuse Derived Fuel) can be used in several grounds of application like turbine, generator, automobiles, engines, cars and aviation/jet propulsion systems.

c) *Merits of the process:* There a lot of advantages of this effective process. First and foremost, this process reduces the quantity of plastic wastes on a large scale and thus reduces environmental pollution. Secondly, the RDF obtained is much cheaper as the input cost is a one-time investment and very much efficient in a long run. Besides, doing away with the use of conventional sources of energy, this process thereby adds values to the sustainability development.

3. Plastic wastes in Cement/Mortar Aggregate: Plastic craps can be effectively and efficiently used in the preparation of cement or mortar mixtures. The plastic wastes to be employed for this purpose are mainly in the forms of low density Polyethylene (LDPE) (plastic bags, water bottles etc.); Polyethylene Terephthalate (PET) (cold drink bottles, water bottles etc.) and E-plastic wastes (abandoned electrical/electronic devices, CRT scraps etc.).

a) *Fine Aggregate:* The best possible material for fine aggregate is sand due to its low cost and easy availability in ample amount. Sand to be used can be chosen according to suitable International Standards and sieved conveniently prior to washing.

b) *Coarse Aggregate:* The coarse aggregate can be chosen as per need. Possible options are sand, crushed coconut shell, coconut fibers etc. This also should be shaped and tested properly before use.

c) *Cement:* The cement can be chosen as per convenience and the quality required. It can be any particular branded cement or ordinary Porter cement. But whatever be the cement used, it should be tested for consistency, setting, soundness etc. beforehand.

d) *Methodology:* The plastic craps has to be collected, segregated, cleaned and then shaped mechanically in convenient size. The mix required to be used must be prepared by conveniently mingling cement, fine aggregate, coarse aggregate, sufficient water and granulated plastic wastes.

e) *Constraints to be considered:* Although an efficient process, but still there are a few a drawbacks of the process to be considered. This process is suitable only for manufacturing lightweight concrete as the addition of plastic reduces the density of the mix. Figure-8 below clearly demonstrates the weight difference between Normal and Lightweight concrete. Moreover, plastic addition also reduces the compressive strength of the mortar aggregate. So before using the mortar, the zone of application must be specified. The application fields of this mixture include floor tiles, roofing material, walling/partition material etc.

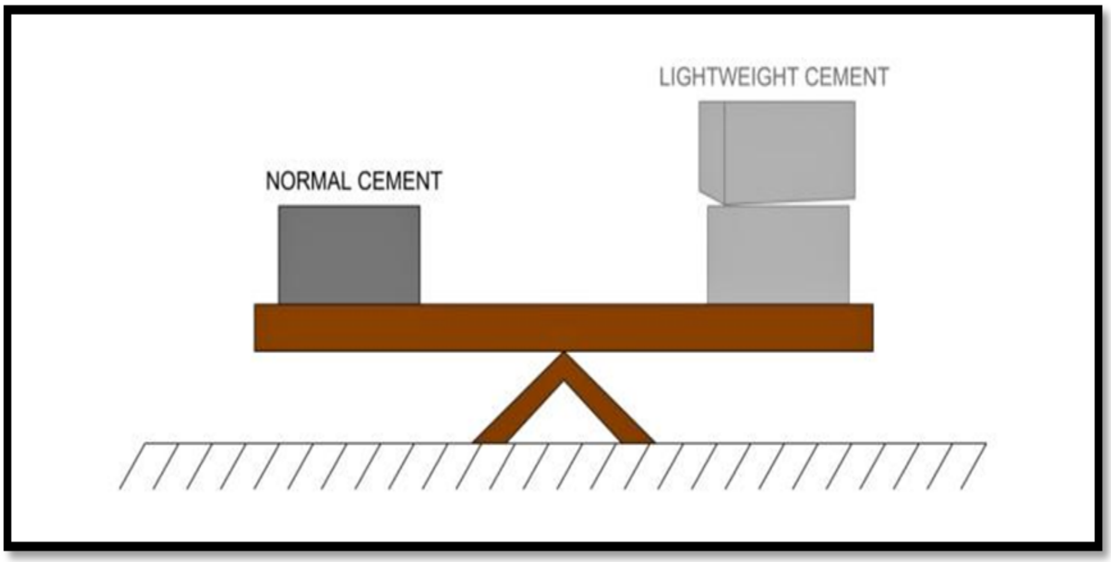

Figure-8. Weight comparison between Normal Concrete (left) and Lightweight Concrete (right).

f) *Merits of the process:* Using plastic wastes in mortar/cement aggregate has several advantages. Firstly, the strength and the workability are improved along with the increment in the durability of the concrete mix. Secondly, the bond strength is increased and the corrosion resistance is improved. Also fungicidal, germicidal and insecticidal properties are developed along with the high acoustical insulation capability. Besides, termite-proof capability and freeze resistance are induced, too. Last but not the least, lightweight cement/mortar aggregate is cost-efficient and easily affordable.

4. Plastic wastes in Toilet Block making: Segregated plastic wastes can be utilized in the creation of toilet blocks or for that matter of fact, as a construction-material for any building.

a) *Methodology:* The plastic wastes segregated and then shredded, are mixed with stone and other materials, viz. waste limestone, ceramic waste and granite. This eco-friendly building material, created mainly out of trash takes up a lot more (approximately 35-40%) plastic waste than that in the procedure of laying roads. The term coined for this material is "Plastone".

b) *Discussion:* For the creation of a single block of plastone, approximately 275-300 plastic bags and five/six waste plastic bottles need to be utilized. Once the raw materials are ready, the manufacturing costs are near about £1 for a single tile, and 65-70 such tiles would be more than sufficient for the creation of a roadside toilet block. This material can also act as a substitute for cement in large buildings or sidewalks.

c) *Use in manufacturing of Toilet components:* Other than the mere creation of toilet blocks, one of the very effective ways of plastic waste management would be the manufacturing of Toilet components. As per international surveys, Styrofoam products fill up to 25-30% of landfill space all around the world. These Styrofoam/polystyrene pellets (otherwise known as EPS foam pellets, obtained from segregated plastic wastes by the AWS/any other segregation technique, and then fed to a compactor for lessening the volume up to almost 98%, and finally shredded into flakes and pellets for re-usage) can be used to make toilet seats and covers (by the process of Injection Moulding).

d) *Finishing:* For the finishing touch post the water bath, holes are drilled for the hinges, the rough edges are smoothened at a sanding machine and thus a final polish is imparted to the toilet seat and cover. The tiny pellets and flakes of polystyrene, obtained from all sorts of packaging wastes, that otherwise looked worthless post segregation, can now be utilized for making thousands of toilet covers and seats.

e) *Merits of the process:* This is really an advantageous process because it is eco-friendly in nature. Besides, this process of plastic waste management is also lasting, durable and cheap.

Figure 9 shown below gives a vivid depiction of the Injection Molding procedure for the making of Toilet Blocks (Plastones) by aptly utilizing plastic, ceramic and limestone wastes. The entire process from the initial Segregation procedure till the solidification of the plastic mould and making of the toilet components has been thoroughly described below.

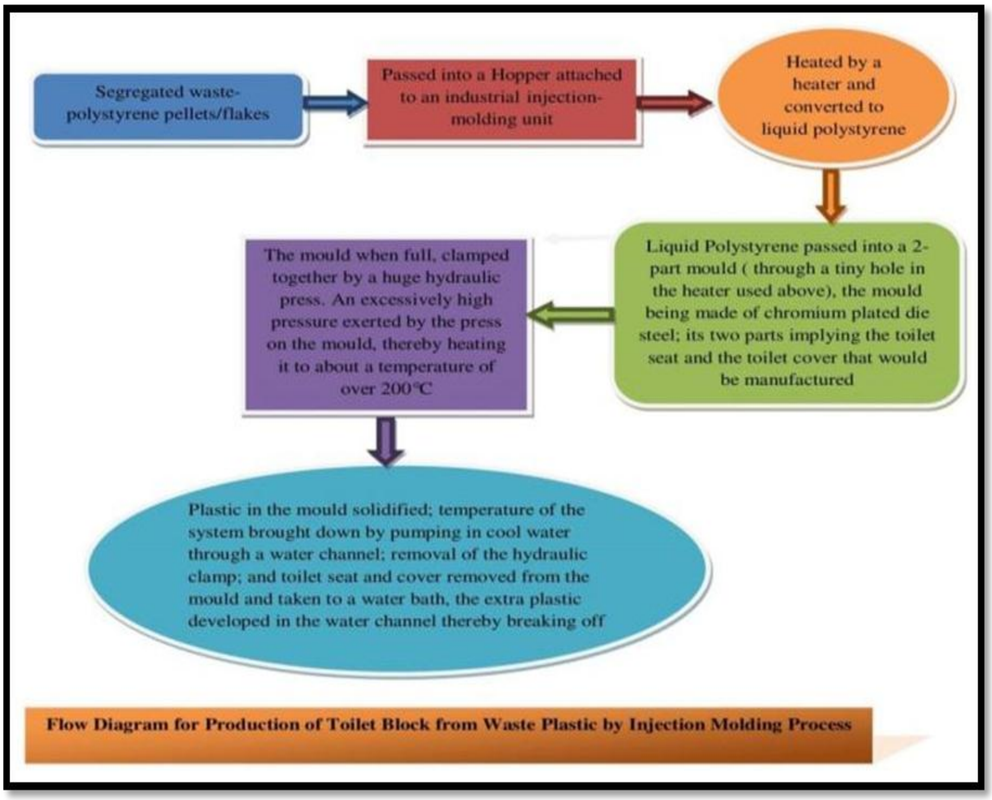

Figure-9. Flowchart showing the Injection Molding method of making toilet components from plastic wastes (Styrofoam).

B. Recycling of Metalized Plastic Wastes (MPW)

a) *Discussion:* Metalized plastic is abundantly used by the food packaging industry. As a result of the changing lifestyle of people, the usage of packaged foodstuffs has increased thereby increasing the amount of Metalized Plastic Wastes (MPW). In spite of several efforts to reduce plastic wastes, proper management of MPW is still a challenging task. Due to its high durability and difficulty in complete disposal in the nature safely, residues exist long. Littering is one of the major demerits of MPW.

b) *Composition:* Surface metalized Polyethylene (PE) and Polypropylene (PP) are two major components of packaged food products. Apart from these two, Polyethylene Terephthalate (PET) bottles are also dominant and most effective in MPW management (recycling). The other plastic packaging components like PE, PP etc. are not as effective and efficient as PET bottles.

c) *Use and Effects:* The MPW (PET bottles and plastic carry bags) in micro-fibrous form can be effectively utilized to manufacture green concrete or sustainable concrete. On mixing conveniently sized MPW fibers in concrete, the deformation due to axial compression and the assessment of the preliminary material features get changed.

d) *Methodology:* Conveniently shredded MPW fibers should be added in proper proportion (0%-2%) to the concrete specimens (with water-cement ratio within 0.45-0.65). But with increasing plastic amount (beyond 1%), the characteristic features like flexural and compressive strengths tend to deteriorate.

e) *Evaluation:* The MPW mixed concrete sample must be tested properly prior to its application. It must be evaluated for workability, strength (slump, compaction factor, compressive strength, splitting tensile strength and flexure strength), stress-strain relationship under axial compression, ductility etc.

f) *Merits of the process:* The major advantage of this process is the reduction of environmental pollution since in this method we are using one of the most hazardous wastes (MPW) to produce something sustainable and useful. The other merits of this MPW recycling process include improved crack resistance, better tensile resistance and post-fracture ductility; cost-efficiency and finally, easy availability of raw materials.

C. *Recycling of Metallic and Wet/Dry Wastes*

a) *For Metallic Wastes:* Metallic wastes collected after segregation can be recycled easily in several ways. If they are iron craps, they can be melted and reused after solidification according to need. The same utilization technique also applies for other metallic wastes. After the recovery of the metals (like Copper, Aluminium, Iron etc.), they can be used to manufacture utensils, weld joints, make machine parts etc.

b) *For Wet/Dry Wastes:* Recycling of wet and dry wastes post segregation is also not a complex task. The dry or the wet wastes can be further categorized as plastic, metallic, fibrous etc. and recycled accordingly. For wet wastes, if needed, they should dried and cleaned properly beforehand for convenient management.

4.1.2. Reduce

Amidst such an environmental dilemma, in order to prevent Mother Earth from pollution, we can pull down the usage of non-biodegradable potential pollutants like plastic and start using biodegradable which will help in maintenance of the ecological balance. For example, instead of plastic carry bags we can use jute/cloth bag, instead of plastic bottles we can use glass/metallic bottles and so on. So far, 18 states and union territories of Indian subcontinent (Delhi, Goa, Gujarat, Andhra Pradesh, West Bengal, Assam etc.) have imposed some sort of bans on the usage of several plastic stuffs.

4.1.3. Reuse

Re-usage is a step ahead of Recycling. It is possible to reuse plastic carry bags, mini trash bags or plastic silverwares for the umpteenth time if used properly. Plastic bottles/containers can be also refilled and reused instead of disposing them off frequently. Reusing plastic can consequently turn down its demand and diminish the adverse environmental impacts posed by it to some extent.

5. CONCLUSION

A circular economy is one that is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. An industrial system that is recuperative or regenerative from both the aspects of intention and design. This paper not only aims at the elimination of waste items making the Earth pollution free but also suggests some novel and effective methodologies for the Recycling, Reducing and Re-using of various forms of disposed wastes. Thereby, some of the most appropriate ways of reducing wastes to a minimum extent by some scientifically approved techniques have been put forwarded here; consequently extending the life cycle of products. With the world's growing population and swiftly rising demands of raw materials, there's better than shifting to an almost-ideal model of a circular economy for the nations worldwide. This paper exactly provides one of the major pathways of that transition, providing durable and innovative products while also lessening the burden of waste products on the environment to an absolutely significant extent. Figure 10 below depicts the Circular Economy discussed above.

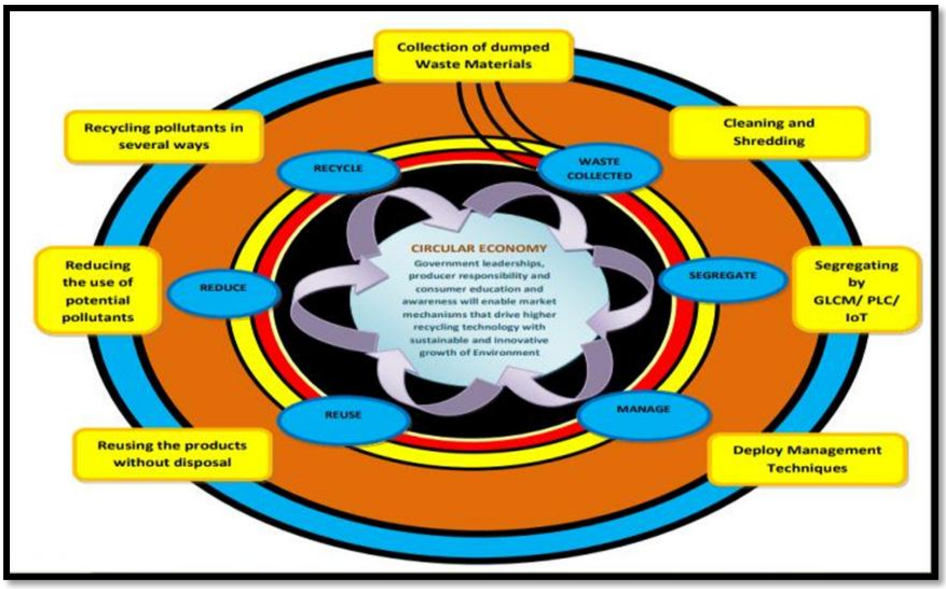

Figure-10. Circular economy demonstration.

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