Sorting of plastic waste for effective recycling

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Abstract: Separation of plastic from various types of waste streams represents one of major problematic
process in energy recovery through different thermochemical processes. The sorting of plastics is a very
essential step in different waste management technique. Manual sorting is suitable when plastic component
are present in large amount but it is a labor intensive process. In automated sorting technique NIR(near
infrared) offers great advantage among all wave sorting technique but not suited for dark coloured plastic
and can be used on transparent bodies. In air sorting lighter particles are separated from heavier ones based
on specific gravity. In electrostatic sorting method materials are separated based on electrostatic charge. In
float-sink separation technique the plastics are in a fluid that has density in between the materials making it
possible for less dense material to float and heavier to sink whereas sorting by selective dissolution is
based on batch dissolution of mixed plastics using solvents. Hydrocyclones enhance the difference of
specific weight by centrifugal force so materials with little difference can be separated as well. The present
paper reviews the available literatures in the area of sorting of plastic waste for effective recycling.

Keywords: Plastic waste; waste management; sorting; recycling

1. Introduction

1.1 Abbreviations

LDPE : Low Density Polyethylene
HDPE : High Density Polyethylene
PP : Polypropylene
PS : Polystyrene
PET : Polyethylene Terephthalate
PVC : Polyvinyl chloride
WRAP : Waste and Resource Action Programme
PLA : Polylactic Acid
POM : Polyoxyymethylene
PMMA : Polymethyl methacrylate
HIPS : High Impact Polystyrene
MIBS : Methyl Isobutyle Carbinol
NMP : n-Methyl-2-Pyrrolidinone
PTC : Polymer Technology Centre
ABS : Acrylonitrile-Butadiene-Styrene
HPVC : Hard polyvinyl chloride
SPVC : Soft polyvinyl chloride

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COPP : Co-polypropylene
HOMOPP : HOMO-polypropylene
GPPS : General purpose polystyrene

2. Separation Techniques of waste plastics

Separation of plastic represent one of major problematic process in waste plastic management system e.g. it is very difficult to distinguish shredded bottles of PVC from shredded PET bottles and this separation process has to be done prior to next process because presence of PVC may decrease the quality of whole batch (Dodbiba and Fujita 2004). However mechanical separating allow plastic from other materials. In many case it is also required to separate different types of plastics (such as PVC, PET, Polyethylene). In several cases plastics are also sorted by color in order to improve the physical appearance of the products derived from post-use material. Mixed plastic waste containing up to 15% PVC is not considered to pose technical problems. Due to presence of additives and contaminants and also due to the modification of the original polymeric structure during its first use (typically chain cross-linking reactions), mechanically recycled plastics only find use in lower grade applications. In cracking process, such pre-treatment consist of a sorting or separation step of the used input- that allows adjusting the chlorine content of the main waste stream. A second possibility is thermal or chemical dehalogination before the pre-treated product is further processed and this can be done in liquid or fluidized bed pyrolysis. In this process HCl is produced is neutralized or separated for industrial use. The relatively low PVC/chlorine content, as found in mixed plastic waste (from packaging) is an acceptable for existing feedstock recycling processes as long as an appropriate pre-treatment of the plastics waste is guaranteed. In mixed plastics separation not all plastics material are sensitive to alien as PET or contaminating as PVC. Some sorting techniques are discussed below. The classifications of plastic sorting methods are shown in figure 1.

2.1 Different sorting techniques

2.1.1 Manual Sorting

Manual sorting technique of material involves identification by shape, color, appearance, trademark of the plastic that distinguishes it for visual identification by the operators (Saiter and Sreekumar 2011). Manual sorting techniques are useful in such situation where plastic components are large enough to justify the time and effort involved, since it is very labour intensive, has bad working environment and is economically unviable (Wienaah 2007). This technique is based on the material identification codes but the possibility of human error cannot be neglected. It has great advantage in price since it is a relatively cheap method.

2.2 Automatic sorting technique

2.2.1 Dry sorting technique

2.3 (N-) IR, X-Rays

According to a mixed plastic recycling study conducted by Waste Resource Action Programme (WRAP), NIR( near-infrared) can effectively remove PLA bioplastics and carbon board from a mixed packaging stream. This technique involves irradiating the unsorted, unidentified plastic: with near infrared waves (600
to 2500 meters in wavelength). This has very high speed of identification. When exposed to near-infrared light waves, different polymers reflect an identification spectrum, this method can accurately identify different polymers (New Avenues in recycling, 2009, www.natureworksllc.com). NIR reflectance spectroscopy offers many advantages for identification and sorting plastic resins, though this method is not suitable for identification of dark colored plastics (Masoumi et al 2012).

Similar to infrared spectroscopy methods, which exposes the unknown plastic to waves and studies the objects response but in X-Ray fluorescence, the unique characteristics come from the organic nature of the polymers rather than a single ion or element. Most of this technology is being applied to the sorting of PVC. The chlorine atoms in PVC give a unique peak in the X-Ray spectrum that is readily detectable. Hyper spectral cameras supplied by stemmer imaging (Imaging and machine vision Europe) that can be use to separate the plastics. The general idea is to generate a spectral fingerprint of plastic passing on a conveyor to identify it by chemical composition and sort it into plastic type.

2.4 Air sorting

Here the flakes of the commingled material, grounded to a ¼” to ½” size, are fed vertically into the air, causing lighter particle to be separated from heavier ones and material is sorted based on the specific gravity (VERC 2001).

![Different plastic sorting methods](image)

Figure 1: Different plastic sorting methods

Another technique which based on the combination of triboelectrostatic separation and air tabling in which triboelectrostatic separator was initially employed to collect the ABS flakes as positively charged fraction and to produce a negatively charged fraction of PP and PVC flakes for further treatment on air table, which is an effective technique to separate materials of different densities (Dodbiba et al 2003).

2.5 Electrostatic sorting technique

Separation can also be achieved by employing electrostatic charging of different plastics. This method separates the plastic materials through their differences in electrostatic charges. The materials are sorted by
letting them fall freely through an electric field produced between two parallel sets of oppositely charged electrodes and are separately collected according to the triboelectric charge that they have. One problem is that it hard to control the gravitational force acting on the falling particles. Therefore if the particles are too small or very low charged, there has to be a very long separation area between electrodes. Electrostatic separation can avoid the problems with contaminants, such as dirt, and can separate polymers of similar density, for e.g. PE and PP. In triboelectrostatic separation technique which consist tribo-charging of materials and separation of charged materials in an electric field. Separation efficiency mainly depends on selective charging and optimum charge density of materials in tribo-charging. However the efficiency of the above process is poor when processing coarse granular mixtures of insulating materials with particle size>2 mm. In this case roll type triboelectrostatic separation methods are more appropriate (Tilmatine et al 2009). Study finds a new type of vertical-reciprocation type tribocharger from which a triboelectric series which can be used as an important indicator for the material separation of plastics was established according to the relationship of the charge polarity and charge density between plastics and charging materials: (negative) HPVC-SPVC-COPP-HOMOPP-LDPE-HDPE-PET-Rubber-HIPS-Calibre-ABS-GPPS-PMMA (positive) (Park et al 2008). They obtained that triboelectric series and several charging properties that can affect the separation efficiency and the charging efficiency of plastics using a newly designed vertical-reciprocation charger set.

2.6 Mechanical sorting

Mechanical sorting technique has been successfully used in mining industry, but very little work has been done in development of mechanical sorting systems for plastic recycling. Mechanical sorting method involves centrifugal force, specific gravity, elasticity, particle shape, selective shredding and mechanical properties. Sorting by centrifugal force will involve designing a bowl type centrifuge that would separate plastics according to their specific gravity with improved separation performance and lower residual moisture content (Teichmann et al). Sorting with the help of centrifuge is much quicker and sorted plastic fractions are much dryer than when separated by gravity action. In the area of mechanical sorting of plastics, a new method Hybrid-Jig which is based on the jigging and flotation, where air bubbles are introduced into the particle bed during jigging to modify the apparent specific gravity by attachment of the particles so that the particles having different surface properties can be separated by jigging even if their specific gravities are similar (Hori et al 2009).

2.7 Sorting by melting

This sorting technique is suitable for sorting only two plastic kind at the time. To be able to use this method, it is essential that melting temperatures of the plastics are significantly different. This technique consists of an heated roll belt separator. Sorting takes place by the selective thermo adhesion of the softened particles to the rolls or belt. It has low operating cost.

2.8 Wet sorting technique

2.8.1 Sink float sorting method
This method is based on density differences of plastics. In this technique, plastics that have to be separated are placed in fluid which have density in between the materials making it possible for less dense material to float and heavier to sink. Water is commonly used for plastics with higher specific gravity (Wienaah 2007). The advantage is that plastic mixture is first expose to wet grinding, where the paper labels and dirt particles are removed and disadvantage is that separation can be slow, difficult to control and give low purity products. In froth flotation technique the materials to be separated first treated with surfactant and then suspended in water and due to reaction with surfactant material, plastics that would normally sink in water are suspended in the water mixture. Air is pumped into the system. The air bubbles adhere to some particles depending upon their resin type and causing the particles to float to the surface and materials which are not get altered are collected at the bottom. Hence in this technique collected materials at the top and bottom can be seen as get separated (Edward).

At least one plastic surface should be hydrophilic than only separation through froth flotation can be observed. It makes the froth flotation very challenging because all plastic have naturally hydrophobic surfaces and will readily float with addition of air bubbles. The froth flotation technique for separation of plastics which involve formation of hydrophilic species on the surface of plastic by effect of flame treatment can be use for plastic separation. In a study it is observed that using a angled flame it is possible to render both side of plastic flake hydrophilic. Flame treatment produces an increased oxygen content of the surface layer (Pascoe and O’Connell 2003). Since froth flotation technique requires the wetting of plastics. One of the commonly used method for wetting of plastics is by chemical conditioning with wetting agents. MC(methyl cellulose)molecules as a wetting agent , separates seven plastics namely POM,PVC,PET,PMMA,PC,PS and ABS into three groups according to floatability. MC molecules absorbed on plastic surface expose some of their polar groups oriented towards the aqueous phase, hence making the plastics surface hydrophilic (Shen et al 2002). In wet separation process hydrophilic particles are wetted by water whereas hydrophobic particles are wetted by oils and air bubbles. Froth flotation work properly when there is difference in surface properties. One of the major advantage with froth flotation is that it separates PET from PVC. Both PVC and PET are hydrophobic, by adding some appropriate reagents that absorb at the surface of PVC and PET can render PET hydrophilic while maintaining the hydrophobicity of PVC.

Thus PVC floats and PET flakes sink. A new froth flotation technique involving a series of six tanks, each tank operate in continuous manner has a specific function, depending upon the plastic that is being recovered. The only difference between is the chemical composition of their contents. According to our need of product, we can select the most appropriate chemical to be used in a given tank (Trans Forum, vol.4). It was originally developed to separate acrylonitrile-butadiene-styrene (ABS) from high impact polystyrene (HIPS). One method using flotation technique for separation of PET and PVC from mixes of the two polymers can be achieved by using tannic acid as wetting agent for PET, and methyl isobutyle carbinol (MIBC) as frother (Abbasi et al 2010).

3. Hydrocyclons

This technique is based on the principle of centrifugal acceleration to separate plastic mixtures (Weinaah 2007). It has no moving parts. The hydrocyclons consist of a conic and linked cylindrical body, in which there is a tangential entrance for the feeding suspension. A hyrdrcyclons transfer fluid pressure energy into
rotational fluid motion. This rotational motion causes relative movement of materials suspended in the fluid thus permitting separation of materials from one another. The hydrocyclon device has a very high throughout rate, but it produces highly accurate density separation if plastic size is small (<6mm nominal size) and have approximately same shape. A similar sorting process for shredded plastics is centrifugal sorting. A cylindrical water-filled centrifuge is used for this purpose. The technique can selectively separate, wash and dewaste plastic flakes from a mixture of polymer waste materials.

3.1 Selective dissolution

It is the batch dissolution of mixed plastics using solvents. The polymers have different solubility in organic solvents (differences amplified by the action of temperature). Different steps like to make soluble, then precipitation, then filtrations and finally evaporation of solvents (Saiter and Sreekumar 2011). This technique helps in complete separation of the polymers by careful control of temperature and selection of appropriate solvent. Individual polymer can be separated from complex mixture, contaminations such as dirt or soil. The disadvantage of this technique is amounts of solvents used, even though most of the solvents are recycled within the process. Research performed at Renessela Polytechnique Institute, uses a single solvent (Xylene), for extracting different post-consumer plastics (PVC, PS, LDPE, HDPE, PP) individually. In this process, Xylene is recovered again and again and feed-back into the plastic chip system. Here, PET needs to be removed using separate solvent (Edward). In a study selective dissolution/precipitation method for polymer mixture separation (SDP) and recycling is used, where excellent was achieved and quality of the recycled polymers remained practically unaltered when this technique was applied in a pilot unit for the separation/recycling of LDPE/PP mixture (Pappa et al 2001). Another study conducted at Cornell University shows that one solvent is not enough. They use combined technology process for sorting plastics. First they separate the non olefins from polyolefins by a simple sink float system then selective dissolution with a different solvent for each plastic group. In this sense this technique combines the cost-effectiveness of sink-float system with low purity and high cost of selective dissolution with high cost but high purity. Solvent used for this method is n-methyle-2-pyrrolidinone (NMP) (Edward).

4. Chemical sorting methods

4.1 Hydrolysis, Glycolysis, Hydroglycolysis

In chemical process, the polymer molecules are converted back to raw monomers. It offers the advantage in which it can be reused in the manufacture of new polymer (www.epr-italia.com). Finding of study shows that the plastic waste, both post-consumer waste and industrial waste, contaminated with a cellulose component can be processed efficiently and economically by the use of hydrolysis (Klason et al). In this process unmixed plastics produced by condensation reactions (polyurethanes, polyamides, polyesters, polycarbonates) can be split in their starting materials (monomers). In glycolysis separation process long-polymers chain are broken into short-chain oligomers that are repolymerized into virgin polymer. Complete depolymerisation does not take place in this process.

The high temperature aqueous-based paint removal method relies on hydrolysis of many coatings in hot water, thus removing the coating from the plastic. This is suited for olefin based plastics due to the fact that
they cannot be degraded under these conditions. It is observed that traditional sorting method which are based on physical characteristics such as specific mass, size, chemical properties but these all methods have some difficulties associated with them, the similar specific mass of most plastics and the contaminants in the waste in particular makes the sorting less efficient (Sena et al 2008). Italian researcher have developed an innovative device called “Multidune”. This device is very sensitive to small differences in mass so overcomes the problem of sorting of plastics which have similar density. It is able to separate out plastics of a low specific mass (around 1g/cm$^3$) (Sena et al 2008).

European project W2 plastics (FP7) aims at fundamental change of the present status of the plastic recycling by applying the magnetic density technology as well as the ultrasonic imaging technology to develop a separation device for the recycling of polyolefins from complex wastes. Numerical algorithms have been applied to simulate the magnetic fluid(magnetized water) for separation of plastics. The device used is divided into three sections: laminar section, separator section, collector section. Laminator section tries to make the flow laminar, in separator section the particles are separated according to their densities under magnetic field, in collector section each kind of particles flows at different height (Houzeaux et al 2010). At PTC, at North Western University a patented breakthrough technology for plastic recycling has been developed that eliminates sorting process by type and color of the plastic. This technology called solid state shear pulverization ($S^3P$), is a continuous one-step process for recycling unsorted pre- or post-consumer plastic waste. Plastic waste can separated by size separation technique using Trommel separator and vibrating screen by the size of wastes.

5. Conclusion

Plastics which have wide application in day to day human life generate large amount of waste, which is a serious environmental problem. The sorting of plastics is very crucial in plastic recycling for energy recovery since separated resins have higher values and are preferred by most reclaimers. Manual sorting is very laborious and human error is considerable. Nowadays there are many different types of automated sorting systems on the market that employ some kind of detection signal and sensor to detect and analyze chemical or physical characteristics of different plastics. It has been observed that whatever sorting methods are existing, have associated drawbacks. Manual sorting is not cost effective and automated systems are sensitive to dirt and produces high level of loss when set-up to deliver high purity. A good sorting technique should be very sensitive to small differences in gravity and can be performed on a laboratory and commercial scale without having high investment.

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6. References

plastic materials for recycling 13, 165-182.