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RESEARCH ARTICLE

Commercial Feasibility Study of PET Bottles Recycling by Solvent Extraction Method.

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Abstract

With increasing amounts of consumption of PET bottles in Bangladesh, huge amount of solid waste has been accumulated and thus polluting environment as these are non biodegradable. The aim of this research is to obtain information on post-consumer PET bottles recycling, its technological and economic aspects. These goals were attained through literature review of some current available recycling process and carrying out laboratory experiments of a recycling process (Dissolution of PET flakes by solvent recovery method using Cyclohexanone as solvent) being developed in Pilot Plant and Process Development Center of Bangladesh Council of Scientific and Industrial Research. FTIR was used to determine the functional group of the product, based on the peak value. The chemical structure of the standard PET and waste PET, before and after the restoration process was confirmed by recording their IR spectra. Experimental results have showed 90% PET recovery and 50% solvent recovery.

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Introduction:-

PET as packaging material has become the first choice for beverage bottles for its unique properties. PET meets the highest standards of cleanliness and hygiene and complies with the Food and Drug Administration (FDA) regulation of USA, UK, Japan, Canada, France, Germany. Besides this PET become a popular packaging material for bottles, jars and containers for its various qualities uniquely such as, giving clarity, excellent properties of carbonation retention, ingress of oxygen and virtually unbreakable, light weight, easy transportation and above all friendly to the environment and recyclable.

Following the great demand in recent years, a large number of industries have been set up for producing food grade PET bottles in Bangladesh Hossain, M. A. and Zakaria, M. F (2010). The production of PET bottles was introduced in the country for marketing drinking water in the early 90's.

In recent years, the generation of wastes has gained considerable importance within modern societies as a result of the change in the consumption habits and lifestyles of consumers. The evolution of societies worldwide has led to phenomena of mass consumption, thus resulting in increasing amounts of wastes produced and increased environmental impact generated by these wastes. In spite of great utility PET bottles can create an environmental problem for their indestructible nature taking up a growing percentage of municipal solid waste streams and pose environmental challenges. The amounts of waste PET bottles have increased accordingly. Fatema Tania, (2014) mentioned huge amount of PET bottles is dumped on the roadside, bank of river and sewerage in the city, which block the flow in the drains and sewerage system of Dhaka city., Bangladesh

According to the World Bank estimate, the waste generation per capita in Dhaka city is 0.5 kg per day in 1990 which equals to 3500 tons of solid waste generation per day in total. Poor land filling facilities and incineration not for the

purpose of energy recovery like U.S.A. rather in open air leads to huge air pollution. In Dhaka City solid waste typically contains 3 to 5% plastics consisting mainly PET bottles, Polyvinyl chloride (PVC), HDPE, LDPE and Polypropylene (PP).

Awaja, F. and Pavel, D. (2005) showed since PET bottles have recyclable characteristics, a small portion of them are reprocessed in Bangladesh and it is estimated that more than 90% of PET bottles are being informally recycled. Most of the used bottles are exported in the form of flakes, which have been processing in the cottage industry. As per Daily Star, Daily News Paper in Bangladesh, (2015) most of them used to export to China but stricter environmental policies in China exports in recent times. So, the trend of collection, separation and recycling of PET bottles in Bangladesh for flakes export purpose has increased (fig. 1). In Dhaka, these activities are organized through a chain of low-income people or sometimes the producer himself by selling the waste bottles to another plastic company.

Reviewing the literature PET bottle can be recycled to virgin PET resin solvent extraction method and blended with PET resins to produce valuable PET products. As per Daily Star, Daily News Paper in Bangladesh, (2015), in Bangladesh the manufacturers of PET bottles and synthetic yarn have to entirely depend on imports and imported 142,000 tonnes of PET resins in fiscal 2014-15 at a cost of around \$ 200 million. Recycling of PET will not only reduce the risk of environmental degradation, but also will save the huge amount of foreign currency every year.



Fig (1): Processing of PET Bottles in cottage industry as PET flakes

Objective:-

The objectives of the present study were

- i) To review the PET recycling process and find a suitable process for the virgin PET recycling process and
- ii) To study the technical and economical feasibility of the developed process

Salient Features of PET:-

PET was first developed for use in synthetic fibres by British Calico Printers in 1941. PET came into prominence in the 1950s as a textile material. Its strength, temperature tolerance and wear-resistance made it an ideal replacement for or addition to natural fibers such as silk, cotton and wool. Although originally produced for fibres, PET began to be used for packaging films in the mid 1960s and then, in the early 1970s, the technique for blowing bi-axially oriented bottles was commercially developed. The PET bottle was patented in 1973 by chemist Nathaniel Wyeth (brother of distinguished American painter Andrew Wyeth). Bottles now represent the most significant use of PET moulding resins.

J. A. Dean, (1987) and Awaja, F. and Pavel, D. (2005) showed PET is a thermoplastic polymer resin of the polyester family. Polyethylene Terephthalate is a polymer of two monomers called Ethylene Glycol and purified Terephthalic Acid, formed by condensation polymerization. Polyoxyethylene oxyterephthaoyl is its IUPAC (International Union of Pure and Applied Chemistry) name. It is used as fiber, injection molded parts, as well as blow-molded bottles and jars. Also special grades are offered with the required properties for the different need based applications. It is one of the most important raw materials used in man-made fibers .

PET is linear thermoplastic (long-chain molecule consists of repeating units shown in Fig (2), white but bluish resin made from terephthalic acid and ethylene glycol through poly-condensation. PET is supplied by the resin manufacturers in the form of small pellets, each about 0.05 grams.

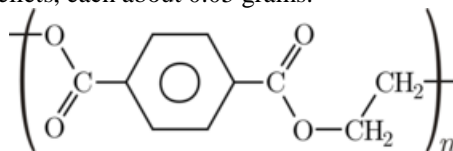


Fig (2): PET repeating unit

Selection of Recycling Method of PET Bottles:-

From Awaja, F. and Pavel, D. (2005) research work different methods of PET recycling have been developed,

- Material/Mechanical recycling
- Chemical recycling
- Thermal recycling etc.

In Material recycling/ Mechanical recycling complete recycling of foreign plastics also occurred. Here normally contamination removed by sorting and washing, drying the shredded PET flakes of post consumer PET bottles. Then PET bottles are re-melted and fibers are produced from the molten matter. But when melt molding is used it is not possible to reuse as PET bottles because of the deterioration of physical properties. Post consumer PET bottles for reuse in food grade application can not be possible for this reason. So recycling of PET bottles using solvent extraction has been selected in this study.

Material and Methods:-

Preparation of PET flakes:-

Used PET bottles were collected from the surroundings of research areas. The bottles were washed several times to remove the contaminants such as glue, label etc. and dried. Air dryer was used to dry the bottles. Then the bottles were shredded into around 4×7 mm pieces with 1mm thickness by cutting tools. The flakes then washed to remove adherent contaminants like traces of oil in stored bottle, detergents, pesticides etc. with hot water and NaOH solution at 80-90 °C for some time. Then it was dried in the oven at 80 °C for half an hour.

Materials:-

Analytical grade NaOH and Cyclohexanone (Merck) were collected from the local market. Oven (MEMERT UM400) was used to dry the flakes. A three neck round bottom flask was used in the laboratory to study the recycling process in solvent extraction method. FTIR (Fourier transform infrared) spectroscopy of the sample was recorded in the transmission mode using FTIR (IR Affinity-1 SHIMADZU) spectrometer.

Solvent extraction:-

Measured amount of Cyclohexanone solution was heated by an electric heater (electric heating mantle) up to approximately 156 °C. 2 g dried flakes were then added at the boiling temperature of solvent. After four hours of heating, PET flakes dissolves upon contact with Cyclohexanone. The solution was then filtered. Collected filtrate was measured for solvent recovery. Wet filter paper containing paste of PET was then dried in an oven for overnight at 80°C.

Pilot plant study:-

Based on the laboratory results the process had been upgraded to study the commercial and technical feasibility of the recycling process. The units required for pilot plant study was designed and fabricated and installed. SS 316 grade stainless steels were used to fabricate reactor. Oil jacketed reactor was fabricated since the dissolution had to be carried out at high temperature.

Result and Discussion:-

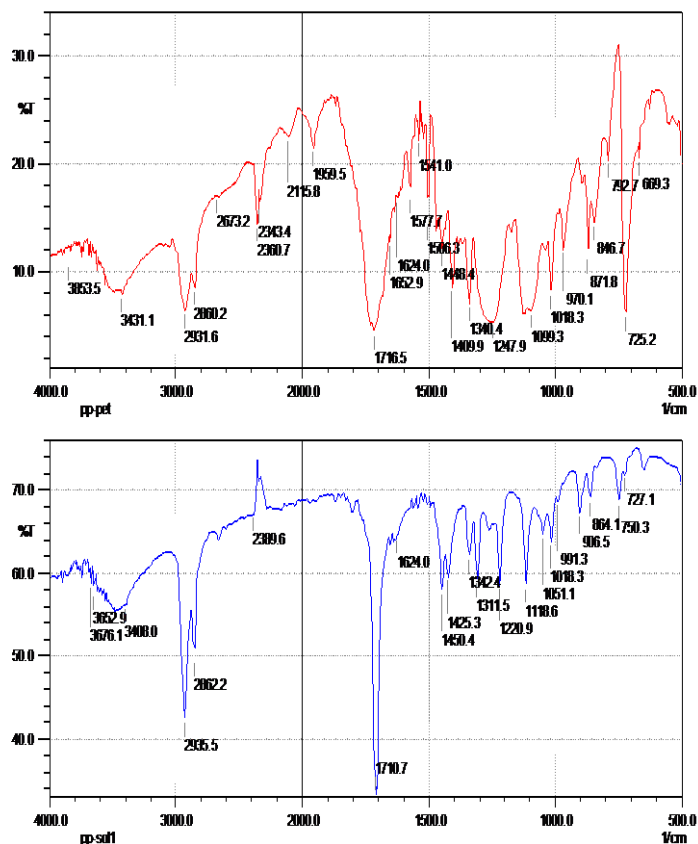


Fig (3): FTIR spectrum of PET polymer

FTIR analysis:-

Quality of produced PET polymer has been investigated by FTIR. Prasad S. G., De A. and De U. (2011) found that FTIR spectroscopy has been one of the most powerful among the qualitative and quantitative methods of studying molecular bonding structure and functional group analysis. Identification and analysis of functional groups in a compound structure of a polymer such as PET is very important.

In the present study the FTIR signals of recycled product of PET with that of virgin PET had been compared and emphasis was given on some functional groups detected in these materials. It is found that the product resin, that is recycled PET shows almost similar graph of virgin PET resin graph. This finding confirms that the quality of recycled PET by this process is very much near and comparable to that of the virgin one.

Discussions:-

Based on the experimental result with 90% PET recovery, a modest 50% solvent recovery and FTIR test (which confirms the quality of the recycled PET by showing similar graph pattern), this process can be considered as a good process for recycling of PET Bottles.

From the chemical structure of PET (Fig 2), it is very clear that PET have a chemical composition of C, H and O. So, FTIR spectrometer is required to understand the molecular bonds among these elements by the analysis of PET sample's spectroscopy.

Prasad S. G., De A. and De U. (2011) described the peaks in FTIR spectra for PET give dual information. Firstly, every peak position is fundamental to molecular bonding structure or functional group existing in the material or resin. Secondly, variation in intensity of particular peak in a spectrum correlates to the proportion of that functional group present in the material.

FTIR spectrum from 4000 cm^{-1} to 500 cm^{-1} for recycled PET resin and virgin PET have been shown in Fig 3. In this figure transmission, %T is plotted as a function of wavelength in cm^{-1} . The minima or dips in the transmission spectra refer to absorption maxima corresponding to characteristic molecules and groups.

PET consists of molecular groups (carbon, hydrogen and oxygen) and these groups have characteristic absorption peaks. FTIR peaks as shown in Fig 3 are mostly reflecting their bond strength.

From Stuart B., George B. and McIntyre P. (2008) the O-H stretching mode in alkanol (OH) and alkyl groups (CH_3 , CH_2 and CH) exist in the infrared absorption spectra in the region $3650\text{--}2500\text{ cm}^{-1}$ which are very similar in both spectra. Two prominent similarity are observed within the spectra of pilot plant product and virgin PET, corresponding 2931.6 cm^{-1} and 2860.2 cm^{-1} to 2935.5 cm^{-1} and 2862.2 cm^{-1} .

Characteristic infrared spectra in the range $1850\text{--}1730\text{ cm}^{-1}$ corresponds to C=O stretching, doublet in the carbonyl group is also comparable within these spectra. Within these range 1716.5 cm^{-1} in recycled product and 1710.7 cm^{-1} in virgin PET spectra is very much matched.

The C=O stretching mode of vibration in aliphatic ketone or alkanal, aromatic ketone, alkanolic acid alkanoyl chloride and alkanooate ester appears in the range $1700\text{--}1680\text{ cm}^{-1}$.

The C-O stretching, strong modes in alkanooate ester and alkoxy ether have their characteristic peaks in the range $1400\text{--}1000\text{ cm}^{-1}$ from Fig 3, it is clear that there are multiple similar peaks between two spectras.

By comparing two spectra in Figure 3 it can be decided that within the range $1000\text{--}500\text{ cm}^{-1}$, there are almost similar signature absorption peaks in these two spectra, such as at 725.2 in recycled PET and 727.1 cm^{-1} in virgin PET.

From the above discussion it can be decided that the quality of recycle PET is almost similar to the quality of virgin PET.

Conclusions:-

Following conclusions can be drawn from the present research work,

1. It is shown that PET bottles can be recycled to produce PET resin
2. 90% PET and 50% solvent can be recovered, that the rates are quite satisfactory. Reflux percentage can be increased if temperature can be controlled further. It will increase the cost as well. At present 142000 tonnes of PET resins are being imported and the amount is increasing every year, so applying this recycling technology around 127800 tonnes can be produced.
4. From FTIR spectrum the quality of recovered or recycled PET is very much comparable to that of the virgin one.
5. Plant for recycle of PET can be established to save the huge foreign currency. It will also help to keep the environment clean.
6. Process parameters are almost optimized.

Recommendations:-

For further research work regarding recycle of PET, following works should done,

1. PET recovery and solvent recovery rates can be improved by using bulk amount
3. More analytical test of the product can be done.
4. The same procedure can be adopted for other solvent.
6. In some cases one can use *Polyethylene Terephthalate* (PET) flakes from other sources rather than water bottles only.
7. Technical and commercial feasibility study should be carried out.

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