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Feasibility Study of Municipal Plastic Waste for Power Generation in Lahore City, Pakistan

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Abstract

In the last century mankind witnessed many innovations and one of them is the emerging of plastic materials in different fields. Due to light in weight and good impact and thermal resistance, these plastics are found to be very useful in manufacturing of certain products as well as household. Use of these materials also helped in boosting the economy of industries which replaced plastic materials with the metallic materials in certain processes. But there is the great drawback associated with these commodities. The most significant is the environmental problem i.e. plastic material is a great source of adding pollution. The world's annual consumption of plastic is increased tremendously from early 1950's to till now. Therefore the plastic waste which is increasing day by day should be recycled. Plastic waste recycling provides the opportunity to collect and dispose of plastic waste in the most environmental friendly way and it can be converted into the energy resource. The major motivation of this research is to study the feasibility of producing energy through municipal waste plastic in Lahore city, Pakistan. A detailed economic analysis is carried out which shows the plastic is the cheaper resource of producing energy and helps in reducing the demand and supply gap of energy in Pakistan in future.

Keywords: Economic feasibility; Plastic waste; Recycling; Waste characterization; Equipment cost

Introduction

In the last century, mankind has witnessed many innovations amongst them is the plastics we know and use today in our daily life. These plastics are found in every household, every country either developed or developing and are independent of our economic situation. But there is a darker side to these commodities [1]. The most significant is; they are adding to the pollution we as humans are creating in this clean world as was once known. The world's annual consumption of plastic materials has increased from around 5 million tons; in the 1950s to nearly 100 million tons; thus, 20 times more plastic is produced today than 50 years ago. This implies that on the one hand, more resources are being used to meet the increased demand of plastic, and on the other hand, more plastic waste is being generated [2]. Even the cities with low economic growth have started producing more plastic waste due to plastic packaging, plastic shopping bags, polyethylene terephthalate (PET bottles) and other goods/appliances using plastic as the major component [3]. On the other hand, plastic waste recycling can provide an opportunity to collect and dispose of plastic waste in the most environmental friendly way and it can be converted into a resource. In most of the situations, plastic waste recycling could also be economically viable, as it generates resources, which are in high demand [4]. Plastic waste recycling also has a great potential for resource conservation and greenhouse gas emissions reduction, such as producing diesel fuel from plastic waste [5]. This resource conservation goal is very important for most of the national and local governments, where rapid industrialization and economic development is putting a lot of pressure on natural resources. This research is based on the principle of 3R (reduce, reuse and recycle) principle. It is aimed at providing awareness to all the stakeholders to minimize the burden on the future generations and preserve our environment [6].

The disposal of municipal waste plastics has become a major environmental problem all over the world. USA, Europe and Japan generate about 50 million tons of post-consumer plastic waste material [7]. Saudi Arabia is one of the major producers of plastic in the world with total production capacity of around six million metric tons per year. The amount of plastic wastes in Saudi Arabia is about 15-wt% in the composition of domestic municipality waste [8]. The number of landfill sites is decreasing. Also land filling could result in plastic additives such as phthalates and various dyes polluting ground water [9].

Incineration is an alternative to landfill disposal of plastic wastes, but this practice could result in the formation of unacceptable emissions of gases such as nitrous oxide, sulfur oxides, dusts, dioxins and other toxins [10]. The option of secondary recycling or mechanical recycling, which is the reprocessing of plastic waste into new plastic products with a lower quality level, is not showing any signs of growth in the recycling industry [11]. Tertiary recycling, this returns plastics to their constituent monomers or to their higher value hydrocarbon feed stock and fuel oil, is gaining momentums an alternative method. Tertiary recycling includes all those processing which attempt to convert the plastic wastes to basic chemicals by the use of chemical reactions such as hydrolysis, methanolysis and ammonoloysis [12] for condensation polymers and to fuels with conventional refinery processes such as pyrolysis, gasification, hydrocracking, catalytic cracking, coking and via breaking for addition polymers excluding PVC [13].

Pyrolysis and catalytic conversion of plastic is a superior method of reusing the waste. The distillate product is an excellent fuel and makes pyrolysis one of the best, economically feasible and environmentally sensitive recycling systems in the world today. Catalytic pyrolysis diesels can be used in any standard diesel engine, trucks, buses, trains, boats, heavy equipment and generators [3].

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Plastics in environment

Three million tons of waste plastics are produced every year in the U.K. alone, only 7% of which are recycled. In the current recycling process usually the plastics end up at city landfills or incinerator. As with any technological trend, the engineering profession plays an important role in the disposal of plastic waste. Discarded plastic products and packaging materials make up a growing portion of municipal solid waste [11].

Expenditure incurred on disposal of plastic waste throughout the world is around US $2 billion every year. Even for a small country like Honk Kong spends about US $14 million a year on the exercise. The Global Environment Protection Agency (GEPA) estimates that by the year 2004 the amount of plastic thrown away will be 65% greater than that in the 1990's [10]. The recycling of the plastic is only about one percent of waste plastic in the stream of waste in developing countries as compared to a rate of recycling of aluminum which is about 40% and 20% for paper, whereas recycling rate in India is very high up to 20% of waste plastic [13].

Research methodology

Solid waste characterization forms the basis of integrated solid waste management. It varies according to social habits and income level by time. Since social changes have accelerated in the globalizing world, the changes in waste characterization occur at shorter periods. For Lahore city, it is required to follow up solid waste content at least with annual periods during the stage of establishing integrated waste management. In this scope, the solid waste characterization for 2013 summer season was completed. Detailed trainings were delivered for solid waste characterization in 2012, and the process was followed up as observed in 2013 summer study.

It was aimed to monitor the urban solid waste characterization which will serve as a basis to waste management to be established in Lahore. Data for comparing door-to-door compressing vehicle collection system with existing collection system were obtained. Waste character was determined with a series of laboratory analysis conducted as well as item group classification (waste characterization) conducted.

Field surveys were carried out in winter and summer seasons of 2012 in the scope of Pakistan Lahore state solid waste characterization study. Waste characterization was observed periodically. The previous methodology followed earlier was used in the study, no change was required. U.S. standard ASTM D5231 "Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste" and "European Commission-Methodology for the Analysis of Solid Waste (SWA-Tool)" were taken as basis in characterization study.

In the characterization study, socio-economic structure was taken into consideration in zoning. Three different social welfare levels, low income, middle income and high income were taken as basis in the areas where samples were collected. Besides, samples were also collected from commercial zones and institutes Table 1. The areas for collecting the samples were determined before starting the study and samples were forwarded to the site according to working schedule determined. Routine collection processes were carried out in the areas of sampling without selecting wastes. The vehicles loaded with waste were weighed before transportation to the site of study the capacity of waste vehicles varies between 5-10 m^3. The details concerning area and amount of waste were taken and recorded from each vehicle arriving Table 2.

No	Area
1	Low income areas
2	Middle income areas
3	High income areas
4	Commercial areas
5	Institutions

Table 1: Classification of different areas for samples collection.

Components	Explanation
Combustibles	Combustible waste which are undefined in other categories
Electrical and Electronic Waste	Every type of electrical and electronic waste
Glass	Every type of waste glasses
Hazardous Materials	Accumulator, Battery, medical waste
Biodegradables	Food waste, fruits, vegetables etc.
Metals	All kind of metals
Non Combustibles	Stone, demolition waste, bond, curbside
Paper-Cardboard	Newspapers, magazines, office papers etc
Pet	Water bottles
Nylon	Shopping bags
Plastics	All kind of plastics except pet
Tetrapak	Milk and juice cardboard
Textile	All kind of textile wastes

Table 2: Solid waste categorization.

The samples which are separated are weighed on digital scale with a sensitivity of 10. Characterization percentage values were obtained automatically by entering the weight of each group into the table.

Results and Discussions

Urban waste was evaluated in 5 categories in characterization study and a total of 48 samples were studied. While waste categories are listed as low income, middle income, high income, commercial and institutions. The number of the wastes collected from the areas under the responsibility of contractor companies is 16.

A total of 215.0 kg waste was forwarded to the site of study for characterization process, and separation process was carried out in 5.0 kg of waste after homogenous mixing. Considering the fact that waste density is nearly 200 kg/m^3, separation process was carried out over nearly 25 m^3 waste. Results are consistent with typical developing country characteristics. They include important components with over 60% of biodegradable and plastics rest are nylon, textile, paper-cardboard, non-combustibles, and combustibles in weight. The higher amount of biodegradables and plastics in the waste collected from different sectors suggest us to use a process that includes turning this waste into usable fuel. Certain processes were studied and there evaluation was done, this shows that hydro catalytic cracking or pyrolysis-catalytic cracking will give us higher efficiencies and better quality of fuel to use further.

Process description

Hydro catalytic cracking or pyrolysis-catalytic cracking is a process that converts waste plastics into valuable liquid hydrocarbon product that can be utilized as energy source for many purposes such as diesel engines, generators, vehicles, etc. The gaseous by-product obtained in the process can be used for domestic use by refilling it in the cylinders and also to run gas turbines. Thus catalytic cracking process can be considered as another non-conventional energy source. We all know that crude oil is the ultimate source of plastics and most of

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the chemicals. Out of total 100 million tons plastics produced every year all over the world, 25 million tons is dumped. By dumping such hefty amount of waste plastics, we are wasting lots of energy in the form of crude oil that is used to make plastics. This wasted energy can be recovered back using catalytic pyrolysis process. By doing this we can save our conventional energy source i.e. crude oil and ultimately country foreign exchange.

Suitable plastic materials for treatment

As a rule of thumb, approximately 950 ml of oil can be recovered from 1 kg of plastics such as poly-olefins including polyethylene (PE) and polypropylene (PP), or polystyrene (PS). Although not suitable, the process can nevertheless tolerate small quantities of plastics containing heteroatoms. Heteroatoms are atoms other than carbon and hydrogen such as chlorine, sulphur and nitrogen. Since heteroatom's are heavier than the light elements such as carbon and hydrogen these increase the density of the plastic. A rough rule of thumb is to take a representative sample of the flaked waste plastic and add it to a jar of water. If more plastic floats than sinks then the plastic scrap is acceptable feedstock for catalytic pyrolysis. The floatable fraction represents mainly poly-olefins (that is polyethylene and polypropylene) and expanded polystyrene. Poly-olefins give the best yield of distillate due to their straight-chain hydrocarbon structure. Polystyrene is beneficial in the mix since it contributes aromatic character to the distillate and improves the pour point properties (that is, the low-temperature viscosity properties).

Process technology [10]

The pyrolysis by direct heating was adopted to produce the paraffin and crude oil from the plastic wastes in the 1990s. The small-scaled process is featured by facilitation, convenience and low equipment investment. However, the temperature caused by pyrolysis is higher and all the reactive time is longer than the other methods. The octane number of gasoline gained is relatively low and the pour point of diesel oil is high. More paraffin is produced in the process of pyrolysis Figure 1.

Although this process is simple and convenient, the converting rate and yield is still lower. The total yield of fuel oil is 50-65%. The other problem for this process is the pyrolysis equipment's corrosion incurred by PVC in mixed plastic wastes. Therefore, it is strongly recommended to establish a reasonable sorting system and apply an efficient technique to eliminate the toxic emissions and highly corrosive hydrochloric acid that is formed. Since the total yield of fuel oil with pyrolysis is still lower and the quality of oil is not satisfied as gasoline and diesel oil, the upgrade by catalytic cracking for the crude products gained with pyrolysis can be used.

Having improved the quality of finished oil, this process has been

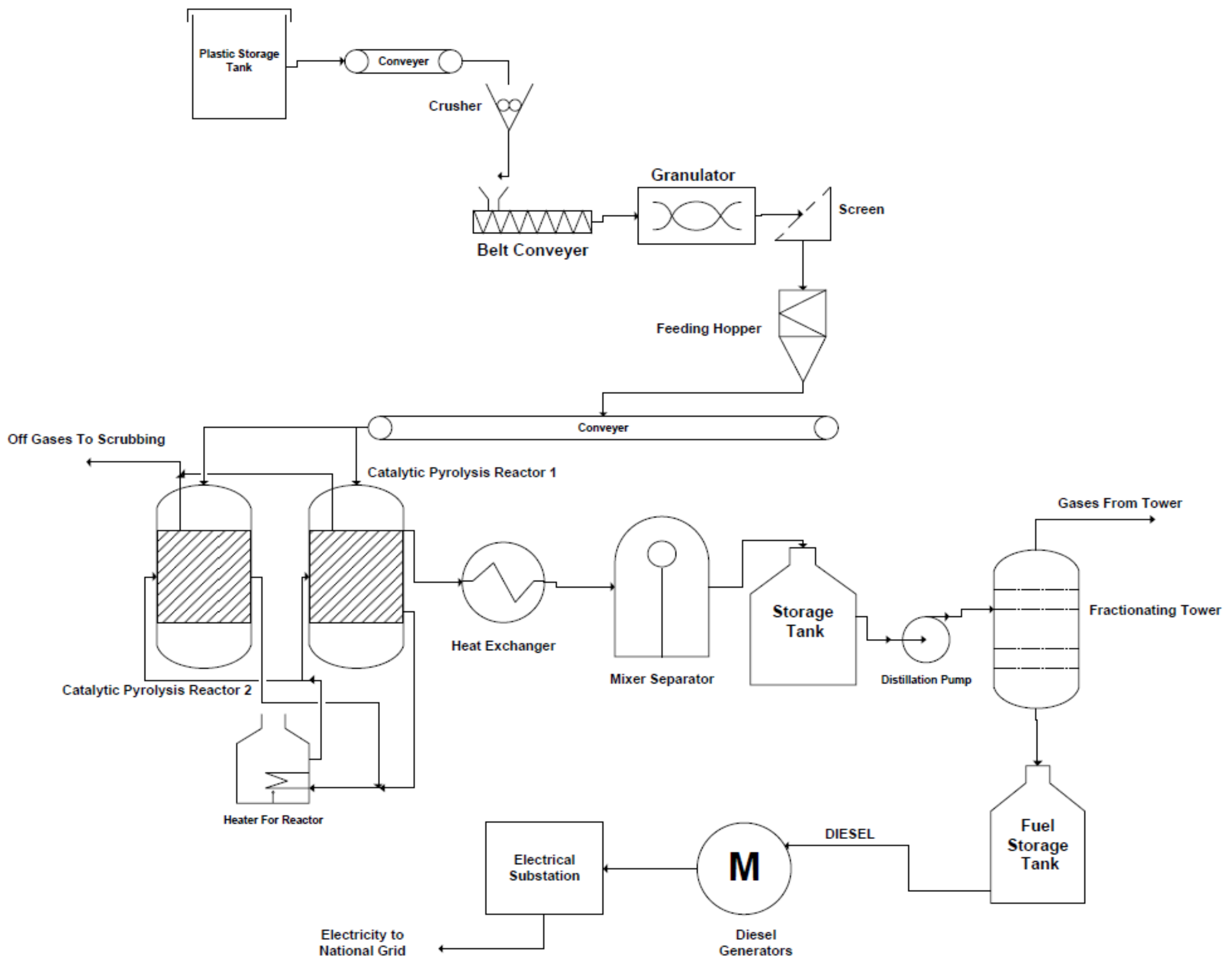

Figure 1: Process flow diagram for pyrolysis.

widely used in many factories. The system consists of the knapper, extrusion machine, pyrolysis reactor, catalytic cracking reactor, fractionating tower, heating and temperature controller, separator of oil and water, and oil can. An improved apparatus apart from the pyrolysis reactor consists of a cylindrical rectangular vessel heated by electrical heating coils or any other form of energy, the said vessel is made of stainless or mild steel, surrounded by heat reflector and insulator to avoid heat loss. It is provided at its side an outlet vent which connects with the condensing section which is made up of stainless or mild steel provided with an outer jacket for circulating cold water or any coolant, the condenser is connected to the receiving section and to a gas meter. The receiving unit is maintained at -40°C to higher temperature to collect the distillate Table 3. The catalyst in the process is shown in the following table. Milling the said ingredients and making slurry using demineralized water, spray drying the slurry to micro-spheres, and calcining at 500°C for 1 h. The finished oil consists of gasoline (60%) and diesel oil (40%).

Properties and purity of fuels

The properties of liquid distillate match with properties (Ex: specific gravity and pour points) of high quality imported crude. The fuels obtained in the waste plastic process are virtually free from contaminants such as lead, sulphur and nitrogen. In the process (i.e.) the conversion of waste plastic into fuels, the properties mentioned above of petrol and diesel fractions obtained are of superior quality with respect to regular commercial petrol and diesel purchased locally and has been proved by the performance test. During the process, hazards related to health and safety is reduced to 90% as compared to regular refinery process.

Quality of fuel

The quality of gasoline and diesel fractions obtained in the process is not only at par with regular fuels in tests like sp-gravity is 0.7365/15°C CCR (conradson carbon residue) ash, calorific value etc. but it is also better in terms of quality in test like flash point, API gravity.

Faujasite-zeolite	05-35 wt%
Pseudoboehmite alumina	10-40 wt%
Polyammonium silicate	01-10 wt%
Kaolin clay	15-60 wt%

Table 3: Percentages of catalyst used in pyrolysis process.

Liquid distillate	>110-115%
Coke	>09-10%
Gas	>21-22%
LPG	>14-16%
Hydrogen	>01-02%

Table 4a: Percentages of products obtained in pyrolysis.

Yield

The average percentage output yield of the products in the first phase of reaction depending on the composition of the waste plastic is as follows Table 4a. The percentage of liquid distillate is mentioned in terms of weight by volume whereas percentage of coke and gas are mentioned in terms of weight by weight. During the second phase of reaction (i.e.) fractional distillation, the average percentage yields of various fuel fractions depending on the composition of the waste plastic are follows: gasoline - 60% and diesel - 30%;

Feasibility study

The production of the fuels from the waste plastic of various sorts has been carried out a number of times to arrive at the unit cost of production. The break-up of the cost for per kg input of the plastic and the related output for the same is depicted in the table given below. From this data and the increasing price of the fuel it is clear that our process is feasible and even economical in the long run. Given is the cost data for the whole process Table 4b.

Market assessment in Pakistan

The market feasibility of the process lies in the product that we achieve from it. As we don't have any proper dumping and landfilling procedure for municipal waste so incinerating and wasting the energy is not a better solution. Also from the unit price data of the fuel it is evident that this fuel is very cheap rather than current fuel price that is growing day by day.

Also we have scarce resources of natural oil reserves so in that case this process will prove much economical in the long run. Investment in this sector will definitely pay back and that data also included proving its economic feasibility.

Conclusion

Plastics present a major threat to today's society and environment. Over 14 million tons of plastics are dumped into the oceans annually, killing about 1,000,000 species of oceanic life or they are landfilled in some remote areas that reduce the fertility of land because most plastics form is not degradable readily. So they may affect the environment very badly. Though mankind has awoken to this threat and responded with developments in creating degradable bio plastics, there is still no conclusive effort done to repair the damage already caused. In this regard, the catalytic pyrolysis studied here presents an efficient, clean and very effective means of removing the debris that we have left behind over the last several decades. By converting plastics to fuel, we solve two issues, one of the large plastic seas, and the other of the fuel shortage. This dual benefit, though will exist only as long as the waste plastics last, but will surely provide a strong platform for us to build on a sustainable, clean and green future. By taking into account the financial benefits of such a project, it would be a great boon to our economy.

Input	Quantity (input kilograms)	Rate per kilograms	Amount Pakistan rupees	Output	Quantity produced	Rate in Pakistan rupees per liter	Amount in Pakistan rupees
Plastic	1.00	12.00	12.00	Petrol	0.300	37.50	22.50
Labor			5.00	**Diesel**	**0.600**	**25.50**	**7.65**
Service charges			2.50	Lube oil	0.100	15.00	1.50
Total	1.00		19.50		1.00		31.65

Basis =1000 Tons/day plastic
Diesel produced per day=1000 × 1000 × 0.6
= 600000 L/day

Table 4b: Feasibility analysis of diesel production from plastic.

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Author's Contributions

Each author of this manuscript writing made considerable contributions including surveying of different zones, plastic waste collection then calculation of the economic feasibility for the project and also contributed in the preparation of this manuscript.

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