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Review Article

Economic Analysis of Fuel Oil Production from Pyrolysis of Waste Plastic

Kinza Hamid*, Rabia Sabir, Khawar Hameed, Ammara Waheed and Muhammad Usama Ansari
Department of Chemical Engineering, University of Wah, Pakistan

***Corresponding author:** Kinza Hamid, Department of Chemical Engineering, Wah Engineering College, University of Wah, Quaid Aveneue, Wah Cantt, Taxila, 47040, Pakistan

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Abstract

The Global plastic production has reached up to 300 million tons in 2015, and waste management has become a serious issue especially in middle and low income countries such as Pakistan. Pakistan, which is producing 1.32 million ton/year of plastic waste, is also facing the issue of environmental pollution as well as unadequate waste dumping ability due to surge in urban population. Among various waste management techniques, pyrolysis has been receiving attention because it offers solution to two most critical problems, energy shortage and environmental pollution. The main purpose of this paper is to produce fuel oil by waste plastic through the pyrolysis process and its cost estimation. Waste plastic decomposes in a various fraction of hydrocarbons catalytically at 400°C. These hydrocarbons are separated through distillation columns and phase separators as light and heavy fuel oil and wax. The economic analysis shows that the estimated total capital investment required for a pyrolysis plant is $0.2 million, the estimated total production cost of pyrolysis plant is $1.6 million/year. The results shows that pyrolysis of waste plastic to produce fuel oil can be the viable solution to meet Pakistan's energy demand as well as to solve waste dumping issue.

Keywords: Pyrolysis; Plastic waste; Environmental impact; Fuel oils; Cost analysis; Polyethylene

Introduction

The word plastic is derived from the Greek word "plasticos" which means it can be mold and re-shaped by heating. It consists of long-chain polymers, petroleum, natural gas, and coal are by-products. Plastic plays a very important role in our society because it is versatile and cheap. That's why global production increases by 5% every year. As the production of plastic increases, a large amount of plastic waste is also produced which causes very serious environmental problems. Plastic is non-biodegradable, it consists of lethal additives; it took 500 years to decompose [1]. There is no proper way to dispose of plastic waste. A large part of the plastic waste is dumped into landfills due to this underground water is polluted and causes many diseases, due to legislative pressure disposing the plastic waste to landfills become unacceptable (disposal of waste to plastic reduced by 35% over the time of 1995 to 2020). On the other hand, some of the plastic waste is incinerated due to which very toxic gasses emit in the environment, which causes the greenhouse effect [2]. Some of the plastic waste is dumped into oceans and causes problems for marine life. According to the report of the UN, if the production rate of plastic waste will remain the same till 2050 then the ocean will accumulate more plastic waste then fishes [3]. Global plastic production reached up to 300 million tones [4,5]. From 1950 to 2015, 6300 million tons of plastic were produced out of which 79% was dumped into landfills, 12% was incinerated, and 9% was recycled. [6]. 60 million tons of plastic produce by China that makes China the largest producer of plastic [7]. Production of plastic increases 5 million tons per year in the UK [8]. Pakistan is also suffering from plastic waste pollution, produces 1.32 million tons/year of plastic waste [9].

Therefore, there is a need to find out an effective way to handle the plastic waste. In this view, recycling of plastic waste is the best way. Recycling is of two types, mechanical or chemical. Mechanical recycling is the conversion of plastic into different products without changing the chemical structure of the plastic [10]. While Pyrolysis is chemical recycling. In pyrolysis, plastic decomposes into a light and heavy hydrocarbons (fuel oil) and in non-condensable gases at 300-900 °C in absence of oxygen [11]. There are two types of pyrolysis, thermal pyrolysis, and catalytic pyrolysis. Thermal Pyrolysis occurs at high temperatures and requires high energy. As there is no catalyst involve in thermal pyrolysis production of low molecular weight hydrocarbon is high and the product from has a low quality which makes the process unfeasible [12]. Catalytic pyrolysis occurs at low temperatures and required less energy which makes this process cost-effective. Catalyst plays a very important role in increasing the efficiency of pyrolysis. The catalyst that most widely sued catalyst is ZSM-5. Zeolite, Y-Zeolite, Ti-Al-Beta, FCC, and MCM-41 [13].

The energy demand of the World is primarily met by fossil fuel. Estimated global energy production with respect to available resources shown in (Figure 1). For the economic growth of the world, the conventional method is method are important but these methods affect the environment negatively. For the production of electricity Coal, Oil, Natural gas considered important fuel. The average need for oil increases by 35% by the year 2050 with a 1.2% increase in the average growth rate. Pakistan also facing a serious energy crisis, which creates, huddles in the progress and development of the country. Industries of Pakistan are in loss due to a shortage of electricity. Pakistan imports 12 million tons of coal and 135 million bbl of crude oil every year to meet the energy demand of the country.

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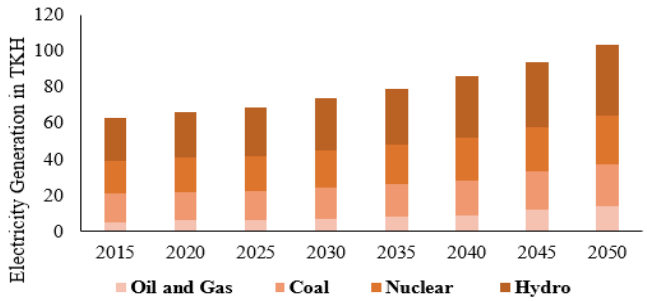

Figure 1: Estimated global electricity productions with respect to energy sources [36].

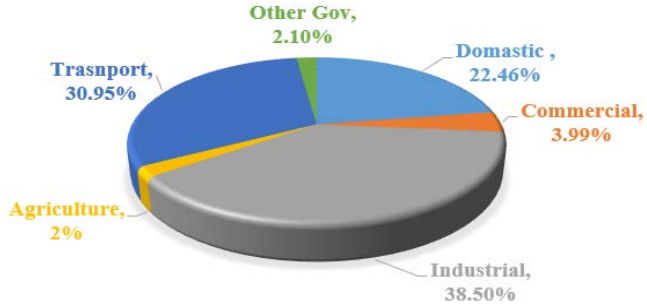

Figure 2: Pakistan Energy Consumption Data [37].

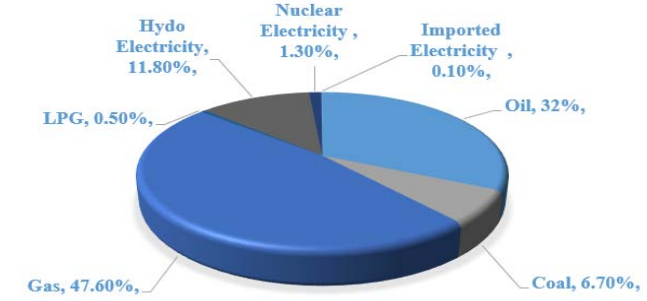

Figure 3: Production of Electricity by different available resources in Pakistan [37].

To run continuously all sectors of Pakistan like domestic, industrial, transport, and power generation demand energy. Pakistan installed a power generation plant but still, there is a huge gap between demand and supply. Nowadays the production cost of electricity increases in Pakistan and affecting both commercial and domestic users. These energy crises affect Pakistan's economy badly. In the last few years, 4% of GDP has been used due to theses crisis [14].

With a daily increase in the pollution of Pakistan, the energy demand is also increased to meet the living standard of people. Pakistan's energy consumption data is shown in (Figure 2). For Pakistan, it becomes very important to produce less electricity than conventional methods (Coal, oil, natural gas) and move towards non-conventional methods (biomass, plastic waste). The non-conventional method will help Pakistan in improving there economy, environmental issues and energy crises [15]. Electricity production in Pakistan by different available resources is shown in (Figure 3).

American scientist Aguado et al, Schiers and Kamminsky, and the United Nations Environment Program (UNEP) recommended four technologies to convert plastic into fuel in 2000, pyrolysis is one of them [16].

In Pakistan Atif Khan, Khizar Nawaz, Zohaib Ashraf, and Muhammad Usama research converting plastic into fuel in A.Q. Khan Institute of Research and Technology [17]. The main purpose of the research is to study the viability of energy production through plastic waste in Lahore city, Pakistan. Through the detailed economic investigation, they end that plastic is the cheaper source of energy production and it will help in fulfilling the future demand and supply gap of energy in Pakistan.

In 2014 US, 84 plants convert 30 million tons of waste plastic into energy. The largest pyrolysis plant is in japan that converts 14,800 tons/year of waste plastic into 8.75 million liters/year of fuel [18].

In Malaysia, JN Sahua, KK Mahalik [19] did a feasible study on catalytic cracking of PP, PE, and PS the catalyst and reactor proposed are amorphous silicate alumina and fluidized bed reactor, respectively, the conversion is 95%.

In Nigeria, AS Olufemi, SA Olagboye [12] worked on the thermal conversion of waste plastic into fuel oil. According to their research, the thermal conversion of plastic of four types (LDPE, HDPE, PP, and mixed plastic) was carried out in a batch reactor at 170 to 3000°C temperature and 1 atm. pressure produce liquid hydrocarbon (fuel oil). They also investigate the effect of reaction time and product yield.

In India Aantony Raja and Advaith Murali research on the Conversion of plastic waste into fuel oil [20]. In their research, they did catalytic pyrolysis of mixed plastic at 500°C by using a mixture of zeolite, clay, aluminum, and silicate in different proportions as a catalyst and product that obtained are petrol, kerosene, and deiseal. Lube oil, furnace oil, and coke.

Some of the pyrolysis plants of mixed plastic are Mogami Kik [21], BP Garngemounth (UK) [22], Nexus Fuels (Atlanta, USA), RES polyflow (Ohio, USA), Vadxx, (Ohio, USA), Pyrolysis System (LLP, India) [23].

Pyrolysis is cost-effective because the raw material (plastic waste) is available in bulk amount and cheap. The capital cost of the Pyrolysis plant is $0.2 million if the flow rate of raw material is 14 kilotons/year and produced 10 kilotons/year of fuel. In this report, the target work is the catalytic pyrolysis of polyolefin (Polyethylene and Polypropylene) over the Ti-Al-Beta catalyst and the economic analysis of the pyrolysis plant. These plastics are mostly used and have a high production rate across the world. Roundabout 60-70% of plastic waste is consist of polyolefin [24].

Analysis of Solid Waste in Pakistan

In worldwide Pakistan ranks 6th in population, so the utilization of material and its waste in Pakistan is more than in other countries in the world. Pakistan has 15th rank in the world to produce pollution, which is quite satisfactory. But the pollution is increasing day by day in Pakistan.

Yearly 20 million tons of solid waste is produced in Pakistan, and this solid waste has been increasing by 2% annually. The growth rate

Table 1: Composition of solid waste in Pakistan [9].

Component	Percentage
Ash, bricks, and dirt	18%
Glass	6%
Textile	2%
Cardboard	7%
Food wastes	30%
Leather	1%
Paper	6%
Plastic	9%
Rubber	1%
Metal	4%
Wood	2%
Yard Waste	14%

Table 2: Percentage physical composition of solid waste in Bahawalpur [26].

Component	Percentage
Vegetable food waste	41.50%
Peper products	9.70%
Juice cartoon	3.30%
Cardboard	3.38%
Soft plastic	2.29%
Hard plastic	5.59%
Diapers	8.50%
textile	2.50%
glass	3.70%
Metal	1.95%
soil	1.22%
Yard Waste	14.10%
other	2.36%

of waste generation is 2.4 % yearly [25].

Composition of Solid Waste in Pakistan

Pakistan is collecting only 50% solid waste for recycling because Pakistan doesn't have enough resources that recycle all solid waste. In total waste there is 9% of plastic material (Table 1), which means Pakistan is producing 1.32 million tons of plastic waste. That means enough capability to reuse this plastic or produce fuel oil by the pyrolysis process [9].

Case Study for Bahawalpur

Bahawalpur is the city of Punjab, and the population of Punjab is more than any other province so the waste material is generated 282 tons per day in Bahawalpur. The waste material of this city mainly consists of glass, metal, soil, textile, hard plastic, soft plastic, cardboard, and juice cartons, etc [26].

All the waste material is biodegradable except soft plastic and hard plastic. The percentage of hard plastic and soft plastic in total Bahawalpur waste is 5.5 % and 2.29%, respectively (Table 2). It means 22.2 tons per day of plastic generated in Bahawalpur, 27% of total waste is recyclable while the remaining waste material is creating pollution in this city.

Process Description

Pyrolysis is defined as the controlled heating of the material in the absence of oxygen at 300°C to 900°C temperature and 1 atm. pressure. In the pyrolysis of plastic, the structure of the macromolecules of plastic is decomposed into smaller molecules and some monomeric compounds. Further decomposition depends on residence time, temperature, presence of the catalyst, and other process conditions. Pyrolysis reaction can occur with or without a catalyst. For the Pyrolysis of Polyolefin (PP, PE), catalytic pyrolysis is favorable because, lower temperature and time, high conversion rate, provides better control over the distribution of hydrocarbons, product yield is high [27].

The raw material that is plastic waste was collected from the dunk yard and is in the dirty form so that waste plastic is first fed into a Washer (W-101) and is washed with water, the ratio of plastic to water is 1:1 by mass. The washed plastic is then sent into a Shredder (S-101) and wastewater is used for the cooling process. In shredder waste plastic is shredded into small pieces with particle dia. of 3mm. After shredder, plastic pieces send into a centrifugal dryer. In centrifugal Dryer (D-101) moister content is removed from plastic at 25°C and 1 atm. The dry plastic is then sent into a single screw extruder (SC-101) and Nitrogen from the nitrogen tank also send into a single screw extruder. The purpose of using a single screw extruder is the achievement of temperature, in reactor 400°C temperature is required for the reaction. So this temperature is achieved through a single screw extruder. Nitrogen is used in this process to create an inert environment in this reaction because pyrolysis is an anaerobic process. The melted plastic obtained from single screw extruder and Ti-Al-Beta catalyst is fed into a Multitude Fixed Bed reactor (R-201) in which plastic is decomposed into a chain of light hydrocarbon (Petrol), heavy hydrocarbons (diesel), and Non- condensable gases, and some unreacted plastic at 400°C and 1.45 atm. The conversion of reactants into the product is 94.7%. After obtaining, the product from the reactor separation process is started in which light and heavy hydrocarbons and Non-Condensable gasses have been separated. Two distillation column and two-phase separate is used for the separation of reactor products. In distillation Column (D-301) unreacted plastic is separated from the main product (petrol, diesel, and non-condensable gasses) at 370°C and 1 atm. The product obtained from D-301 is then sent to the second distillation column (D-302) in which heavy hydrocarbon (deiseal) is separated from a light hydrocarbon (petrol) and non-condensable at 170°C and 1 atm. After the distillation mixture of petrol and non-condensable gases fed into a two-phase separator (V-301) in which petrol is separated from non-condensable gases at 25°C and 1.8 atm [19]. The process flow diagram of pyrolysis of plastic shown in (Figure 4).

The density and kinematic viscosity of waste plastic fuel oil is heather then diesel but the flashpoint, pour point, and gross calorific value is lower than diesel [28,29]. The properties of fuel oil are shown in (Table 3).

Waste plastic oil blended up to 70% with diesel without any loss

Table 3: Comparison of properties of waste plastic fuel oil with Diesel [29].

Properties	Diesel	Waste Plastic oil
Density at 15ºC, (kg/m³)	860	875
Kinematic Viscosity at 40ºC (cSt)	2.107	3.254
Flash Point (ºC)	50	41
Pour point (ºC)	56	49
Gross Calorific Value (kJ/kg)	42,500	41,388
Cetane Number	50	53
Water Content (%)	-	0.12
Ash Content (%)	0.01	0.007
Sulphur Content (%)	0.045	0.03

in the engine performance. This oil blended with diesel in different fractions. The gross calorific value of waste plastic oil is 41KJ/kg, which is lower than diesel. The gross calorific value of oil increased by blending diesel up to 20% [29]. The advantage of blending waste plastic oil with conventional oil is the reduction in consumption and cost of fuel oil. As compared to diesel fuel, diesel blend oil is more suitable for the high compression ratio of diesel engines [30]. In 2018, waste plastic oil has a 57% market demand among different fuel oil. This fuel oil has a large number of applications such as diesel fuel oil, gasoline fuel to car, power factories, in the ship, and generation of electricity with an overall value of 0.81$. Waste plastic is also utilized in the characterization and synthesis of the hydrogenation process, the higher rate of energy conversion of 95wt% [31].

The Reaction of the Product

Polyethylene (C_2H_4) Catalytic Pyrolysis

$$36C_2H_4 \xrightarrow{Ti-Al-Beta} H_2 + CH_4 + C_2H_6 + C_2H_4 + C_3H_6 + C_3H_8 + C_4H_{10} + C_8H_{16} + C_{16}H_{32} + C_{28}H_{56} + 5C$$

Polypropylene (C_3H_6) Catalytic Pyrolysis

$$29C_3H_6 \xrightarrow{Ti-Al-Beta} 16H_2 + CH_4 + C_2H_6 + C_2H_4 + C_3H_6 + C_3H_8 + C_4H_{10} + C_8H_{16} + C_{16}H_{32} + C_{28}H_{56} + 20C$$

Economic Analysis of Pyrolysis Plant

There are many different methods of plastic waste management. In (Figure 5), different waste management methods are shown. New technologies and economic play a very important role in the recycling of plastic. The selection of the method depends on the type of plastic, ease, or difficulties in partial or total isolation from other plastics and the cost of the process.

In all over the word mechanical recycling of plastic preferred most among all recycling process of plastic, but if consist of wide varieties of processing techniques and methods that required a large amount of energy, which increase the cost of the process. All kinds of plastic cannot be recycled mechanically, highly contaminated plastic, or there cross-linked products or by-products with toxic substances remain in the environment. Thermal recycling is another method of plastic recycling. Through this process, highly contaminated plastic can be recycled, but the cost of this process is high among all recycling process and in this process very harmful gases emitted in the environment and cause air pollution.

These two methods are very costly and harm the environment. As compared to these methods pyrolysis is much better. The cost of a pyrolysis plant is best in the case of a large scale plant or maybe the same as a mechanical and thermal recycling plant but it does not emit toxic gases in the environment [2].

Much research has been conducted on catalytic pyrolysis by using various kinds of catalysts. The most recent research on pyrolysis is to refuse oil derived pyrolysis [32], improvement in hydrocarbon compounds in bio-oil of biomass catalytic pyrolysis [33], Kinetic Modelling Investigation of Cellulose Pyrolysis [34].

Table 4: Total Cost of Equipment in 2019 [35].

Equipment	Flowrate (kg/hr)	Cost $
Washer	2242	15,000
Shredder	2242	5,000
Dryer	118v1	2000
Packed Bed Reactor	1986	2146
Single Screw Extruder	1986	16500
Heat Exchanger (HE-201)	1986	2300
Heat Exchanger (HE-303)	1986	3000
Heat Exchanger (HE-306)	1986	4000
Pump (P-301)	1986	8600
Pump (P-303)	1986	8600
Distillation Column (T-301)	1986	16525
Distillation Column (T-302)	1161	10725
Two-Phase Separator	1028	900
Total		**105000**

Capital Investment

A large sum of money is required for the purchase and installation equipment, utilities, machinery before starting the operation in an industrial plant. Land and facilities of service must be obtained and the plant must be built completely with all piping and instrumentation. It is also necessary to have money to pay expenses for plant operations. The total capital cost required for the installation and working of the plant is known as total capital investment [35].

Fixed Capital Investment

The capital investment required to supply manifesting and plant facilities is known as fixed capital investment. The subdivision of fixed capital investment is:

- Direct Cost
- Indirect Cost

Direct cost

The cost which is directly used in plant construction in addition to equipment cost is known as a direct cost.

Total cost of equipment: The cost of every equipment (Table 4) calculated by using different cost index and equation 1:

$$\text{Equipment Cost in 2019} = C_e \times \frac{2019\ cost\ index}{2017\ cost\ index} \quad (1)$$

The direct cost of plastic pyrolysis plant is shown in (Table 5).

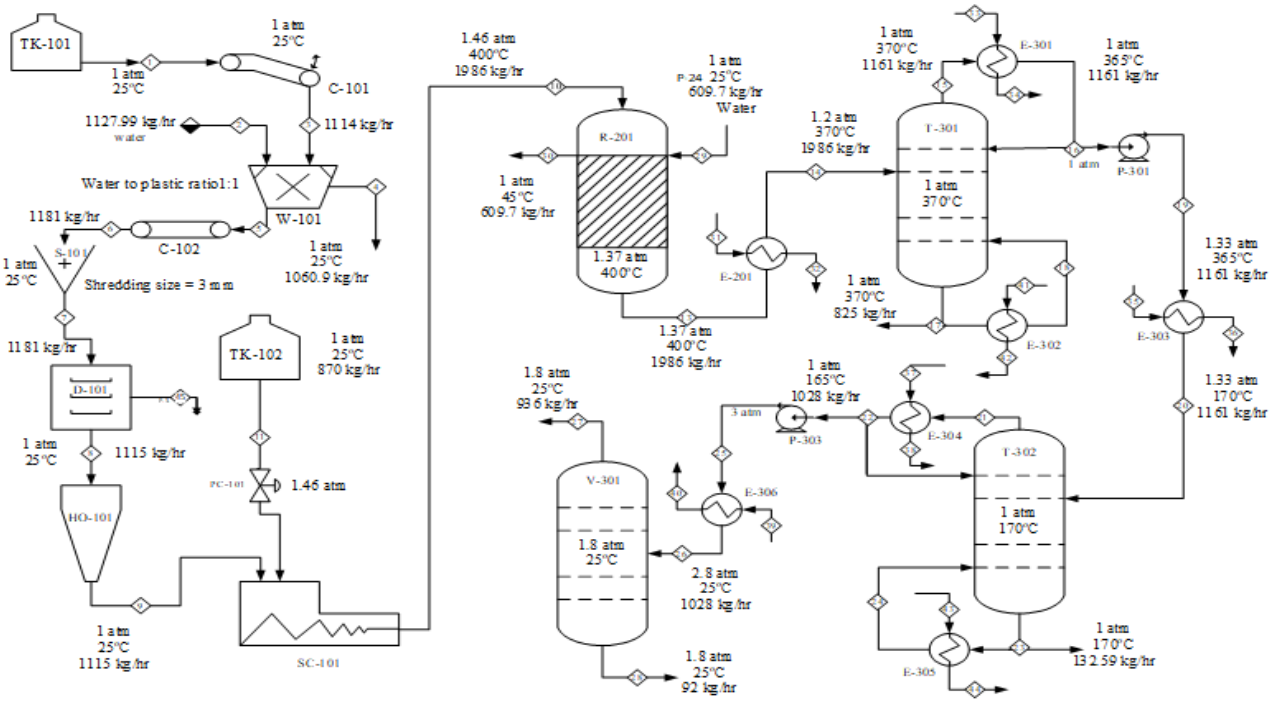

Figure 4: Process Flow Diagram [19]. D-101: Dryer; S-101: Shredder; SC-101: Extruder; R-201: Reactor; T-301, T-302: Distillation Column; V-301: Two phase Separator; E-201, E-301-306: Heat Exchanger; P-301-P-303: Pump.

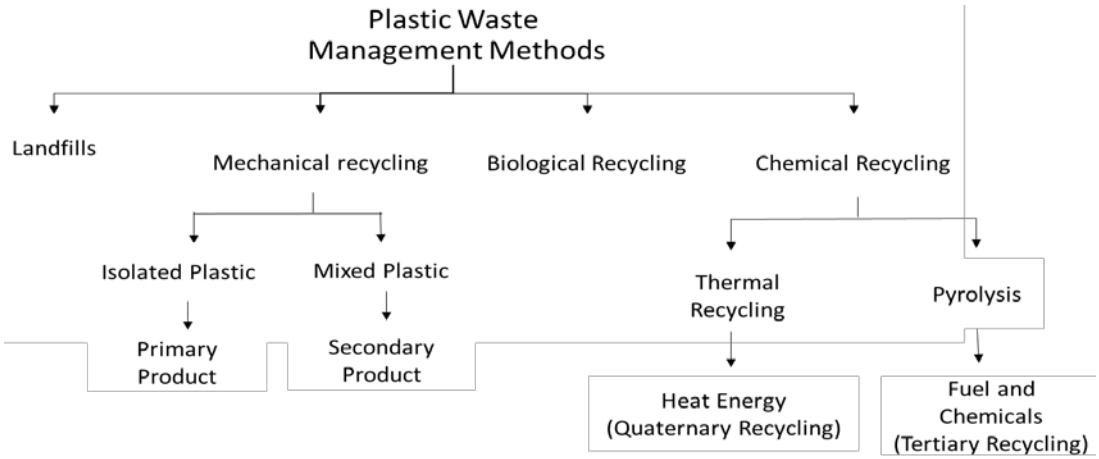

Figure 5: Plastic Waste Management Methods [2].

Indirect cost

Indirect cost of pyrolysis plant is shown in (Table 6)

Fixed capital investment = Direct Cost + Indirect Cost (2)

Fixed capital Investment = $210806

Total capital investment

Total capital investment = Fixed capital investment + working capital investment (3)

Working capital investment = 15% of fixed capital investment

Working capital investment = $ 31620

Total capital investment = $242426

Total production cost

Total production cost = Variable Cost + Fixed Operating Cost + Overhead Cost (4)

Variable cost

Variable cost of plastic pyrolysis is shown in (Table 7)

Variable Cost = Raw material Cost + Miscellaneous Cost + Utilities Cost (5)

Fixed operating cost

The fixed operating cost of pyrolysis plant is shown in (Table 8)

Table 5: Direct Cost of Plastic pyrolysis plant [35].

Items	Range	%	Cost $
Purchased equipment	---	100%	104999
Installation	25-55% of purchased equipment cost	30%	26249
Instrument and Control	6-30% of purchased equipment cost	15%	6299
Piping	40-80% of purchased equipment cost	50%	41999
Electricity	10-15% of purchased equipment cost	10%	10499
Building	15% of purchased equipment cost	15%	15749
Land	4-8% of purchased equipment cost	4%	4199
Service facility	30-80% of purchased equipment cost	40%	31499
Yard Improvement	10-20% of purchase equipment cost	10%	10499
Insulation cost	8-9% of purchased equipment cost	8%	8399
Total	**---**	**---**	**155391**

Table 6: Indirect Cost of Plastic Pyrolysis Plant [35].

Items	Range	%	Cost $
Engg. & supervision	8% of total direct cost	8%	15287
Contractor fee	2-8% of direct plant cost	3%	5732
Construction Expenses	10% of Total direct plant cost	10%	19109
Contingences	Direct plant cost	8%	15287
Total	**----**	**---**	**55415**

Table 7: Variable Cost of Plastic Pyrolysis Plant [35].

Items	Cost $
Raw material	1058745
Miscellaneous	1984.3
Utilities	535
Variable Cost	**1061264**

Direct production cost = Variable Cost + Fixed Cost (6)

Direct production cost = $1272070

Overhead Charges

Overhead cost is 30% of direct production cost

Overhead Charges = 0.3 × 1272070 = $381621

Total production cost = Direct Production Cost + Overhead Charges (7)

Total production cost = $1653691/year

Total production rate = 47 ton/day = 15510 ton/year

Production Cost ($/ton) = Total production cost/Total production rate (8)

Production Cost ($/ton) = $106.6/ton

Profitability analysis

If Selling Price = $550/ton

Profit = Selling price - production cost = $443.4/ton

Total Production = 15510 ton/year

Table 8: Fixed Operating Cost of Plastic Pyrolysis Plant [35].]

Type	%FCI	Cost $
Maintenance	7	14756
Operating Cost of Labor	10	21080
Laboratory Cost	20	42161
Supervision Cost	15	31620
Plant Overheads	50	105403
Capital Charges	10	21080
Insurance	1	2108
Local Taxes	2	4216
Royalties	1	2108
Fixed Operating Cost	**-**	**244532**

Profit per year = $6877134/year

Total Income = $8530500/year

Gross Profit = $6876809/year

Net Profit = $2063042.7/year (with 30% tax)

Depreciation = $10013.28

Net Profit = Gross profit - Taxes - Depreciation= $4803753.72/year

Rate of return

Rate of return = ((Net Profit)/(Total Capital Investment)) ×100 = 19.81%

Payback period

Payback Period = 1/rate of return

Payback period = 5 years

Conclusion

The consumption and production of plastic increased day by day and result in waste generation. Pyrolysis of plastic is the most effective way as compared to disposal of plastic into landfills, it can reuse the energy and raw material for waste that reduces plastic waste and environmental impact caused by the disposal of plastic waste.

In catalytic pyrolysis of plastic, the catalyst and type of rector used are Ti-Al-Beta and Fixed bed reactor, respectively. The technical assessment of the pyrolysis plant and economic analysis has been done. Preliminary screening of this plant reveals that it is highly feasible and gives reasonable conversion and yield. The economic analysis shows that the estimated total capital investment required for a pyrolysis plant is $0.2 million, the estimated total production cost of pyrolysis plant is $1.6 million/year and annual $8.5 million/year revenue can be generated by the implementation of this process and 5 years needed to get our investment back. The expected net profit obtained from this plant is $4.8 million/year. The rate of return of this plant is 19.81%.

Through the pyrolysis of plastic two major problems that are plastic waste management and other is the energy crises of Pakistan can be solved. By pyrolysis excess amount of plastic converted into fuel oil so that the problem of plastic waste management is solved. On

the other hand, Pakistan faces energy crises, Pakistan import.

Pyrolysis of plastic is an alternate method of production of fuel oil. Pakistan is facing the petroleum crisis. Pakistan imports crude oil by investing millions of dollars. In Pakistan, only 27% of total waste is recycled and the remaining waste is disposed into landfills [9], which causes serious environmental pollution. But if these waste plastic converted into fuel it will solve many problems of Pakistan. According to research, from 14k tone/year of plastic, 10k tone/ year of fuel oil can be produced. This fuel oil can help fulfill the crude oil demand of Pakistan. On the other hand, this fuel is directly used in electricity generation, and currently, Pakistan faces any electricity shortage. Through plastic fuel oil, this problem can also be solved.

Future Aspects

Pyrolysis of plastic is a very cost-effective and green technology. By this process of plastic recycling:

- An environmental problem caused by plastic waste can be solved.
- The use of fossil fuel can be reduced.
- Energy crises can be solve.

References

1. Rajmohan KVS, Ramya C, Viswanathan MR, Varjani S. "Plastic pollutants: effective waste management for pollution control and abatement". Current Opinion in Environmental Science and Health. 2019; 12: 72-84.
2. Panda K, Singh RK, Mishra DK. "Thermolysis of waste plastics to liquid fuel. A suitable method for plastic waste management and manufacture of value added products-A world prospective". Renewable and Sustainable Energy Reviews. 2010; 14: 233-248.
3. Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, et al. "Plastic waste inputs from land into the ocean". Science. 2015; 347: 768-771.
4. Eriksen M, Lebreton LCM, Carson HS, Thiel M, Moore CJ, Borerro JC, et al. "Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea". PLoS One. 2014; 9: e111913.
5. Miandad R, Nizami AS, Rehan M, Barakat MA, Khan MI, Mustafa A, et al. "Influence of temperature and reaction time on the conversion of polystyrene waste to pyrolysis liquid oil". Waste Manag. 2016; 58: 250-258.
6. Babayemi JO, Nnorom IC, Osibanjo O, Weber R. "Ensuring sustainability in plastics use in Africa: consumption, waste generation, and projections". Environ Sci Eur. 2019; 31.
7. Geyer R, Jambeck JR, Law KL. "Production, use, and fate of all plastics ever made". Sci Adv. 2017; 3.
8. S Nizami, et al. "Developing waste biorefinery in Makkah: A way forward to convert urban waste into renewable energy". Appl Energy. 2017; 186: 189-196.
9. Umer M, Abid M. "Economic Practices in Plastic Industry from Raw Material to Waste in Pakistan: A Case Study". Asian J Water Environ Pollut. 2017; 14: 81-90.
10. Ragaert K, Delva L, Van Geem K. "Mechanical and chemical recycling of solid plastic waste". Waste Management. 2017; 69: 24-58.
11. Al-Salem SM, Antelava A, Constantinou A, Manos G, Dutta A. "A review on thermal and catalytic pyrolysis of Plastic Solid Waste (PSW)". Journal of Environmental Management. 2017; 197; 177-198.
12. Olufemi, Olagboye S. "Thermal conversion of waste plastics into fuel oil". Int J Petrochemical Sci Eng. 2017; 2: 252-257.
13. K Li, Lee SW, Yuan G, Lei J, Lin S, Weerachanchai P, et al. "Investigation into the Catalytic Activity of Microporous and Mesoporous Catalysts in the Pyrolysis of Waste Polyethylene and Polypropylene Mixture". Energies. 2016; 9: 1-15.
14. Javed MS, Raza R, Hassan I, Saeed R, Shaheen N, Iqbal J, et al. "The energy crisis in Pakistan: A possible solution *via* biomass-based waste". J Renew Sustain Energy. 2016; 8.
15. Tareen WUK, Dilbar MT, Farhan M, Nawaz MA, Durrani AW, Memon KA, et al. "Present status and potential of biomass energy in Pakistan based on existing and future renewable resources". Sustainability (Switzerland). 2020; 12: 249.
16. Haig S, Morrish L, Morton R, Onwuamaegbu U, Speller P, Wilkinson S. "Plastic to oil IFM002 final report 2". Xionconsulting. 2015.
17. Nawaz KK. "Feasibility Study of Municipal Plastic Waste for Power Generation in Lahore City, Pakistan". J Chem Eng Process Technol. 2015; 6: 229.
18. Banu JR, Sharmila VG, Ushani U, Amudha V, Kumar G. "Impervious and influence in the liquid fuel production from municipal plastic waste through thermo-chemical biomass conversion technologies-A review". Sci. Total Environ. 2020; 718: 137287.
19. Sahu JN, Mahalik KK, Nam HK, Ling TY, Woon TS, Rahman MSBA, et al. "Feasibility study for catalytic cracking of waste plastic to produce fuel oil with reference to Malaysia and simulation using ASPEN Plus". Environ Prog Sustain Energy. 2014; 33: 298-307.
20. Raja and Murali A. "Conversion of Plastic Wastes into Fuels". J Mater Sci Eng B. 2011: 86-89.
21. Ocean Recovery Alliance. "2015 Plastics-To-Fuel Project Developer's Guide". Ocean Recover. Alliance. 2015.
22. Buekens. Introduction to feedstock recycling of plastics. Editors. In: Scheirs J, Kaminsky W. Feedstock recycling and pyrolysis of waste plastics: converting waste plastics into diesel and other fuels. 2006: 816.
23. Andersen M, Satre KA, Fredriksen S, Pfeiffer C. "Simulation of the Pyrolysis Process: from Plastic Waste to Environmental Friendly Fuel". 2018: 303-307.
24. "Plastic Pollution". 2020.
25. Hamid SH, Amin MB. "Lifetime prediction of polymers". J. Appl. Polym. Sci. 1995; 55: 1385-1394.
26. Batool SA, Ch MN. "Municipal solid waste management in Lahore City District, Pakistan". Waste Manag. 2009; 29: 1971-1981.
27. Sharuddin SDA, Abnisa F, Wan Daud WMA, Aroua MK. "A review on pyrolysis of plastic wastes". Energy Conversion and Management. 2016; 115: 308-326.
28. Khan MZH, Sultana M, Al-Mamun MR, Hasan MR. "Pyrolytic Waste Plastic Oil and Its Diesel Blend: Fuel Characterization". J Environ Public Health. 2016; 2016: 7869080.
29. Patel N, Shadangi KP. "Characterization of Waste Engine Oil (WEO) pyrolytic oil and diesel blended oil: Fuel properties and compositional analysis". Mater Today Proc. 2020; 33: 4933-4936.
30. Kim TY, Lee SH. "Combustion and emission characteristics of wood pyrolysis oil-butanol blended fuels in a DI diesel engine". Int J Automot Technol. 2015; 16: 903-912.
31. Miandad R, Rehan M, Barakat M, Aburizaiza A, Khan H, Ismail I, et al. "Catalytic pyrolysis of plastic waste: Moving toward pyrolysis based biorefineries". Front Energy Res. 2019; 1: 1-27.
32. Rajca P, Poskart A, Chrubasik M, Sajdak M, Zajemska M, Skibinski A, et al. "Technological and economic aspect of Refuse Derived Fuel pyrolysis". Renew Energy. 2020; 161: 482-494.
33. Bhoi PR, Ouedraogo AS, Soloiu V, Quirino R. "Recent advances on catalysts for improving hydrocarbon compounds in bio-oil of biomass catalytic pyrolysis". Renewable and Sustainable Energy Reviews. 2020; 121: 109676.
34. Leng E, Ferreiro AI, Liu T, Gong X, Costa M, Li X, et al. "Experimental and Kinetic Modelling Investigation on the Effects of Crystallinity on Cellulose Pyrolysis". J Anal Appl Pyrolysis. 2020; 152: 104863.
35. Blank TL. Engineering Economy. 7th Edition. 2017.

36. Sadiqa, Gulagi A, Breyer C. "Energy transition roadmap towards 100% renewable energy and role of storage technologies for Pakistan by 2050". Energy. 2018; 147: 518-533.

37. Ministry of Energy (Petroleum Division). Pakistan Energy Yearbook. 2018.