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Conversion of Waste Plastics into Gasoline and Diesel

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***Abstract*— Energy is the most dynamic driving force of modern civilization. It is an irrefutable truth that industrialization is raised by energy consumption. Fossil fuel having limited reserve is not an ultimate solution of energy source. This paper addresses an experimental study of a new propagation of energy that can be a good support of fossil energy as well as meet the environmental concern. Waste plastic get rid of Thermosettings polymers and PET has been effectively converted into liquid fuel and it can be a great alternative source of energy. The process utilizes the unhygienic disposal waste plastic and makes them ecofriendly. Petrochemicals are the main source of polymer. In absence of oxygen using Al_2O_3 and ZnO as catalyst, the plastic wastes are heated up to 350^0C-450^0C temperature into a stainless steel reactor and the gaseous stream were condensed and collected in receiving chamber. Performance and property tests are conducted of the derived fuel. ASTM test result showed zero sulfur contents resulting high performance and environmentally friendly at the same time. The experiment has been conducted with highest standards of safety, quality, reliability and environmental sustainability in converting hydrocarbon fuel of this locality.**

Keywords—Waste plastic; gasoline; diesel; catalytic cracking; distillation

I. INTRODUCTION

Plastics have privileged the modern civilization with a lot of facilities by its versatile uses and immense supply in our daily life. Plastic is a high molecular weight material having awesome durability, sustainability much tensile strength than its weight was invented by Alexander Parkes in 1862. [1] Plastics are also called polymers. Due to the convenience to manufacturing and use, the world plastic production has been increasing day by day. It was commercially manufactured from 1.5 million tons in 1950 to 260 million tons in 2007 .One of the major concerns for extensive use of the plastics is the disposal of the waste plastic. In addition, the plastics are produced from non-sustainable oil or coal, and thus it is a non-sustainable product. There were 30.7 million tons of waste plastic generated in the U.S. in 2007, which accounts for 12.1% of the total municipal solid wastes. [3] In U.K., 4.9 million tons of plastics were consumed in 2007. [4] Europe consumes about 25% of the global plastic production, which is equivalent to 60 million tons per year. [2] The world's annual consumption of plastic which was five million tons in the 1950's has skyrocketed to a global production of 245 million tons in 2008 and waste plastic generation is rapidly increasing. Plastic waste is the third largest contributor to municipal and industrial waste systems after food and paper.

In Bangladesh first the plastic industry begins with a small industry 1960's. At present there are 3000 plastic manufacturing units, 98% of which belong to the Small-Medium Enterprises (SMEs). [5] At present total consumption of polymers including imported polymers and recycled plastic wastes is 750,000 tons in FY 2010- 2011.[10] This corresponds to the per capita consumption of plastics in Bangladesh is 5 kg per year against the world average 30 Kg. Per capita consumption in India and ASEAN countries are 8kg and 17kg respectively. 20-25% of landfill weight is plastics. [5] Landfills are chosen to dispose of Municipal Solid Waste (MSW) in the Bangladesh, with an overall increase in MSW consistent with increases in the population. Plastics made up only 1% of MSW in 1960. This has increased to 12% (30 million tons) in 2008. 43% of this is containers and packaging, 22% is nondurable goods, and 35% is from durable goods. This means that 11.3 million tons of just containers and packaging end up in landfills each year. Most people agree that recycling is a preferred method of dealing with plastics. However, only 24% of municipal waste is recycled and 9% is composted, for a total of only 33% of waste that is recovered. [5]

The waste plastics have selective use by recycling other wastes those are not feasible with economical recycling they are thrown to the landfill. The quality of recycled plastics is another important matter, again and again recycling break the polymer string and bulk density of polymer decrease gradually and the loss their food grade quality and become as unhygienic as it can create cancer cell in human body. So catalytic cracking is the best way to utilize such a waste plastics in most precious way. The technology helps to save land resources by utilizing waste plastics to generate valuable energy. Currently, a majority of the waste plastic is land filled and it is not sustainable because waste plastic takes very long time to decay. [2] However, it seems that Bangladesh has no other choices but continues to do so in the foreseeable future.

Bangladesh is a small country with its limited land resources, the society as a whole has to pay increasing attention to the environmental sustainability for the next generations.

II. METHODOLOGY

A. *Raw materials*

Raw materials used from waste plastic polymers namely low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS) and other thermoplastic polymers. These plastics collected from waste plastics which are thrown to the landfill. Most prominently the waste plastics were merely used in purpose of recycling. These raw materials were collected from the first hand buyers to apprehend the most intellectual way to converting the waste plastics into liquid fuel instead of recycling or making environmental pollution.

B. *Catalysts*

Conversion of waste plastics into liquid fuel Al_2O_3 and ZnO are used for this process. Each 200g raw polymer batch executed with different percent of single catalyst or both either.

C. *Reactor Description*

Main reactor was made by stainless steel having thickness (0.24 inch), diameter (4.25 inch) and height (9 inch). After charging the reactor is totally sealed off by gasket and flange. Sensing temperature done by thermocouple. There are two 1000W coils one of them is beneath of the reactor to power up the reactor solely and other is spiral over the bottom of the reactor supposed to heat uniformly to the charged feed. A discharge tube was bended and spiraled with copper tube having thickness of (0.5mm) was used to condense the fuel vapor by cooling water circulated by a centrifugal pump. The maximum capacity of the reactor is 3.5kg waste plastics at a time. The full reactor surrounded by concrete chamber having thickness (3.5 inch), length (15 inch), width (15 inch), height (16 inch) for purposed to impeded heat loss and high safety region. There are two discharge paths to vent gases and collect liquid. The long height of discharge tube is to assure high reflux ratio to get low viscous fuel.

D. *Schematic diagram & process description:*

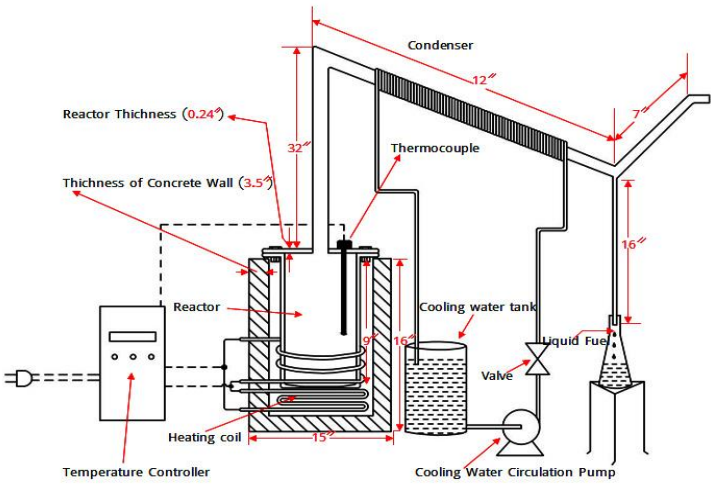

Fig. 1. Schematic diagram of the waste plastic to liquid fuel process.

The production method for the conversion of waste plastics into liquid fuel is based on the catalytic cracking and the condensation of the resulting hydrocarbons. For the production process of liquid fuel, the plastics that are suitable for the conversion are introduced into a reactor where they will decompose at 350-450°C. Depending on the catalytic cracking conditions and the type of plastic used, carbonous matter gradually develops as a deposit on the inner surface of the reactor. After cracking, this deposit should be removed from the reactor in order to maintain the heat conduction efficiency of the reactor. After the resulting hydrocarbons are distilled from the reactor, some hydrocarbons with high boiling points such as diesel, kerosene and gasoline are condensed in a water-cooled condenser. The liquid hydrocarbons are then collected in a storage tank through a receiver tank.

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E. Process description:

After the waste plastics are collected, it was washed to remove the impurities and then it also dried to remove any water droplets. Finally, it was shredded and cut into pieces for ease of feeding the raw materials and for good heat transfer. 200gram of solid waste plastic is weighed and feed to the reactor and the reactor is properly sealed to protect the gas from leaking. Isolation system was checked carefully prior to start the experiment through bubble test. Then the heater was started and the reaction continued, until the last drop of oil is noticed in the measuring cylinder. The solid waste plastic is first melted and then cracked in the same reactor (converted to smaller units or gases) at different temperatures. Finally, the gas is allowed to pass through the metal tube. The gas from the tube is directly condensed by the continuous circulation of the cooling water pump.

Heat exchange between cooling water and hot stream was accelerated using icebergs and controlling the circulation flow rate. When the first distillate has seen in the measuring cylinder, the temperature and time is noted down. The volume of fuel oil produced was monitored with time and temperature. Temperature was sensing by thermocouple and the whole heating process was controlled and monitored by a temperature controller. Every experiment initial raw material was 200 gram and catalyst percentage was different. Each experiment temperature profile was same and temperature monitoring was same procedure. Temperature was controlled by temperature controller and temperature range was 350^0 -450^0 C. For 1st experiment is started with 200 gram of waste plastics and 3% of aluminum oxide (Al_2O_3). 2nd experiment is started with 200 gram of waste plastic and 4% of Aluminum Oxide (Al_2O_3). 3rd experiment is started with 200 gram of waste plastics mixture and 5% of Aluminum Oxide (Al_2O_3). All experimental initial raw materials are same and temperatures are same but catalyst percentage is different. This type of experiment main goal is conversion rate determine and compounds range determination. 5% aluminum oxide (Al_2O_3) and waste plastics mixture to liquid fuel production conversion rate is high. The procedure is repeated for the Zinc Oxide (ZnO) catalyst also. Same procedure is followed for the mixture of Zinc Oxide (ZnO) and Aluminum Oxide (Al_2O_3) catalyst. The reaction/experiment duration is 50 to 60 minutes. Better result is observed in the mixture of Zinc Oxide (ZnO) and Aluminum Oxide (Al_2O_3) catalyst when the percentage is 5%. Beneath the minimum catalyst percentage production of fuel is significantly low and over the percentage proceeds gum formation and grease type semisolid products.

III. Result and Discussion

The stainless steel reactor having previously described dimension provided us the liquid fuel from waste plastic by hydrocarbon cracking reaction. From the initiation the reactor took 15 minutes around to be heated at intended temperature. First droplet was found at 350^0C. After achieving the intended temperature, fuel was continuously being supplied by the reactor. Then the production of fuel started and gradually the rate of production was increased. The time vs. production curve are analyzed to find out the duration time of the reactor and shown at Fig. 2.

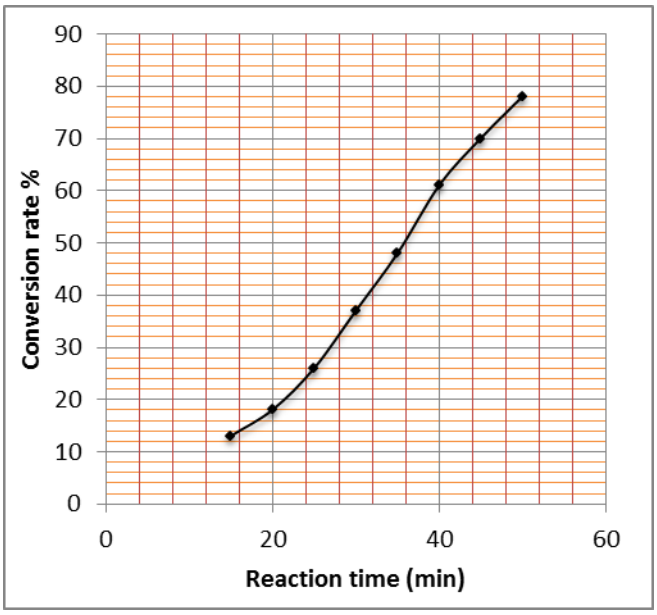

Fig. 2. Conversion rate % vs. Reaction time (min) curve

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Without catalyst the conversion rate was low. After adding some small amount of catalyst the conversion rate increased gradually till a certain percentage about 4% to 6% after that percentage the liquid fuel conversion rate started to fall. At high percentage of catalyst the grease type paraffin comes out from the reactor and the liquid portion of the product stuck at room temperature. The semisolid portion was also flammable. Catalyst percentage vs. conversion rate curve is given at fig. 3.

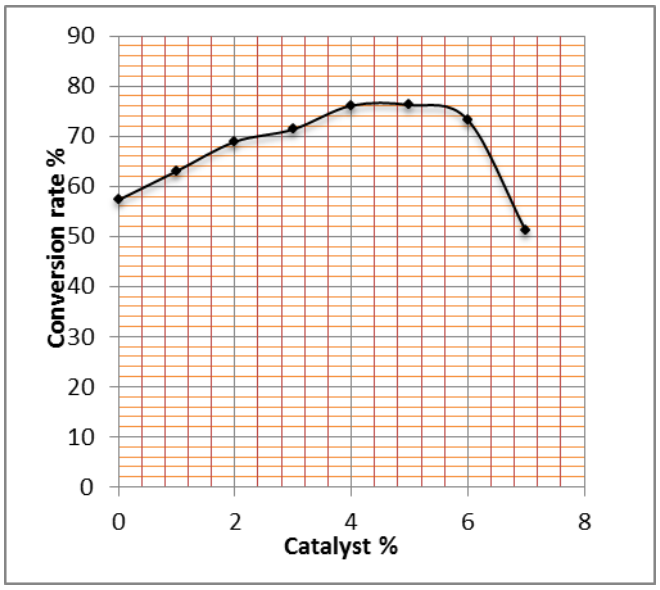

Fig. 3. Conversion rate % vs. catalyst % curve

Fuel sample was tested as ASTM standard. All test reports provided by Petromax Refinary Ltd. Khulna Bangladesh [10] and Super Petrochemical (Pvt.) Limited, Karnafully, Chittagong Bangladesh. To identify as a commercial liquid fuel some tests were done which was analyzed at table:

TABLE I. WASTE PLASTIC FUEL QUALITIES COMPARED WITH OTHERS FUEL

Sl. No.	Test name & Method	Result	Compared value & Quality
01.	API Gravity @ 60/60^{0}F	47.68	42.6 (Natural Gas Condensate)[8] >40 on paraffin based petroleum [6]
02.	Density @15^0 kg/L (ASTM D 1298)	0.7897	0.72–0.78(Gasoline) 0.8-0.89(Diesel)
03.	Total Acid No. (ASTM D 664)	1.01	0.35-1.5(Diesel)[9]
04.	Ash Content (ASTM D 482)	0.0029	Max. 0.1(Diesel)[9]
05.	Copper Strip Corrosion(3 hours at 100^{0}c) (ASTM D 130)	No.1	No.1 (Gasoline) [9] No.3(Diesel)
06.	Carbon Residue On 10% bottom, %wt (ASTM D 189)	0.1	Max. 0.35(Diesel & Gasoline)[11]
07.	Cetane Index (ASTM D 976)	65.5	>45(Diesel) [7]
08.	Pour Point, ^{0}C (ASTM D 97)	<3	Feasible
09.	Flash Point, ^{0}C (ASTM D 93)	20	Max. 32 (Diesel)[11]
10.	Water Content, %wt (ASTM D 95)	1.36	Negligible (Diesel & Gasoline)
11.	Sediment%wt (ASTM D 473)	0.009	Max. 0.1 (Diesel & Gasoline)[11]
12.	Distillation % Recovery, vol^{0}C (ASTM D 86)		282-348(Diesel)[11] 136-202(Gasoline)
	Initial Boiling point	86	50 (Natural Gas Condensate)[8]

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	10% Volume		132	88(Natural Gas Condensate) [8]
	20%Volume		146	98(Natural Gas Condensate) [8]
	30% Volume		156	113(Natural Gas Condensate) [8]
	40% Volume		184	124(Natural Gas Condensate) [8]
	50% Volume		217	156(Natural Gas Condensate) [8]
	60% Volume		252	180(Natural Gas Condensate) [8]
	90% Volume		343	304(Natural Gas Condensate) [8]
13.	Colour, ASTM D 1500		3	0.5-1.5(Gasoline) 2.5-3(Diesel)
14.	Reid Vapour Pressure, psi		0.6	Min. 0.2(Diesel) 8-15(Gasoline)
15.	Kinematic Viscosity Centipoise @ 60° F (ASTM D 445)		2.6983	2.6-4.1(Diesel)[11] 0.37-0.44(Gasoline)[11]
16.	RON (ASTM D 2699)		85.9	91-95 (Gasoline) [13]
17.	Doctor Test (ASTM D 4952)		Negative	Low sulfur content
18.	Residue On Evaporation g/100 ml (ASTM D 381)		22.876	Max. 7 (Gasoline)
19.	Oxidation Stability, minutes (ASTM D 525)		>300	Min. 240 Gasoline (87% octane +up to 10% ethanol)
20.	GHV Kcal/kg (ASTM D 3177-89)		10780.7309	9960-10514 (Diesel & Gasoline)
21.	PONA (ASTM D1319)	Paraffin	37.5%	Avg. 57.4%(Gasoline)[6];47%(NGC)[8]
		Olefin	2.5%	Max.9.2%(Gasoline)[6];0.7%(NGC)[8]
		Naphthene	20%	Avg. 21.3%(Gasoline)[6];35%(NGC)[8]
		Aromatic	40%	Max.35%(Gasoline[6]);17.3% (NGC)[8]

Distillation curves provide a breadth of information about the crude oil or the petroleum fuel. In certain respects, the boiling point distribution is representative of the composition of the petroleum fraction. Therefore, in principle, by determining the presence and volume percent of the components in a conventional hydrocarbon fuel solution, the overall physical properties can be determined. ASTM Distillation tests for gasoline, naphtha (A naphtha is a volatile petroleum fraction, usually boiling in the gasoline range), and kerosene (D86). The comparison of the distillation curve among waste plastic fuel , Natural Gas Condensate [8] and Arabian Light Crude Oil is described [12] at following Fig. 4.

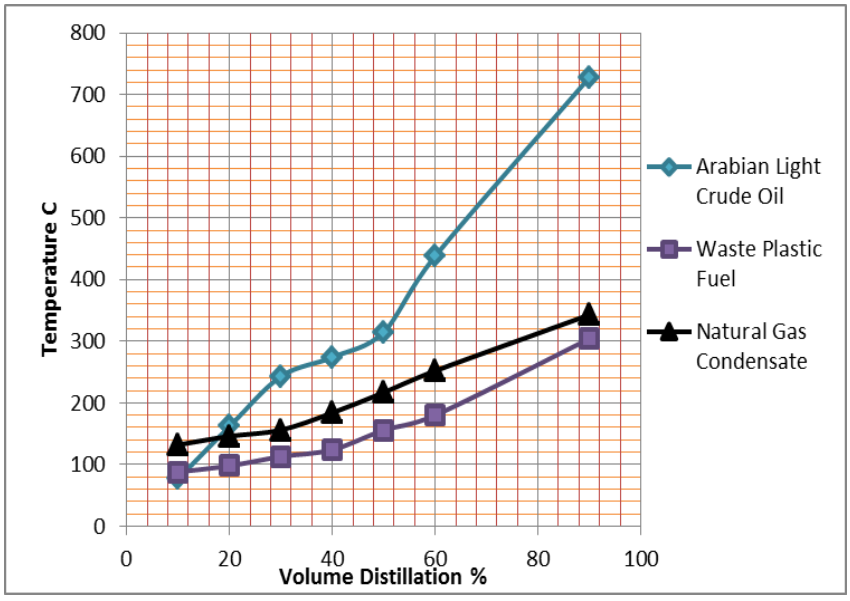

Fig. 4. Distillation curves of Arabian light crude oil, Waste plastic fuel, Natural gas condensate

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The fuels produced from this process do not contain sulphur content according to the Doctor test because there is no sulphur in the waste plastic feedstock. This is an advantage compared with the classic fossil fuels such as diesel because sulphur content in the fuels could form SO_2 after combustion. SO_2 is a pollutant causing severe air pollutions, which affects people health and damages the concrete structure. Therefore, this technology is environmental friendly and has significant positive impact on the local government and community

IV.CONCLUSION

In this study, catalytic cracking of the hydrocarbon polymers, PE, PP and PS was investigated both theoretically and experimentally in a lab-scale reactor for maximizing the diesel, gasoline oil products. Properties of fuel, reaction condition, comparing with commercial grade fuel were investigated. Based on the achievements, the distribution of the product and the process was optimized. We have a future plan of building a pilot plant based on the results of studies on the lab-scale reactor. In this batch process, the current continuous feeding system has major leaks and needs some modification. Catalyst applying system is also deserve some modification too. The feeding system should be able to control the required feeding rate and prevent back-flow of the high temperature cracking vapour. On the other hand, the oxygen leaking into the feeder must be prevented. Better and effective distillation columns will be included on the pilot plant.

ACKNOWLEDGMENT

REFERENCES

[1] Brydson, J.A. and ScienceDirect. *Plastics materials*. 1999 1999; Available from: http://www.sciencedirect.com/science/book/9780750641326
[2] PlasticsEurope, *The Compelling Facts About Plastics 2007*. 2008: Brussels.
[3] USEPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States:*
Facts and Figures for 2008. 2008, USEPA.
[4]. Watch, W., *Waste Watch Information Sheet Plastics*. 2008, Waste Watch Institution.
[5] International Conference on Mechanical, Industrial and Energy Engineering 2014 25-26 December, 2014 Khulna, BANGLADESH ICMIEE-PI-140291
[6] Modern Petroleum Refining Process, B.K. Bhaskara Rao, Fifth Edition 2007, ISBN 978-81-204-1715-1 pp. 69,70,152

[7]. A Text Book of Engineering Chemistry, S.S. Dhara, Ninth Edition 2004, ISBN: 81-219-0539-9 pp. 153, 157,158
[8] Eastern Refinery Bangladesh Ltd. http://www.erl.com.bd
[9] http://webserver.dmt.upm.es/~isidoro/bk3/c15/Fuel%20properties.pdf
[10] http://www.youthbd.com/petromax-refinery-ltd
[11] The basis of this table and associated references was taken from: American Petroleum Institute (API), Alcohols and Ethers, Publication No. 4261, 3rd ed. (Washington, DC,
June 2001), Table B-1.
[12] Journal of Petroleum Research & Studies ISSN: 22205381 volume: 278 issue: 4th Pages: 215-231
[13]. Oil and Gas Journal Data Book. 2000 Edition, PennWell, Tulsa, Oklahoma, 2000

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