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FULL LENGTH ARTICLE

Pyrolysis of waste plastic into fuels

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ABSTRACT

Plastic waste has created a serious environmental concern because it's non-biodegradable; secondly major energy problem is rapid depletion of fossil fuels. These problems can be well solved by thermal and catalytic pyrolysis of plastic waste. New reactor has been designed and fabricated to achieve high temperature of above 500 ⁰C. Waste LDPE plastic was chosen because of its low melting point of 98-115 ⁰C. Firstly thermal pyrolysis was carried at 430⁰C and achieved a conversion of 98.16% and oil yield of 84.6%. Later catalytic pyrolysis was done using $CaCO_3$at 430⁰C, having catalyst to plastic ratio of 0.2, and achieved a conversion of 99.25% and an oil yield of 86%. The fuel obtained was subjected to atmospheric distillation to obtain Gasoline, naphtha, kerosene, light gas oil, heavy gas oil and components having carbon range of C_6-C_{38}.

Keywords: *Low density polyethylene, thermal cracking, basic catalyst$CaCO_3$, catalytic cracking, atmospheric distillation.*

INTRODUCTION

Waste plastics represent a large fraction of municipal solid waste. In India, the quantity of plastic waste produced yearly is almost 960 million tons [1]. Thermoplastic like polyolefin, PET etc. make up high portion of waste. Many treatment techniques like land filling, incineration, mechanical recycling has been used, but it leads to waste of land and also emissions of dioxins to the environment. Secondly major threat world facing is fossil fuel crisis; these fuels may last for another 43-167 years [2]. Thermal cracking or pyrolysis is a new technique of waste management involving degradation of the polymeric materials by heating in absence of oxygen to a temperature of 500-800⁰C. which leads to formation of liquid hydrocarbons, noncondensable high calorific gasesandcarbonised char.By using catalyst it reduces temperatureof pyrolysis, and also helps in getting good quality of products, this process is called as catalytic pyrolysis? D.W park *et al.* [3] Degraded Polyethylene in a fluidized bed reactor using solid acid catalyst like natural zeolites, silica alumina, HZSM-5 etc. to obtain gasoline range chemicals. Paliocarniti et al. [4] used silica alumina, zeolites and obtained crude having 50% of its fractions with boiling point greater than 400 ⁰C.Guohua Luo et al. [5] catalytically degraded Poly propylene and HDPE plastic to obtained hydrocarbon in the range of C-5 to C-11. Chao Tang et al. [6] developed highly efficient catalyst DeLaZSM-5, which dramatically increased degradation rate and the oil yield. Sajid Hussain Shaha etal. [7] did thermal pyrolysis at low temperature of 250 ⁰C and obtained 48.6% oil yield.M. Amutio et al. [8] obtained high olefin content oil from HDPE by a two-step pyrolysis involving thermal pyrolysis in spouted bed laterfollowed by catalytic cracking in Fluidized bed cracker. F. Pinto et.al [9] found the optimum product yield was obtained when plastic particle size was 3 mm; initial pressure 0.41 MPa; reaction time 20min; mean run temperature 430°C; and mean run pressure 3.5 MPa in an autoclave reactor. [10]

The literature reveals that many works has been carried on catalytic cracking using acid catalyst. This work aims to reveal the impact of thermal as well as catalytic cracking using cheaply available basic catalyst. Low density Polyethylene plastic like used packaging covers, used milk covers was used for the work, since it has the lowest melting point of 98-115 ⁰C [2] thereby conserves energy for cracking.

Design and Fabrication of pyrolysis reactor

- ***a)*** **<u>Reactor shell</u>**- Reactor shell is made of forged mild steel having I.D of 120 mm, thickness of 10mm. whose allowable pressure is 70 bar (71.38 Kg/cm^2),by this arrangement high pressure and high temperature cracking can be achieved.
- ***b)*** **<u>Bottom enclosure</u>**-A flat plate enclosure of thickess 8mm was designed by using equation (1).

$$e = C_p D_e \sqrt{\frac{P_i}{f}}$$ ...*(1)*

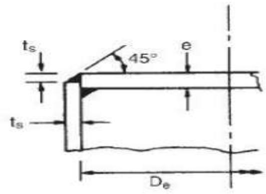


Fig.1 Bottom plate enclosure

Where, C_p=0.55 [11], D_e=D_i=120mm , P_i = 200 psi,(14.02 kg-f/cm^2) , f=13.8*10^2 Kg-f/cm^2.

c) **Design of top enlosure**:-A flange plate head is designed, the maximum thickness of 6mm is estimated using equation (2).

$$e = C_p D_e \sqrt{\frac{P_i}{f}}$$ ..(2)

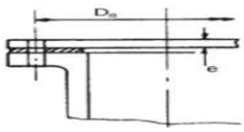


Fig. 2 Top flange plate

Where, Cp - 0.44 [11], D_e =B.C.D = 165 mm, Pi=200 psi, f=2447 .32 Kg-f/cm$_2$

d) **Volume of the reactor**: - Reactor height is 181mm, therefore volume of the reactor is 2.05 litres.

e) **Heat source** - Electric heater made of Inconel tubular heater of 2KW and 230 V is clamped on the reactor along with glass wool insulation of 20mm thickness on it and temperature of above 550 ^{0}C can be attained.

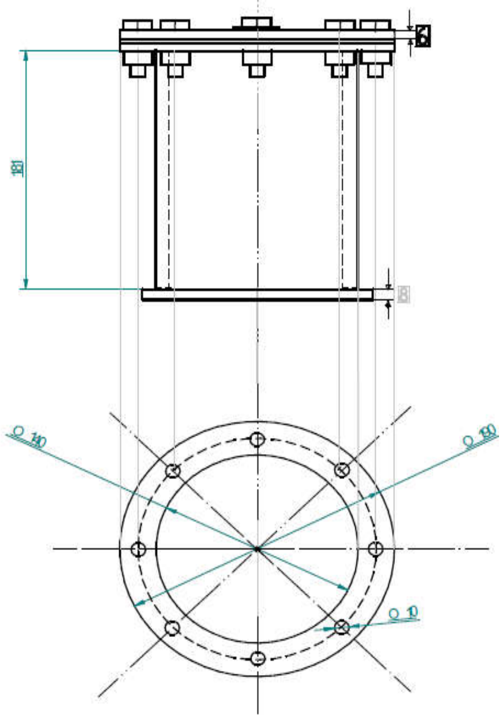


Fig.3 Design of pyrolysis reactor

EXPERIMENTATION

THERMAL PYROLYSIS

Low density polyethylene (LDPE) waste packaging covers were cleaned, dried and shredded.300g of LDPE was fed into the reactor. Thermal pyrolysis was carried for 4 hours and at a temperature of430 ^{0}C.The pyro gases released were condensed using a metal condenser.

CATALYTIC PYROLYSIS

30 grams of $CaCO_3$ catalyst was placed at the bottom later 300 grams of waste LDPE plastic was added and again 30 grams of catalyst. Which resembles sandwich system, catalyst/plastic ratio was maintained as 0.2, the reactor was operated at a temperature of 430^{0}C for a duration of 4 hours.

ATMOSPHERIC DISTILLATION OF CRUDE OIL

To separate the mixed fractions, Crude oil obtained from thermal and catalytic process was distilled in the same reactor by taking out the cut fraction in the temperature range of 40- 380 ^{0}C.

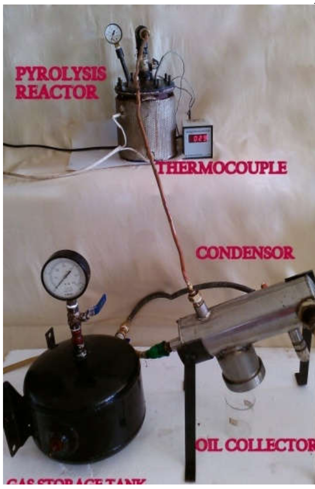


Fig .4 Experimental setup

Fig .5 Distillation setup

RESULT AND DISCUSSION

Thermal and catalytic cracking mass balance:

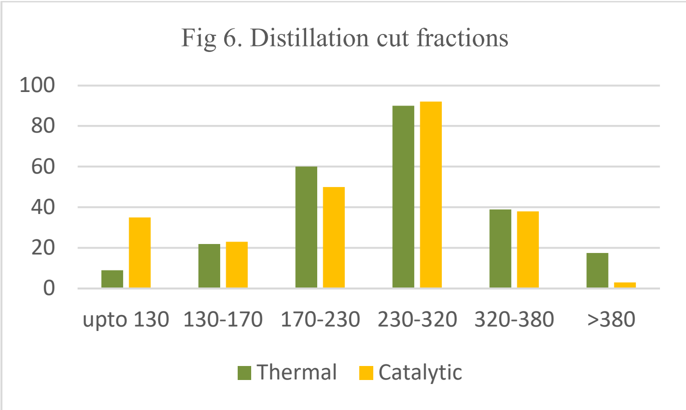
- Mass $_{reactant}$ = Mass $_{Products}$ ……(3)
- % conversion = 1-(wt. of residue/ wt. of plastic) …. (4)
- Oil Yield =wt. of desired product (Liquid)/wt. of plastic reacted… (5)

Table 1. Mass Balance of plastic

Mass in grams →	Plastic Gms.	Liquid Gms.	Gases Gms.	Char Gms.	Conversion %	Oil yield
Thermal	300	254	40.5	5.5	98.16	84.6
Catalytic	300	258	41.4	0.9	99.7	86

Table 2. Characterization of fuel obtained based on boiling point

Temp ^{o}C	Ther. oil (ml)	Cat. oil (ml)	Fraction	Carbon range [12]	Uses
Up to 130	9	35	Straight run gasoline	C_6-C_{10}	Gasoline pool
130-170	22	23	Naphtha (Medium and heavy)	C_6- C_{10}	Catalytic reforming and aromatic plant feedstock
170-230	60	50	Kerosene	C11-C12	Aviation turbine fuel, LAB feed stock
230-320	90	92	Light gas oil	C13-C17	High speed diesel component
320-380	39	38	Heavy gas oil	C18-C25	High speed diesel component
>380	17.5	3	Reduced crude oil	>C25	Feed to Vacuum distillation
Total	237.5	241			



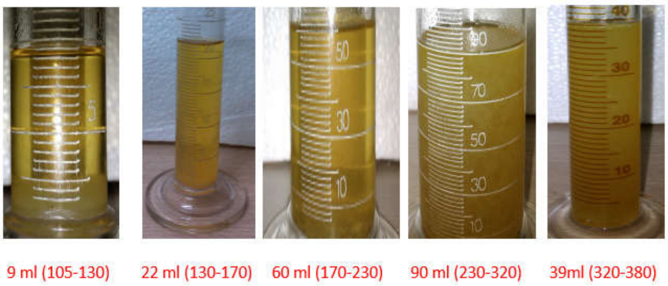


Fig. 7 Thermal pyrolysis cut fractions

Fig. 8 Catalytic pyrolysis cut fractions

ANALYTICAL CHARACTERIZATION:

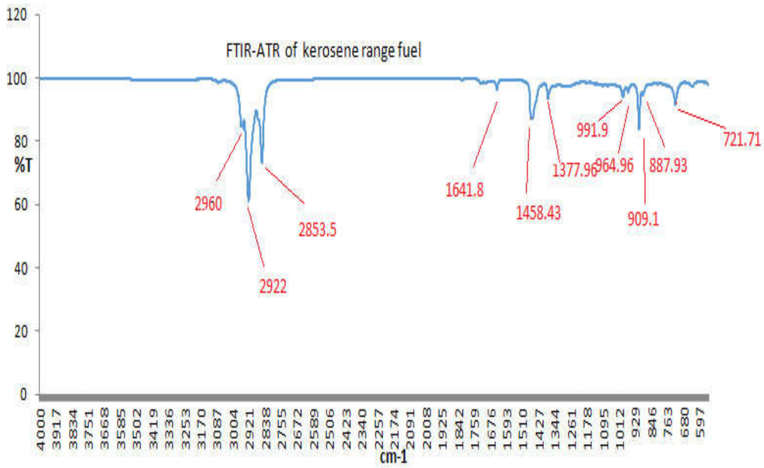


Fig. 9 FTIR-ATR of Kerosene range Pyro fuel

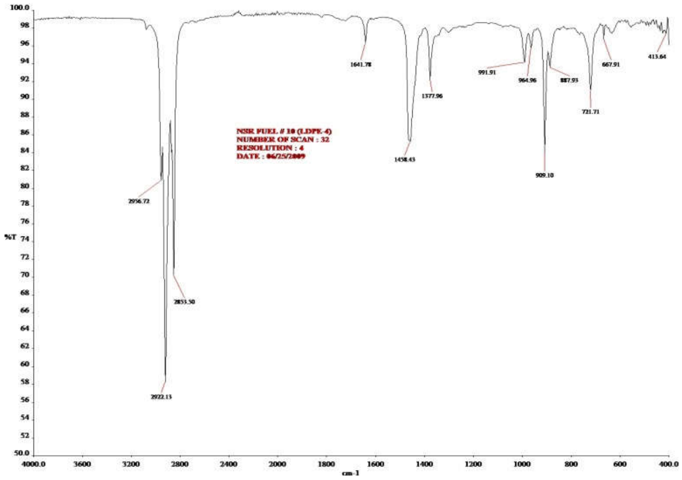


Fig. 10 FTIR-ATR of kerosene

Table 3.wavenumber having respective funtional group

Band Peak Number	Wave Number (cm^{-1})	Functional Group Name
1	2956.72	$C-CH_3$
2	2922.13	$C-CH_3$
3	2853.50	CH_2
4	1641.78	Non-Conjugated
5	1458.43	CH_3
6	1377.96	CH_3
7	964.96	$-CH= CH_2$
8	909.10	-CH=CH-(Trans)
9	887.93	$-CH= CH_2$
10	721.71	-CH=CH-(Cis)

CONCLUSIONS

The FTIR-ATR graph was analysed and the composition elements were found depending on wavenumber. Alkanes,Alkenes were found.The FTIR-ATR of kerosene ranged fuel has similar peaks as that obtained from FTIR-ATR of conventional kerosene.Thus the cut fractions obtained at specific temperature has the properties of respective fuel obtained at that temperature.

By the thermal pyrolysis of plastic waste conversion of 98.16% was achieved, whereas by the catalytic pyrolysis conversion of 99.7% was achieved, the yield of oil obtained in thermal is 84.66% while that in catalytic it is 86%, by catalytic pyrolysis more lighter fractions are obtained than compared to thermally derived oil. Thus, the new basic catalyst $CaCO_3$ can be used as a catalyst to crack LDPE plastic. Likewise, in acid catalyst there is addition of H^+ ion and leads to formation of unstable carbenium ion, in basic catalyst there is removal of H^+ ion by the OH^- ion of the base. The oil obtained can be physically characterized based on their boiling point as Gasoline, Naphtha, kerosene and high speed diesel component having carbon range of C_6-C_{38}.

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