

## Arduino Controlled Catalytic Pyrolysis of Plastic/Municipal Waste to Higher Hydrocarbons

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**Summary:** Worldwide, the broad usage of plastic has resulted in the massive production of plastic pollution. In this work, it was demonstrated that municipal plastic waste could be converted into valuable liquid products. This study shows the catalytic and non-catalytic pyrolysis of low-density polyethylene (LDPE), polypropylene (PP), and high-density polyethylene (HDPE). Pyrolysis was carried out in the absence of Oxygen, and three types of fractions: gas, liquid, and solid residues were obtained. The proportions of liquid or gas residue depend on the operating conditions such as temperature and the type of catalyst. The product obtained was then characterized through ASTM D-97, ASTM D-86, ASTM D-4294, Cloud Point, Conradson Carbon Residue, FTIR Analysis, ASTM D-611, Density and Specific Gravity. The use of catalysts showed more quantity of lower boiling points products due to further cracking of carbon chains and pour points decrease was also observed generally with the use of catalyst specially by using bentonite. A decrease in Pour Point indicated a decrease in paraffin content, therefore, reducing wax content, and so it indicated better flow properties at lower temperatures. Pour point and viscosity observed were interconnected with each other, sample having high pour points had high viscosity, hence showing the flowing ability of the liquid. Also, the Sulphur contents of all the samples falling under Euro II and Euro II category. C-<sub>Stretching</sub>, C=S<sub>Stretching</sub> and C-B<sub>ending</sub> bonds were noted using the FTIR analysis. One of the important purposes of this study was to convert the waxes obtained from thermal pyrolysis of HDPE and LDPE to higher chain hydrocarbons, which was achieved by using bentonite as the catalyst and also flowing properties of the liquid improved by using the catalyst. HDPE with bentonite gave the highest percent of liquid fuel (75.15%) obtained which in turn shows the best result obtained through all our experiments.

**Keywords:** Fuel; Catalyst; Waste to energy; Pyrolysis; Arduino.

### Introduction

Human evolution over the years has completely transformed the normal functioning of the world. Humans have completely revolutionized how the world operates by using basic elements like water, earth, air, and fire to advance technologies at the expense of a single touch. All this wouldn't have been possible without the resources and development provided by nature. One of the major inventions of humankind in the early 1900s is plastic. Over the years, plastic has substituted different materials like wood, metal, ceramic, and more due to its properties like lightweight, durability, and low cost [1].

Waste plastic disposal is a serious and emerging issue that must be redressed immediately to sustain the environment and life. But the world's dilemma now is the excessive use of non-biodegradable plastic. Plastic doesn't degrade easily and accumulates the landfill spaces hundreds of years after being disposed of, polluting the planet and creating environmental crises for further generations. Recycling this plastic waste is the only viable solution, but it must be done effectively. A very insightful approach to reducing plastic is using the reuse, recycle and reduce (3R's) principle. The 3 Rs principle

focused on reuse, recycle and reduce. Reduce is simply minimizing the amount of plastic used and switching towards other reusable materials. Reuse means utilizing things multiple times until they can't be used further. Recycling is the transformation of junk/waste into useful material. The 3 Rs is an effective approach to tackle the rising plastic waste in the world. [2].

Recycling can be categorized into three main types; primary recycling, secondary recycling & tertiary recycling. Primary recycling is closed-loop recycling in which material is mechanically recycled to produce similar use and function. It is estimated that the plastic can be used twice to three times as it quietly decreases after each run. Similarly, the materials are mechanically recycled to produce a new product in secondary recycling. In tertiary recycling, materials are processed to produce chemicals and fuel. [3]. Our project will focus on tertiary recycling, producing fuel from plastic/municipal waste by conducting pyrolysis. [4]. The generation and use of plastic have increased over the past few years, which has thus resulted in plastic accumulation in landfills. The mounds in landfills have led to a global

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environmental crisis in the spread of diseases, waste accumulation, unsanitary conditions, degradation of land, water pollution, and more.

Research indicates that only about 5% of all plastic produced is recycled. The remaining plastic remains in landfills, and the ocean takes more than 450 years to biodegrade [5]. Secondly, considering the limited natural resources, i.e., the non-renewable resources are scarce and will not last forever. Considering all the reasons stated above, we have decided to conduct the pyrolysis of plastic/municipal waste to generate fuel. It would lead to reusing, recycling, and reducing the plastic matter present on the earth for its betterment. It is aimed in current study to conduct catalytic pyrolysis of the plastic waste and convert it into fuel by using low-cost catalysts to increase the quality of fuel and to reduce wax generation that has been found to be formed in conventional pyrolysis method. We have used three different types of plastic (PP, HDPE, and LDPE) with two different types of catalysts (bentonite clay and kaolin clay) in the ratio of 1:3.

## Experimental

### Materials

The waste plastic material was obtained from local scrap vendors and then crushed accordingly for use. The catalyst materials (bentonite and kaolinite) were provided by a local ceramics industry. The liquid fuel produced was further analyzed with FTIR using Nicolet iS20 FTIR Spectrometer ATR method in order to understand the chains being formed during pyrolysis and presence of aromatics, Sulfur analysis was done in order to understand the amount of sulfur present in the liquid fuel to compare with the international allowable limits, Cloud and pour point tests were administered to understand the flowability of the liquid fuel under

different temperatures, ASTM D-86 was done to understand the initial and final boiling points of the fuel, TBP for the conversion purpose, Diesel index for the safe use in diesel engine, Cetane number and API gravity to understand the behavior of the produced fuel as compared with fossil fuel derived diesel.

### Detailed Description of Selected Process

The description of the process is that; It is a semi-batch process. Raw materials used are PP, LDPE, HDPE. The catalysts used are Bentonite Clay and Kaolin Clay in the ratio of 1:3. The product obtained is fuel in different carbon ranges. The temperature range will be from 25°C to 550 °C. Pressure will be 1 bar. The reactor is fully insulated, and the process nearly adiabatic. The vacuum is created with the help of a compressor to provide an oxygen-free environment. An electrical way of heating is used. To control the temperature of the process Arduino system is used.

The whole process is shown in Process Flow Diagram in

Fig. 1. All processes ahead will be following it. As the raw material is put inside, the first step creates a vacuum by the compressor through valve V1. While valve V4 is closed, and as the vacuum is created, the V1 should be closed. The pressure now inside the reactor is -0.8 bar. The temperature of vapors is sensed through a K-type thermocouple T1 connected to an Arduino controller. The electrical heating element is then turned on, and a set point of the temperature of 5°C is given through the controller. As the temperature rises, the pressure also rises; as the pressure goes just above 1 bar, valve V4 is opened. Gradually thermal cracking of raw material stalls, and the hydrocarbon vapors rise and go to the spiral tube in the condenser through GI piping.

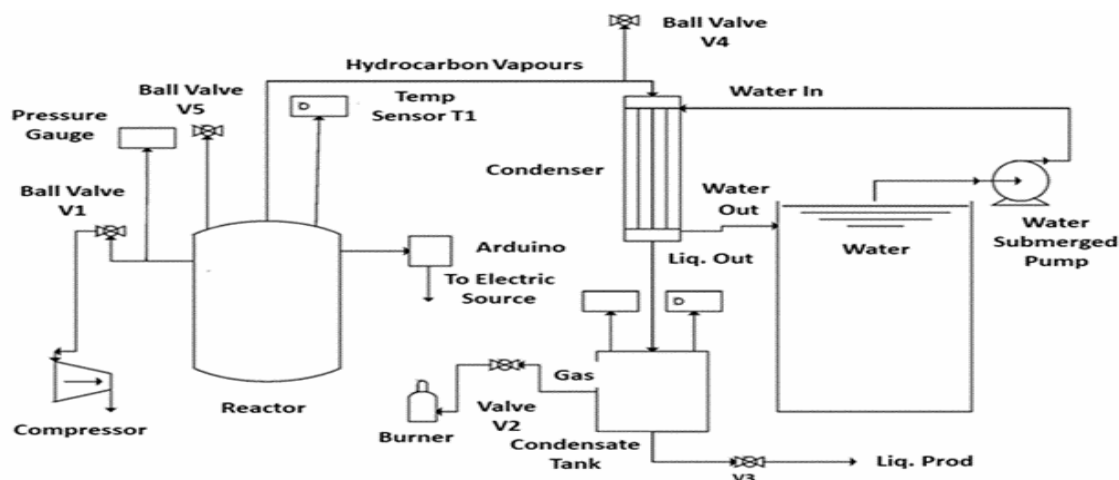


Fig. 1: Process Flow Diagram.

Inside the condenser, vapors travel inside the helical pipe while water is pumped through a submergible pump from a water chiller at a flow rate of 6 L/min and a temperature of 25°C. Through heat exchange from water which is in the outer pipe, the vapors are condensed inside the helical tube to liquid fuel, and then it is collected inside a container beneath it. The liquid fuel is then can be collected from the collecting vessel through valve V3. While, the gaseous product that is incondensable gases also produced, which are not condensed, goes out from the upper side through valve V2 to where a Bunsen burner Is connected through which gaseous product is burned. The process completes in such a way that at the temperature of 500°C, the flame that is burning by incondensable gases stops due to an insufficient number of gases, and the liquid product stops collecting in the collecting vessel. The whole raw material n incinerates while the solid residue remains inside the vessel that can be scrapped out after the reactor comes back at ambient temperature so the reaction can be started again.

The Arduino system as shown in

*Fig. 2* is used to show the temperature of the reactor on the screen when the K-type thermocouple is

connected with Arduino through a module named as MAX6675 shown in

*Fig. 2(a).*

This module performs cold-junction compensation and digitizes the signal from a k-type thermocouple. It has a maximum range of 0°C to 1024°C depending on the thermocouple it is paired with. The Arduino system is also used to control the electrical heating element by connecting it through a module named as relay cut-off module shown in

*Fig. 2(b)* which is used to connect the electrical heating element to Arduino. The relay module is basically a power switch which on receiving signals completes the circuit and lets the current flow and vice versa. The Arduino system was then connected to a lap top as shown in

*Fig. 2(c).* Arduino is programmed in such a way that when the required temperature is reached it sends a signal to the relay cut-off module and then the relay module cuts off the source of the heating element. The software used in controlling has a user interface as shown in

*Fig. 2(d).*

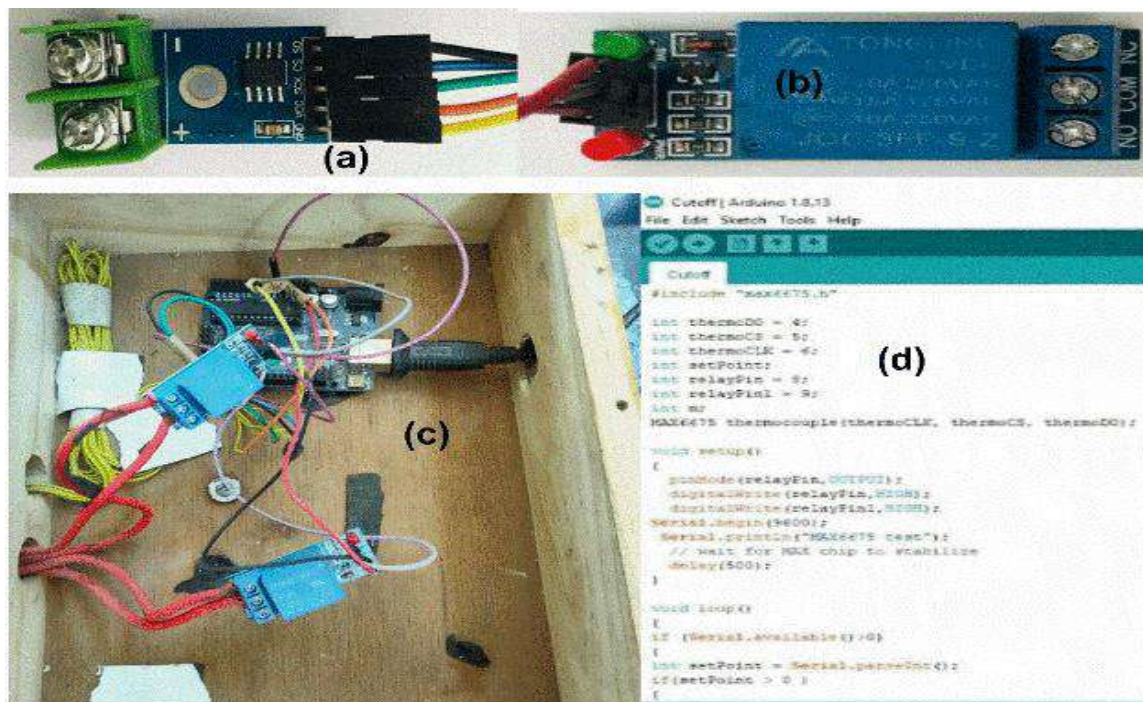


Fig. 2: (a) MAX6675 Module, (b) Relay Module, (c) Arduino system integrated with pyrolysis reactor, (d) Software User Interface.

The raw material was put inside the reactor, as shown in

Fig. 1, through a blind flange of 3 inches, and closed tightly so no air should enter it while the product collected continuously until the raw material is finished. The temperature reaches a maximum of 550°C, and the product withdrawn by maintaining different temperatures in different cycles.

## Results and Discussion

### FTIR Analysis

The chemical composition of all the 12 samples of plastic oil, either by not using the catalyst or using any one of the two types of catalysts (bentonite and kaolin) at the temperature of 500°C and a 1:3 ratio of catalyst to plastic feed was obtained by using FTIR technique. The oil obtained from all the plastic types carry similar assignments of different ranges, including 2850-2950  $\text{cm}^{-1}$ , which corresponds to C-H stretching, and the range of 1450-1650  $\text{cm}^{-1}$  corresponds to C=C stretching [6]. Also peak at wave-number 887  $\text{cm}^{-1}$  represents C-H bending. The results are in line with the literature values [7, 8].

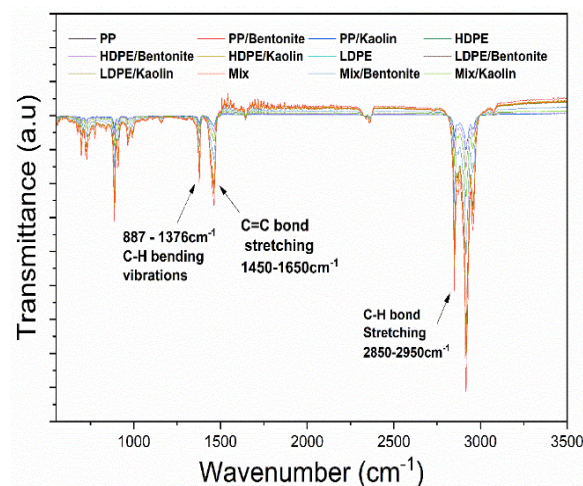


Fig. 3: FTIR of all the liquid samples obtained after pyrolysis.

### ASTM analysis

The liquid fuels were then evaluated with ASTM D-86 testing. The results are provided in the

Fig. 4 in which the results are presented separately without catalyst and with the use of catalyst material. The ASTM for all four type of samples is presented without catalyst in

Fig. 4(a) in which we can see that the maximum temperature range is for PP and is 370 °C. While other samples also have range above 350 °C, which indicates the production of more high boiling liquid fuel production without the use of catalyst. The effect of Bentonite and Kaolinite can be seen in

Fig. 4(b) and

Fig. 4(c) respectively and here it can be inferred that the high boiling fractions are not present as the maximum temperature limit is below 350 °C. It predicts that catalyst has played its role and reduced the boiling ranges of the fuel components. The liquid fuel content of mix plastic feed increased between 20 – 80 vol.% for both Bentonite and Kaolinite catalyst samples.

### Diesel Yield

The diesel content from the ASTM analysis was based on the initial and final boiling points taken from a local refinery and as shown in

Fig. 5 (a) –(d) for all types of materials without and with catalyst use. From all the liquid products obtained from pyrolysis, it has been seen that HDPE produces the highest amount of liquid product but with the wax content when no catalyst is used as shown in

Fig. 5 (b).

Though bentonite and Kaolinite reduced the wax content but reduced diesel percentage, as shown in

Fig. 5 (a) – (d). Analysis shows that bentonite works better with PP, LDPE, and kaolin with mixed plastic and HDPE due to its highly dense structure.

### API Gravity

The API gravity of HDPE, LDPE, PP and Mix are 55.8, 49.1, 44.7 and 51.5 respectively as can be witnessed in

Fig. 6 (a) – (d). The API gravity of the Mix/bentonite and PP/bentonite is lower than that of Mix/ Kaolin and PP/Kaolin as can be observed in

Fig. 6(a) and

Fig. 6(d) HDPE/Kaolin has API gravity within the range for diesel as 38.9 as shown in

Fig. 6 (b) below [9].

The API of the fuel produced decreases in an order from HDPE>>LDPE >>Mix>>PP Plastic which is very interesting to note and can be attributed to the density of the feed material used [10].

### Cetane Number

The cetane number of the fuel content was analyzed as given in

Fig. 7 (a) – (d) and it was observed that the cetane number was the highest for each type of

material without using catalyst with the mixed plastic has the highest cetane number as shown in

Fig. 7(d). The cetane number decreases with the use of catalyst material, which indicates more formation of alkenes and aromatics [11].

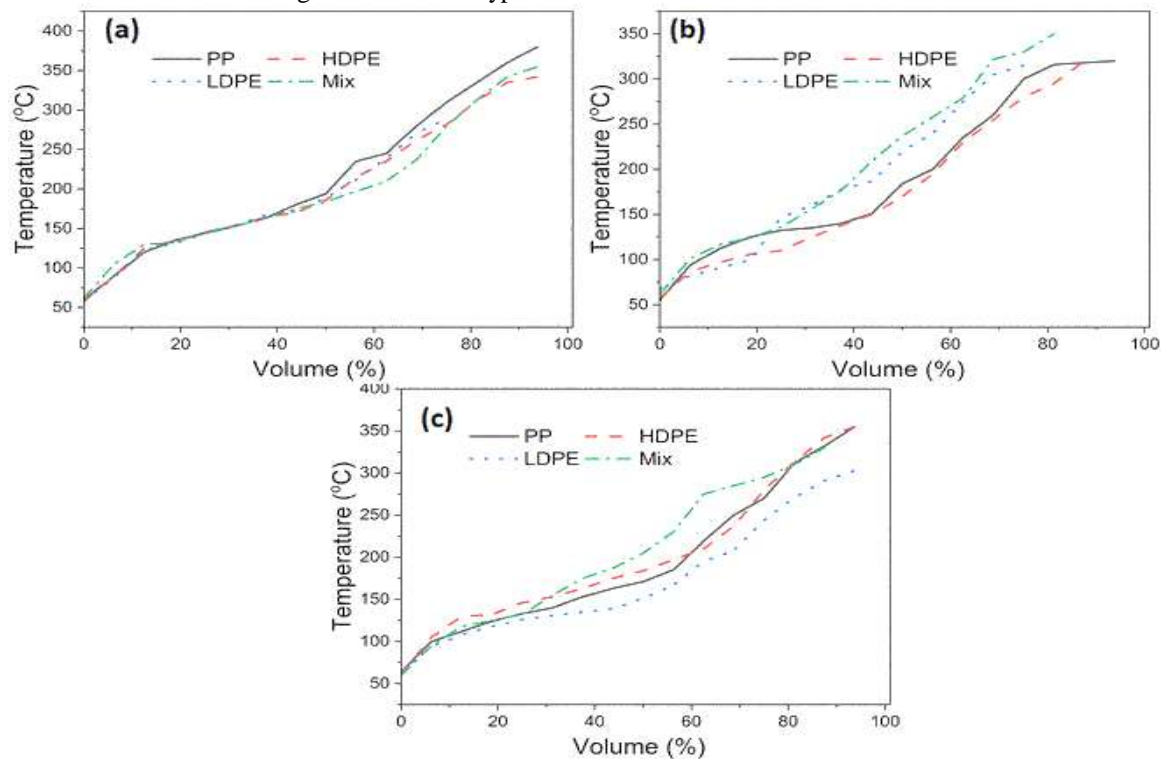


Fig. 4: (a) ASTM No Catalyst, (b) ASTM Bentonite, (c) ASTM Kaolin.



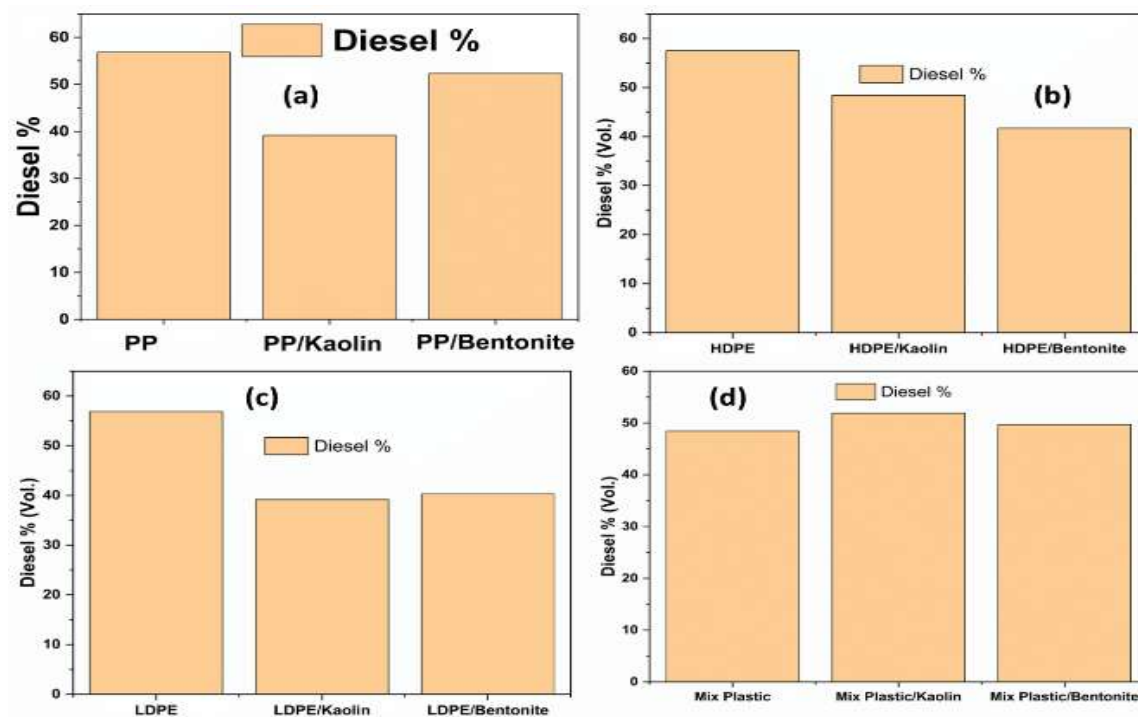


Fig. 5: Diesel yield from (a) PP without catalyst and with Kaolin and Bentonite, (b) HDPE without catalyst and with Kaolin and Bentonite, (c) LDPE without catalyst and with Kaolin and Bentonite, (d) Mix Plastic without catalyst and with Kaolin and Bentonite.

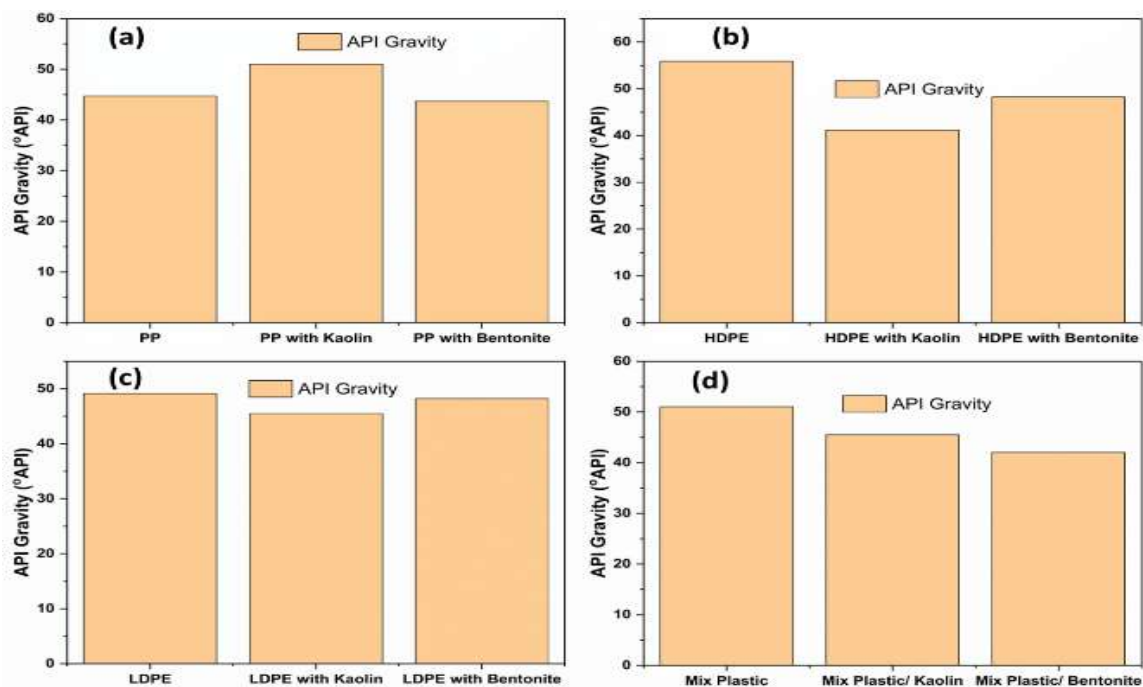


Fig. 6: API Gravity Comparison (a) PP without catalyst and with Kaolin and Bentonite, (b) HDPE without catalyst and with Kaolin and Bentonite, (c) LDPE without catalyst and with Kaolin and Bentonite, (d) Mix Plastic without catalyst and with Kaolin and Bentonite.

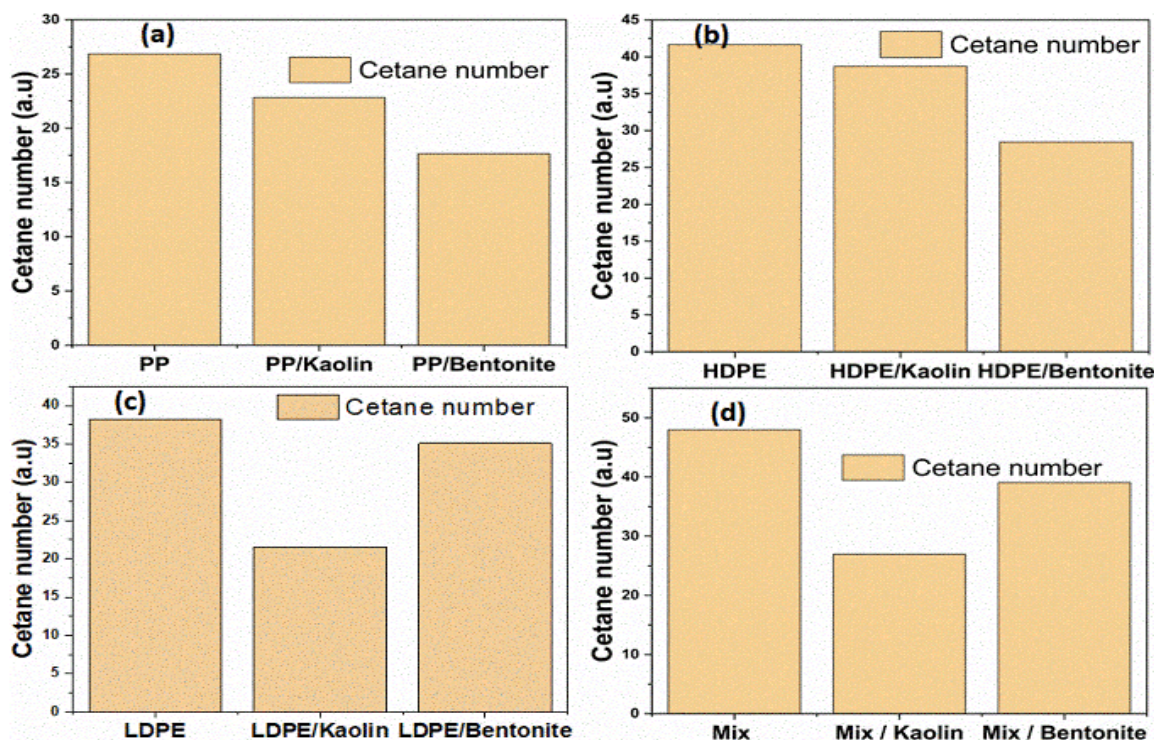


Fig. 7: Cetane Number Comparison (a) PP without catalyst and with Kaolin and Bentonite, (b) HDPE without catalyst and with Kaolin and Bentonite, (c) LDPE without catalyst and with Kaolin and Bentonite, (d) Mix Plastic without catalyst and with Kaolin and Bentonite.

#### Viscosity

The effect of use of catalyst can be observed from

Fig. 8 (a) – (d). One of the main problems with the pyrolysis of plastic waste was the wax content produced by the ethylene double bond as also confirmed by the FTIR analysis of the liquid samples and evidenced by literature [12].

Usage of the catalysts, e.g. bentonite and kaolin, decrease the viscosity. LDPE has the highest viscosity of all [13], as shown in the

Fig. 8, but reduces significantly by using catalysts, which advocates more formation of smaller chains of hydrocarbons and less wax content in the final product. The viscosity obtained is much lower than the ones reported by Chanyeong Park et. Al. [14].

#### Pour Point and Cloud Point

At low temperatures, the fuel's paraffin starts forming crystals that restrict the fuel from flowing [15]. The pour point determines if the fuel is suitable for low-temperature installations [16]. The results revealed that the PP and Mix/Kaolin pour point meet the standards of commercial diesel fuel as portrayed in

Fig. 9 (a) – (d) in which the comparison of all the samples is given.

#### Sulfur Content Analysis

The sulfur content in samples is depicted in the Fig. 10 ranges from 130 to 379 ppm. It is evident that mixed plastic consists of a negligible amount of sulfur content in it. Additionally, it was observed from the Figs that the sulfur content in both catalytic and noncatalytic pyrolysis samples doesn't exceed the maximum allowable euro II limit for diesel (200 – 500 ppm) [17]. High sulfur content is undesirable as  $SO_x$  emissions cause several environmental pollution problems, such as the formation of acid rain.

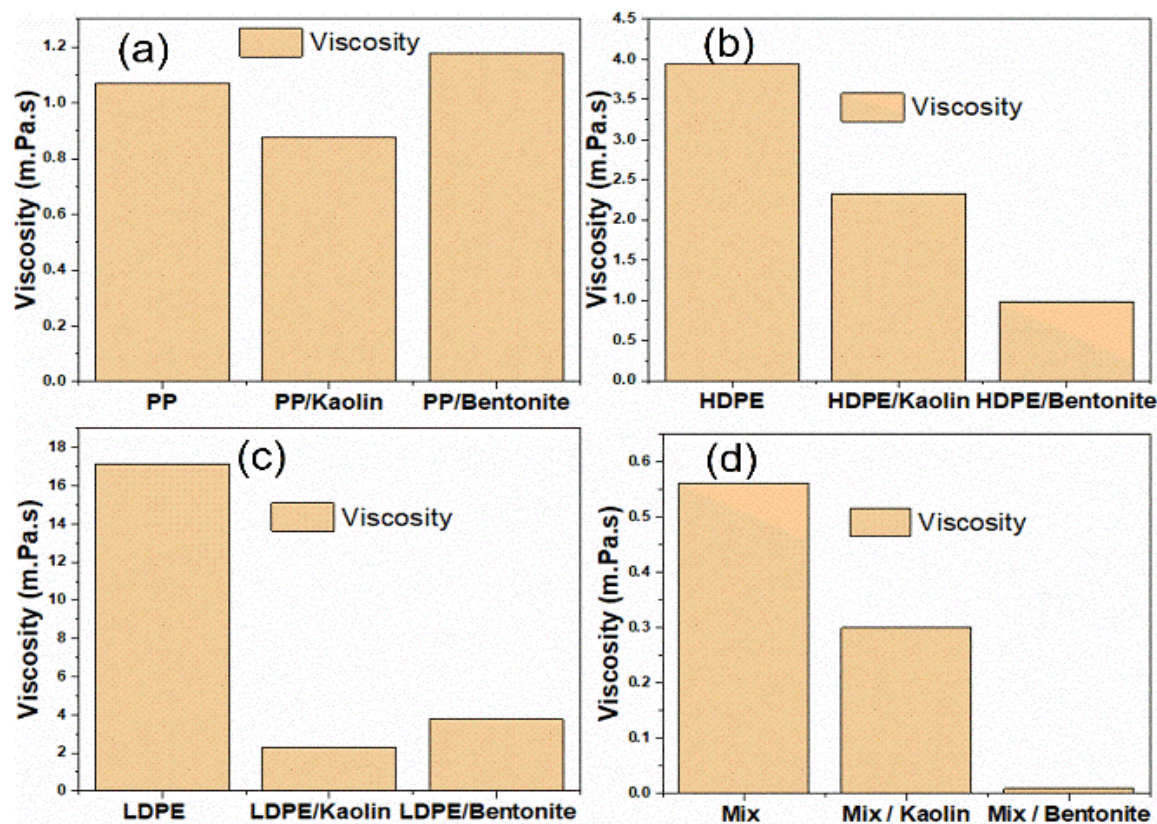


Fig. 8: Viscosity Comparison (a) PP without catalyst and with Kaolin and Bentonite, (b) HDPE without catalyst and with Kaolin and Bentonite, (c) LDPE without catalyst and with Kaolin and Bentonite, (d) Mix Plastic without catalyst and with Kaolin and Bentonite.



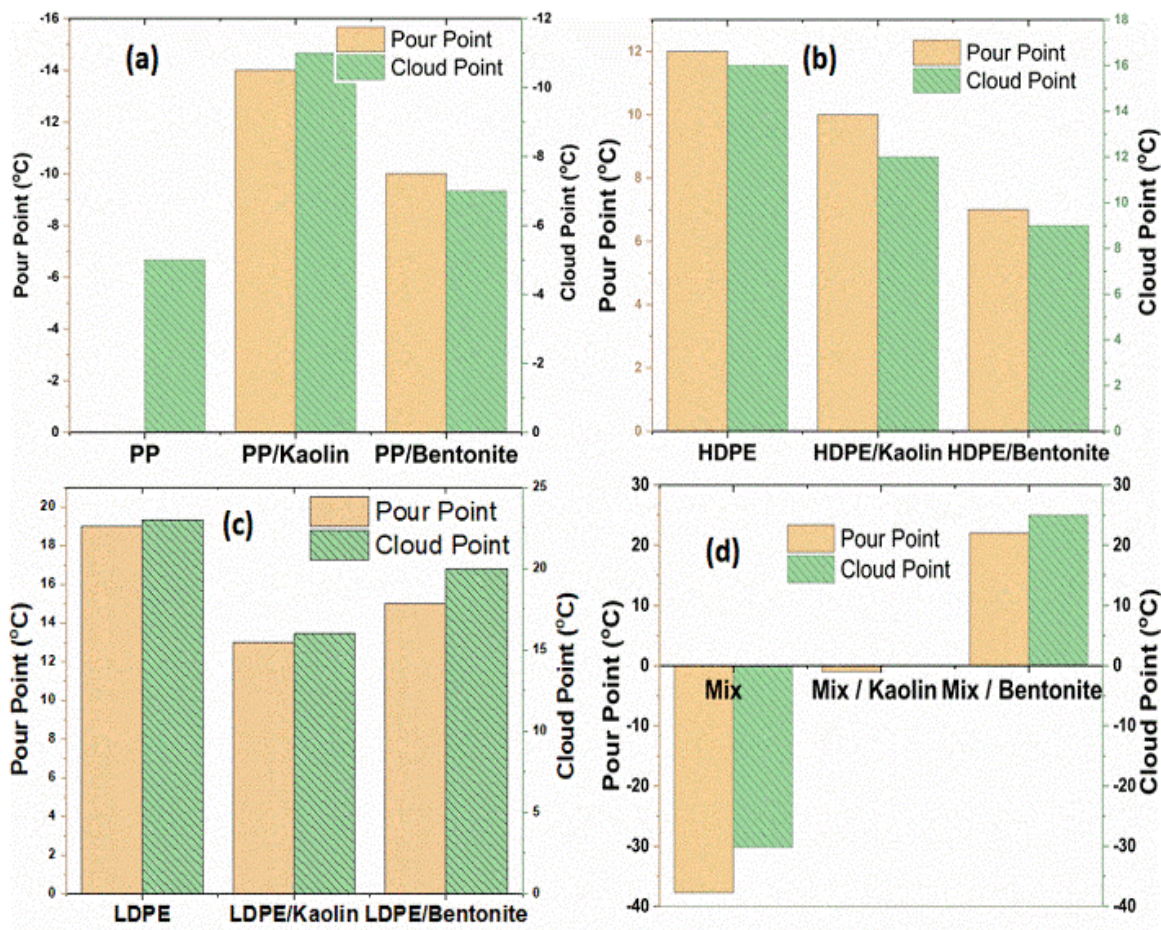


Fig. 9: Pour Point and Cloud Point Comparison Chart (a) PP without catalyst and with Kaolin and Bentonite, (b) HDPE without catalyst and with Kaolin and Bentonite, (c) LDPE without catalyst and with Kaolin and Bentonite, (d) Mix Plastic without catalyst and with Kaolin and Bentonite.

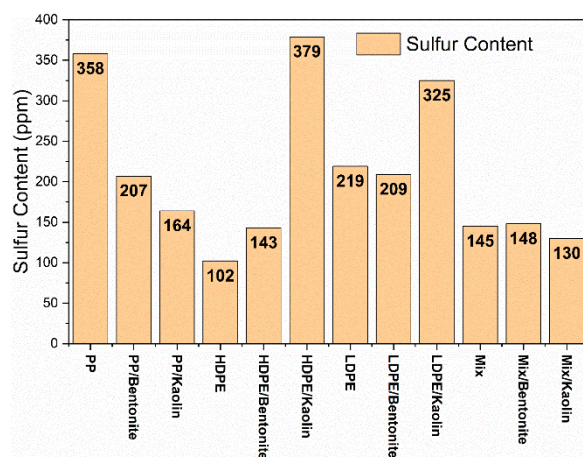


Fig. 10: Sulfur Content Analysis.

The pyrolysis of plastic produced liquid fuel, char and incondensable gases. Liquid product mass amount corresponds to the amount of liquid fuel obtained from the storage tank as provided in

Fig. 11 (a) – (d) for PP, HDPE, LDPE and Mix samples without and with catalyst. The yield obtained is comparable to that reported by Krishnasamy Sivagami *et al.* [18]. Likewise, the char content mass is obtained by noting the mass of char obtained from the reactor after the completion of pyrolysis process. Finally, the non-condensable gases mass is obtained by subtracting the cumulative mass of liquid product and char from the mass of initial plastic feed entered. All the values are provided in **Error! Reference source not found.**

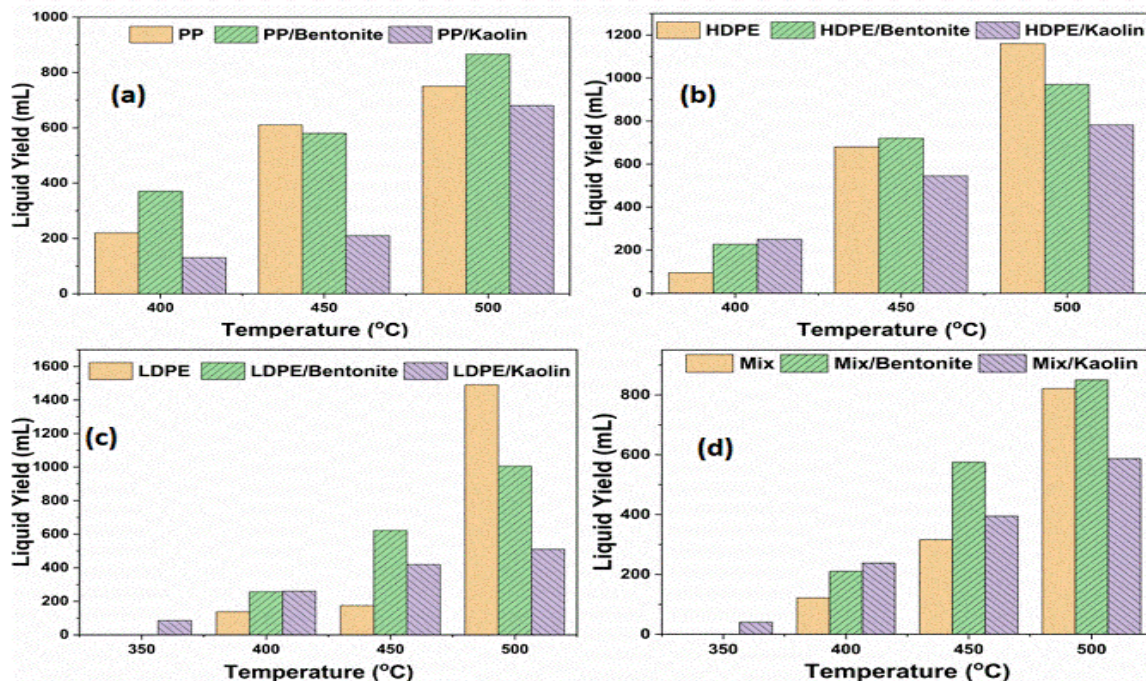


Fig. 11: Liquid yield at different temperatures with and without catalyst for (a) PP, (b) HDPE, (c) LDPE, (d) Mix.

Table-1: Sample size and yield analysis.

Catalyst	Reactant	Product		
		Liquid product	Char Wt. %	Incondensable gases
	Plastic (2 kg)	Wt. %		Wt. %
Bentonite clay 0.66 kg	PP	73.00	17.65	9.3468
	HDPE	75.14	0.795	24.0586
	LDPE	73.81	9.35	16.8364
	MIX	66.38	2.825	30.794
Kaolin clay 0.66 kg	PP	39.37	12.43	48.198
	HDPE	64.34	26.49	9.1684
	LDPE	50.74	21.49	27.765
	MIX	50.14	9.62	40.227
Without catalyst	PP	63.2	19.9	16.9
	HDPE	72.75	1.05	26.194
	LDPE	70.23	7	22.761
	MIX	48.63	6.25	45.114

The sample size used during the study is provided in the

for different feed compositions and the yield of solid, liquid and gasses is also reported accordingly.

#### ASTM to TBP Conversion

The API method (1993) is a generalized correlation in the following form serves as the foundation for the Riazi-Daubert method for the interconversion of ASTM D-86 distillations to TBP distillations [19].

$$TBP = a(ASM - D86)^b$$

The parameters  $a$  and  $b$  can be estimated from the

Table-2 [19]. The ASTM conversion to TBP is given in

Fig. 12 for PP,  
Fig. 13 for HDPE,  
Fig. 14 for LDPE and in  
Fig. 15 for Mix without and with catalyst material.

Table-2: Values for constants  $a$  and  $b$  for ASTM to TBP conversion.

vol%	a	b	Range a, (°C)
0	0.9177	1.019	20-320
10	0.5564	1.09	35-305
30	0.7617	1.0425	50-315
50	0.9013	1.0176	55-320



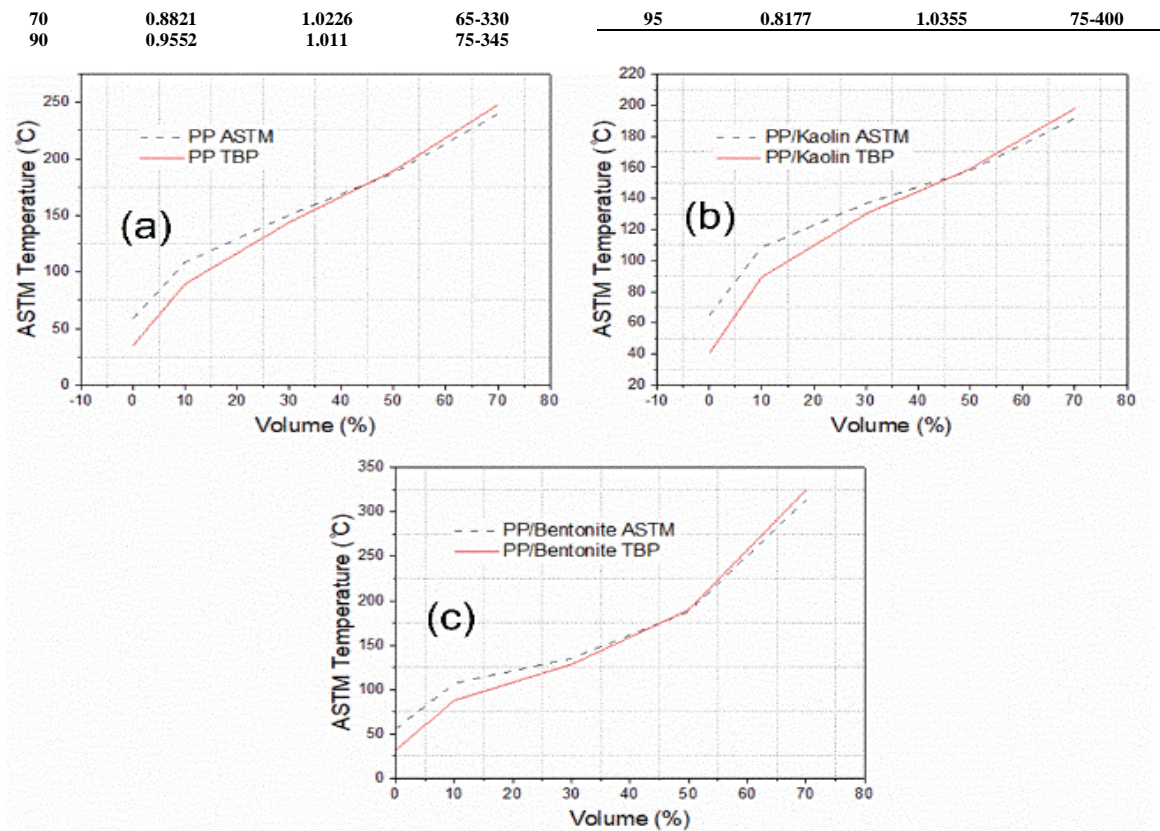


Fig. 12: ASTM to TBP conversion for (a) PP, (b) PP/Bentonite, (c) PP/Kaolin.

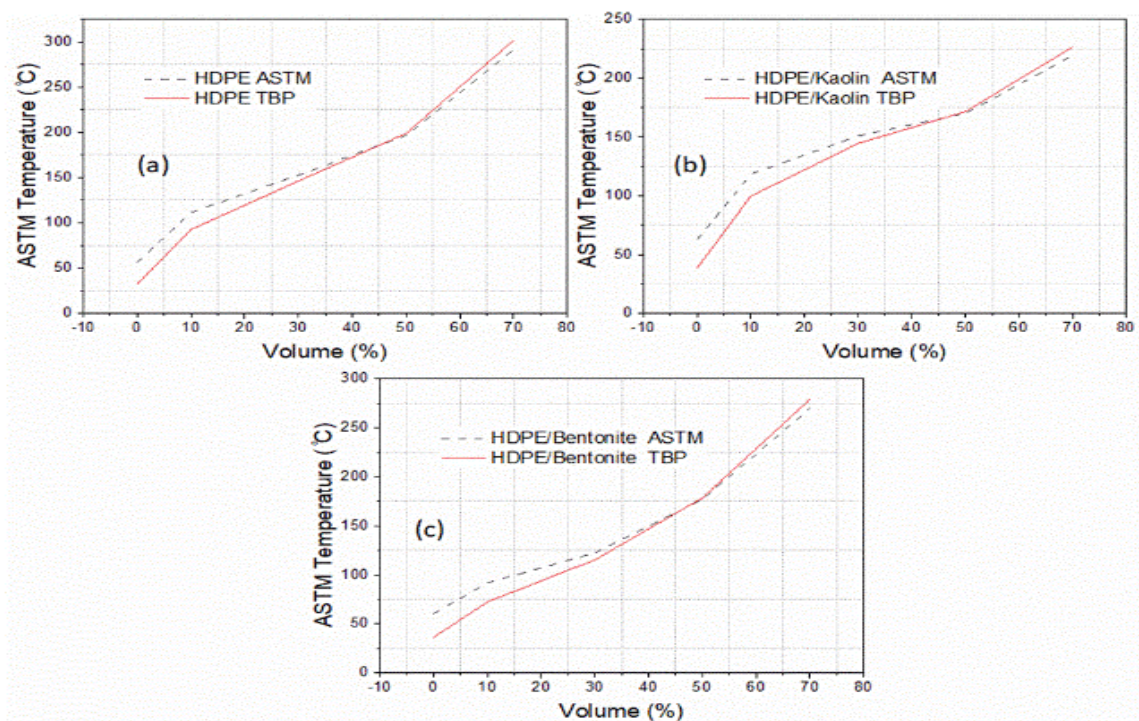


Fig. 13: ASTM to TBP conversion for (a) HDPE, (b) HDPE/Bentonite, (c) HDPE/Kaolin.



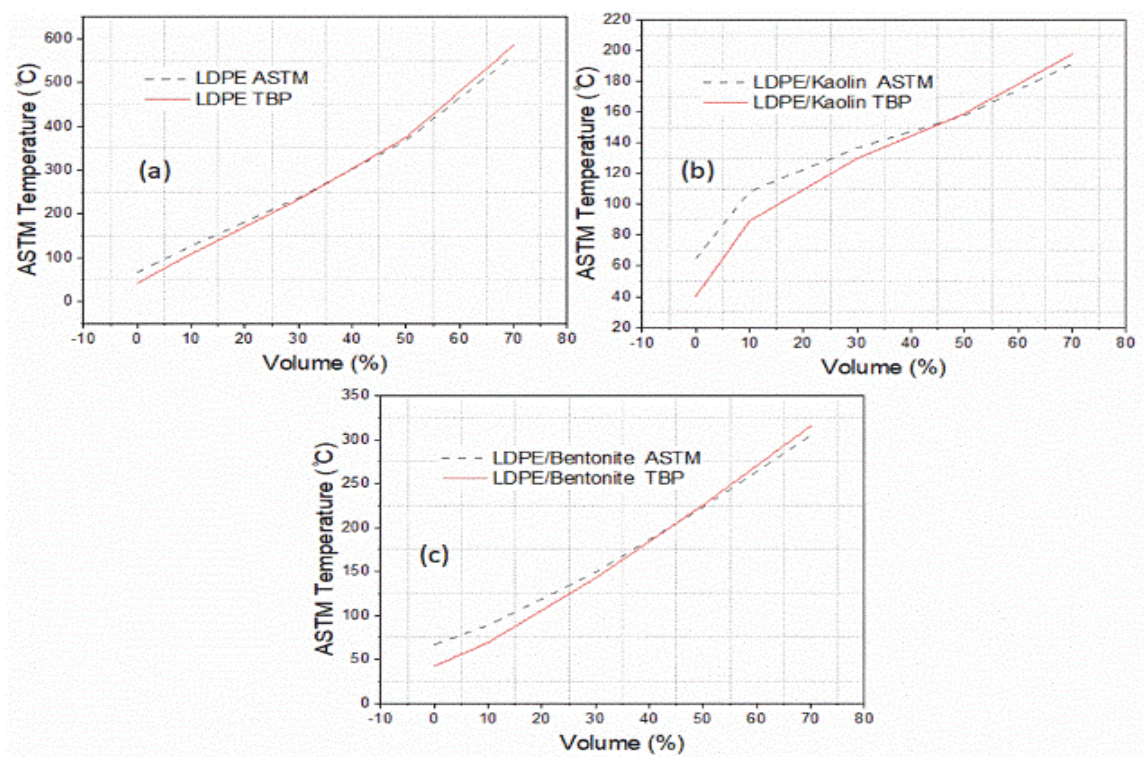


Fig. 14: ASTM to TBP conversion for (a) LDPE, (b) LDPE/Bentonite, (c) LDPE/Kaolin.

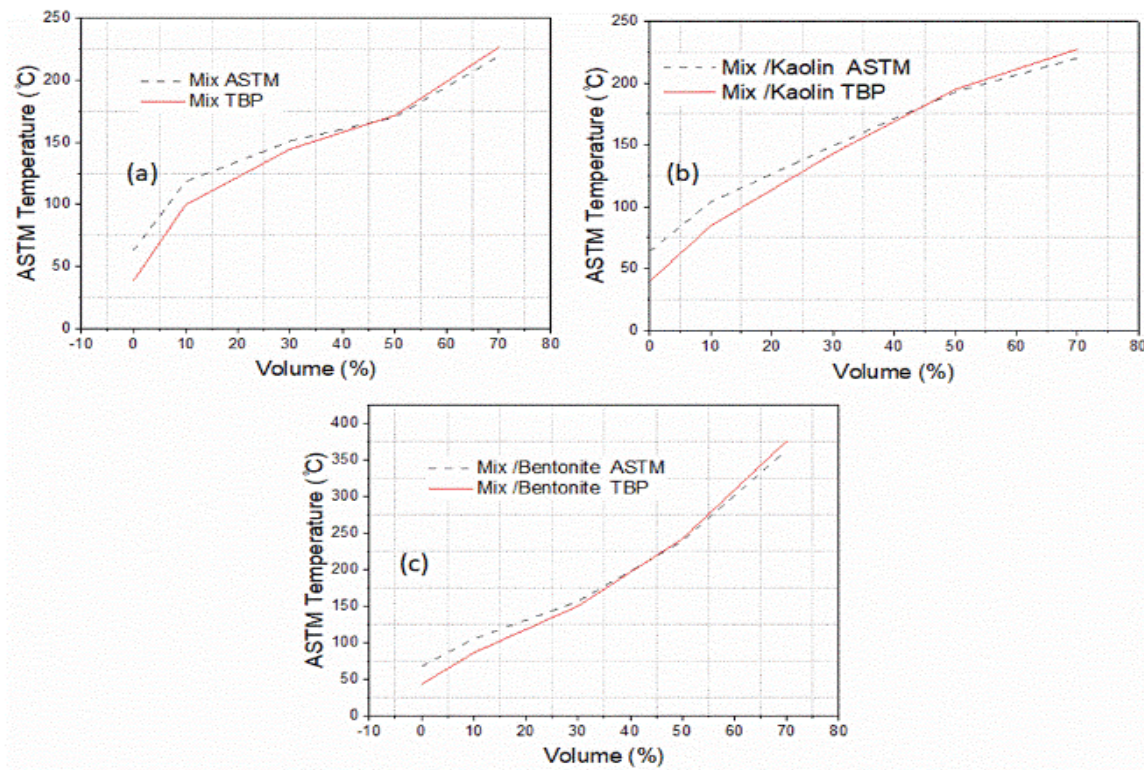


Fig. 15: ASTM to TBP conversion for (a) Mix, (b) Mix/Bentonite, (c) Mix/Kaolin.



## Conclusion

From the above table we can draw many conclusions. As far as liquid product is concerned, HDPE plastic gave us the highest amount liquid fuel percent whether process was carried out with or without catalyst. Results are summarized below:

**Without Catalyst** HDPE (72.76%) > LDPE (70.24%) > PP (63.2%) > MIX (48.64%)  
**With Kaolin** HDPE (64.32%) > LDPE (50.75%) > MIX (50.15%) > PP (39.37%)  
**With Bentonite** HDPE (75.15%) > LDPE (73.8%) > PP (73.0%) > MIX (66.38%)

It can also be concluded from the above results that for a particular type of plastic and with that selected plastic by carrying out processes by three different conditions (without catalyst, with bentonite catalyst and with kaolin catalyst), we generally noticed a trend of obtaining highest amount of liquid fuel percent by using bentonite as a catalyst for all kinds of plastics and the number of liquid percent decreased by using kaolin as catalyst. Results are summarized below:

**For HDPE** With Bentonite (75.15%) > Without Catalyst (72.76%) > With Kaolin (64.32%)  
**For LDPE** With Bentonite (73.8%) > Without Catalyst (70.24%) > With Kaolin (50.75%)  
**For PP** With Bentonite (73.0%) > Without Catalyst (63.2%) > With Kaolin (39.37%)  
**For Mix Plastic** With Bentonite (66.38%) > Without Catalyst (48.64%) > With Kaolin (50.15%)

From the above evaluations we came to know that with the plastic type of HDPE, liquid fuel % increased from 64.32% with kaolin, to 72.76% without catalyst and reaching its highest value of 75.15% with bentonite clay catalyst. Subsequently by using bentonite clay as catalyst, liquid fuel % increased from 66.38% with mix plastic to 73.0% with PP, to further increase to 73.18% with LDPE and finally reaching the highest value of 75.15% with HDPE. Hence it is observed that with the use HDPE as plastic and bentonite clay as catalyst, optimum results are achieved. The current study paves the way for a full-scale pilot plant to become operational and produce commercial grade yields for better understanding. The problem at hand is the disposal of the gases evolved during the process and needs to be further optimized to be used as the feed for combustion required for pyrolysis.

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