Optimization and Prediction of Reaction Parameters of Plastic Pyrolysis Oil Production Using Taguchi Method

Gopinath, Soundararajan*+; Devan, P.K.
Department of Mechanical Engineering, R M K College of Engineering and Technology, Puduvoyal, Tamil Nadu, 601206 INDIA

ABSTRACT: *Design of Experiments (DoE) is a powerful guiding tool that can help researchers to identify the main variables that affect the performance characteristics. The present paper elaborates the optimization and prediction of reaction parameters like type of plastic, catalyst and temperature using Taguchi's L_9 orthogonal array method with three levels and three parameters to obtain the highest yield of plastic oil. To determine the effect of each parameter, the Signal to Noise (S/N) ratio was calculated based on the experiments conducted. In this investigation, contributions of reaction parameters were analyzed by Analysis of Variance (ANOVA) using statistical software Minitab-16. Based on the investigation, the reaction parameters like type of plastic: Low-Density Polyethylene (LDPE), catalyst: Silica alumina (SA), and temperature: 500°C are optimized to get the better yield of oil. Based on the confirmatory trial, the oil yield of about 95.4%, the gas yield of about 3.4%, and solid residue as 1.2% were obtained, which is better than the normal trails.*

KEYWORDS: *ANOVA; Orthogonal array; Plastic oil; Pyrolysis; Taguchi's DoE.*

INTRODUCTION

Plastic plays a vital role in our day to day life in different forms. Demand for plastics has been increasing due to the rapid growth of human needs. Due to its availability and unique properties it is used in wide range of applications. However, the accumulations of plastic wastes grow year by year, resulting in generation of 5.6 million tons of plastic wastes every year in India. Out of these, only 60% is recycled and remaining is dumped in landfills. Generally plastic contains long hydrocarbon chain and it is non-degradable. The major types of plastics are polyethylene terephthalate (PET), High density polyethylene (HPDE), Low density polyethylene (LPDE), Polypropylene (PP), Polystyrene (PS) and Polyvinyl chloride (PVC). Some of the PETs are used in printing sheets, electrical insulation, magnetic tapes, photographic film, and X-rays. HPDE finds applications in Lather bottles, oil containers, toys, milk bottles. LPDEs are used for making plastic covers, trash bags, and wrapping foils. PPs are found in furniture, pails, and storage containers. PSs are used in making toys, electronic components, construction, and medical appliances [1]. PVCs are used in making credit cards, window frames, automotive interiors, synthetic leather, and medical devices.

In the present paper, elaborate work related to oil extraction and optimization of reaction parameters is investigated. *Bukkarapu et al.* [2] reviewed the pyrolysis of plastic wastes. LDPE has a volatility of 99.7% (wt)

* *To whom correspondence should be addressed.*
+ *E-mail: gp.nath4@gmail.com ; pkdevan68@gmail.com*
1021-9986/2020/2/91-103 13/$/6.03

and it has negligible amount of moisture content. Different reactors were studied and analyzed. The oil yield from semi batch reactor was about 92.3% which was 20-30% higher than the fixed and fluidized bed reactor. The widely used catalysts in plastic pyrolysis are Zeolites, Fluid Catalytic Cracking (FCC) and Silica-alumina catalysts. The chemical composition of plastic oil was determined by FT-IR, GC/MS and found that aliphatic compounds are more than aromatic compounds.

Nisar et al. [3] carried out an experimental study on thermal decomposition of polyethylene by thermo gravimetric analysis. They found that reaction rates are improved with increase in amount of catalyst. Alumina acidic (20% wt) catalyst improves the catalytic cracking of polyethylene whereas alumina neutral catalyst has poor reactivity towards polymer. *Sharma et al.* [1] investigated the production and characterization of pyrolysis oil from HDPE waste plastics grocery bags. Gas chromatography and mass spectroscopy provide the compositions of chemical compounds and found that 94.0% of aliphatic paraffinic hydrogen and smaller amount of aliphatic olefinic hydrogen and aromatic hydrogen were present in the HDPE pyrolysis oil. *Khan et al.* [4] have conducted an experiment to obtain the pyrolytic oil from waste HDPE and characterization of plastic oil revealed that the properties were similar to those of diesel fuel. It was reported that liquid yield was 77.03% at 2 hour duration. If the duration time increases, liquid yield and char production decreases. Higher calorific value was observed when compared to conventional diesel fuel.

During pyrolysis maintaining high temperature leads to several issues. Therefore reduction of temperature is important and it was achieved by using the catalyst having more surface area and pore size. The study was made to analyse the thermal degradation during the Pyrolysis process of Polyvinyl chloride with the addition of catalyst as silica gel (20% by wt) [5]. It was observed that degradation temperature was highly improved upto the maximum of 88°C by thermo gravimetric analysis.

Nisar et al. [5] studied the kinetics of Polypropylene thermal degradation by ozawa Flynn Waal method, Tang Wanjun method and Coats-Redfern equations. In the theoretical methodology, he observed that activation energy level was higher. Experiment was carried out and temperature was measured by K-type thermocouple and the gas samples are monitored by gas chromatography. *Nisar et al.* [6] made on experimental study on influence of temperature on pyrolysis from waste tire rubber. The Elemental analysis was made on liquid (C_{16}-C_{19}), gas (C_1-C_5) and tar products obtained during the pyrolysis process and influence of temperature were recorded [7]. Using chromatograms the presence of alkanes were confirmed.

Lee et al. [8] investigated the characteristics of pyrolytic oil by thermal and catalytic degradation. Experiment was conducted at degradation temperature of 420°C using FCC as a catalyst with a maximum holding time of about 5 hours. In thermal degradation, there was no effect of holding of time in yield of oil, but in catalytic cracking gradual increase in oil yield upto 2-3 hours of holding time. From the comparative study, higher yield of liquid was obtained during catalytic cracking. *Nisar et al.* [7] investigated on catalytic cracking of polyethylene using gas chromatography. The test was carried out at inert atmosphere at a temperature range of 300°C to 800°C in a Shimadzu PYR-2A pyrolyzer. Investigator suggested that 500°C to 800°C is optimum for the pyrolysis of plastic, because yield of volatile products are much similar for standard polymers at the above temperature ranges.

Kaimal et al. [9] made an experimental study using pyrolytic oil as alternative fuel for diesel engines. The blends of plastic oil (25%, 50% and 75%) on the volume basis are prepared and tested on single cylinder, 4stroke water cooled DI diesel engine. Comparative study was investigated on brake thermal efficiency and emission characteristics. Better thermal efficiency, reduced smoke (22%) and NO_x (17.8%) were witnessed at 25% blend when compared to standard diesel fuel [10-11]. From the literature it was observed that, yield of the oil was affected by reaction parameters such as catalyst, temperature and type of polymers.

EXPERIMENTAL SECTION

Selection of Materials

Branching of polymer structure in LDPE results in weaker intermolecular force, due to its lower hardness and tensile strength compared to HDPE [10-11]. The bonds of LDPE structure are easier to break by thermal cracking process, due to less crystalline and better ductility in nature. Another advantage of using LDPE in day to day life is better water resistant property. Because

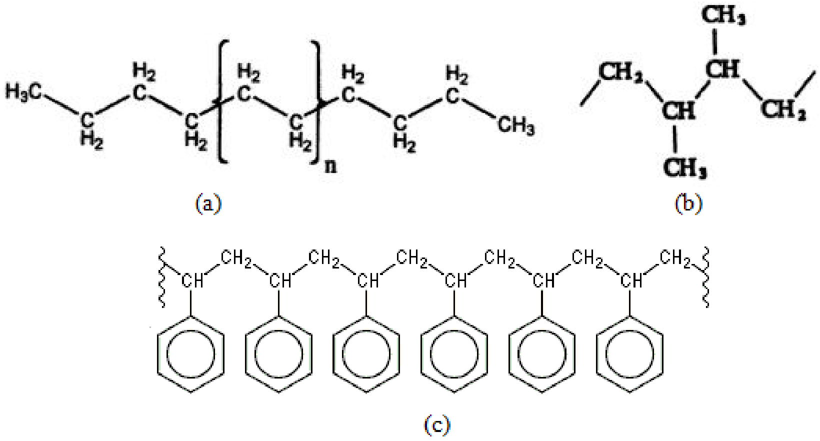

Fig 1: Molecular structures of (a) LDPE (b) PP (c) PS.

Fig 2. Samples of (a) LDPE (b) PP (c) PS

of its better hardness, rigidity it was not most preferable in industrial purpose. However it melts more than 170°C. The molecular structure and samples are shown in Fig. 1 and Fig. 2. A carbon atom is attached to phenyl group consisting of long hydrocarbon chain to form a structure of polystyrene (PS). It was obtained from petroleum chemical as styrene monomers. Due to its heat resistance, better hardness & strength breaking of bonds were more than 210°C.

The proximate analysis was carried out to find the ash content of the different plastics and results are shown in the Table 1. The ash content of plastics is approximately zero, indicating that higher liquid yield can be obtained from the plastics.

Pyrolysis Process

Pyrolysis is the process of degradation of polymers in the absence of oxygen and it is also known as thermal cracking. Pyrolysis is the most predominant technique, which converts mass of energy into liquid and gaseous products. Temperature and catalyst are more important parameters in the process of pyrolysis. Zeolites, FCC and Silica Alumina are used as catalysts to speed up the reaction process [11]. The operating temperatures of pyrolysis process are 500°C, 550°C and 600°C.

Catalyst

Heterogeneous catalyst such as Zeolites, FCC and Silica alumina are most widely used because of its ion exchange capabilities in nature. The Zeolite consists of SiO_2/Al_2O_3 at different ratios. During thermal cracking, higher ratio of SiO_2/Al_2O_3 produces lower fraction of C_{12}-$C_{20,}$ whereas lower ratio results in light olefins. To crack heavy oil fraction into lighter fraction FCC was used. Since FCC contains Zeolite crystals like silica and

Table 1: Proximate analysis of plastics.

Type of plastics	Fixed carbon (wt. %)	Volatile (wt. %)	Ash (wt. %)	Moisture (wt. %)
Low-density polyethylene	0.00	99.70	0.00	0.03
Polypropylene	1.22	95.08	3.55	0.15
Polystyrene	0.12	99.63	0.00	0.25

alumina with significant proportions it influences the composition and catalyst structure. In a semi batch reactor pyrolysis 10% - 20% of FCC improves the liquid yield by 11% by severe steaming at the temperature of about 550°C. Silica – Alumina catalyst contains amorphous acid with bronsted acid and ionized hydrogen atom in its structure [10-11]. Lower ratio of Silica – Alumina results in higher liquid yield at 500°C. From literature, it was found that catalyst weight by 10% was optimum, but the ratio of Silica – Alumina influences the speed of the reaction.

Temperature

Temperature is another important parameter which influences the production of pyrolytic oil. It plays a major role in thermal cracking process. In polymers, molecules are branched and tightly packed by Van der Waals force. The braking of polymer chain occurs at higher temperature due to molecule vibration in their structure. Pyrolysis of LDPE at 365°C resulted in less yield because fumes of materials are formed in the reactor at this temperature. Based on thermogravimetry analysis it was observed that loss of weight initiates at a temperature of 400°C for PP because faster degradation occur due to tertiary carbon chain [11]. During thermal degradation tertiary carbocation occurs at above 475°C. At lower temperature 300°C no liquid yield was obtained due to its long carbon chain structure for PS. Above 500°C phenyl group is detached and liquid and gas yield were observed. It is observed that the liquid yield of polymers occurs between 500°C & 600°C with the presence of a suitable catalyst.

Taguchi Method of optimization

Taguchi is one of the statistical methods to develop the Design of Experiments (DOE) and provides the robust design using its orthogonal array (OA).Taguchi deals with signal to noise ratio (S/N), in which the signals are the output values and Noise, are the values which affect the output parameters [12-14]. There are three types of S/N ratios namely, Higher the Better (HTB), Nominal the Best (NTB) and Lower the Better (LTB). Based on the utility of the parameter, suitable S/N ratio is selected to determine the standard deviations and means. In this investigation L_9 orthogonal array with three parameters and three levels is selected based on the following formula.

Minimum Trails = P*(L-1) +1 = 3 *(3-1)+ 1 = 7 ≈ 9

The results are analyzed using Signal to Noise ratio, the oil yield is determined using the relation Higher the Better (HTB) , gas and solid yields are determined using Lower the Better (LTB). in which, Y_{ij} is the observed response value in the experiment; i = 1,2,…..,n ; j = 1,2, ….., n and n = number of replications.

$$\frac{S}{N}\text{ratio}(\text{HTB}) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^2}\right)$$

$$\frac{S}{N}\text{ratio}(\text{LTB}) = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}y_{ij}^2\right)$$

Experimental investigation

A pyrolysis setup consists of the following components is shown in Fig 3. A semi batch reactor of diameter 1500mm and height 1200mm, condenser of diameter 1200mm and height of 1000mm with immersed 8mm copper tubes are the main components of pyrolysis setup. The water is used as coolant and circulated thought the outer shell with the aid of pump. Electric furnace is used to maintain the reactor at constant temperature. The K-type thermocouple with the accuracy of 0.1°C and range from -50°C to 1200°C is used to measure the temperature. The raw material is placed inside the reactor and the process is initiated to extract the oil.

Semi batch reactor is placed on electric furnace, the dried small pieces of plastics along with catalyst are fed into the reactor and appropriate temperature is maintained. The vapor from the reactor is sent to the

Table 2: Parameters and their levels.

Parameters	Levels		
	1	2	3
Type of Plastic	LDPE	PP	PS
Catalyst 10wt%	Zeolites (Zs)	FCC	Silica – Alumina (SA)
Temperature °C	500	550	600

Table 3: L9 orthogonal array.

Exp. No	Type of Plastic	Catalyst 10wt%	Temperature °C
1	LDPE	ZS	500
2	LDPE	FCC	550
3	LDPE	SA	600
4	PP	ZS	550
5	PP	FCC	600
6	PP	SA	500
7	PS	ZS	600
8	PS	FCC	500
9	PS	SA	550

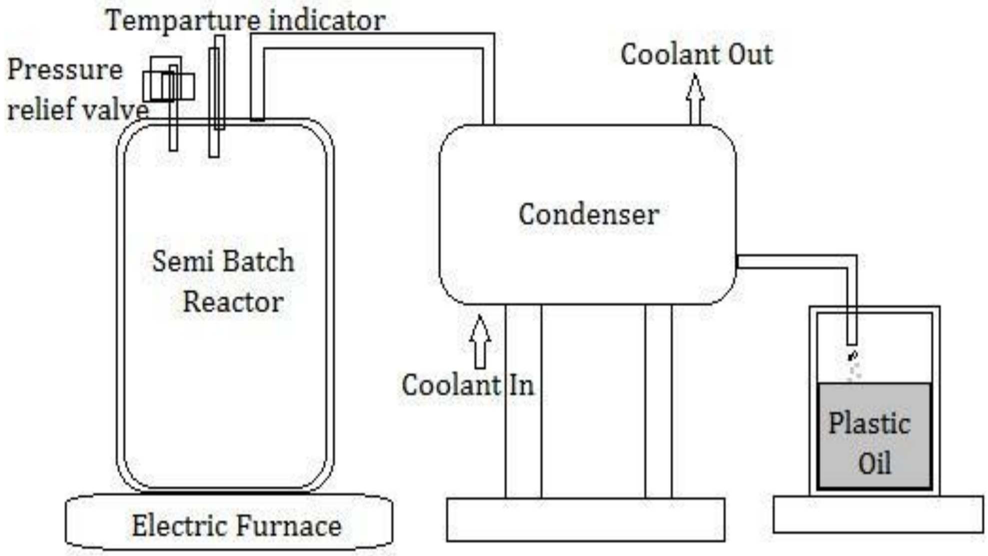

Fig. 3: Schematic of pyrolysis setup.

condenser and it is cooled by circulating the water. The Liquid oil is collected from the output of the condenser; the uncondensed gases are collected in a container, after measurement it is flared to the atmosphere. Solid waste is collected after the completion of the pyrolysis process. The gas yield was determined from the mass balance equation [15-16] as difference between total mass m_T (wt%) and the sum of liquid yield m_L (wt%) and solid residue m_S (wt%) as given below

$$m_g = m_T - (m_L + m_s)$$

Reaction Mechanism

The reaction mechanism involves Initiation, Depropogation, Isomerization and Aromatization. Pyrolysis process takes place in the absence of oxygen at high temperature leading to breaking of polymer structure to form hydrocarbon radicals which contains more number of carbons. However, the breaking leads to formation of free radicals abundantly and need to stabilize them through inter or intra molecular chain transfer. Due to the abundance of hydrogen atom in the structure, intramolecular chain transfer occurs in polyethylene degradation [17]. Attraction of nearby hydrogen atom from surrounding molecules results in intermolecular chain transfer, whereas intramolecular chain transfer attracts the hydrogen atom from its own chain. The unsaturated end and terminal free new radical are formed through stabilization of radical which occurs through β-scisson. This scisson is a continuous process upto the hydrocarbon molecules are to saturate or structure contains carbon double bond neither at one end nor at both ends [18-19]. However, consecutive β-scisson leads to yielding of oligomer fraction and in further scisson β-scisson of chain end carbonium ions leads to form liquid fraction (C_{10} to C_{25}).

RESULTS AND DISCUSSION

Property Analysis of plastic pyrolysis oil

The properties of the plastic oil are compared with the standard diesel and gasoline and given in the Table 4. Important properties of plastic oil are comparable with standard diesel and gasoline. Viscosity of plastic oil, at different temperatures is given in the Table 4. Characterization of fuel was done using Gas Chromatography/ Mass Spectroscopy (GC/MS) Make & Model: JEOL GCMATE II GC-MS with data system, Maximum Resolution: 6000 with double focusing instrument). The results of GC-MS of LDPE Oil are presented in Fig 4 and Table 5.

GC/MS involves effective vaporization of the sample and separation of various components using a capillary column packed with a stationary phase. Inert carrier gases such as argon, helium or nitrogen propel the compounds. As the components become separated, they are removed from the column at different times and referred as retention time [17-21]. Those components leave the GC columns are ionized by the mass spectrometer using electron or chemical ionization sources. Ionized molecules are then accelerated through the instrument's mass analyzer, which quite often is an ion trap and separated based on their different mass-to-charge (m/z) ratio are shown in the Fig 4 to analyze the compounds present in the oil. Thus GC/MS test proves that more amount of aliphatic compounds are present when compared to aromatic compound [24-25]. It also indicates that aliphatic (CH) group (alkanes and alkenes) are abundant with carbon number C_{10} to C_{25}

Experimental results based on L_9 orthogonal array

L_9 Orthogonal array is selected with the help of minimum trail calculation. The experiments are conducted for every trial and results are tabulated in Table 6. The statistical software Minitab is used to formulate the experimental values. The S/N ratios are calculated based on the output quality characteristics using the suitable equations and values are tabulated in Table 7. The combined S/N ratio is obtained by average weighted methodology which provides the equal weightage to each output characteristics.

Effect of reaction parameters on yield of Pyrolytic oil

Fig. 5 shows the main effects plots for combined S/N ratios, values are obtained from the Table 7. It is seen from the Fig. 5 that types of plastic is most significant as indicated by a substantial slope. There was a steep rise in slope for catalyst contribution, because it increases the speed of the reaction by addition of different catalyst at same quantity (10% wt). The temperature slope was also observed. However, the most dominant factors are catalyst (10% wt) followed by types of plastics (Polymers) and temperatures, which are corresponding to the higher the better S/N ratio [22]. The best level of

Table 4: Property comparison of Standard fuels with plastic oil.

Physical properties	Standard value (ASTM 1979)		Experimental results (Typical value)		
	Diesel	Gasoline	LDPE	PP	PS
Calorific value (MJ/kg)	43	42.5	39.5	40.8	43.0
Density @15°C (g/cm^3)	0.807	0.780	0.78	0.86	0.85
Ash content (wt%)	0.01	-	0.02	0.00	0.006
Flash point °C	52	42	41	30	26.1
Viscosity (mm^2/s)	1.9-4.1	1.17	5.56^a	4.09^a	1.4^a
			4.46^b	3.12^b	1.02^b
			3.42^c	2.04^c	0.92^c

^{a} viscosity @25°C , ^{b} viscosity @40°C, ^{c} viscosity @50°C

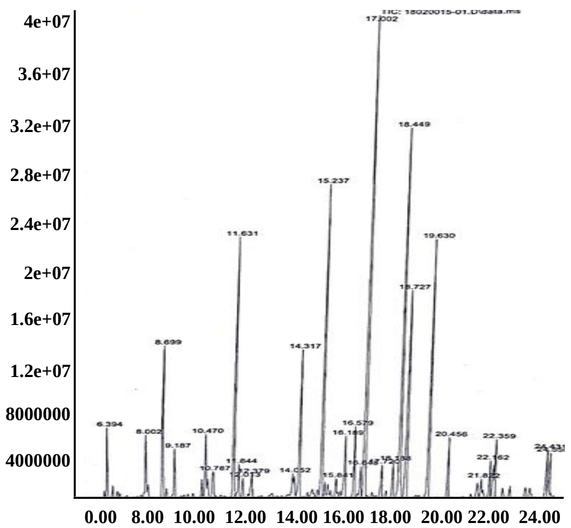

Fig. 4: GC plot of LDPE oil sample at 450°C by catalytic pyrolysis.

parameters is identified as type of plastics: LDPE, catalyst (10% wt.): SA and temperature: 500°C. Hence the optimum level setting was indicated as $A_1B_3C_1$.

Interaction Effects of Reaction parameters

Interaction effect reveals that effect of change of factor over another response factor which influences on the response variable. The combined objective of this investigation was shown in the Fig. 6. It is observed from interaction plot that moderate interaction effect exists between type of plastic and catalyst 10wt%. During these interactions it is clearly revealed that moderate effect is observed except for LDPE. [23] Higher interaction effect is observed between types of plastic and temperature, because non parallel lines intersecting with one another with grater slope as shown in Fig. 6. However, the polymers with long hydrocarbon chain having sustainable amount of intermolecular force needs higher temperature to break the bonds when compared to weaker intermolecular force polymers (LDPE). From the Interaction plot it was observed that intersecting plots shows the higher influence on corresponding factor, whereas parallel or non-intersecting plots reveals no interaction effect between the factors.

Analysis of Variance

The Statistical technique (ANOVA) used for interactions of each parameter results and it quantifies their effects. It helps the researchers, to determine the optimal factors at different levels. ANOVA defines the contribution of the parameters in the trail run based on the roles of dependent and independent variables. The percentage contribution of input parameters are illustrated in the Table 8 based on the combined objective of S/N ratio. Tabulated values show the significant factors and insignificant factors as error terms (In Percentage contribution). However, the detailed contribution of input parameters provides better concept of combined objective during Taguchi prediction.

Fig. 7 clearly reveals that the percentage contribution of reaction parameters, types of plastic: 23.69%, catalyst: (10wt %): 51.78% and remaining 18.7% by temperature. Generally catalysts were used to speed up the reaction and it doesn’t involve in any chemical reaction during the experimental process.

Table 5: GC-MS analysis of LDPE oil sample at 450°C by catalytic pyrolysis.

Number of Peak	Retention Time min	Area %	Molecular Formula	Compound Name
1	6.394	1.51	$C_{10}H_{20}$	1-Decene
2	8.002	2.13	$C_{10}H_{20}$	2-Methyl-2-Nonene
3	8.699	3.96	$C_{10}H_{22}$	Decane
4	9.187	1.26	$C_{10}H_{22}$	Decane
5	10.470	2.46	$C_{11}H_{22}$	n-1-Undecene
6	10.787	1.14	$C_{11}H_{24}$	n-Undecane
7	11.631	6.67	$C_{12}H_{24}$	1-Dodecene
8	11.844	1.03	$C_{12}H_{26}$	n-Dodecane
9	12.013	0.58	$C_{13}H_{26}$	1-Tridecene
10	12.379	1.08	$C_{13}H_{28}$	Tridecane
11	14.052	1.67	$C_{14}H_{28}$	1-Tetradecene
12	14.317	4.16	$C_{14}H_{30}$	Tetradecane
13	15.237	8.31	$C_{14}H_{30}$	Tetradecane
14	15.841	0.79	$C_{15}H_{30}$	1-Pentadecene
15	16.189	2.31	$C_{15}H_{32}$	Pentadecane
16	16.579	1.99	$C_{16}H_{32}$	1-Hexadecene
17	16.848	1.16	$C_{16}H_{34}$	n-Hexadecane
18	17.002	15.01	$C_{18}H_{36}$	1-Octadecene
19	17.720	1.13	$C_{18}H_{36}$	1-Octadecene
20	18.188	1.14	$C_{18}H_{38}$	n-Heptadecane
21	18.449	10.78	$C_{18}H_{36}$	1-Octadecene
22	18.727	6.52	$C_{18}H_{38}$	n-Octadecane
23	19.630	6.78	$C_{19}H_{40}$	Nonadecane
24	20.456	1.86	$C_{20}H_{42}$	Eicosane
25	21.822	0.98	$C_{21}H_{44}$	n-Heneicosane
26	22.162	1.06	$C_{22}H_{46}$	Docosane
27	22.359	2.41	$C_{22}H_{46}$	Docosane
28	24.431	1.46	$C_{24}H_{50}$	n-Tetracosane
29	24.550	1.61	$C_{25}H_{52}$	Pentacosane

Table 6: L9 Orthogonal array with the output characteristics.

Exp. No	Oil (wt%)			Gas (Wt%)			Solid (wt%)		
	Replication 1	Replication 2	Average	Replication 1	Replication 2	Average	Replication 1	Replication 2	Average
1	88.91	88.89	88.90	7.96	8.00	7.98	3.13	3.11	3.12
2	88.45	88.55	88.50	9.39	11.41	10.40	2.16	0.04	1.10
3	91.27	91.13	91.20	8.71	8.69	8.70	0.02	0.18	0.10
4	85.28	85.12	85.20	12.12	13.28	12.70	2.60	1.60	2.10
5	88.90	89.90	89.40	7.45	6.55	7.00	3.65	3.55	3.60
6	89.67	90.33	90.00	6.37	6.03	6.20	3.96	3.64	3.80
7	80.99	82.01	81.50	17.68	17.72	17.70	1.33	0.27	0.80
8	90.47	90.33	90.40	6.12	6.08	6.10	3.41	3.59	3.50
9	94.34	94.06	94.20	5.31	5.89	5.60	0.35	0.05	0.20

Table 7: Signal to noise ratio.

Trail	Signal to Noise ratio			Combined S/N Ratio
	Oil (wt%)	Gas (Wt%)	Solid (wt%)	
1	38.9780	-18.0401	-9.8831	3.6850
2	38.9389	-20.3407	-0.8279	5.9234
3	39.1999	-18.7904	20.0000	13.4698
4	38.6088	-22.0761	-6.4444	3.3628
5	39.0268	-16.9020	-11.1261	3.6662
6	39.0849	-15.8478	-11.5957	3.8804
7	38.2232	-24.9595	1.9382	5.0673
8	39.1234	-15.7066	-10.8814	4.1785
9	39.4810	-14.9638	13.9794	12.8322

Experimental validation

Confirmatory experiment

The DOE tool Taguchi predicts the levels of reaction parameters like types of plastic, catalyst and temperature based on the combined objective of the signal to noise ratio. However, the confirmation experiment was carried out at the same experimental setup to validate the predicted results. The experimental investigation was carried out thrice and results were compared with predicted results as shown in Fig. 8 and Table 9. It was found that the signal to noise ratio of predicted and validated was correlated.

CONCLUSIONS

The experimental work reveals that optimization of oil production using waste plastic as raw material by DOE Taguchi considering three parameters with three levels and its influence was analyzed by ANOVA. The confirmation experiments were conducted on the pyrolysis setup. Based on the investigation, the effects are

1) The combined objective of DOE tool predicts the parameter as LDPE, SA and 500°C with the signal to noise ratio of 17.88.

Table 8: Analysis of variance for combined S/N ratio.

Source	DF	Seq ss*	Adj Ms*	F	P	Contribution %
Type of plastic	2	30.42	15.21	4.11	0.20	23.69
Catalyst 10wt%	2	66.51	33.26	8.99	0.10	51.78
Temperature °C	2	24.12	12.06	3.26	0.24	18.77
Error	2	7.40	3.70			5.76
Total	8	128.45				100.00

**Seq ss – Sequential sum of squares*
**Adj ss – Adjacent Mean square*

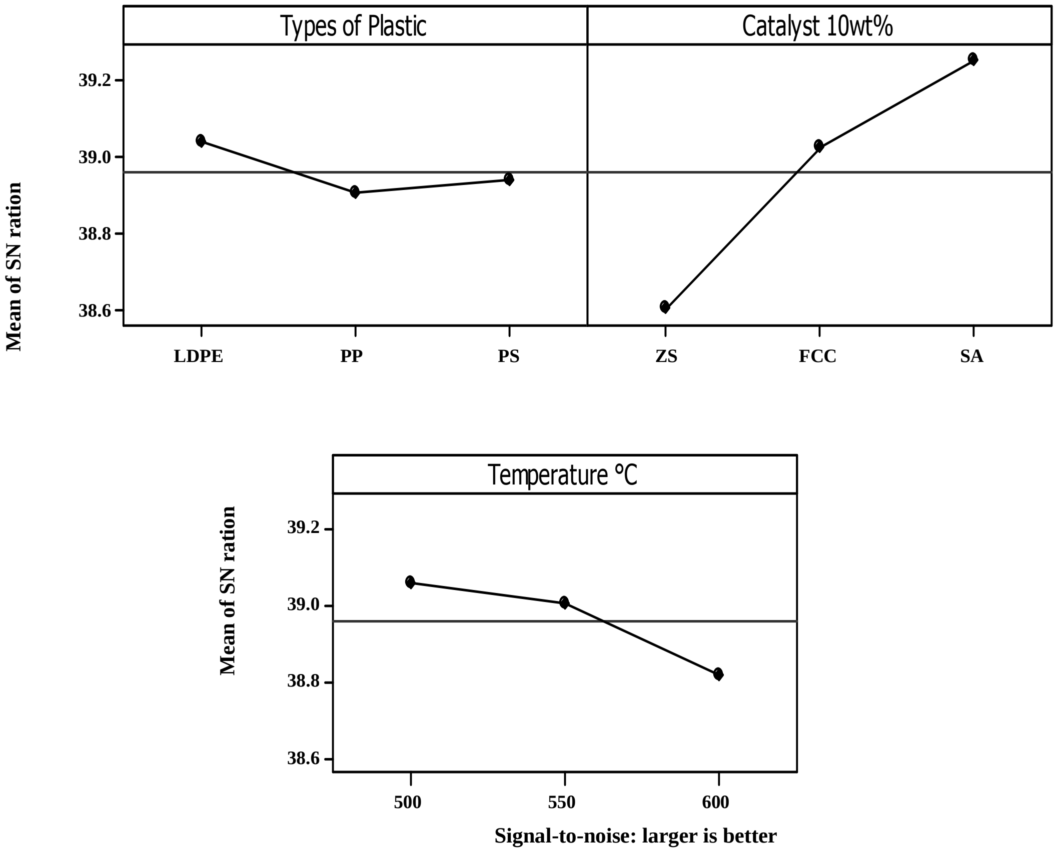

Fig. 5: Main effects plot for S/N ratios.

2) Based on the interaction plot, parameters with highest interaction were types of plastic and temperature. The Effect of interaction is much higher considering other parameters.

3) Based on the analysis, the effect of catalyst contributes 51.78%, types of plastic and temperature as 23.69% and 18.77% respectively.

4) The confirmatory experiments conducted with predicted values shows increase of oil yield 95.4 (wt%), decrease of gas yield 3.4 (wt%) and solid residue as 1.2(wt%).

FUTURE WORK

The paper presents batch production of pyrolytic oil, however, in future using the same methodology with optimized parameters; large scale plastic pyrolysis oil production can be carried out.

Table 9: Results of Confirmatory experiment with predicted values.

	Signal to Noise Ratio	oil (wt%)	Gas (Wt%)	Solid (wt%)
Predicted	17.88	-	-	-
Confirmed Trail 1	17.85	95.3	4.5	0.2
Confirmed Trail 2	17.87	95.2	3.6	1.2
Confirmed Trail 3	17.86	95.7	2.1	2.2
Average (Trail 1,2&3)	17.86	95.4	3.4	1.2

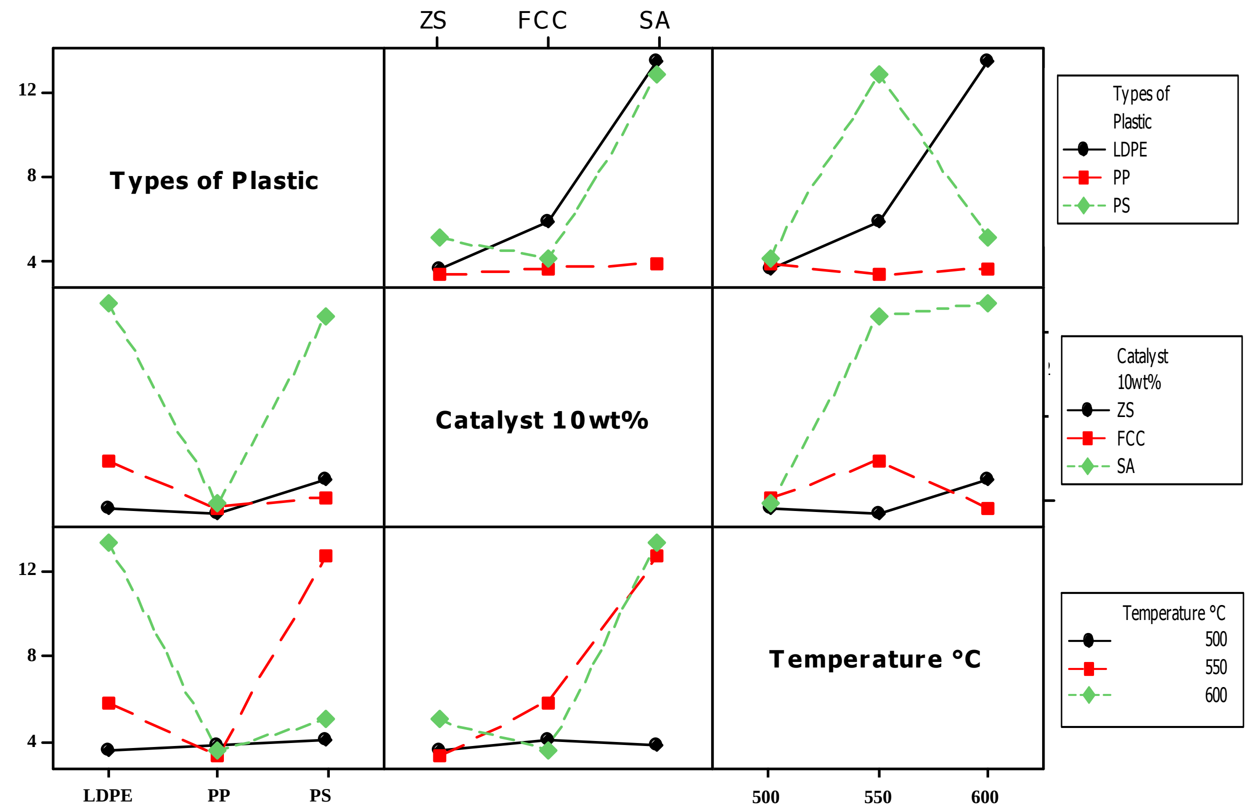

Fig.6: Interaction plot for combined S/N ratios.

Nomenclature

LDPE	Low Density Polyethylene
HPDE	High Density Polyethylene
PP	Poly propylene
PS	Polystyrene
PVC	Polyvinylchloride
FCC	Fluid Catalytic cracking
SA	Silica Alumina
DOE	Design of Experiments
OA	Orthogonal Array
S/N ratio	Signal to Noise ratio
H_2O	Water
ANOVA	Analysis of Variance
GC/MS	Gas chromatography–Mass spectrometry

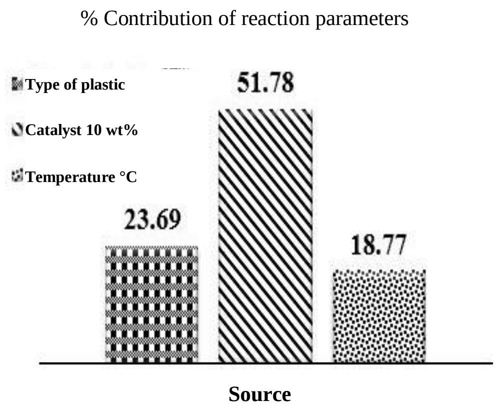

Fig.7: Contribution of reaction parameters.

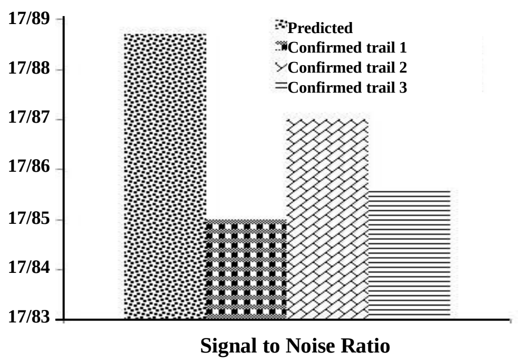

Fig.8: Comparison of predicted and confirmatory experiment S/N ratio.

Acknowledgment

The authors would like to acknowledge the wholehearted support from RMK college of Engineering and Technology through FUELS laboratory for carrying out this research work. The authors would like to acknowledge the Sophisticated Analytical instrument facility at IIT Madras for characterization of plastic oil. The authors are also thankful to Sri Annai Enterprises, Vellore, Tamil Nadu for continuous supply of plastic resources.

Received : Aug. 13, 2018 ; Accepted : Jan 9, 2019

REFERENCES

[1] Brajendra K. Sharma, Bryan R. Moser, Karl E. Vermillion, Kenneth M. Doll, Nandakishore Rajagopalan, Production, Characterization and Fuel Properties of Alternative Diesel Fuel from Pyrolysis of Waste Plastic Grocery Bags, *Fuel Processing Technology*, **122**: 79-90 (2014).

[2] Kiran Raj Bukkarapu, D. Siva Gangadhar, Y. Jyothi, Prasad Kanasani, Management, Conversion, and Utilization of Waste Plastic as a Source of Sustainable Energy to Run Automotive: A Review, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*,**40** (14): 1681-1692 (2018).

[3] Nisar J., Khan M.S., Iqbal M., Shah A., Ali G., Sayed M., Khan R.A., Shah F., Mahmood T., Thermal Decomposition Study of Polyvinyl Chloride in the Presence of Commercially Available Oxides Catalysts, *Advances in Polymer Technology*.); **37**: 2336–2343 (2018).

[4] Khan M.Z.H., Sultana M., Al-Mamun M.R., Hasan M.R., Pyrolytic Waste Plastic Oil and Its Diesel Blend: Fuel Characterization, *Journal of Environmental and Public Health*, Article ID 7869080, 6 Pages, (2016).

[5] Nisar J., Khan M.A., Iqbal M., Shah A., Khan R. A., Sayed M., Mahmood T, Comparative Study of Kinetics of the Thermal Decomposition of Polypropylene Using Different Methods, *Advances in Polymer Technology*, **37**: 1168-1175 (2018).

[6] Nisar J., Ali Gh., Ullah N. Ahmad Awan I., Iqbal M., Shah A., Sirajuddin, Sayed M., Mahmood T., Khan M., Pyrolysis of Waste Tire Rubber: Influence of Temperature on Pyrolysates Yield, *Journal of Environmental Chemical Engineering*, **6**. 3469-3473 (2018).

[7] Nisar J., Khan M.S., Khan M.A., Catalytic thermal Decomposition of Polyethylene Determined by Thermogravimetric Treatment, *Journal of the Chemical Society of Pakistan*, **36**(5): 829-836 (2014).

[8] Kyong-Hwan Lee, Thermal and Catalytic Degradation of Pyrolytic Oil from Pyrolysis of Municipal Plastic Wastes, *Journal of Analytical and Applied Pyrolysis*, **85**(1–2): 372-379 (2009)

[9] Viswanath K. Kaimal, P. Vijayabalan, A Study on Synthesis of Energy Fuel from Waste Plastic and Assessment of its Potential as an Alternative Fuel for Diesel Engines, *Waste Management*, **51**: 91-96 (2016)

[10] Chuan Ma, Jie Yu, Ben Wang, Zijian Song, Jun Xiang, Song Hu, Sheng Su, Lushi Sun, Chemical Recycling of Brominated Flame Retarded Plastics from e-Waste for Clean Fuels Production: A Review, *Renewable and Sustainable Energy Reviews*, **61**: 433-450 (2016)

[11] Shafferina Dayana Anuar Sharuddin, Faisal Abnisa, Wan Mohd Ashri Wan Daud, Mohamed Kheireddine Aroua, A Review on Pyrolysis of Plastic Wastes, *Energy Conversion and Management*, **115**: 308-326 (2016)

[12] Probir Kumar Bose, Madhujit Deb, Rahul Banerjee, Arindam Majumder, Multi Objective Optimization of Performance Parameters of a Single Cylinder Diesel Engine Running with Hydrogen Using a Taguchi-fuzzy Based Approach, *Energy*, **63**: 375-386, (2013)

[13] Mustafa Kemal Balki, Cenk Sayin, Murat Sarıkaya, Optimization of the Operating Parameters Based on Taguchi Method in an SI Engine used Pure Gasoline, Ethanol and Methanol, *Fuel*, **180**: 630-637 (2016).

[14] Senthilkumar N., Tamizharasan T., Effect of Tool geometry in Turning AISI 1045 steel: Experimental Investigation and FEM Analysis, *Arabian Journal for Science and Engineering*, **39**(6): 4963-4975 (2014).

[15] Blazso M. Composition of Liquid Fuels Derived from the Pyrolysis of Plastics. In: Scheirs J, Kaminsky W, (Editors), "Feedstock Recycling and Pyrolysis of Waste Plastics: Converting Waste Plastics into Diesel and other Fuels", Hungary: John Wiley & Sons Inc., 315-342 (2006).

[16] Jasmin Shah, Rasul Jan M., Fazal Mabood, Catalytic Pyrolysis of Waste Tyre Rubber into Hydrocarbons Via Base Catalysts, *Iranian Journal of Chemistry and Chemical Engineering (IJCCE)*, **27**(2): 103-109 (2008).

[17] Buekens A.G., Huang H., Catalytic Plastics Cracking for Recovery of Gasoline-Range Hydrocarbons from Municipal Plastic Wastes, *Resources, Conservation and Recycling*, **23**(3): 163-181 (1998).

[18] Imtiaz Ahmad, M. Ismail Khan, Hizbullah Khan, M. Ishaq, Razia Tariq, Kashif Gul & Waqas Ahmad Pyrolysis Study of Polypropylene and Polyethylene Into Premium Oil Products, *International Journal of Green Energy*, **12** (7): 663-671 (2015)

[19] Achyut K. Panda, R.K. Singh, D.K. Mishra, 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*, **14**(1): 233-248 (2010)

[20] Sasa V. Papuga, Petar M. Gvero, Ljiljana M. Vukic, Temperature and Time Influence on the Waste Plastics Pyrolysis in the Fixed Bed Reactor, *Thermal Science*, **20**(2): 731-741, (2016),

[21] Rinku Verma, K.S. Vinoda, M. Papireddy, A.N.S. Gowda, Toxic Pollutants from Plastic Waste-A Review, *Procedia Environmental Sciences*, **35**: 701-708, (2016)

[22] Karabas, Hülya, Biodiesel Production from Crude Acorn (Quercus Frainetto L.) Kernel Oil: an Optimisation Process Using the Taguchi Method. *Renewable Energy*, **53**: 384-388 (2013)

[23] Senthilkumar N., Tamizharasan T., Experimental Investigation of Cutting Zone Temperature and Flank Wear Correlation in Turning AISI 1045 Steel with Different Tool Geometries, *Indian Journal of Engineering & Materials Sciences*, **21**(2): 139-148 (2014).

[24] Laesecke J., Ellis N., Kirchen P., Production, Analysis and Combustion Characterization of Biomass Fast Pyrolysis Oil – Biodiesel Blends for Use in Diesel Engines, *Fuel*, **199**: 346-357 (2017)

[25] Shafferina Dayana Anuar Sharuddin, Faisal Abnisa, Wan Mohd Ashri Wan Daud, Mohamed Kheireddine Aroua, A Review on Pyrolysis of Plastic Wastes, *Energy Conversion and Management*, **115**: 308-326, (2016).