

Waste To Fuel - A Review on Current Work

K. I. V. Vandana

Assistant Professor

Department of Mechanical Engineering

*PVP Siddhartha Institute of Technology, Kanuru, Vijayawada,
AP. India*

M. Rajyalakshmi

Assistant Professor

Department of Mechanical Engineering

*PVP Siddhartha Institute of Technology, Kanuru, Vijayawada,
AP. India*

M. Swathi Manasa

UG Student

Department of Mechanical Engineering

*PVP Siddhartha Institute of Technology, Kanuru, Vijayawada,
AP. India*

P. Ramya Sai

UG Student

Department of Mechanical Engineering

*PVP Siddhartha Institute of Technology, Kanuru, Vijayawada,
AP. India*

Abstract

Among the many irremediable wounds that man is inflicting upon the environment, the improper disposal of waste plastic is growing into an alarming issue of concern. Despite its amazing properties of strength, durability and its light weight, plastics have a major drawback that they can take up to 500-1000 years to naturally degrade. Waste plastic affects humans, animals and marine life, as it increases pollution enormously. It also causes soil infertility where dumped. Plastics are made up of long chain molecules called polymers. They are light weight polymers of carbon along with hydrogen, nitrogen, Sulphur and other organic and inorganic elements. Plastic pyrolysis involves subjecting plastic to high temperature of 400⁰C to 450⁰C, in absence of oxygen. During pyrolysis, Plastic breaks down into smaller molecules of pyrolysis oil, pyrolysis gas and carbon black. Plastic pyrolysis end products are hydrocarbons. In the present paper the work carried out so far is discussed.

Keywords: Pyrolysis, Plastic Waste, Low Grade Plastic

I. INTRODUCTION

Another lesser known factual reality is that for the production of plastic, 7% of the global crude oil is consumed. The Japanese inventor Akinori Ito popularized the ingenious idea converting waste plastic back into fuel oil through plastic Pyrolysis.

Pyrolysis is chemical reaction in which large molecules are broken down into smaller molecules. At any given temperature the molecule is in vibrating stage. This is called molecular vibration. The frequency at which molecules vibrates is directly proportional to the temperature of molecules. During pyrolysis the object's molecules are subjected to very high temperatures leading to very high molecular vibrations. At these high molecular vibrations, every molecule in the object is stretched and shaken to such an extent that molecules starts breaking down into smaller molecules. This is pyrolysis. Pyrolysis is great way of recycling waste plastics.

Plastic Pyrolysis is the process of converting waste plastic into industrial fuels like Pyrolysis Oil, Carbon Black and Hydrocarbon Gas. Pyrolysis is a thermo chemical decomposition of organic material at elevated temperature without the participation of oxygen. In this process long polymer molecules are broken down into shorter chains of hydrocarbons with the help of heat and pressure. Essentially the process is mimicking the natural process by which organic materials are broken down into oil in the nature which takes million of years. The Pyrolysis process does this with intense heat in a closed system in a short amount of time. A catalyst can be used to lower the temperature and increase the yield.

Some benefits of Pyrolysis are that the process does not generate harmful pollutants and that the by-products can be used as fuel for running the plant. In the case of plastic, some of the valuable fuels and solvents that can be extracted through waste plastic Pyrolysis are gasoline, kerosene, diesel, benzene, toluene and xylene. And a kilo of waste (typically PP) can yield up to a liter of fuel whereas the incineration of the same quantity of plastic would produce 3 kilos of CO₂!

So through this process of Pyrolysis, the bane of abhorrent plastic waste, can now become a boon and a source of abundant fuel. This will reduce plastic in landfills, reduce emissions and be a reliable alternative to the depleting fossil fuels.

II. LITERATURE REVIEW

D. S. Scott et al., [1] conducted a test program to attempt to produce higher value products from polyethylene. Both thermal and catalytic pyrolysis tests have been done in an atmospheric-pressure fluidized-bed reactor. From the results they identified that catalytic pyrolysis was giving promising yields of a liquid hydrocarbon product that could be refined to yield a transportation fuel. They also discussed that product composition from the pyrolysis of polyethylene can be controlled over a wide range by a suitable combination of type of catalyst, temperature, and particle size. Paul T. Williams et al (1990)[2] experimented by shredding automotive tyre waste in pyrolysis process in a batch reactor and determined the compositions and properties of the

derived gases, pyrolytic oils and solid char that as the pyrolysis temperature was increased, The percentage mass of solid char decreased and Chemical class composition analysis by liquid chromatography showed that an increase in temperature produced a decrease in the proportion of aliphatic fractions and an increase in aromatic fractions for each heating rate and molecular mass range increases. FTi.r. analysis of the oils indicated the presence of alkanes, alkenes, ketones or aldehydes, aromatic, polyaromatic and substituted aromatic groups. Elizabeth A. Williams et al (1997) [3] Studied the pyrolysis of a plastic mixture in a fluidised bed reactor. The influence of temperature on product yield and composition was studied. This gave widely differing product yields of gas and oil at high temperatures and wax at lower temperatures. The oils were analysed for their functional groups using Fourier transform infrared spectroscopy. The molecular weight distribution was also determined using size exclusion chromatography. It was found that as temperature is increased the amount of aromatic compounds in the oil is increased. H. M. Cheng et al (1998)[4] Synthesized rope-like bundles of single-walled carbon nanotubes (SWNTs) similar to those obtained by laser vaporization and electric-arc techniques by the catalytic decomposition of hydrocarbons at a temperature of about 1200 °C using an improved floating catalyst method. The SWNTs obtained have larger diameters and are self-organized into ropes. The addition of thiophene was effective in promoting the growth of SWNTs and in increasing the yield of either SWNTs or multi-walled carbon nanotubes under different growth conditions. Adrian M. Cunliffe et al (1998) [5] Pyrolyzed shredded scrap tyres in a nitrogen purged static-bed batch reactor at temperatures between 450 and 600°C and found that the oil yield was to decrease with increasing final pyrolysis temperature and the yield of product gases increased. Significant quantities of light aromatics such as benzene, toluene, xylene and styrene were also found. The results showed that the derived tyre oils had fuel properties similar to those of a light petroleum fuel oil. F.Pinto et al (1999)[6] Presented that Pyrolysis of plastic waste could have an important role in converting waste into economically valuable hydrocarbons, which can be used as fuels depending on the plastic composition. The desired end product can be obtained with the right blending of input composition which helps to obtain a specific end product with improved nature and properties which results in higher heating value or octane number obtained by addition of PS or PP, to increase the aromatic or the alkene contents, respectively in the presence of a suitable catalyst”.

Kiran et al (2000) [7] has used a Gray–King apparatus to pyrolyze waste polyethylene (PE), polystyrene (PS), both separately and with different compositions, for generation of oils and gases that can be convenient to obtain hydrocarbons and to recover crude petrochemicals or to generate energy from waste plastics. The results showed that waste PS yielded higher liquid, and waste PE yielded higher gaseous products. The dominant liquid product of PS waste was styrene whereas for waste PE, propenyl-benzene was the dominant pyrolysis product. A.V. Bridgwater et al (2000) [8] discussed that Fast pyrolysis is a technology for producing high yields of liquid fuels that can be used in many applications as direct substitutes for conventional fuels or as a source of chemicals. Pyrolysis offers potential for waste treatment by fixing contaminants in the char while also producing a clean liquid fuel. L.Sorum et al (2001)[9] Studied the pyrolysis characteristics and chemical kinetics of Municipal solid waste and concluded that the Plastics like PS, PP, LDPE and HDPE were 100% volatile and their HHV (higher heating values) were between 42 and 47MJ/Kg.PVC on other hand, has similar content of hydrocarbons. The degradation of PS,PP, LDPE and HDPE occurred at 350-500°C while PVC had a complete different degradation behavior, occurring between 200 and 525°C.N. Isabel de Marco Rodriguez et al (2001) [10] observed that when car tyres, have been pyrolyzed in an autoclave at 3008°C, 4008°C, 5008°C, 6008°C and 7008°C there is no significant influence of temperature on the amount and characteristics of pyrolysis products over 5008°C.Tyre pyrolysis liquids are a complex mixture of C–C organic compounds, with a great proportion of aromatics with high gross calorific values and pyrolysis gases are composed of hydrocarbons of which C and C are predominant, together with some CO, CO and SH with very high gross calorific values of 68–84 MJ/m. Roberto Aguado et al (2004) [11] proposed that the conical spouted bed reactor may be a solution to the problems arising in fluidized beds handling sticky solids which can cause defluidization and carried out experiments in order to avoid defluidization in batch mode in the temperature range of 450–600°C and proved that in this reactor, the cyclic movement of sand particles allows for their uniform coating with fused plastic. Furthermore, the high velocity of the particles generates collisions helps to avoid their agglomeration. Ayhan Demirbas et al (2004) [12] decomposed three types of waste plastics polystyrene (PS), polyethylene (PE) and polypropylene (PP) under pyrolysis conditions, into three fractions: gas, liquid and solid residue and concluded that the valuable chemical raw materials including benzene, toluene and other condensed aromatic hydrocarbons may be obtained by refining the pyrolytic oil. The results showed that waste PS yielded higher liquid, and waste PE and PP yielded higher gaseous products. The dominant pyrolytic liquid product of PS waste was styrene. B.M. Caballer et al (2004) [13] studied that when whole car tyre, have been pyrolyzed in an autoclave at 300, 400, 500, 600 and 700°C, over 500°C there is no effect of temperature on gases and liquids yields. Tyre pyrolysis liquids have been characterized, including elemental analysis, gross calorific value, gas chromatography/mass spectroscopy and distillation. Tyre derived liquids are a complex mixture of C6–C24 organic compounds, aromatics, nitrogenated and oxygenated compounds. Significant quantities of valuable light hydrocarbons such as benzene, toluene, xylene, limonene, etc. were obtained .The tyre oil fractions with the same boiling range as commercial automotive diesel oils and heating diesel oils fulfil the present specifications of such commercial products. C. Díez et al (2004) [14] made a comparison of two similar processes run on different scales. On one hand, tyre pyrolysis experiments were run in a fixed-bed laboratory reactor and on the other hand, in a tyre pyrolysis pilot plant with a rotatory reactor and found that the solid fractions from both processes when subjected to chemical analyses and thermal analyses, there are no significant differences and the gas fractions from both processes when analysed by gas chromatography the results showed a small differences in composition and calorific value, because of the different operating conditions of each facility, mainly the heating ramp and residence time. Dinesh Mohan et al (2006) [15] focused on the characteristics of the resulting biooils, which are the main products of fast wood

pyrolysis. Nearly 100 types of biomass have been tested, ranging from agricultural wastes such as straw, olive pits, and nut shells to energy crops such as miscanthus and sorghum. Forestry wastes such as bark and thinning and other solid wastes, including sewage sludge and leather wastes, have also been studied. They worked on wood/biomass pyrolysis, both fast and slow, survey and both the physical and chemical aspects of the resulting bio-oils depending on properties and type of wood. Haiping Yang et al (2007) [16] investigated the pyrolysis characteristics of three main components (hemicellulose, cellulose and lignin) of biomass using, respectively, a thermo gravimetric analyzer (TGA) with differential scanning calorimetry (DSC) detector and a pack bed and observed that the main gas products from pyrolyzing the three components were similar, including CO₂, CO, CH₄ and some organics and concluded that hemicellulose had higher CO₂ yield, cellulose generated higher CO yield, and lignin owned higher H₂ and CH₄ yield. William J. Hall et al (2007) [17] collected and investigated three plastic fractions :- equipment containing cathode ray tubes (CRTs), plastic from refrigeration equipment, and plastic from mixed WEEE and recycled them by batch pyrolysis. Determined that the halogen content of the oils was relatively low but the halogen and metal content of the chars was high. The pyrolysis oils were found to contain valuable chemical products and the pyrolysis gases were mainly halogen free, making them suitable as a fuel. M. Arabiourrutia et al (2007) [18] carried out an experiment on scrap car tyres pyrolysis in a conical spouted bed reactor in batch operation. The pyrolysis products have been analysed online in a gas chromatograph. Temperature has a great influence on the product distribution of gas, liquid, aromatics and tar fraction. The gas and aromatic fractions increase with temperature, whereas liquid and tar fractions decrease.

Paul T. Williams et al (2007) [19] reported that pyrolysis and liquefaction of polyethylene and polypropylene produced a mainly oil product and a gas composed largely of methane, ethane, propane and butane. Polyvinyl chloride produced hydrogen chloride gas and mostly a solid residue. Polyethylene terephthalate produced mainly carbon dioxide and carbon monoxide and mostly a solid residue. The oils produced from the mixed waste plastic samples contained high concentrations of alkanes but also high concentrations of single ring aromatic compounds. Gartzén López et al (2010) [20] has carried out continuous pyrolysis of scrap tyres in a conical spouted bed reactor and the results have been compared with those obtained operating in batch mode. The main differences between the continuous and batch processes are in the yield of light aromatics, which is higher in the continuous process, and in that of the heavy liquid fraction or tar, which is higher in the batch process. These are the advantages of the continuous process, although hydrogenation of the liquid fraction is required in order to use it as fuel. The excellent performance of the conical spouted bed reactor for the tyre pyrolysis process is due to the solid cyclic movement, the good contact between phases, the high heating rate and the reduced residence time of the volatile products. A. López et al (2010) [21] studied about pyrolysis of plastics and concluded that "Pyrolysis liquids contain a mixture of styrene, ethyl-benzene, toluene, etc., and can be used as high GCV alternative fuels. Pyrolysis solids are composed of inorganic properties processed by raw materials, along with some char formed in the pyrolysis and may be used for additional power generation. Pyrolysis gases contain a mixture of hydrocarbons along with some CO and CO₂, and have very high gross calorific values (GCV) and fraction can be used to supply the energetic demand of the process". Chunfei Wu et al (2010) [22] investigated that plastics from municipal solid waste produce hydrogen using 2-stages pyrolysis-gasification process. Catalyst: plastic ratio, gasification temperature and water injection are the parameters studied on hydrogen produced by this process. Hydrogen yield varied by changing these parameters. Dr. P.V. Thorat et al (2013)[23] studied and concluded that "THERMOFUEL process can be considered as another non-conventional energy source. Thermo-fuel is a process that converts waste plastics into valuable liquid hydrocarbon product that can be utilized as energy source for many purposes such as diesel engines, generators, vehicles, etc. Crude oil is the ultimate source of plastics and most of the chemicals." Christine Cleetus et al (2013) [24] produced a petroleum based fuel from waste plastic by using the catalysts silica, alumina, Y zeolite, barium carbonate, zeolite, and their combination with polymer to catalyst ratio of 10 : 1. The inert atmosphere for the pyrolysis was provided by using nitrogen as a carrier gas and found that the combination of silica alumina and zeolite is the optimum catalyst.

YB Sonawane et al [25] conducted experimental studies on Pyrolysis of HDPE waste used in the form of carrybags by using natural zeolite and alumina as catalysts. with this study they found that oil yield obtained with alumina is higher than that of natural zeolite and calorific value determined with alumina is also higher so alumina is better catalyst. The oil obtained without catalyst and with alumina and natural zeolite has hydrocarbon fractions from C₄ to C₃₇. Sonawane YB et al (2015) [26] carried out pyrolysis of polypropylene (PP) waste and carried out reactions by purging the nitrogen gas in required quantity in the reactor to create pyrolytic conditions and found that in absence of catalyst, process gives about 80.82% of liquid fuel and in presence of 10 % natural zeolite, about 86.40 % yield is obtained. It is observed that by using natural zeolite, oil percent can be enhanced and one can obtain high calorific value fuel than that of oil without catalyst. Results of oil samples showed presence of petroleum fractions (C₅-C₂₀) with some high molecular weight fractions from C₂₀-C₃₀. Sonawane Y.B. et al [27] focused to study the effect of raw Dolomite and Scolecite as catalysts for enhancing quantity and quality of liquid production in pyrolysis process and concluded that dolomite is best catalyst in pyrolysis as it fulfils most of the criteria. With experimental samples, they showed increase in the concentration of C₁₀-C₂₀ hydrocarbon fractions and calorific values of liquid fuel samples obtained with Dolomite as compared to Scolecite and without catalyst.

III. METHODOLOGY

In the present paper, a study has been conducted on different processes of thermo chemical decomposition of organic material at elevated temperature without the participation of oxygen.

In this process long polymer molecules are broken down into shorter chains of hydrocarbons with the help of heat and pressure. Essentially the process is mimicking the natural process by which organic materials are broken down into oil in the nature which takes million of years. The Pyrolysis process does this with intense heat in a closed system in a short amount of time. A catalyst can be used to lower the temperature and increase the yield.

All the conversion processes basically includes the following steps:

A. Shredding

Firstly, the waste material must be segregated and, if possible, be cleaned. Then it is shredded to speed up the reaction and to ensure that the reaction is complete.

B. Anaerobic Heating

The shredded material must be heated in a controlled manner in an oxygen-free reactor. One of the most crucial factors in this operation is maintaining the right temperature (~430C for plastic) and the rate of heating, as they define the quality and the quantity of the final product.

C. Condensation

The gas that comes out from the reactor must be condensed by passing it through a condensation tube or by directly bubbling it in water.

D. Distillation

This mixture of oil that you obtain can be used as furnace oil but it isn't sufficiently pure for engines. If you want to use it as engine fuel, it need to extract and purify the desired products from the mixture through fractional distillation.

Pyrolysis reactor creates following process conditions to carry out plastic pyrolysis:

- Absence of oxygen
- Temperature of more than 370⁰C
- Agitation to accelerate heat exchange

In pyrolysis as a process, the polymer waste is not burned, instead it is broken down into usable finished products like Pyrolysis Oil, Hydrocarbon Gas and Carbon Black.

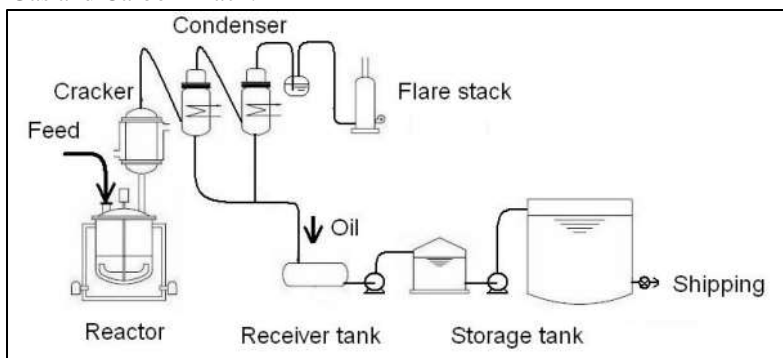


Fig. 1: Experimental Setup

IV. CONCLUSION

Plastic has become the most common material since the beginning of the 20th century and modern life is unthinkable without it. Unfortunately, what makes it so useful, such as its durability, light weight and low cost, also makes it problematic when it comes to its end of life phase. The massive pollution of world with plastic waste is therefore emerging as a global challenge that requires a global response. By studying, different pyrolysis processes, it is understood that waste plastic may be converted into hydrocarbon gas without producing toxins during the process. But the effects of different plastic additives presented in the waste plastic on the quality of the gases produced from pyrolysis process are yet to be investigated. More tests are needed to verify the pyrolysis process in a pilot scale particularly for treatment of mixtures of bulk plastics. Currently, due to the moderate oil prices, pyrolysis process is not likely to be economically competitive. However, environmental considerations may hasten the industrial implementation of pyrolysis process in the near future.

REFERENCES

- [1] D. S. Scott, S. R. Czernik, J. Piskorz, and D. St. A. G. Radlein, "Fast Pyrolysis of Plastic Wastes", *Energy & Fuels*, Vol.4, 1990, Pages 407-411.
- [2] Paul T. Williams, Serpil Besler and David T. Taylor, "The pyrolysis of scrap automotive tyres The influence of temperature and heating rate on product composition", *FUEL*, 1990, Vol. 69, pages 1474-1482.
- [3] Elizabeth A. Williams, "Paul T. Williams, "Analysis of products derived from the fast pyrolysis of plastic waste" *Journal of Analytical and Applied Pyrolysis*, Vol. 40-41, 1997 Pages 347-363.

- [4] H. M. Cheng, F. Li, G. Su, H. Y. Pan, L. L. He, X. Sun And M. S. Dresselhaus, "Large-Scale and Low-Cost Synthesis of Single-Walled Carbon Nanotubes by the Catalytic Pyrolysis Of Hydrocarbons", *Applied Physics Letters*, Volume 72, Number 25, 1998, Pages 3282-3284.
- [5] Adrian M. Cunliffe, Paul T. Williams, "Composition of oils derived from the batch pyrolysis of tyres", *Journal of Analytical and Applied Pyrolysis*, Vol. 44, 1998, Pages 131-152
- [6] F. Pinto, P. Costa, I. Gulyurtlu, I. Cabrita, "Pyrolysis of plastic wastes. 1. Effect of plastic waste composition on product yield", *Journal of Analytical and Applied Pyrolysis*, Vol. 51, 1999, Pages 39-55.
- [7] N. Kiran, E. Ekinici, C.E. Snape, "Recycling of plastic wastes via pyrolysis", *Resources, Conservation and Recycling*, Vol. 29, 2000, Pages 273-283.
- [8] A.V. Bridgwater, G.V.C. Peacocke, "Fast pyrolysis processes for biomass", *Renewable and Sustainable Energy Reviews*, Vol.4, 2000, Pages 1-73.
- [9] L. Sorum, M.G.Gronli, J.E.Hustad, " Pyrolysis Characteristics and Kinetics of Municipal Solid Wastes", *Fuel*, Vol. 80, 2001,Pages 1217-1227
- [10] Isabel de Marco Rodriguez, M.F. Laresgoiti, M.A. Cabrero, A. Torres, M.J. Chomón, B. Caballero, "Pyrolysis of scrap tyres", *Fuel Processing Technology*, Vol. 72, 2001, Pages 9-22.
- [11] Roberto Aguado, Rubén Prieto, María J. San José, Sonia Alvarez, Martín Olazar, Javier Bilbao, "Defluidization modeling of pyrolysis of plastics in a conical spouted bed reactor", 2004
- [12] Ayhan Demirbas, "Pyrolysis of municipal plastic wastes for recovery of gasoline-range hydrocarbons", *Journal of Analytical and Applied Pyrolysis* Vol.72, 2004, Pages 97-102.
- [13] M.F. Laresgoiti, B.M. Caballero, I. de Marco, A. Torres, M.A. Cabrero, M.J. Chomón, "Characterization of the liquid products obtained in tyre pyrolysis", *Journal of Analytical and Applied Pyrolysis*, Vol. 71, 2004, Pages 917-934.
- [14] C. Díez, M.E. Sánchez, P. Haxaire, O. Martínez, A. Morán, "Pyrolysis of tyres: A comparison of the results from a fixed-bed laboratory reactor and a pilot plant (rotatory reactor)" *Journal of Analytical and Applied Pyrolysis*, Vol. 74, 2005, Pages 254-258
- [15] Dinesh Mohan, Charles U. Pittman, Jr., and Philip H. Steele, "Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review", *Energy & Fuels*, Vol. 20, 2006, Pages 848-889
- [16] Haiping Yang, Rong Yan, Hanping Chen, Dong Ho Lee, Chuguang Zheng, "Characteristics of hemicellulose, cellulose and lignin pyrolysis", *Fuel*, Vol. 86, 2007, Pages 1781-1788.
- [17] William J. Hall, Paul T. Williams, "Analysis of products from the pyrolysis of plastics recovered from the commercial scale recycling of waste electrical and electronic equipment", *Journal of Analytical and Applied Pyrolysis*, Vol. 79, 2007, Pages 375-386.
- [18] M. Arabiourrutia, G. Lopez, G. Elordi, M. Olazar, R. Aguado, J. Bilbao, "Product distribution obtained in the pyrolysis of tyres in a conical spouted bed reactor", *Chemical Engineering Science*, Vol. 62, 2007, Pages 5271 - 5275.
- [19] Paul T. Williams, Edward Slaney, "Analysis of products from the pyrolysis and liquefaction of single plastics and waste plastic mixtures", *Resources, Conservation and Recycling* Vol.51, 2007, pages 754-769
- [20] Gartzén López, Martín Olazar, Roberto Aguado, Javier Bilbao, "Continuous pyrolysis of waste tyres in a conical spouted bed reactor", *Fuel*, Vol. 89, 2010, Pages 1946-1952
- [21] A. López, I. de Marco, B.M. Caballero, M.F. Laresgoiti, A. Adrados, "Pyrolysis of municipal plastic wastes: Influence of raw material composition", *Waste Management*, Vol. 30, 2010, Pages 620-627.
- [22] Chunfei Wu, Paul T. Williams, "Pyrolysis-gasification of post-consumer municipal solidplastic waste for hydrogen production", *international journal of hydrogen energy*, Vol 35, 2010, Pages 949 - 957
- [23] Dr. P.V Thorat, Miss Sandhya Warulkar And Mr. Harshal Sathone Et Al., "Thermofuel - Pyrolysis of Waste Plastic To Produce Liquid Hydrocarbons" *Advances in Polymer Science and Technology: International Journal* 2013, Pages 14-18
- [24] Christine Cleetus, Shijo Thomas, and Soney Varghese, "Synthesis of Petroleum-Based Fuel from Waste Plastics and Performance Analysis in a CI Engine" *Journal of Energy* Vol 2013, 2013, 10 pages
- [25] YB Sonawane, MR Shindikar, MY Khaladkar, "Onsite Conversion of Thermoplastic Waste into Fuel by Catalytic Pyrolysis", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 3, Issue 9, 2014, pages 15903-15908
- [26] Sonawane YB, Shindikar MR and Khaladkar MY, "Use of Catalyst in Pyrolysis of Polypropylene Waste into Liquid Fuel", *International Research Journal of Environment Sciences*, Vol. 4(7), 2015, pages 24-28
- [27] Y.B. Sonawane, M.R. Shindikar, M.Y. Khaladkar, "Transforming Low Density Polyethylene Waste into Diesel Grade Fuel by Catalytic Pyrolysis", *International Journal of Research in Chemistry and Environment*, Vol. 6 Issue 4, 2016, pages 10-15