

## Liquid Fuel Production by Co-Pyrolysis of Polythene and Sawdust

M. S. Haque<sup>1</sup>, M. K. Hasan<sup>1</sup>, J. Ferdous<sup>1</sup>, M. S. Hossain<sup>1</sup>, M. R. Islam<sup>1</sup>, H. Haniu<sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Rajshahi 6204, Bangladesh

<sup>2</sup>Department of Mechanical Engineering, Kitami Institute of Technology, Kitami City, Hokkaido 090-8507, Japan

E-mail: jfe092016@gmail.com

### Abstract

*This analysis focuses on the production of liquid fuel from polythene and sawdust by a fixed-bed LPG heating reactor system. The percentage of polythene and sawdust was varied in the blend at reactor temperature 430°C. In this co-pyrolysis process, the mixture of polythene and sawdust not only increased bio-oil yields but also improved bio-oil characteristics. So, it can be an effective alternative to fossil fuels. 10cm diameter and 30 cm height reactor was used and heated by means of precisely designed LPG burner. The feed materials are fed into the reactor and the obtained final products are oils, char and gas. The liquid and char products were collected separately while the gas was flared into atmosphere. The condensed pyrolytic oils were characterized through proximate and ultimate analysis, gross calorific values and thermo-gravimetric analysis. The maximum and minimum liquid yields were 80wt% for 100wt% polythene and 35.71% for 100% sawdust, where the feed sizes were 2cm×2cm for polythene and 600µm-1800µm for sawdust. With the increase of sawdust, the liquid yield decreases and char and gas yield increases. The results show that it is possible to use the obtained pyrolytic oil as a potential source of liquid hydrocarbon fuels.*

Keywords: Liquid Fuel, Co-pyrolysis, Polythene, Saw dust.

### 1. Introduction

Municipal solid wastes can play a vital role to mitigate the global energy crisis. Biomass and thermo plastic materials constitute an important fraction of municipal solid waste. In twelve European countries the municipal solid wastes show an average composition of 65% lignocellulosic materials and 15% polymeric materials. The residues produced by intensive agriculture in green houses are also a mixture of vegetable and plastic materials, basically polyethylene and polypropylene [1]. Plastic residues are not bio degradable and only a small fraction is recycled by the industry. Most of these products are buried in garbage dumps and in some cases incinerated [2], although the recycling of these materials is now an important alternative to landfill.

Moreover, polyolefines show very convenient characteristics for use in the production of composite materials such as polymers reinforced with natural fibers. Thermochemical recovery processes allow the obtainment of combustible gases or energy. Gasification and pyrolysis do not crease the environmental problems caused by incineration, although the low energetic content of the gas obtained is a significant disadvantage [3].

The thermal decomposition of saw dust and other lignocellulosic residues has been studied in previous works, which indicate that the thermal decomposition ranges from approximately 200 °C to 400 °C in an inert atmosphere [4, 5]. Numerous studies on the thermal decomposition of polyolefines and in particular, polyethylene have been carried out especially in vacuum or inert atmosphere [6-22]. Polyolefinic materials such as high density polyethylene (HDPE) show a different behavior to lignocellulosic materials. Under pyrolysis conditions, the material decomposition starts at approximately 400 °C and progresses very rapidly up to 450-470 °C without producing solid residue that could be used as combustible for supplying energy to the global process. The use of mixtures of bio mass with other fuels of greater energetic content (coal or petroleum derived) in these processes (co-pyrolysis or co-gasification) substantially increases the value of the gas produced and the thermal efficiency of the process [23]. In addition, the use of a mixture of renewable fuel with fossil or fossil derived fuels reduces the total carbon-di-oxide emissions and the environmental impact.

Very little is known about interactions of plastic with bio mass [24]. In principle, the possibility of a simultaneous degradation of bio mass and HDPE is apparently difficult given the different temperature ranges of decomposition of each material. Different Thermo gravimetric studies suggest that, in general, lignocellulosic materials decompose at a lower temperature than plastic materials [3, 24-26].

Some authors however, using different types of experimental systems have indicated slight interactions, not yet well defined, but related with the presence of char generated during the bio mass decomposition and to the

interaction of the complex radical mechanisms of the degradation of both materials [26]. The main differences observed are that the maximum rate of decomposition of polyethylene decreased and the corresponding temperature was slightly higher. The product distribution was also affected by the presence of biomass char, the importance of this influence depending on the amount of char formed in the degradation of the lignocellulosic material [26].

Pyrolysis is thermal decomposition occurring in the absence of oxygen. Co-pyrolysis is a process which involves two or more materials as feedstock. Bio-oils produced from biomass materials are mainly composed of oxygenated hydrocarbons. The oxygen content of bio-oils usually varies from 45 to 50 wt%.

Since the conventional fuels have been diminishing very swiftly at a risky rate day by day the focus on alternative renewable sources of energy has been ever increasing. As a result biomass has been getting continued and increased attention. Biomass is a potential source of renewable energy. Besides it is a fact that the whole world is generating a significant amount of polythene & saw dust. Mostly these are underutilized and unutilized. In many places it is creating environmental and disposal problems as well. An attempt has been taken to convert these wastes into value added materials and energy by co-pyrolysis process.

In Bangladesh there is a huge amount of biomass solid wastes from agricultural by products or industrial waste that are not effectively and efficiently used. In this study two widely available waste materials polythene & sawdust have been taken into consideration. This wastage may be used for energy recovery as fuel. The conversion of the polythene & saw dust into liquid product by co-pyrolysis process may be considered as a promising option.

The pyrolysis oil may be used as a fuel in dedicated diesel engines and in industrial gas turbines. From this fuel electricity can be generated. Besides there are many scopes to upgrade the oil for obtaining high grade fuel and valuable chemicals. The solid char can be used for making activated carbon. The char has its potential as a solid fuel. Thus, for developing country like Bangladesh, the potential and possibilities of this new technology can be investigated extensively.

## 2. Materials and Methods

### 2.1 Feed Materials

Waste Polythene was collected locally from dumped site in Rajshahi City Corporation, Bangladesh. Polythene was then chopped and sized of 2cm×2cm. The sawdust sample was collected from a saw mill near Rajshahi city and used as feedstock. The sawdust sample was separate into various size among them the amount of 600µm-1800µm size was more. The sawdust contains some amount of moisture. The feed stocks were sun-dried and finally oven-dried by an oven at a temperature of 70°C for 1 hour to remove moisture from the samples. Oven drying was performed at the Metallurgy Laboratory of Mechanical Engineering Department of RUET, Rajshahi. For the purpose of investigating the suitability of waste plastic as feedstock for pyrolysis to obtain value-added liquid product, the Proximate and ultimate analysis and Thermo-gravimetric analysis (TGA) have been considered. The proximate analysis was carried out according to the American Society for Testing Materials (ASTM) Standard D3172-73 (1984) test procedures for solid fuel, titled “Standard Method for Proximate Analysis of Coal and Coke”. It was conducted in the laboratory of Institute of Fuel Research and Development, Bangladesh Council of Science and Industrial Research (BCSIR), Dhaka, Bangladesh.

The ultimate analysis was carried out by an Elemental Analyzer of model EA 1108 according to the ASTM D3176-84 standard test procedures in the laboratory of Analytical Research Division, BCSIR, Dhaka, Bangladesh. The technique used for the determination of CHNS was based on the quantitative “dynamic flash combustion” method. The results of proximate and ultimate analysis for the sample polythene and sawdust are presented in Table 1.

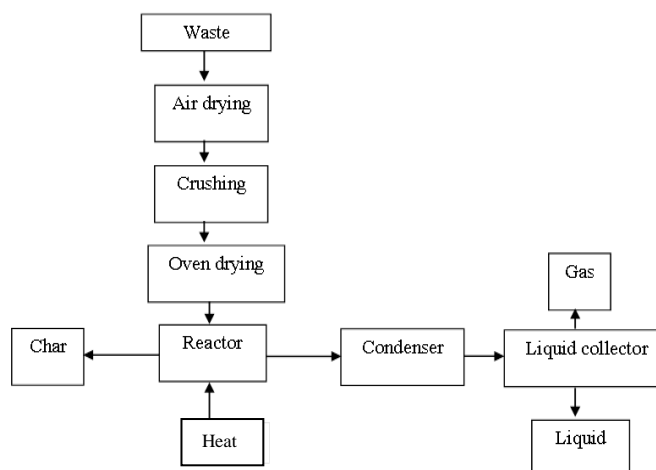
**Table 1.** The Proximate and Ultimate analysis of Polythene and sawdust

Proximate Analysis [wt%]	Polythene	Sawdust	Ultimate Analysis [wt%]	Polythene	Sawdust
Moisture	0.41	6.4	Carbon (C)	83.93	47.1
Volatile matter	96.88	74.8	Hydrogen (H)	12.84	5.9
Fixed carbon	0.28	18.3	Oxygen (O)	0.80	46.9
Ash	2.43	1.2	Nitrogen(N)	-	0.1
			Others	2.43	

### 2.2 Method

The main components of the system are fixed bed reactor chamber, LPG cylinder with burner, condenser, liquid collector, Pm 20700 series 45 pyrometer, N<sub>2</sub> gas cylinder with a pressure regulator and gas flow meter, LP gas cylinder, LP gas burner and Ni-Al thermocouple. The polythene (size: 2cm×2cm) and sawdust (size: 600 to

1800 $\mu$ m) were mixed together at the weight ratio of 100:0, 75:25, 50:50, 25:75 and 0:100. The blended feed materials were supplied into the fixed bed reaction chamber by the action of gravity force. Before experiments the reactor was purged by flowing N<sub>2</sub> gas at 4 L/min for 5 sec to remove inside air. The reactor was heated externally by a LPG burner at a temperature of about 450°C for 60 min and this temperature was measured by a Nickel-Alumel thermocouple. L.P gas from a cylinder was passed through the reactor at a controlled rate. This high temperature with short vapor residence time convert the feedstock into gaseous mixture and solid char. L.P gas helps to dispose of the gaseous mixture (liquid and gas) to the collector through the condenser. The liquid product is collected in the liquid receiver and the non-condensable gas is flared of the atmosphere. After each experiment the system was cooled down and liquid oil and char was collected and weighted. The gas weight was determined by subtracting the liquid and char product weight from the feedstock. Hereafter, the system has been made ready for the next run. Each time the used feed weight was 400gm. The flow path of the fixed bed pyrolysis of the polythene and sawdust is given in Fig. 1.

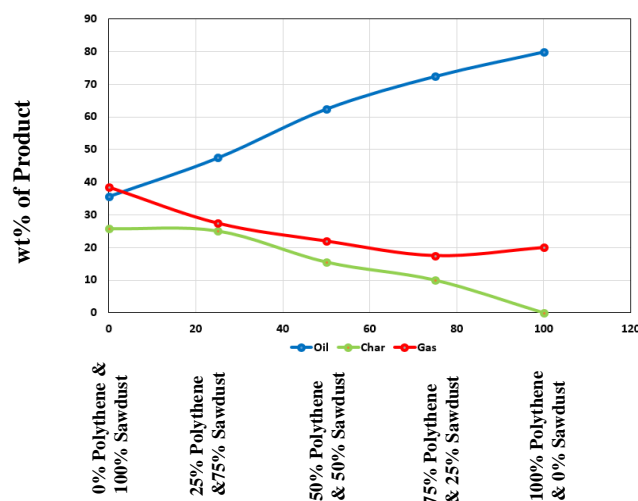


**Fig.1.** Process flow chart for fixed bed biomass pyrolysis

### 3. Results and Discussion

#### 3.1 Pyrolysis Product Yields

Fig. 2 shows the pyrolysis product yield distribution for different blends of polythene and sawdust. The maximum liquid product of 80 wt% was obtained by using 100% polythene waste feed. On the other hand minimum amount of liquid product of 35.71 wt% was obtained from 100% sawdust as a feed material. Consequently, the maximum char and gas of 25.7 wt% and 38.59 wt% respectively were found from 100% sawdust feed. The blend of 50% polythene and 50% sawdust yielded 62.50 wt% liquid, 15.50 wt% char and 22 wt% gas. The liquid product yield increases whereas the char and gas product decreases with the increase of polythene in the blend. On the other hand, the liquid product yield increases whereas the char and gas product decreases with the increase of sawdust in the blend.



**Fig.2.** Pyrolysis product yield distribution for different blends of polythene and sawdust

### 3.2 Analysis of Product Yield

The obtained pyrolysis liquid products were characterized in terms of fuel properties (density, viscosity, higher calorific value). Fig.3, 4 and 5 shows the changes of density, viscosity and higher calorific value with respect to the wt% of polythene and sawdust. The maximum and minimum liquid product density were 798.75 kg/m<sup>3</sup> and 708 kg/m<sup>3</sup> for 100% and 0% sawdust respectively. On the other hand, the maximum and minimum liquid product viscosity were 7.3 cP and 4.7 cP for 100% and 0% sawdust respectively.

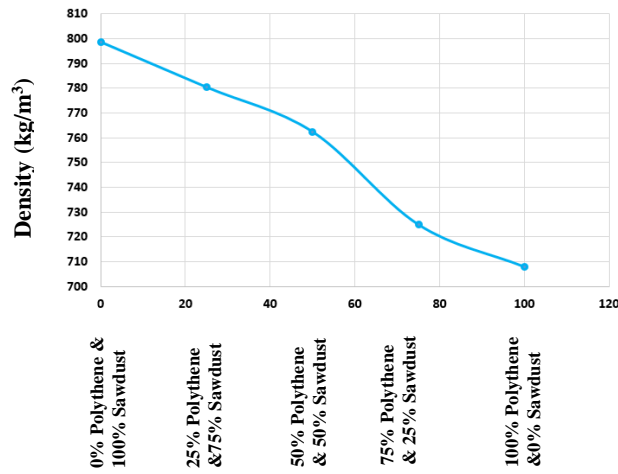


Fig.3. Density Vs wt% of Polythene and sawdust

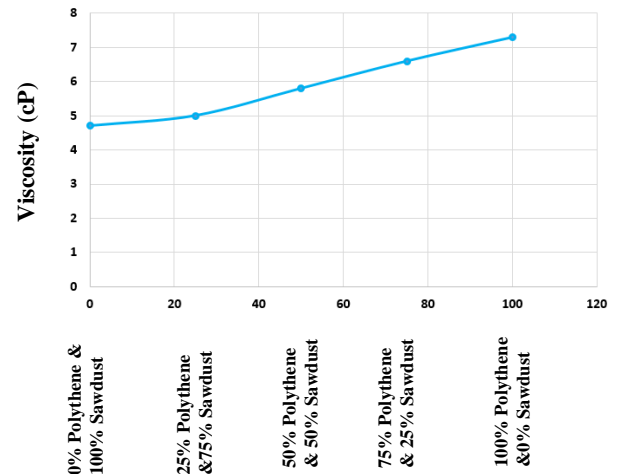


Fig.4. Viscosity Vs wt% of Polythene and sawdust

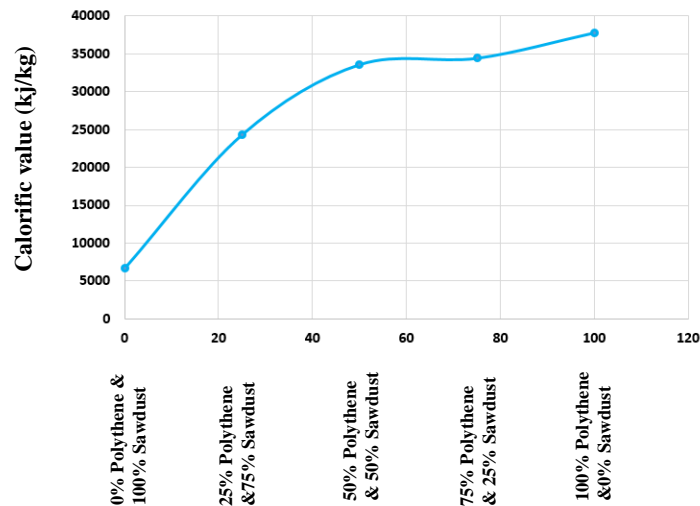


Fig.5. Calorific value Vs wt% of Polythene sawdust

Again, the maximum and minimum calorific value were 37800 kg/m<sup>3</sup> and 6720 kg/m<sup>3</sup> for 100% and 0% sawdust respectively. The higher calorific values for mixture of 50% polythene and 50% sawdust is 33600 kJ/kg. The flash point temperature increases with the increase of wt% of sawdust and the maximum flash point temperature is 99 °C. The density and flash point temperature increases whereas the viscosity and calorific value of the liquid product decreases with the decrease of polythene in the blend. The various fuel properties of the obtained liquid product is shown in table 2.

**Table 2.** Fuel properties of the pyrolytic liquid products

Feed Materials	Density (kg/m <sup>3</sup> )	Viscosity (cP)	Calorific Value (kJ/kg)	Pour point (°C)	Flash point (°C)
100% Polythene (500gm)	708	7.3	37800	<-6.2	80
75% Polythene (300gm)	725	6.6	34440	<-6.2	82
25% Saw dust (100gm)					
50% Polythene (200gm)	762.5	5.8	33600	<-6.2	85
50% Saw dust (200gm)					
25% Polythene (100gm)	780.5	5	24360	<-4	90
75% Saw dust (300gm)					
100% Saw dust (350gm)	798.75	4.7	6720	<-6.2	99

#### 4. Conclusions

The variation of polythene and sawdust in the feed blends was found to influence the liquid product yields remarkably. The liquid product yield increases whereas the char and gaseous product decreases with the increase of polythene waste in the blends. The maximum liquid yield is 80% for 100% polythene and 0% sawdust at reactor temperature 450°C. The fuel properties show that choosing pyrolysis conditions properly it is possible to obtain liquid product as a substitute of conventional fuels which are quite closer to the petroleum fuels.

#### Acknowledgement

The work has been carried out under subproject (CP No.: 3615), financed by the Higher Education Quality Enhancement Project (HEQEP), University Grand Commission of Bangladesh (UGC).

#### References

- [1] Sharypov, V. I., Marin, N., Beregovtsova, N. G., Baryshnikov, S. V., Kuznetsov, B. N., Cebolla, V. L., WeberPinto, J. V., Co-Pyrolysis of Wood Bio mass and Synthetic Polymer Mixtures, Part I: Influence of Experimental Conditions on the Evolution of Solids, Liquids and Gases, *J. Anal. Appl. Pyrolysis*, 64 (2002), pp. 15-28.
- [2] Neto, R., Pinto, F., Technical Viability Study of Gasification Technology to Process Coal Mixed with Wastes, *Proceedings, 1st World Conference on Bio mass for Energy and Industry*, Sevilla, Spain, June 5-9, 2000, James & James, Science Publishers Ltd., 2001, pp. 1537-1540.
- [3] L. Sørum, L., Grønli, M. G., Hustad, J. E., Pyrolysis Characteristics and Kinetics of Municipal Solid Wastes, *Fuel*, 80 (2001), pp. 1217-1227.
- [4] Bilbao, R., Millera, A., Arauzo, J., Kinetics of Weight Loss by Thermal Decomposition of Xylan and Lignin. Influence of Experimental Conditions, *Thermochim. Acta*, 143 (1989), pp. 137-148.
- [5] Bilbao, R., Millera, A., Arauzo, J., Kinetics of Weight Loss by Thermal Decomposition of Different Lignocellulosic Materials. Relation between the Results Obtained from Isothermal and Dynamic Experiments, *Thermochim. Acta*, 165 (1990), pp. 103-112.
- [6] Conesa, J. A., Marcilla, A., Font, R., Caballero, J. A., Thermo-gravimetric Studies on the Thermal Decomposition of Polyethylene, *J. Anal. Appl. Pyrolysis*, 36 (1996), pp. 1-15.
- [7] Westerhout, R. W. J., Waanders, J., Kuipers, J. A. M., van Swaaij, W. P. M., Kinetics of the Low-Temperature Pyrolysis of Polythene, Polypropene, and Polystyrene Modeling, 20 Experimental-Determination and Comparison with Literature Models and Data, *Ind. Eng. Chem. Res.*, 36 (1997), pp. 1955-1964.
- [8] Bockhorn, H., Hornung, A., Hornung, U., Schawaller, D., Kinetic Study on the Thermal Degradation of Polypropylene and Polyethylene, *J. Anal. Appl. Pyrolysis*, 48 (1999), pp. 93-109.
- [9] Oakes, W. G., Richards, W. G., The Thermal Degradation of Ethylene Polymers, *J. Chem. Soc.*, 4 (1949), pp. 2929-2935.
- [10] Wall, L. A., Madorsky, S. L., Brown, D. W., Straus, S., Simha, R., The De-polymerization of Poly-methylene and Polyethylene, *J. Am. Chem. Soc.*, 76 (1954), pp. 3430-3437.
- [11] Ranzi, E., Dente, M., Faravelli, T., Bozzano, G., Fabini, S., Nava, R., Cozzani, V., Tognotti, L., Kinetic Modeling of Polyethylene and Polypropylene Thermal Degradation, *J. Anal. Appl. Pyrolysis*, 40-41 (1997), pp. 305-319.
- [12] McCaffrey, W. C., Cooper, D. G., Kamal, M. R., Tertiary Recycling of Polyethylene Mechanism of Liquid Production from Polyethylene by pyrolysis Reactive, *Polym. Degrad. Stab.*, 62 (1998), pp. 513-521.
- [13] Poutsma, M. L., Fundamental Reaction of Free Radicals Relevant to Pyrolysis Reactions, *J. Anal. Appl. Pyrolysis*, 54 (2000), pp. 5-35.
- [14] Lehrle, R. S., Pattenden, C. S., Intramolecular Hydrogen Transfer in Thermal Degradation: Comments on the Size Distribution of the Back bite Rings, *Polym. Degrad. Stab.*, 63 (1999), pp. 153-158.
- [15] Bockhorn, H., Hornung, A., Hornung, U., Mechanisms and Kinetics of Thermal Decomposition of Plastics from Isothermal and Dynamic Measurements, *J. Anal. Appl. Pyrolysis*, 50 (1999), pp. 77-101.
- [16] Urzendowski, S. R., Guenther, A. H., Kinetics Constants of Polymeric Materials from Thermo-gravimetric Data, *J. Therm. Anal.* 3 (1971), pp. 379-395.

- [17] Wu, C-H., Chang, C-Y., Hor, J-L., Shih, S-M., Chen, L-W., Chang, F-W., On the Thermal Treatment of Plastic Mixtures of MSW: Pyrolysis Kinetics, *Waste Management*, 13 (1993), pp.221-235.
- [18] Font, R., Marcilla, A., García, A. N., Caballero, J. A., Conesa, J. A., Kinetic Models for the Thermal Degradation of Heterogeneous Materials, *J. Anal. Appl. Pyrolysis*, 32 (1995), pp.29-39.
- [19] Madorsky, S. L., Rates of Thermal Degradation of Polystyrene and Polyethylene in a Vacuum, *J. Polym. Sci.*, 9 (1952), 2, pp. 133-156.
- [20] Sawaguchi, T., Inami, T., Kuroki, T., Ikemura, T., Studies on Thermal Degradation of Synthetic Polymers. 12. Kinetic Approach to Intensity Function Concerning Pyrolysis Condition for Polyethylene Low Polymer, *Ind. Eng. Chem. Process Des. Dev.*, 19 (1990), 1, pp.174-179.
- [21] Jellinek, H. H. G., Thermal Degradation of Polystyrene and Polyethylene. Part III, *J. PolymSci.*, 4 (1949), 1, pp. 13-36.
- [22] Ranzi, E., Dente, M., Goldaniga, A., Bozzano, G., Favarelli, T., Lumping Procedures in Detailed Kinetic Modeling of Gasification, Pyrolysis, Partial Oxidation and Combustion of Hydrocarbon Mixtures, *Prog. Energy Combust. Sci.*, 27 (2001), pp. 99-139.
- [23] García-Pérez, M., Chaala, A., Yang, J., Roy, C., Co-Pyrolysis of Sugarcane Bagasse with Petroleum Residue. Part I: Thermo-gravimetric Analysis, *Fuel*, 80 (2001), pp. 1245-1258.
- [24] Matsuzawa, Y., Ayabe, M., Nishino, J., Acceleration of Cellulose Co-Pyrolysis with Polymer, *Polym. Degrad. Stab.*, 71 (2001), pp. 435-444.
- [25] Di Blasi, C., Linear Pyrolysis of Cellulosic and Plastic Waste, *J. Anal. Appl. Pyrolysis*, 40-41(1997), pp. 463-479.
- [26] Jakab, E., Blazsó, M., Faix, O., Thermal Decomposition of Mixtures of Vinyl Polymers and Lignocellulosic Materials, *J. Anal. Appl. Pyrolysis*, 58-59 (2001), pp. 49-62.
- [27] Aguado, R., Combustion and Pyrolysis of Wood Wastes in Conical Spouted Bed, Ph. D. thesis, Universidad del País Vasco, Bilbao, Spain, 1999.
- [28] Jakab, E., Blazsó, M., The Effect of Carbon Black on the Thermal Decomposition of Vinyl Polymers, *J. Anal. Appl. Pyrolysis*, 64 (2002), pp. 263-277.
- [29] Li, B., He, J., Investigation of Mechanical Property, Flame Retardancy and Thermal Degradation of LLDPE–Wood-Fiber Composites, *Polym. Degrad. Stab.*, 83 (2004), 2, pp. 241-246.
- [30] Lattimer, R. P., Pyrolysis Field Ionization Mass Spectrometry of Polyolefins, *J. Anal. Appl. Pyrolysis*, 31 (1995), pp. 203-225.
- [31] Blazsó, M., Polyaromatization in Common Synthetic Polymers at Elevated Temperatures, *J. Anal. Appl. Pyrolysis*, 25 (1993), pp. 25-35.
- [32] Bridgwater, A.V. and Bridge, S.A. (1991). “A Review of Biomass Pyrolysis and Pyrolysis Technologies”. In: Bridgwater, A.V. and Grassi, G. (Eds). *Biomass Pyrolysis Liquid Upgrading and Utilisation*. London: Elsevier Science; 11-92.
- [33] Lede, J. of Nancy, France- “Chemical Engineering aspects of solid (Biomass) particle pyrolysis” – Developments in thermo-chemical Biomass conversion Volume -1, London, 1997.
- [34] Bridgwater, A.V. (1992). Thermochemical Biomass Conversion Technologies and Their Impact in Europe” In: Proceeding of the Second International Energy Conference, Energy From Biomass Residues. Kuala Lumpur; 17- 19.