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Temperature distribution of the plastics Pyrolysis process to produce fuel at 450°C

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Abstract

This paper aims to investigate the temperature distribution in the reactor of a plastics pyrolysis process from waste bottles of beverage to produce fuel. This process is considered an alternative technology to replace fossil fuel. This experiment was conducted using a cylindrical reactor, which has dimension of 0.31 m in diameter and 1 m high. In order to understand the temperature distribution in the reactor, five thermocouples were placed to measure temperature at the bottom and the top of the reactor as well as in the middle, with the different position of each thermocouple of 0.19 m respectively. The temperature outside the reactor and outside the condenser was also measured. Data Acquisition recorded all temperature data. The reactor was used to process 1,500 g plastics. The Computational Fluid Dynamic (CFD) was also used to know the contour of temperature inside the reactor. The result showed that to increase temperature from the ambient temperature to 450°C, 72 minutes of time were needed. The lowest temperature of 310°C was measured at the top of the reactor, whereas different temperature in the middle of the reactor was found to be 46°C respectively. The pyrolysis process of 1,500 g plastics was completed in 110 minutes to produce 21 g of fuel. This fact shows that the pyrolysis process of plastics can produce fuel at 450°C in the reactor and 75°C outside the reactor.

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Keywords: Pyrolysis;Plastics;Temperature;Reactor; CFD

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1. Introduction

Consumption of drinking water in packages increases and almost all its packaging is made from plastics. There are six plastics categories in the world: High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polypropylene (PP), Polyvinyl Chloride (PVC), Polystyrene (PS) and Polyethylene Terephthalate (PET). Drinking water packaging is included in Polyethylene Terephthalate (PET). Plastic is made from petroleum derivatives and considered to be difficult to parse and to be a pollutant (air, land and water)[1]. This phenomenon will become a potential problem in the future. On the other hand, the amount of fuel decreases and a solution is needed to overcome this condition. Plastic is a potential ingredient to be converted into fuel by a pyrolysis process.

Pyrolysis is a thermal process with less or absence of oxygen. In the pyrolysis process (heating in an oxygen-free atmosphere), the organic components of the decomposed material generate liquid and gaseous products, which can be used as fuels and/or a source of chemicals[2]. The process is influenced by some important parameters such as temperature and time. Some papers report that the pyrolysis process happened at the temperatures of 350°C, 460°C, 500°C, 520°C, 600°C, 650°C, 685°C, 730°C, 780°C, 850°C, 900°C and within the duration of 15 minutes, 30 minutes, 60 minutes, or 120 minutes[2,3,4,5,6]. However, the discussion about the temperature distribution in the reactor is not included. Temperature distribution is important to be recorded because it can estimate the area in which thermal cracking occurs. Thermal cracking is the most important step in pyrolysis of plastic to produce fuel.

Several researchers have studied the pyrolysis process to produce fuel from waste plastics. Toshiro et al[7] has investigated the thermal cracking of household waste plastics with variation of temperatures at 700°C, 750°C, 800°C and 850°C. Kyong et al studied about the comparative result of catalytic and non-catalytic degradation of waste polymer plastics[8]. N. Miskolczi et al reported about the pyrolysis process of two types of plastics (HDPE and PP) from agricultural and packaging sectors[3] at 520°C. E. Butler et al discussed the review of waste polyolefin plastics[9]. Research on the use of waste plastic bottles made from PET for producing fuels using the pyrolysis process is less conducted.

The aim of this research is to study temperature distribution in the pyrolysis process of waste plastic bottles as drinking water packages (PET), which are immensely available in Indonesia. This research used lab-scale reactor experiment to analyze temperature distribution in the reactor. The simulation of Computational Fluid Dynamic (CFD) was also used in this research to know the temperature contour inside the reactor.

2. Materials And Method

2.1. Materials

Plastics used in this research werewaste plastic bottles of drinking water. Firstly, the bottleswere dried and chopped into small pieces. For the pyrolysis process, 1,500 g of plastic pieces were then put into the reactor.

2.2. Method

The layout of the experiment can be seen in Fig 1. The experiment was performed in a cylindrical reactor made from steel with the dimension of 0.31 m in diameter and 1 m high. Five K type thermocouples were placed in the reactor from the bottom to the top, while the distance of each thermocouple was 0.19 m. The condenser was made from a copper tube with diameter of 3/8 inch and length of 2.5 m. The temperature was recorded using Data Acquisition every 2 seconds. Power of the electrical heater was 2700 Watt. The reactor was sealed with ceramic fiber with thickness of 2 cm. The boundary condition in Computational Fluid Dynamic (CFD) simulation can be seen in Table 1:

Table 1. Boundary Condition in CFD

No	Parameters	Condition	Value
1	Type of flow	Laminar	-
2	Operating Pressure	Absolute Pressure	101,325 Pa

3	Material	Air	-
		Density	1,225 kg/m^3
		Cp	100,643 x 10^1 J/kg.K
		Thermal Conductivity	0.242 x 10^{-1} W/m.K
		Viscosity	1,789 x 10^{-5}
4	Inlet	Velocity Inlet	0.749 x 10^{-3} m/s
5	Heater	Temperature	733 K
		Wall Thickness	0.002 m

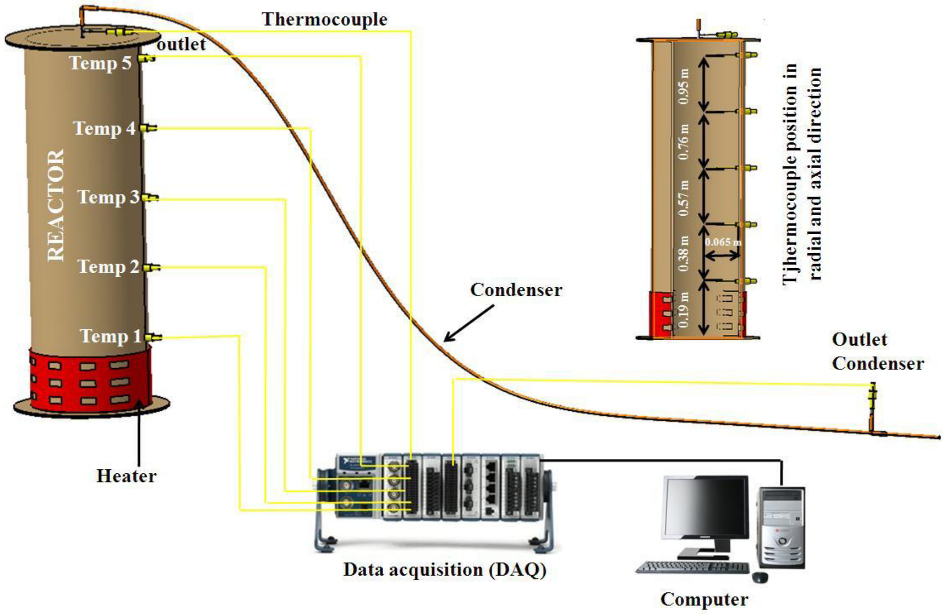

Fig. 1. Experiment Layout of the Plastic Pyrolysis Process

3. Result and Discussion

Fig 2. shows the profile of temperature inside the reactor during the heating process at the room temperature to the pyrolysis temperature of 450°C. This figure shows that there was a temperature gradient inside the reactor during the pyrolysis process due to the heat transfer. For the first few minutes after the experiment started, the temperature inside the reactor was stable or unchanged because the furnace had just heated up and a low heat reached the reactor. Heat transfer occurred after 10 minutes from the beginning, in which the Temp 1 reached 79°C. The maximum gradient temperature was reached at 100°C. This phenomenon is similar to what is described by Low et at [10], but the difference is that in this experiment the heat transfer occurred by the 30th – 40th minute from the beginning and the temperature reached was 120°C – 140°C. In this condition, heat transfer to the reactor began and temperature of both liquid and gas or vapor phase sections received. The temperature profile shows that sudden change inside the reactor occurred by the 30th-40th minute and by the 60th -70th minute, indicating that the temperature of gas inside the reactor changed during this period. This phenomenon also occurred in the research conducted by Feng[11], where sudden change of gas temperature inside the reactor took place by the 16th minute to the 20th minute without effects on the reactor wall.

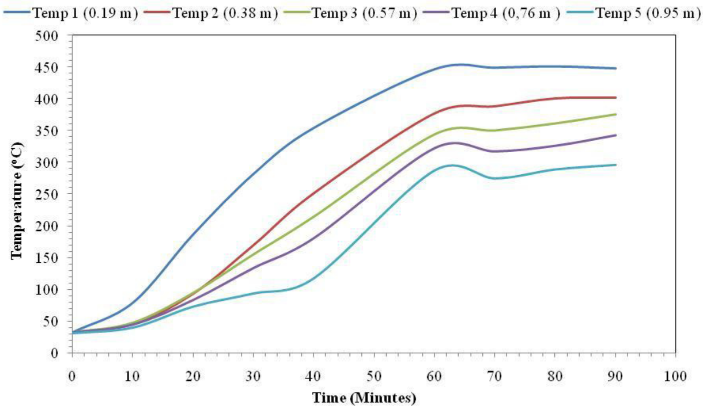

Fig. 2. Profile of Temperature in Initial Heating Process

Fig. 3 shows the steady state condition of the plastic pyrolysis process. Temperature combustion of plastics by the electrical heater reached 450°C and remained at this temperature until the end of the experiment. Similar result is also shown by Nasrollah et al[1] at temperature of 450°C for Shipping Protection Styrofoam Boxes (SPFB) products. Each thermocouple showed the constant differences about 50°C – 60°C except for Temp 4. This condition happened because of the thermal cracking process of plastics. In the thermal cracking process, plastics consumed more heat, and this made the differences between Temp 3 and Temp 4 only about 20°C. Thermal cracking in this research occurred at the temperature of 354°C (Temp 4) and 374°C (Temp 3). Other research reported by Sang et al[4] with materials from Polypropylene (PP), Polyvinyl Chloride (PVC), Polystyrene (PS) and Low Density Polyethylene (LDPE) shows that pyrolysis at a low temperature of 350°C – 450°C is mainly de-volatilized by plastic cracking as a result of producing high molecular weight hydrocarbon.

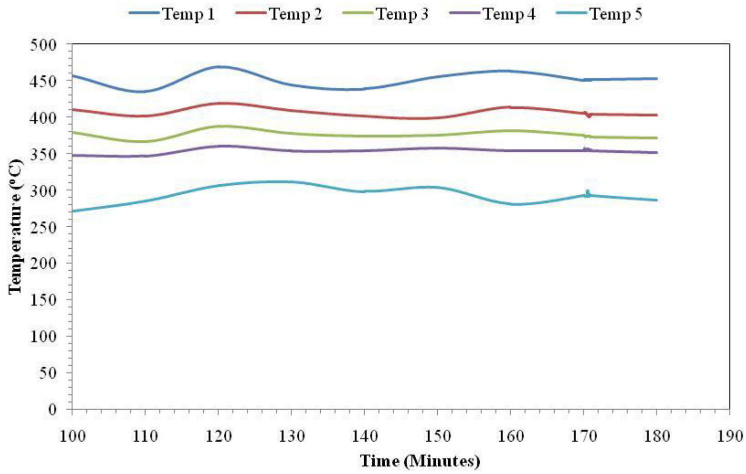

Fig. 3. Profile of Steady State Temperature at the Reactor

Fig. 4 and Fig. 5 show the temperature contour and value inside the reactor based on CFD simulation. Fig. 4 shows the contour of airflow inside the reactor. Whereas Fig. 5 shows the heat transfer in the radial direction from the length of 0 m (the wall inside the reactor), 0.065 m, 0.12 m, 0.18 m, 0.24 m and 0.3 m from each thermocouple position. Maximum temperature of the wall inside the reactor that reached 450°C (723 K) is shown in red region. However, the temperature inside the reactor in 0.12 m radial distance at 0.19 m high was 440°C (713K). In 0.065 m radial position, the temperature was recorded 450°C (723 K). This phenomenon occurred due to convection heat transfer from the wall inside the reactor to the gas flow. The maximum temperature decreased in the radial direction at 0.38 m high. The temperature reduced from 408°C to 348°C, which had potential to the thermal cracking process.

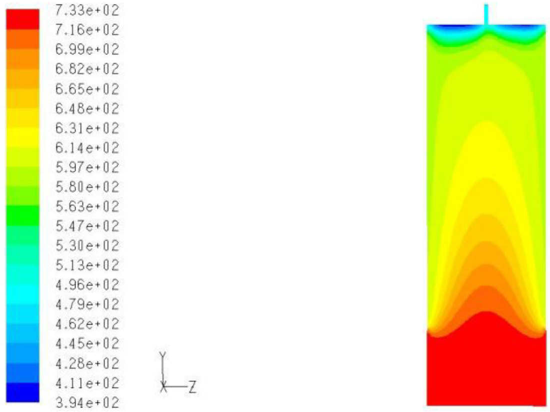

Fig. 4. Temperature Contour inside the Reactor

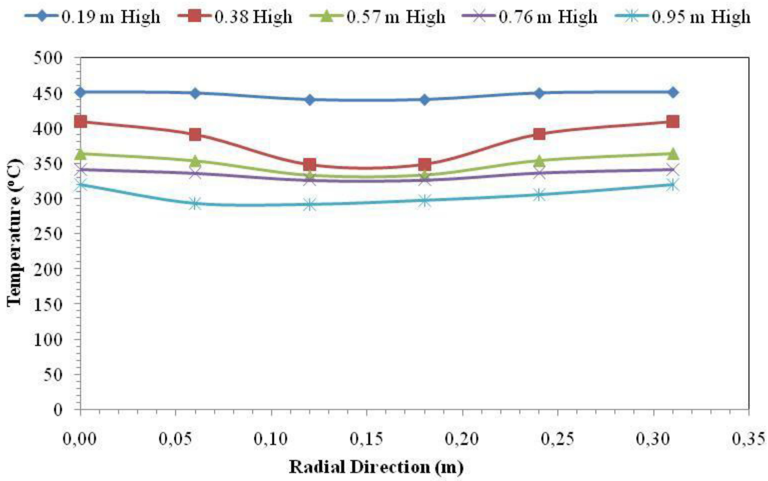

Fig. 5. Temperature Distribution in the Radial Direction Based on CFD Simulation

Fig 6. shows the temperature profile of the experiment and CFD simulation in the axial direction. Temperature at Temp 1 (0.19 m from bottom) was 451°C but simulation resulted 449°C as the heat source by the electrical heater inside the wall reactor was 460°C. Temperature at Temp 5 (0.95 m from bottom) of the experiment was 293°C, whereas CFD simulation was 292°C. The temperature difference between the experiment and CFD simulation is relatively small. Although this simulation based on gas flow using air properties is the same as that of Chuanwei[12], it has the same result in the temperature distribution inside the reactor. The weakness of this model is its inability to predict the amount of mass fraction as modeled by Bagher et al[13]. As described in Fig. 7, Table 2 and 3, the R square of the experiment and CFD simulation is 0.999, indicating that the model has good correlation. The significance (F) of Anova was resulted as 3,528 x 10^{-6}, which is less than 0.05, and it proves that the model is valid to be used to predict the temperature inside the reactor.

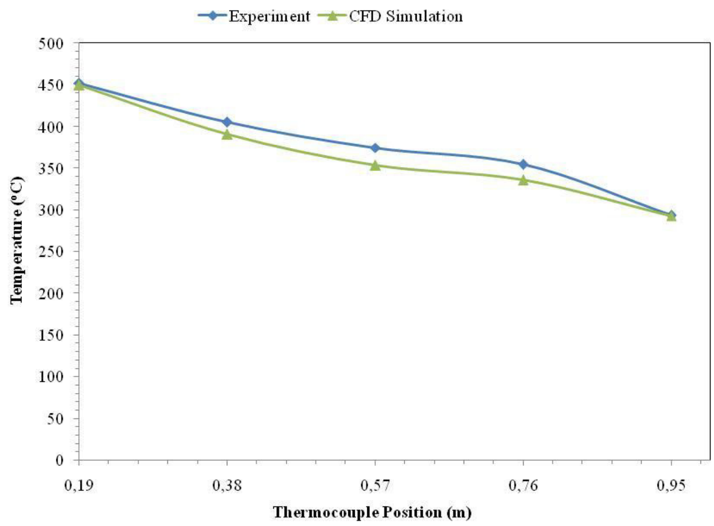

Fig. 6. Comparison of Temperature Distribution in the Axial Direction

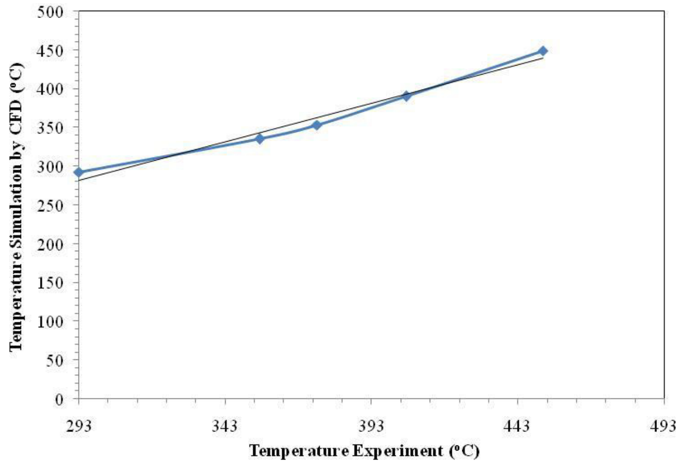

Fig. 7. Regression of the Experiment and CFD Simulation

Table 2. Table of Regression

Regression Statistics	
Multiple R	0.999
R Square	0.999
Adjusted R Square	0.749
Standard Error	9.628
Observations	5

Table 3. Anova

	df	SS	MS	F	Significance (F)
Regression	1	677441.625	677441.625	7307.541	3.528×10^{-6}
Residual	4	370.817	92.704		
Total	5	677812.443			

Table 2 shows the final result of 1,500 g plastics in the pyrolysis process at 450°C. The experiment resulted in that from 1,500 g of waste plastic, it produced 21 g of liquid/fuel, 450 g of char and 1,029 g of gas. This belongs to the slow pyrolysis category in which the result is different from that of Achyut et al[14] but similar to the result of Saha et al[15]. This result is small because of the use of plastics from PET, the condenser that is only the tube, and the free convection type to the air in this experiment.

Table 4. Final Result of Pyrolysis

No	Mass of Initial Product (g)	Final Product		
		Liquid / Fuel (g)	Char (g)	Gas (g)
1	1,500	21	450	1,029

Fig. 8 shows the temperature profile outside the reactor and outside the condenser. The mean temperature outside the reactor was 80°c and outside the condenser was 37°C. This result shows good condition to produce liquid/fuel from plastic. Temperature fluctuation in both the outlet reactor and the condenser occurred due to the fact that the reactor and the condenser were directly bordered by the environment temperature.

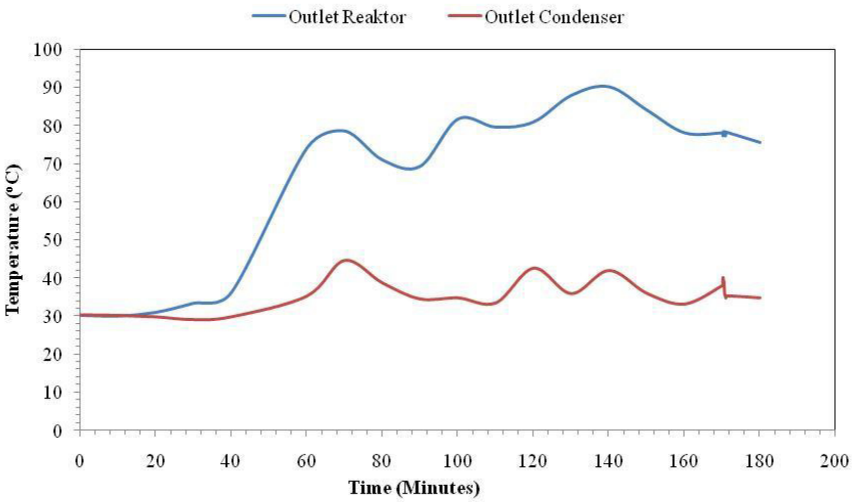

Fig. 8. Profile of the Outlet Reactor and Condenser Temperature

4. Conclusion

From this experiment, the temperature distribution has been studied in the reactor for the plastic pyrolysis process. The temperatures from the bottom upward (Axial Direction) (Temp 1, Temp 2, Temp 3, Temp 4, Temp5) are: 451°C, 404°C, 374°C, 354°C, 293°C. This value has small difference with that of the CFD simulation; therefore, the model can be used to predict the temperature distribution inside the reactor. The contour of the simulation can be used properly. To improve the result, a simulation using properties of plastic in a gas form to predict mass fraction of plastics is needed. However, the final product of liquid/fuel of waste drinking bottles is considered very small, it is only 21 g.

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References

1. Nasrollah Hamidi, Fariba Tebyanian, Ruhullah Massoudi, Louis Whiteised. Pyrolysis of Household Plastic Wasted. *British J. of Applied Science & Technology* 2013; 3 : 417 – 439.
2. A. Lopez, I. de Marco, B.M. Caballero, M.F. Laresgoiti, A. Adrados. Influence of Time and Temperature on Pyrolysis of Plastic Wastes in a Semi-Batch Reactor. *Chemical Engineering Journal* 2011 ; 173 : 62 – 71
3. N. Miskolczi, A. Angyal, L. Bartha, I. Valkai. Fuel by Pyrolisys of Waste Plastics from Agricultural and Packaging Sectors in a Pilot Scale Reactor. *Fuel Processing Technology* 2009 ; 90 : 1032 – 1040.
4. Sang Shin Park, Dong Kyun Seo, Sang Hoon Lee, Tae-U. Yu, Jungho Hwang. Study on Pyrolisis Characteristics of Refuse Plastic Fuel Using Lab-Scale Tube Furnace and Thermogravimetric Analysis Reactor. *J. of Analytical and Applied Pyrolysis* 2012 ; 97 : 29 – 38
5. Motoyuki Sugano, Akihiro Komatsu, Masanori Yamamoto, Mika Kumagai, Takayuki Shimizu, Katsumi Hirano, Kiyoshi Mashimo. Liquefaction Process for a Hydrothermally Treated Waste Mixture Containing Plastics. *J. Mater Cycles Waste Manag* 2009 ; 11 : 27 – 31.
6. F.J. Mastral, E. Esperanza, P. Garcia, M. Juste. Pyrolysis of High-Density Polyethylene in a Fluidised Bed Reactor. Influence of the Temperature and Residence Time. *Journal of Analytical and Applied Pyrolysis* 2002 ; 63 : 1 – 15
7. Toshiro Tsuji, Koji Hasegawa, Takao Masuda. Thermal Cracking of Oils from Waste Plastics. *J. Mater Cycles Waste Manag* 2003 ; 5 : 102 – 106
8. Kyong-Hwan Lee and Dae –Hyun Shin. A Comparative Study of Liquid Product on Non-Catalytic and Catalytic Degradation of Waste Plastics Using Spent FCC catalyst. *Korean J. Chem Eng* 2006 ; 23 : 209 – 215.
9. E. Butler, G. Devlin, K. McDonnell. Waste Polyolefins to Liquid Fuels Vie Pyrolysis : Review of Commercial State-of-the-art and Recent Laboratory Research. *Waste Biomass Valor* 2011 ; 2 : 227 – 255
10. S.L. Low, M.A. Connor, G.H. Covey. Turning Mixed Plastic Wastes into a Useable Liquid Fuel. *Proceeding 6th World Congress of Chemical Engineering Melbourne Australia* 2001 : 23-27 September
11. Feng Gao. Pyrolysis of Waste Plastics into Fuel. *Dissertation Chemical and Process Engineering University of Canterbury* 2010
12. Chuanwei Zhuo. Synthesis of Carbon Nanoubes from Waste Polyethylene Plastics. *Thesis Mechanical Engineering Northeastern University* 2009
13. Bagher Anvaripur, Mohammad Shah Bin, Zahra Maghareh. Computational Fluid Dynamics Modelling of High Density Polyethylene Catalytic Cracking Reactor. American J. Of Oil and Chemical Technologies 2013;1:1-6
14. Achyut K. Panda, R.K. Singh, D.K. Mishra. A Suitable Method for Plastic Waste Management and Manufacture of Value Added Produt-A World Prospective. *Renewable and Sustainable Energy Review* 2010; 14 : 233 – 248
15. B. Saha, A.K. Ghoshal. Thermal Degradation Kinetics of Polyethylene Terephthalate from Waste Soft Drinks Bottles. *Chemical Engineering Journal* 2005;111:39-43