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DESIGN AND FABRICATION OF FIXED BED PYROLYSIS REACTOR USING SCRAP TIRE FOR PYROLYSIS OIL PRODUCTION

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ABSTRACT
In this research, a design and construction of fixed bed pyrolysis reactor and solid waste tire for pyrolysis oil production have been completed and the characteristics of the pyrolysis oil have already been checked and compared to the other research experimental results. A fixed bed reactor, reactor shield, solid horizontal condenser, oil or gas burner for furnace heating and the reactor shield has been designed properly for accurate experimental operation. This fixed bed batch type pyrolysis reactor method will demonstrate the energy saving concept of solid waste tires by creating energy stability of the present world. From this experiment prod-uct yields (weight %) for liquid or pyrolytic oil (wt. %) 34 %, char (wt. %) 57 %, gas (wt. %) 9%.

Keywords: Pyrolysis, Used Tires, Temperature, Pyrolytic Gas, Pyrolytic Oil.

1. INTRODUCTION

Pyrolysis of solid waste tires is an advanced renewable source of energy in this world. Around the world, 1.1 billion vehicles are running on the road and 1.7 billion of new tires produces annually and transport is increasing as population growth (Aziz et al., 2015; Rahman et al., 2016; Utlu et al., 2006). Every year 1.3 billion of solid waste tires produced around the world (Kotresh & Belachew, 2014). In fact, many city corporations' municipalities facing solid waste tire disposal problem. However, maximum constituents in tire composition are 60% rubber, 20% steel, and 20% fiber respectively (Oladiran & Meyer, 2007). Some of the previous research groups studied that the gross calorific value (GCV) of pyrolysis oil is near about approximately 33.7 MJ / kg, 37 MJ/kg, 40 MJ/ kg (Rada et al., 2012a), 41-44 MJ/kg (Osayi et al., 2014). End-of-Life tires (ELTs) is growing rapidly and creates socioeconomic and serious environmental problem (Acevedo & Barriocanal, 2014). In addition to that pyrolysis is considered one of the most modern approaches among all of the solution of solid waste recycling management. Moreover, pyrolysis is an environmentally friendly thermochemical processing of solid waste tire. In the product of pyrolysis is a gas with a higher calorific value, pyrolytic oil and as temporary raw material sources of benzene, toluene, xylene (BTX) or limonene and char that can be used as fuel, activated carbon or carbon black (Antoniou & Zabaniotou, 2013; Fernández et al., 2012; Önenc et al, 2012).

In natural, the purification of pyrolysis oil involved co-pyrolysis process in which it produces high-grade quality pyrolytic oil. The characteristics of pyrolysis oil e.g. decrease the viscosity, increase oil yields, decrease the water content and increase the calorific value of the oil (Abnisa & Daud, 2014). The first steps have already been taken for the production of pyrolysis oil commercially from the waste tire in 2013 (Islam et al., 2013). Though it was too late due to Bangladesh preliminary energy consumption in 2012 was an estimated 56% natural gas, 24% traditional biomass and waste, 16% oil, 3% coal,1% hydropower and solar. It is estimated that from 2015-16 overall gas demand will be 3800 million cubic feet per day from 19 gas fields and other 25 gas field under the process of discovering. However, for cool production among five coal fields around the country contains 3.3 billion metric tons' coal. In fact, now 75% of total energy consumption within 100% demand provided by natural gas in Bangladesh. In 2015 natural gas contributes to over 89% of total power consumption. Sector wise require power is fertilizer (18%), industry (14%) and commercial/households (12%) and captive power generation (12%) (Haque, 2015). The solid waste tire has occupied the largest in quantity likely 90000 metric tons annually become scrap and disposed of in Bangladesh (Erdem et al., 2009). However, a typical renewable pyrolysis oil production technique from waste tire which filling the demand of oil potentially around the world. Pyrolytic oil from scrap tire is one of the most prominent sources of energy around the world (Uddin et al., 2012). Among various thermos-chemical conversion process, pyrolysis is an advanced technology for the production of liquid oil because it is simple and cost effective. Finally, it is thermal chemical decomposition of organic materials at a temperature range of 400-650^0 C to produce char, tar, and gas (Islam et al., 2001).

The conversion of the solid waste tire to pyrolytic oil, a different system was used some of these are fluidized bed pyrolysis reactor, fixed bed pyrolysis reactor, a conical spouted bed reactor, fluidized bed reactors and semi-batch reactor. Among these reactors fixed bed pyrolysis method considered as an advanced technology in which the feedstock's feed in the reactor and external supply of heat. During this experiment the liquid (wt. %) 34 %, char (wt. %) 57 %, gas (wt. %) 9% were produced.

2. CONSTRUCTION OF PYROLYSIS SYSTEM

The required parts of the pyrolysis plant were assembled carefully and the liquid gasket was used for sealing of joints. Firstly, a concrete slab supported by four pillars was placed inside underground holes as the base of the pilot plant and the furnace was made on a concrete slab by using fire bricks. Two burners were connected at the bottom of the furnace. The reactor chamber was placed on the furnace supporting with two mild steel rods. The insulated side walls were placed around the reactor. A cover plate was attached at the top of the furnace. Two fixed parts of side wall were attached to the exhaust pipes and other two portable parts were connected with fixed parts by means of nut-bolts. A gas flow line with a gate valve was connected to the fractionating column. The purpose of the fractionating column was to sepa-rate the heavy compounds from volatiles and gasses. However, the proper flow of gasses through the pipelines was maintained by separating the heavier compounds of higher density as well as higher viscosity and the fractionating column was attached to the vertical conden-ser. The vertical condenser was connected with the horizontal condenser. A digital pyrometer prob was inserted into the reactor through the cover plate. Fractionating column and the gas pipelines were supported by the metallic stand and insulated by insulating material named glass wool having a thickness of 3 cm. Finally, a hole was made to place the liquid collector at the outlet of the horizontal condenser.

2.1 Pyrolysis plant design

In figure 1 waste tires were collected from the dump sites of the cities using trucks or lorry, weighed and stockpiled nearest sites in the plant; collected tires were cleaned using com-pressed air from the compressor and loaded this cleaned tire in the shredder for small size chip production. The shredded tires were carried into the dryer for initial warm up condition in which waste tires pieces' warm up in the way of the dryer before entering the dryer using chimney flue gas. Finally, the shredded tires were feed into the fixed bed pyrolysis reactor, which already in heating condition. The reactor was vertically placed in the concrete structure and the reactor height was 990 mm and diameter were 400 mm having throught 250 mm di-ameter. Inside of the reactor, there were three u-shaped spirals and two halves hexagonal stainless steel pipe of 19 mm diameter. The total length of each spiral pipe was 1370 mm and the bending radius was 76 mm. The pipes provided uniform and faster heating inside tires re-actor. At the bottom of the reactor, there was another throught of 200 mm diameter for char removal for pilot-scale plants. The small pieces of tires were heated about 4300 C by passing the hot flue gases through fixed bed fire tubes and due to the combustion held in the pyrolysis reactor 90% of hot gases are produced by the furnace and rest 10% of the combustion prod-ucts passes through condenser one and two as non-condensable gases and vapor for the pro-duction of yield. From the estimation of oil production from condenser one 20L/h and from second condenser 1L/h for pilot-scale pyrolysis oil production respectively. The flue gasses produced from fixed bed pyrolysis reactors are exhausted into the atmosphere through a chimney, via carrier gas pre-heater and feedstock dryer and the solid wastes as carbon black and steel tires from the tires directly sold to the recycling plant and steel manufacturing indus-try. The gaseous likely vapor products produced from the reactor were used to compress by the compressor for higher oil production and some parts of the gaseous products as heat ener-gy were supplied to the reactor for pyrolysis reaction. Finally, an oil pump was used in pumped oil to the storage tanks and sold to the refinery industry as used in feedstock oil.

3. MATERIAL AND METHOD

3.1 Materials

The material used for the production of pyrolysis oil, char and gas usually solid scrap tires especially several brands of tires were available in Bangladesh, GAZI, CEAT, Apollo, and Birla. The tire was used in truck or bus and net weight about 50 kg each. The waste tires were collected locally from a dump site in Rajshahi city of Bangladesh. The tire was steel cord free that chopped into the sizes of 63 × 13× 3 cm, 43× 13× 3 cm etc. easily.

3.2 Method

The water flow controlled very carefully to condenser pyrolysis during operation and the temperature of the fixed bed pyrolysis reactor measured by using a thermometer. However, a gas flow meter used for measuring gas flow rate in pyrolysis operation and during condensation the liquid product collected in the collector.

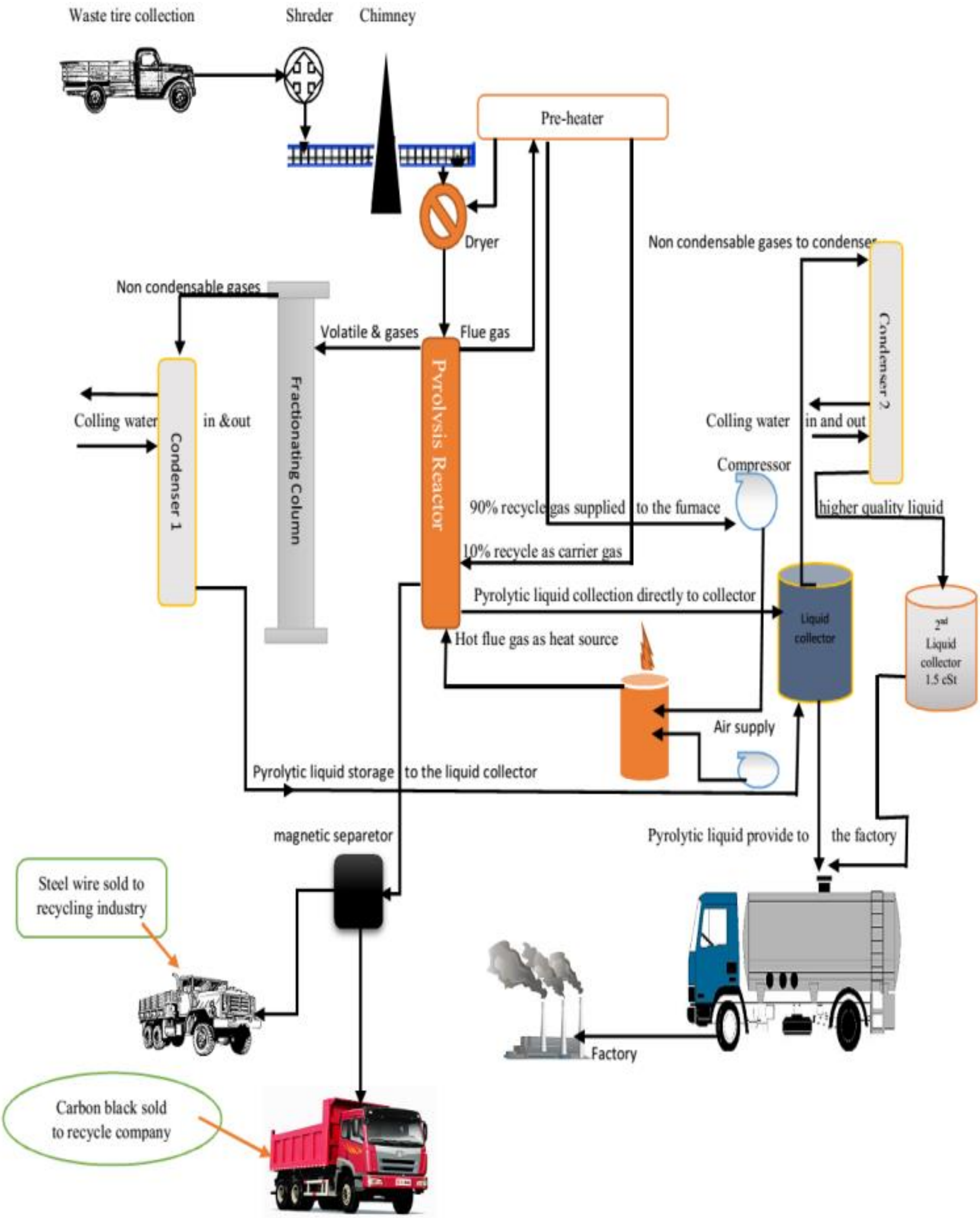

Figure 1 Conceptual design for pilot pyrolysis plants.

4. RESULTS AND DISSCUSSION

4.1 Pyrolysis products from the pilot plant

Pyrolysis is an environment-friendly, attractive method for recycling waste tire (Islam et al., 2011). Paralyzed tire can produce liquid, char, gasses. A total of two runs was carried out by using prepared tire waste samples. The product distributions obtained from the pilot plant experiments are presented in Table 1. The table 1 shows that the first running time for the plant was 330 minutes and enabling product yields: liquid 33wt%, char 57wt%, and gasses 10wt%. The characteristics of pyrolytic liquid are the most important factor to identify the nature of that oil' a few properties of pyrolytic liquid were much closer to petroleum products. The comparison between pyrolytic liquid and petroleum products (Table 2).

4.2 Effect of time on the heating operating temperature

The heating operation is a very important factor for pyrolysis plant. The reactor and furnace were designed in such a way that the produced heat was transferred into reactor chamber quickly and uniformly. The initial reactor temperature was 30^0C. Then after every 30 minutes, temperature reading was recorded during heating of the reactor. The reactor was heated at an increasing rate up to first 100 minutes of running operation. Then the next 80 minutes was maintained at a constant temperature near about 430^0C (± 10^0C) and maximum % of yield obtained during intermediate temperature. In figure 3 & 4 illustrates the effect of time on heating and cooling operation presented below.

Table 1 Product yields distribution of tire pyrolysis for different sizes

No of Obs.	Running Time (min)	Feed size (cm)	Tire feed (Kg)	TPO (Wt. %)	Char (Wt. %)	Gas (Wt. %)
1.	300	43×13×3	200	34	57	9

Table 2 The comparison between pyrolytic liquid and petroleum products

Properties	Pyrolytic liquid	Diesel(Nabi, et al., 2014)	Furnace oil
density(kg/m^3	950	830	930
Viscosity (cSt)	4.0	2	6.2
HCV (MJ/kg)	42	46.5	46

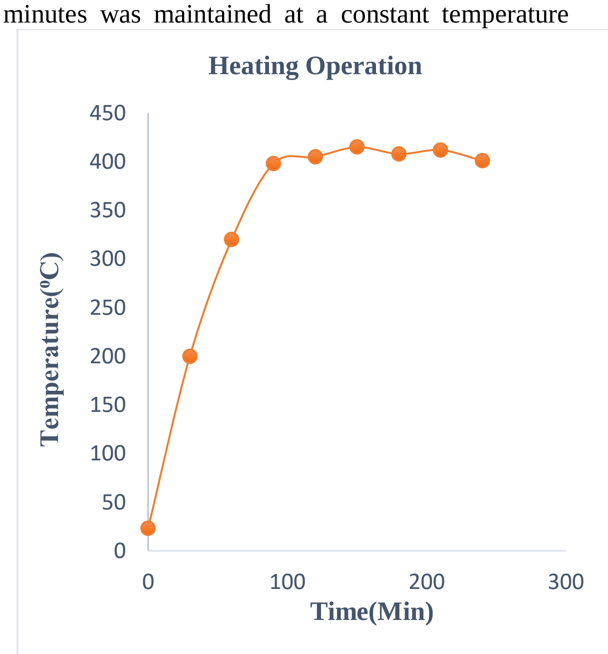

Figure 3 Temperature distribution during the reactor's heating operation

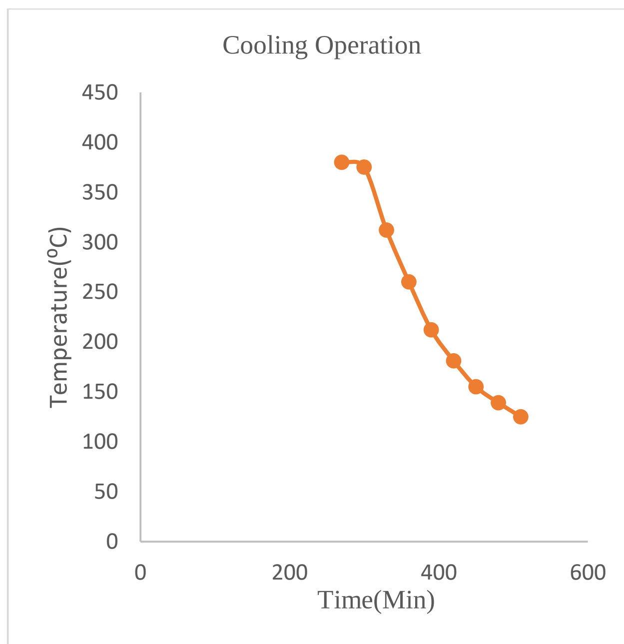

Figure 4 Temperature distribution during the reactor's cooling operation.

4.3 Effect of time on the cooling operating temperature

At the time of cooling operation, the portable parts of the insulated side wall of the furnace were removed for cooling purpose. Next, 180 minutes was taken as a cooling period where temperature decreased to 50^0C. The total time for the reactor heating and cooling operation of the pilot plant was 360 minutes.

5. ENVIRONMENTAL ASPECTS

The production of pyrolysis liquid, char, and gases from waste scrap tires crucially involved for the production of environmentally hazardous products and the disposal of waste tires by combustion and energy recovery the characteristics of emissions are the main factor, which must be studied.it is found that from the pyrolysis plant enormous amount of pyrolysis carrier gas produced and 10% of total production. Gaseous, metallic and fugitive emissions were produced during pyrolysis oil production from waste tires. During the operation of condensation few non-condensable gasses like are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethene (C_2H_4), propane (C_3H_8), propene (C_3H_6), butane (C_4H_{10}), butene (C_4H_8), butadiene (C_4H_6), carbon dioxide (CO_2), carbon monoxide (CO) and hydrogen sulphide (H_2S).The gas composition presents in the combustion flame actually depends on the property of the natural rubber presents on the tires materials like as styrene–butadiene rubber, natural rubber (polyisoprene),nitrile rubber, chloroprene rubber, polybutadiene rubber ;which leads the pollution level and original molecular originates particle from rubber (Tires, 1983).Thermal degradation of produces higher concentrations of alkenes and dienes and butadiene also creates light hydrocarbons; gas composition products rely on the temperature of pyrolysis, heating rate, type of reactor etc. (Rada et al., 2012b; Williams et al., 1990). Increasing pyrolysis temperature produces an increase in hydrogen, methane C_1–C_4 hydrocarbons, carbon dioxide, carbon monoxide, hydrogen sulphide hydrogen (Kaminsky et al., 2009; Williams & Brindle, 2002). During the full operating condition pyrolysis plant produces three sources of emissive substances (1) waste water (2) pyrolysis combustion chamber (3) fugitive emissions.

5.1 Gaseous emission from pyrolysis gas combustion

1 tons of waste tires pyrolysis operations produce 0.1 tons of gas.40 % of produced gas used for pyrolysis plant, 30% for drying and another proportion is used for flare spark. Pyrolysis emissive substances, trends to pollutants (Sulphur, chlorine, metals) which may either in the oil or in carbon black product. Portland cement plants in united states firing TDF in their separate 43 plants since 2004 and 40% of the clinker producing company uses TDF in their plants.

5.2 Dioxin-furan air emissions

The California Integrated Waste Management (Giugliano et al., 1999) for the Barletto quotes that tests at baseline conditions and with 36% heat replacement with TDF were both at less than 0.100 ng TEQ/M3 @ 11%. These emissions are well below the U.S. MACT limit of 0.200 ng / @ 7%. Dioxin-furan emission data summary for kilns, wet kilns, long dry, preheater and preheater-precalciner kilns with and without TDF and preheater or preheater-precalciner kilns firing TDF with and without in-line raw mill are shown in table 4.

5.3 Filterable particulate matter emissions

Portland cement kilns in U.S.A (Richards et al., 2008) operating results showed (table 8) that average emission rate of 0.064 pounds per ton of dry kiln feed for TDF-firing kilns is slightly lower than the 0.099 pounds per ton of dry kiln feed value for non-TDF firing kilns , Nitrogen Oxides , Sulfur dioxide average emission rate of 443 ppmvd @7% O_2 , 153 ppmvd @7% O_2. For TDF-firing kilns is lower than the 696 ppmvd @7% O_2 and200 ppmvd @ 7%O_2 value for non-TDF firing kilns in the case of Carbon Monoxide average emission rate of 604 ppmvd @7% O_2 and for TDF-firing kilns is higher than the 435 ppmvd @7% O_2 and for Hydrocarbons average emission rate of 48 ppmvd as propane @7% O_2TDF-firing kilns are slightly higher than the 37 ppmvd as propane @7% O_2value for non- TDF firing kilns. (Giugliano et al., 1999) quotes that CO concentrations remained 20 at approximately 200 ppmvd as the TDF firing rate increased from 0% to 36% of the total kiln are shown in table 3.

Table 3 Particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO) & total hydrocarbons (THC) emissions data summary for kilns with and without TDF data summary for kilns.

Parameter	PM emissions for Kilns		NO_x emissions for Kilns		SO_2emissions for Kilns		CO emissions		THC emissions	
	With TDF	Without TDF	With TDF	Without TDF	With TDF	Without TDF	With TDF	Without TDF	With TDF	Without TDF
Number of Emission Test Values	59	100	20	10	19	10	20	11	22	7
Average Concentration, ng TEQ/NM^3@ 7% O_2	0.064	0.099	696	443	153	200	604	435	24	37

Median Concentration, ng TEQ/NM^3@ 7% O_2	0.047	0.065	409	707	165	089	409	182	38	17
Standard Deviation, ng TEQ/NM^3@ 7%O_2	0.059	0.113	189	408	127	239	565	494	74	10
Minimum Concentration, ng TEQ/NM^3@ 7% O_2	0.002	0.000	252	240	1.5	0.000	0.000	5.1	0.4	1.1
Maximum Concentration, ng TEQ/NM^3@ 7% O_2	0.262	0.658	1,055	1,563	697	587	1,525	1,234	355	127

Table 4 Dioxin-furan emission data summary for kilns, wet kilns, long dry, preheater and preheater-precalciner kilns with and without TDF and preheater or preheater-precalciner kilns firing TDF with and without an in-line raw mill.

Parameter	Kilns		Wet Kilns		Long Dry Kilns		Preheater and Preheater-Precalciner Kilns		Preheater and Preheater-Precalciner Kilns Firing TDF	
	With TDF	Without TDF	With TDF	Without TDF	With TDF	Without TDF	With TDF	Without TDF	In-Line Raw Mill Operating	In-Line Raw Mill Offline
Number of Emission Test Values	97	161	12	31	9	34	76	90	35	34
Average Concentration, ng TEQ/M^3 @ 7% O_2	0.021	0.062	0.036	0.056	0.029	0.060	0.018	0.068	0.008	0.005
Median Concentration, ng TEQ/M^3 @ 7% O_2	0.004	0.013	0.011	0.021	0.013	0.020	0.002	0.012	0.0004	0.002
Standard Deviation, ng TEQ/M^3 @ 7% O_2	0.054	0.119	0.058	0.120	0.038	0.112	0.054	0.125	0.023	0.009
Minimum Concentration, ng TEQ/M^3 @ 7% O_2	0.000	0.000	0.0003	0.0003	0.005	0.0009	0.000	0.000	0.000	0.000
Maximum Concentration, ng TEQ/M^3 @ 7% O_2	0.380	0.644	0.189	0.644	0.122	0.579	0.380	0.616	0.124	0.045

6. CONCLUSIONS

In this experimental study, the unit production cost of pyrolytic oil from scrap tires is far lower than the conventional petroleum product price in Bangladesh and the reliability of pilot plant basis pyrolysis oil production from waste tires is a futuristic improvement in the sector of industrial renewable energy research. The main products that can be found from the pyrolysis reactor are fuel, gas, and char. The maximum liquid product was found to be 34 of tire feed. Other two by-products were solid char and gas with their yields of 57 and 9of weight respectively. The highest temperature of the reactor was 45. The use of waste tire for the production of pyrolysis oil will decrease the land filling, furnace oil export, steel export and it will decrease dissipation of waste tires in Bangladesh with the aim of safer energy production. The process also offers the potential for production of economically attractive non-fuel products.

REFERENCES

Abnisa, F., & Daud, W. M. A. W. (2014). A review on co-pyrolysis of biomass: an optional technique to obtain a high-grade pyrolysis oil. *Energy Conversion and Management, 87*, 71-85.

Acevedo, B., & Barriocanal, C. (2014). Fuel-oils from co-pyrolysis of scrap tyres with coal and a bituminous waste. Influence of oven configuration. *Fuel, 125*, 155-163.

Antoniou, N., & Zabaniotou, A. (2013). Features of an efficient and environmentally attractive used tyres pyrolysis with energy and material recovery. *Renewable and Sustainable Energy Reviews, 20*, 539-558.

Aziz, M. A, Shams, F., Rashid, M. M., & Uddin, M. (2015). Design and development of a compressed air machine using a compressed air energy storage system. *ARPN Journal of Engineering and Applied Sciences, 10*(23), 17332-17336.

Erdem, H. H., Dagdas, A., Sevilgen, S. H., Cetin, B., Akkaya, A. V., Sahin, B., . . . Atas, S. Thermodynamic analysis of an existing coal-fired power plant for district heating/cooling application. *Applied Thermal Engineering, 30*(2-3), 181-187.

Fernández, A., Barriocanal, C., & Alvarez, R. (2012). Pyrolysis of a waste from the grinding of scrap tyres. *Journal of hazardous materials, 203*, 236-243.

Giugliano, M. C., S. Ghezzi, U. and Grosso, M. (December 1999). Experimental Evaluation of Waste Tire Utilization in Cement Kilns,. *Air and Waste Management Association,Pittsburgh, Pennsylvania, USA, 49*, 1405-1411.

Giugliano, M., Cernuschi, S., Ghezzi, U., & Grosso, M. (1999). Experimental evaluation of waste tires utilization in cement kilns. *Journal of the Air & Waste Management Association, 49*(12), 1405-1414.

Haque, M. S. M. M. "Bangladesh Fuel Additional Information," Bangladesh Petroleum Corporation, 2015.

Islam, M. R., Nabi, M. N., & Islam, M. N. (2001). *Characterization of biomass solid waste for liquid fuel production.* Paper presented at the Proc. of.

Islam, M., Islam, M., Mustafi, N., Rahim, M., & Haniu, H. (2013). Thermal recycling of solid tire wastes for alternative liquid fuel: the first commercial step in Bangladesh. *Procedia Engineering, 56*, 573-582.

Islam, M., Joardder, M., Hasan, S., Takai, K., & Haniu, H. (2011). Feasibility study for thermal treatment of solid tire wastes in Bangladesh by using pyrolysis technology. *Waste management, 31*(9), 2142-2149.

Kaminsky, W., Mennerich, C., & Zhang, Z. (2009). Feedstock recycling of synthetic and natural rubber by pyrolysis in a fluidized bed. *Journal of Analytical and Applied Pyrolysis, 85*(1–2), 334-337. doi:http://dx.doi.org/10.1016/j.jaap.2008.11.012

Kotresh, K., & Belachew, M. G. (2014). Study On Waste Tyre Rubber As Concrete Aggregates. *International Journal of Scientific Engineering and Technology, 3*(4), 433-436.

Nabi, A. R., Masud, M. H., & Alam, Q. I. (2014). Purification of TPO (Tire Pyrolytic Oil) and its use in diesel engine. *IOSR Journal of Engineering, 4*(3), 1.

Oladiran, M. T., & Meyer, J. P. (2007). Energy and exergy analyses of energy consumptions in the industrial sector in South Africa. *Applied Energy, 84*(10), 1056-1067.

Önenc, S., Brebu, M., Vasile, C., & Yanik, J. (2012). Copyrolysis of scrap tires with oily wastes. *Journal of Analytical and Applied Pyrolysis, 94*, 184-189.

Osayi, J. I., Iyuke, S., & Ogbeide, S. E. (2014). Biocrude production through pyrolysis of used tyres. *Journal of Catalysts, 2014*.

Rada, E. C., Ragazzi, M., Dal Maschio, R., Ischia, M., & Panaitescu, V. N. (2012a). Energy recovery from tyres waste through thermal option. *UPB Sci Bull., series D, 74*(4), 201-210.

Rada, E. C., Ragazzi, M., Dal Maschio, R., Ischia, M., & Panaitescu, V. N. (2012b). Energy recovery from tyres waste through thermal option. *Scientific Bulletin, Politehnica University of Bucharest, Series D, Mechanical Engineering, 74*, 201-210.

Rahman, M. A., Ruhul, A., Aziz, M., & Ahmed, R. (2016). Experimental exploration of hydrogen enrichment in a dual fuel CI engine with exhaust gas recirculation. *International Journal of Hydrogen Energy*.

Richards, J., Goshaw, D., Speer, D., & Holder, T. (2008). Air emissions data summary for Portland cement pyroprocessing operations firing tire-derived fuels. *PCA R&D Serial*(3050), 60077-61083.

Tires, S. (1983). A Resource and Technology Evaluation of Tire Pyrolysis and Other Selected Alternate Technologies. *EG&G Idaho, Inc., Dodds, Domenico, Evans & Lassahn*.

Uddin, M. S., Joardder, M. U. H., & Islam, M. N. (2012). Design and construction of fixed bed pyrolysis system and plum seed pyrolysis for bio-oil production. *International Journal of Advanced Renewable Energy Research, 7*(1), 405-409.

Utlu, Z., Sogut, Z., Hepbasli, A., & Oktay, Z. (2006). Energy and exergy analyses of a raw mill in a cement production. *Applied Thermal Engineering, 26*(17-18), 2479-2489.

Williams, P. T., & Brindle, A. J. (2002). Catalytic pyrolysis of tyres: influence of catalyst temperature. *Fuel, 81*(18), 2425-2434. doi:http://dx.doi.org/10.1016/S0016-2361(02)00196-5

Williams, P. T., Besler, S., & Taylor, D. T. (1990). The pyrolysis of scrap automotive tyres: The influence of temperature and heating rate on product composition. *Fuel, 69*(12), 1474-1482. doi:http://dx.doi.org/10.1016/0016-2361(90)90193-T