International Conference on Mechanical, Industrial and Materials Engineering 2013 (ICMIME2013)
1-3 November, 2013, RUET, Rajshahi, Bangladesh.

Paper ID: ET-31

Characterization and Improvement of Char Product Obtained from Pyrolysis Conversion of Solid Tire Wastes into Liquid Fuels

M.S. Hossain[1], M.R. Islam[2], H. Haniu[3]
[1]Department of Refrigeration and Air Conditioning,
Rajshahi Polytechnic Institute, Rajshahi, Bangladesh
[2]Department of Mechanical Engineering
Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh,
[3]Department of Mechanical Engineering
Kitami Institute of Technology, Kitami city, Hokkaido 090-8507, Japan
E-mail: samim_ppi@yahoo.com

Abstract

Characterization and improvement of by-product char obtained from tire waste pyrolysis plants have been taken into consideration in this study. The char samples were collected from a commercial plant and also from a pilot plant. The samples were characterized through sieving , proximate and ultimate analysis, calorific values and TG/DTG analysis to investigate their suitability for upgrading / improved utilization. Upgrading experiments on char samples have been conducted by using briquetting technology. Tire char were mixed with rice husk at 25wt%, 35wt%, and 45wt% of total mixture and briquettes were produced by using screw press high compaction technique. The briquettes produced using 25wt% of tire char showed good compaction quality with substantial increase in heat value and bulk density. Char plate were also produced from tire derived char powder by low compaction technology using sugarcane molasses, cow dung and boiled rice water as binding materials. Boiled rice water creates very good bonding of the char powders among three types of binding materials. Thus, the tire derived pyrolytic char have good potential to be used as fuel.

***Keywords**:* Solid tire wastes, Pyrolysis, Char product, Characterization, Improvement

1. Introduction

It is estimated that about 90,000 metric tons tires become scrap and are disposed of every year in Bangladesh [1]. The disposal of non-biodegradable solid tire wastes from human activity is a growing environmental problem for the modern society, especially in developing countries. Unfortunately, most of these scrap tires are simply dumped under open sky and in landfills in developing countries. Open dumping may result in accidental fires with highly toxic emissions or may act as ideal breeding grounds for disease carrying mosquitoes and other vermin with the aid of rain water. Landfills full of tires are not acceptable to the environment because tires do not easily degrade naturally. In recent years, many attempts have been made to find new ways to recycle tires: reconstruction of waste tires, shredding or grinding and crumbling to recycle rubber powders, incineration to supply thermal energy in utility boilers to produce electricity, in cement kilns and brick fields.

However, grinding is quite expensive because it is performed at cryogenic temperatures and requires energy-intensive mechanical equipment, while incineration may produce hazardous polycyclic aromatic hydrocarbons (PAHs) and soot during the combustion process.

Pyrolysis as an attractive method to recycle scrap tires has recently been the subject of renewed interest. Pyrolysis of tires can produce oils, chars, and gases, in addition to the steel cords, all of which have the potential to be recycled. Tire pyrolysis liquids (a mixture of paraffin's, olefins and aromatic compounds) have been found to have a high gross calorific value (GCV) of around 41-44 MJ/kg, which would encourage their use as replacements for conventional liquid fuels [2-10]. In addition to their use as fuels, the liquids have been shown to be a potential source of light aromatics such as benzene, toluene and xylene (BTX), which command a higher market value than the raw oils [2-4, 8, 11-13]. Similarly, the liquids have been shown to contain monoterpenes such as limonene [1-methyl-4-(1-methylethenyl)-cyclohexene], a high value light hydrocarbon. Pyrolytic char may be used as a solid fuel or as a precursor for the manufacture of activated carbon [2, 8, 10, 14]. Roy et al. [9] found that another potentially important end-use of the pyrolytic carbon black (CBp) may be as an additive for road bitumen. Furthermore, active carbons were prepared from used tires and their characteristics were investigated by Roy et al. [9], Zabaniotou and Stavropoulos [15], and Zabaniotou et al. [16]. Some of the previous research groups [2, 4, 8, 11, 17] studied the composition of evolved pyrolysis gas fraction and reported

that it contains high concentrations of methane, ethane, butadiene and other hydrocarbon gases with a GCV of approximately 37 MJ/m^3, a value sufficient to provide the energy required by the pyrolysis process.
Very different experimental procedures have been using to obtain liquid products from tire wastes by pyrolysis technology including [18-22]. all over the world for the last two decades. Within the past ten years, research and development works have also been carried out for the fixed-bed fire-tube heating pyrolysis reactor system at Rajshahi University of Engineering & Technology (RUET). Pyrolysis of various organic solid wastes in the fixed-bed fire-tube heating pyrolysis reactor including pilot plant have been successfully completed and the results are published elsewhere[18-23].
The products yield distributions in the RRE Ltd. tyre wastes pyrolysis plant were found oil: 45 wt%, char: 35 wt%, and gases: 10 wt%, in addition to the steel cords: 10 wt% of solid tire waste. Among the four products oil and gases are using as fuels while steel cords can be recycled in steel industries. A large amount of carbon black is producing in each run of tire waste pyrolysis and there is no economic and sustainable use of this by-product. The pyrolysis plant at RRE Ltd. is dumping the by-product char in the plant site and facing a serious problem for its management. However, it is a crucial issue to find out a sustainable use of this char product. Thus, in this study several attempts have been taken into consideration for the development of new techniques of using the char product.

2. Charaterization of Char Sample

2.1. Bulk density

Bulk density of the char product greatly depends on the particle size. The collected char samples were screened and classified according to sieve mesh sizes of BS 410-86 specification. When the particle size range increases then the bulk density decreases for both commercial and pilot plant pyrolysis char are presented graphically in Fig 1.

2.2. Weight percentage

It is one way of expressing the composition of a mixture in a dimensionless size (mole fraction is another). Weight/mass fraction can refer to the fraction of the weight/mass of one size range to the total mass of a mixture. The weight percentage distribution for the collected char samples are presented in Fig. 2. The results show that the highest weight percentages of char particle sizes were 300-600 µm (47.30wt%) and 2.36 mm < (70.60wt%) for commercial and pilot plant, respectively.

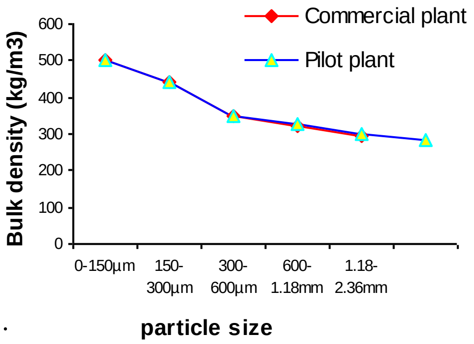

Fig. 1: Bulk density distribution of char product from commercial and pilot plant for different size range

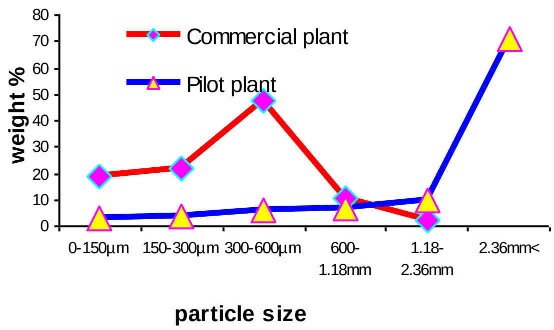

Fig. 2 : Weight percentage distribution of char product from commercial and pilot plant for different size range

2.3. Proximate, ultimate analysis and gross calorific value

Proximate, ultimate analysis and gross calorific value of the char samples compared to solid tire and coal are shown in Table 1,2,3 respectively. The table shows that volatile content of char products is very low compared to solid tire and coal while the fixed carbon content is high. Ash present in pyrolytic char is higher than that of solid tire and it is lower than that of coal. Elemental composition by ultimate analysis, in terms of carbon, hydrogen, nitrogen, oxygen and sulfer (CHNOS) content of the selected pyrolytic tire char is essential for their uses as fuel or any other feedstock. The GCV of the pyrolytic char fraction is 28 MJ/kg, which is comparable with that of the good quality coal.

Table 1. Proximate analysis of solid tire, pyrolytic tire char compared to coal

Sl. No.	Component (wt.%)	Solid tire	Pilot plant char	Commercial plant char	Bangladeshi coal (Barapukuria)
1.	Moisture	0.64	0.60	0.5~1	10.00
2.	Volatile matter	64.46	5.60	7.4	29. 20
3.	Fixed carbon	30.02	84.29	86.00	48.40
4.	Ash	4.88	9.51	6~6.5	12.40

Table 2. Elemental analysis of char compared to coal

Sl. No.	Sample (wt.%)	Solid tire	Pilot plant char	Commercial plant char	Bangladeshi coal (Barapukuria)
1.	C	85.37	81.23	77.30~83.34	64.41
2.	H	7.65	0.92	0.70~1.10	3.96
3.	N	0.47	0.35	0.25~0.40	1.32
4.	S	1.6	2.54	2.35~3.35	0.52
5.	O+Ash	4.91	14.96	11.81~19.40	29.79

Table 3. Gross calorific value of char samples

Test	Solid tire	Pilot plant char	Commercial plant char	Bangladeshi coal (Barapukuria)
GCVs (MJ/kg)	28-40	28.00	28.2	25.68

2.4. TGA and DTG analysis of char sample:

Thermo gravimetric analysis (TGA) and differential thermal gravimetric analysis of char samples are shown in Fig. 3. TG curve indicate the fractional weight loss of volatile in the char sample with temperature and time. DTG indicate the rate of weight loss for the samples.

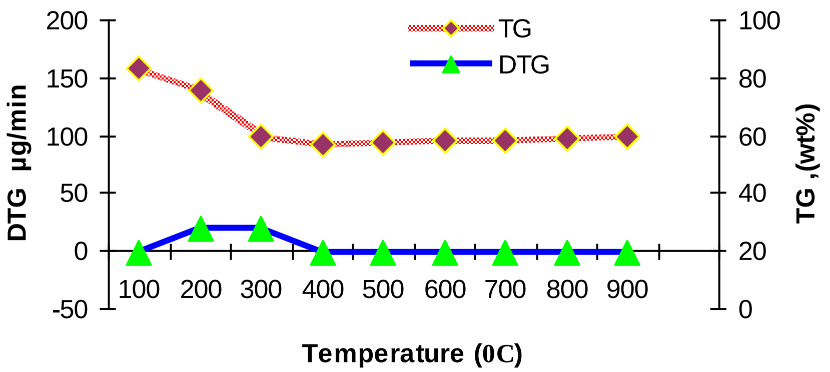

Figure 3 TG and DTG plots for tire char at heating rate of 60^0C/min

3. Improvement of Tire Char Powder

The improvement of tire-derived pyrolytic char have been conducted by using biomass briquetting technology.

Densification / briquetting technology

Usually briquetting technology is used for biomass fuel. Biomass briquetting is the densification of loose biomass material to produce compact solid composites of different sizes with the application of pressure. Briquetting of residues take place with the application of pressure, heat and binding agent on the loose materials to produce the briquettes. The densification techniques provides the following benefit :

- This is one of the alternative methods to save the consumption and dependency on fuel wood.
- Densities fuels are easy to handle, transport and store.
- They are uniform in size and quality.
- The process helps to solve the residual disposal problem.
- The process assists the reduction of fuel wood and deforestation.
- Indoor air pollution is minimized.

Briquetting technology

There are two types of briquetting technologies

- High compaction technology
- Low compaction technology

High compaction technologies

High compaction technology or binder less technology consists of the piston press and the screw press. If fine materials which deform under high pressure, are pressed, no binders are required. The strength of such compacts is caused by vender Wales' forces, valence forces, or interlocking. Natural components of the material may be activated by the prevailing high pressure forces to become binders.

Screw press technology

In the screw press technology, the biomass is extruded continuously by a screw through a taper die which is heated externally to reduce the friction. The screw press technology uses a screw to force the feedstock under high pressure into a heated die thereby forming large cylinders 25 to 100mm in diameter. Normally the die temperature is maintained between 250^0C to 300^0C depending on the raw materials. The raw materials get heated up to 220^0C in this process. The concept is to heat the biomass at a temperature which is sufficient enough to soften the lignin, which is one of the major component of all types of vegetation, as well as pushing through the die to get it compacted. In this process lignin itself works as the binding material so that there is no need to add any additional binding material. This technology is currently operating in Bangladesh and gained much popularity. The merits and demerits of this technology are:

- The output is continuous and the briquette is uniform in size.
- The outer surface of the briquette is partially carbonized facilitating easy ignition and combustion. This also protects the briquettes from ambient moisture.
- A concentric hole in the briquette helps in combustion because of sufficient circulation of air.
- The machine runs very smoothly without any shock load.
- The machine is light compared to the piston press because of the absence of reciprocating parts and flywheel.
- The machine parts and the oil used in the machine are free from dust or raw material contamination.
- The power requirement of the machine is high compared to that of piston press.
- Briquette quality and production procedure of screw press is definitely superior to the piston press technology.

3.1. Production of tire char-rice husk mixed briquette

Literature studies [24] shows that good compaction in biomass briquetting is obtained from a mixing of feed size 6-8 mm with 10-20% powdery component (< 4 mesh). Higher compaction is also obtained with moisture content of the feed materials less than 10% [25]. Besides, in order to upgrade heat value and combustibility of the biomass briquette, charcoal or coal in fine form can be added up to 20% [23]. Characterization study shows that more than 95% of commercial plant char is within sizes < 4 mesh. Moisture content of tire char is also less than 10% with a heat value of 28 MJ/kg, sufficiently higher than that of coal (25 MJ/kg). Thus, we have a better option for utilization of tire char as a suitable additives in biomass briquetting. Collected tire char samples were mixed manually with rice-husk at three different proportions.

The mixed dry feed materials were taken into the feeding hopper for briquette production. Then the furnace was started to heat the die. The screw was rotated inside the die by an electric motor. The briquetting machine uses a large screw to grind, compress and extrude the biomass into briquettes. The natural lignin content in the husk is liberated under high pressure and temperature. When temperature of die raised up to 300^0 C, the material can feed continuously into briquetting machine. In the briquetting process lignin serves as the binder and bonded the particles of char-rice husk together. Finally the briquettes were collected into collector. The whole operational procedure for the complete briquettes production is presented by a flow chart in. The diameter of the briquettes is closely related to the output port of the machine. In this process pallets of briquette produce around 1 to 4 cm diameter and length 70 to 100 cm.

The physical properties of tire char mixed have been studied for the investigation of their improvement. The tire char were mixed with rice husk at 25wt%, 35wt% and 45wt% of total mixture. The mixture with lowest weight percentage of tire char showed better compaction behavior with good machine performance. briquettes were became brittle with the increase amount of tire char in the mixture. Besides, power consumption by the motor also increased with the increase of char in the mixture. Tire char-rice husk mixed briquettes production results are summarized in Table 4.

Table 4. Briquettes production results

Sl. No.	Mixed wt% of tire char	Compaction quality	Power consumption
1.	25%	Good (Not brittle)	Low
2.	35%	Poor (brittle)	Medium
3.	45%	Very poor (Almost does not form briquettes)	high

Physical properties of 25wt% tire char mixed briquettes are presented in Table 5. The Table shows that heat value of the char mixed briquettes is higher than that of rice husk briquettes. The presence of char in the briquettes reduces its compressive load bearing capacity. This is due to the poor binding ability of char particle. Table 7 also shows that volume of the tire char increased about four times after making briquettes.

Table 5. Physical property of tire char mixed briquettes

Sl. No.	Property	Rice husk briquettes	Mixed briquettes (25wt% char - 75wt% rice husk)	Commercial plant char	Pilot plant char
1.	Heat value (MJ/kg)	19.36	20.38	28.20	28.00
2.	Compressive stress (N/m^2)	5040000	4420000	-	-
3.	Density (kg/m^3)	1145	1227	360	350

3.2. Production of Char Plate

Char plate were produced by using low compaction technology. A manually operated piston cylinder arrangement have been developed for production of char plate using cow-dung, boiled rice water or sugarcane molasses as binding material. Sufficient amount of cow dung or sugarcane molasses was mixed with tire char and spreaded over the floor. A 60mm x 60mm square shaped piston-cylinder arrangement was placed continuously on the spreaded char. The piston was pressed manually, char compacted and char plate were obtained with sufficient amount of strength. The char plate were sun dried and prepared for their characterization to be used as solid fuel. Boiled rice water produce very good compaction among the three types of binding materials. Sugarcane molasses increases the heat value of the tire char plate. The characteristics of char plate of different binding material are shown in Table 6.

Table 6. Characteristics of tire char plates

Sl. No.	Tire of binder materials	Mixing ratio(wt%)	Compaction quality	Heat value(MJ/kg)
1	Sugarcane molasses	10	Good	27.17
2	Cow dung	10	Good	26.18
3	Boiled rice water	10	Very good	25.38

Very good = higher strength than rice-husk briquettes; good = almost equal strength of rice-husk briquettes

4. Conclusions

In the presented study on the tire derived char the follow conclusions may be drawn:

- The highest weight percentages of char particle sizes were 300-600µm (47.30wt%) and 2.36mm < (70.60wt%) for commercial and pilot plant, respectively.
- Volatile content of char products is very low compared to solid tire and coal while the fixed carbon content is high. Ash present in pyrolytic char is higher than that of solid tire and it is lower than that of coal.
- Elemental analysis of the pyrolytic char showed the results (by weight): C = 77.30-83.34%; H = 0.70-1.10%; N = 0.25-0.40%; S = 2.35-3.35% and O + ash = 13.36-18.15%
- Thermal decomposition behavior shows that <10wt% moisture and volatile are present in the char samples.
- Heating value of the char mixed briquettes is higher than that of rice husk briquettes. The presence of char in the briquettes reduces its compressive load bearing capacity. Volume of the tire char decreased about four times after making briquettes.

- Boiled rice water produce very good compaction among the three types of binding materials to produce char plate. Sugarcane molasses increase the heat value of the tire char plate.

References

[1] Bangladesh Bureau of Statistics, Government of Peoples Republic of Bangladesh. Statistical Year Book of Bangladesh 2008. 28^{th} ed.; Dhaka, 2009.

[2] Rodriguez IM, Laresgoiti MF, Cabrero MA, Torres A, Chomon MJ, Caballero B. Pyrolysis of scrap tires. Fuel Processing Technology 2001;72:9–22. [and references therein]

[3] Laresgoiti MF, Caballero BM, De Marco I, Torres A, Cabrero MA and Chomon MJJ. Characterization of the liquid products obtained in tire pyrolysis. J. Anal. Appl. Pyrolysis 2004;71:917–934.

[4] Gonzalez JF, Encinar JM, Canito JL, Rodriguez JJ. Pyrolysis of automotive tire waste. Influence of operating variables and kinetic study. J. Anal. Appl. Pyrolysis 2001;58–59:667–83 [and references therein].

[5] Diez C, Martinez O, Calvo LF, Cara J, Moran A. Pyrolysis of tires. Influence of the final temperature of the process on emissions and the calorific value of the products recovered. Waste Management 2004;24:463-469.

[6] Dai X, Yin X, Wu C, Zhang W, Chen Y. Pyrolysis of waste tires in a circulating fluidized-bed reactor. Energy 2001;26:385-399.

[7] Pakdel H, Pantea DM, Roy C. Production of dl-limonene by vacuum pyrolysis of used tires. J. Anal. Appl. Pyrolysis 2001;57:91–107.

[8] Cunliffe AM, Williams PT. Composition of oils derived from the batch pyrolysis of tires. J. Anal. Appl. Pyrolysis 1998;44:131–52. [and references therein]

[9] Roy C, Chaala A, Darmstadt H. Vacuum pyrolysis of used tires End-used for oil and carbon black products. J. Anal. Appl. Pyrolysis 1999;51:201–221.

[10] Barbooti MM, Mohamed TJ, Hussain AA, Abas FO. Optimization of pyrolysis conditions of scrap tires under inert gas atmosphere. J. Anal. Appl. Pyrolysis 2004;72:165–170.

[11] Williams PT, Brindle AJ. Aromatic chemicals from the catalytic pyrolysis of scrap tires. J. Anal. Appl. Pyrolysis 2003;67:143–164.

[12] Williams PT, Brindle AJ. Temperature selective condensation of tyre pyrolysis oils to maximise the recovery of single ring aromatic compounds. Fuel 2003;82:1023–1031.

[13] Pakdel H, Roy C, Aubin H, Jean G, Coulombe S. Formation of limonene in used tire vacuum pyrolysis oils. Environ. Sci. Technology 1992;9:1646.

[14] Cunliffe AM, Williams PT. Influence of process conditions on the rate of activation of chars derived from pyrolysis of used tires. Energy & Fuels 1999;13(1):166–175.

[15] Zabaniotou AA, Stavropoulos G. Pyrolysis of used automotive tires and residual char utilization. J. Anal. Appl. Pyrolysis 2003;70:711–722.

[16] Zabaniotou AA, Madau P, Oudenne PD, Jung GC, Delplancke MP, Fontana A. Active carbon production from used tire in two-stage procedure: industrial pyrolysis and bench scale activation with H_2O-CO_2 mixture. J. Anal. Appl. Pyrolysis 2004;72:289–297.

[17] Murena F, Garufi E, Smith RB, Gioia F. Hydrogenative pyrolysis of waste tires. Journal of Hazardous Materials 1996;50:79-98.

[18] Islam, M.R., Parveen, M., HANIU, H and Sharker, M. R. Innovation in pyrolysis technology for management of scrap tire: a solution of Energy and Environment. International Journal of Environmental Science and Development, Vol. 1; No.: 1; pp. 89-96; April 2010.

[19] Islam, M. R, Kim, S. I., Haniu H. and Beg, M. R. A. Fire-tube heating pyrolysis of car tire wastes: end uses of product liquids as fuels and chemicals. International Energy Journal, Vol. 9, No. 3; pp: 189-198; September 2008.

[20] Islam, M. R., Haniu, H. and Beg, M. R. A. Liquid fuels and chemicals from pyrolysis of motorcycle tire waste: product yields, compositions and related properties. FUEL, Vol. 87, No. 13-14; pp. 3112-3122; October 2008.

[21] Islam, M. R., Tushar, M. S. H. K. and Haniu, H. Production of liquid fuels and chemicals from pyrolysis of Bangladeshi bicycle/rickshaw tire wastes. Journal of Analytical and Applied Pyrolysys, Vol. 82, No. 1; pp. 96-109; May 2008.

[22] Islam, M. R., Haniu, H. and Beg, M. R. A. Limonene-rich liquids from pyrolysis of heavy automotive tire wastes. Journal of Environment and Engineering, Vol. 2, No. 4; pp. 681-695; October 2007.

[23] Kader, M. A. Development of self sufficient pyrolysis system for production of liquid fuel from organic solid waste. M.S.Engg. thesis Dept. of ME, RUET, 2013.

[24] Sugumaran, P Seshadri, S. Keywords evaluation of selected biomass for charcoal production. Biomass carbonization calorific value. Charcoal Nopr.niscair.res.in › ... › JSIR Vol.68 [2009] › JSIR Vol.68(08) [August 2009]

[25] Abkr, Y. A. and Abasaeed, A. E. (2006). Experimental evaluation of a conical-screw briquetting machine for the briquetting of carbonized cotton stalks in Sudan, Journal of Engineering Science and Technology, vol.1(2), 2006, pp. 212 – 220.