ESTIMATION OF LIQUID FUEL AND ENERGY PRODUCTION FROM PYROLYSIS OF WASTE TIRES

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Abstract

The pyrolysis process is a new technology for dealing with daily generated scrap tires. The process involves heating the tires in absence of oxygen to high temperatures between 300°C and 900°C. The final products are gas, liquid and solid char. The pyrolytic liquid has a high calorific value (40 – 41 MJ/kg) and its properties are similar to those of diesel fuel and it can be used as diesel alternative. This process is optimized for maximum liquid product yield.

This research reviews experimental works run on the pyrolysis process investigating its optimal conditions. In addition, a case study in Jumayel city, Libya, is studied to calculate the amount of energy that can be recovered as liquid fuel from pyrolysis of scrap tires.

The results showed that 250 ton of pyrolytic oil with energy of 315 kW is recoverable from 480 ton of disposed tire for the year of 2019.These results were extended for the next decay.

Keywords: Pyrolysis; scrap tires; pyrolytic liquid.

Introduction

Due to population growth and industrialization spread, environmental degradation is the main problem humanity face today. Huge quantities of solid refuse are generated daily.

Recovery of resources from nonconventional sources, like municipal and/or industrial organic wastes, refused plastics and used tires becomes essential to reduce the environment degradation rate. Part of energy demand can be provided from waste recovery.

The disposal of organic solid wastes from human activity is a growing environmental problem for modern society, especially in developing countries. One of the very common and most seriously hazardous solid wastes in the world is the scrap tires (Williams, 2005). The dumping of used tires in landfills is accompanied by several hazards. Tires take up large amounts of valuable landfill space providing an ideal breeding ground for mosquitoes. Once ignited, tire fires result into highly toxic emissions. Tires are not biodegradable for short term; thus, for proper management, they need to be recycled and retreaded rather than discarded. Many recycling processes can be adopted for scrap tires such as fuel source, pyrolysis, de-polymerization, in asphalt and reclaiming.

Pyrolysis is the process of thermal degradation of tire rubber into smaller, less complex molecules at high temperatures (300–900°C) in an inert atmosphere (i.e. absence of oxygen). The pyrolysis of solid tire wastes has received increasing attention since its process conditions may be optimized to produce high heating value liquids, char and gases as shown in Figure (1) (Islam et al., 2010).

The gross calorific value of tire pyrolysis liquids (a mixture of paraffins, olefins and aromatic compounds) has been found to be around 41-44 MJ/kg. This high energy density is considered as an advantage for the pyrolytic liquid to replace the conventional liquid fuels such as diesel which has 43 MJ/kg calorific value (Islam et al., 2008).

Light aromatic fuels, such as benzene, toluene and xylene (BTX) are obtained from final pyrolysis liquid product. Moreover, solid fuel and activated carbon may be manufactured from pyrolytic char.

Pyrolysis gas fraction contains high concentrations of methane, ethane, butadiene and other hydrocarbon gases with a GCV of approximately 37 MJ/m3, which meets the energy requirement of the pyrolysis process (Cunliffe et al., 1998; Pakdel et al., 2001).

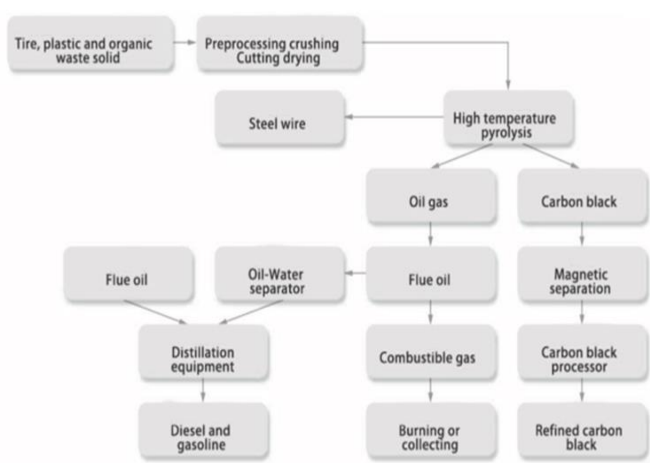


Figure (1): Products of Pyrolysis of Scrap Tires.

The only raw material required for most tire pyrolysis processes is scrap tires. Whole tires are usually added manually to the reactor. If the processor is using chipped tires, the chips are stored in a chip silo and are fed from the silo into the reactor using a vibratory feeder or a screw conveyor to achieve a controllable and known feed rate. The yields percentage and composition of the derived products are influenced by the operating conditions in terms of the range of reactor temperatures, feed size, flow rate of inert gas, heating rate, and heating time.

Effect of Pyrolysis Temperature and Feed Size

The relative product yields of gas, liquid and solid obtained from scarp tire pyrolysis are influenced by the reactor temperature, feed size, residence time or inert flow rate, heating rate and the reaction time.

These factors have been investigated by a number of researchers (Islam et al., 2010; Shameem et al., 2015). The pyrolysis temperatures were considered for different fixed variables such as the feed size, the heating rate and the residence time in terms of inert flow rate.

Islam et al. (2010) performed experiments on fixed-bed fire-tube heating reactor system and found that the optimum liquid yields conditions for this reactor system were operating temperature 475oC, feed size 4 cm3 and vapor residence time 5sec.

Shameem et al. (2015) investigated a similar system for the influences of pyrolysis temperature between 300°C and 600°C, heating rate, operating time and sample size on yield, and the optimum pyrolytic oil of 42.0% which was obtained for tire pyrolysis at 450ºC. The results showed insignificant effect of sample size on pyrolytic oil productivity within the tested range of 0.75 cm3-1.25 cm3. However, the maximum yield of pyrolytic oil was obtained with tire size of 0.75 cm3 for total load of 1.5 kg. More oil and less char are optimized when operating time is less than 45 minutes. The experimental work of thermal pyrolysis of bicycle tire have been done using the batch reactor to produce liquid fuel with calorific value of 34.61MJ/kg. The measured properties of the end liquid product showed that it can be used as liquid fuels and as chemical feed stocks. The obtained maximum liquid yield was (49%) at 600°C temperature with a heating rate of 20°C/min. Char yields increase at lower temperature and gaseous product increases at higher temperature (Pradhan et al. 2011).

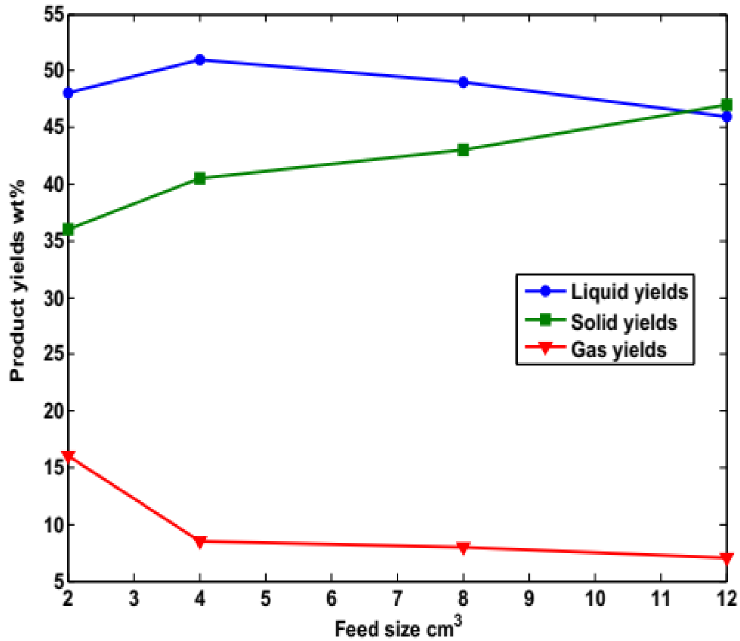


Figure (2): Product Fractions of Pyrolysis vs. Feed Size.

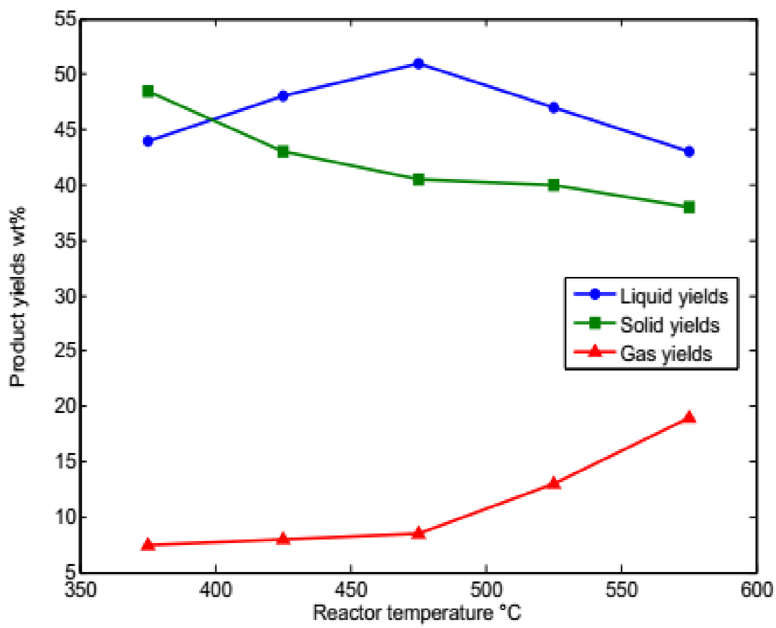


Figure (3): Product Fractions of Pyrolysis vs. Temperature.

Pyrolytic Liquid

Based on its fuel properties, tire-derived pyrolytic liquids may be considered as a valuable component for use with automotive diesel fuels. Moreover, the liquids may be directly used as fuels for industrial furnaces, power plants, and boilers (Williams, 2005). The important requirements for diesel fuel are its ignition quality, viscosity, and water, sediment, and sulfur contents. Therefore, the pyrolytic liquids require preliminary treatments such as decanting, centrifugation, filtration, desulphurization, and hydro treating to be used as fuels.

Table (1): Pyrolytic Oil vs. Diesel Elemental Composition and Physical Properties (Islam et al., 2010).

Element	Pyrolytic Oil	Diesel	Physical Properties	Pyrolytic Oil	Diesel
C	86.52	84-87	Density	943	820-860
H	9.35	12.8-15.7	Viscosity	4.62	2.0-4.5
N	0.53	<3000 ppm	Flash point	≤ 30	≤ 55
S	1.30	<7000 ppm	Pour point	-4	-40--30
O	2.10	0.0	GCV	41.60	44-46
Ash	0.20	0.0			

Fuel properties of the pyrolytic liquids were compared to commercial automotive diesel. The density and the viscosity of liquid products from automotive tire wastes were higher than that of the diesel but too much lower than that of heavy fuel oil (980 kg/m3 at 20oC) and (200 cSt at 50oC). The flash point of the tire-derived liquids (≤30oC) is low when compared with petroleum-refined fuels. The outcomes of the experiment executed in a fixed-bed fire-tube heating pyrolysis reactor system by Islam et al. (2010) concluded that fuel properties of the pyrolysis liquids such as density, viscosity, GCV, carbon and hydrogen contents are almost comparable to those of the commercial automotive diesel fuels but they are of higher sulphur content and low flash point. The pyrolytic liquids abundantly contain olefins, especially limonene and light aromatics, which have higher market values as chemical feedstock than their use as fuels (Islam et al., 2010).

Estimation of Recoverable Energy from Pyrolysis of Tires

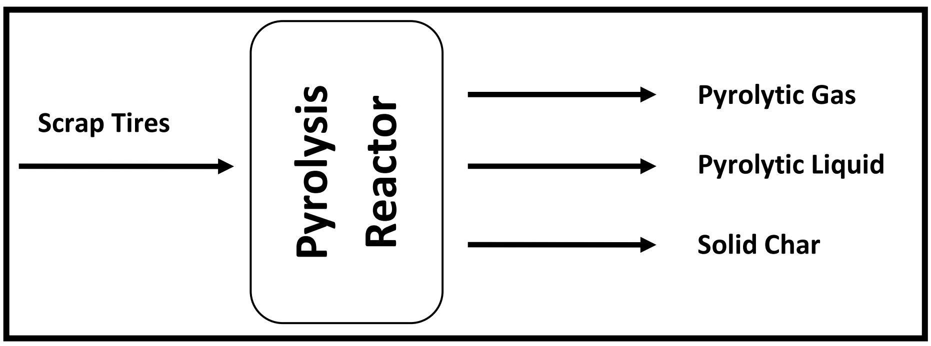
The total population of Jumail city, west of Libya, is about 120000 citizens according to the Bureau of Statistics and Census, 2020. The solid waste management system adopted by the local municipal authority lacks efficiency. There is no system of wastes collection and sorting is followed and all kinds of wastes are simply assembled manually from homes and tire repair workshops. Wastes are dumped in non-configured landfill, which is located in low populated areas, amongst farms, in direct contact with soil and exposed to rain and leaching waters. Therefore, solid waste management system needs to be established concerning different types of refuses. This study introduces the theoretical estimations of the recoverable energy from expired tires that community in the city might benefit from.

It is commonly known that one tire is wasted per person per year in the world. However, some reports indicate that the annual tire consumption in the industrialized countries per person is (3.1) tire per citizen.

No official statistics are available for Libyan citizens, but some studies consider that the rate of consumption in Libya is about 1 tire per 2 persons (Wanis, 2016). It is assumed that the tire consumption rate is identical for all Libyan cities. If the national or local population of a certain area is known then the annual consumption rate of tires and how much oil fuel can be extracted from waste tires can be estimated.

The Overall Steady-State mass Balance on the Pyrolysis Unit

$$\textbf{mass in} = \textbf{mass out}$$



$$\begin{bmatrix}\textbf{total annual quantity}\\ \textbf{of scrap tires}\end{bmatrix} = \frac{\textbf{\# tire}}{\textbf{person}} \times \textbf{population} \times \textbf{mass of one tire}$$

$$\begin{bmatrix}\textbf{Total energy recoverd}\\ \textbf{from pyrolytic oil}\end{bmatrix}$$
$$= \begin{bmatrix}\textbf{Total annual quantity}\\ \textbf{of scrap tires feed}\end{bmatrix} \times \begin{bmatrix}\textbf{Fractional conversion of}\\ \textbf{scrap tires to liquid}\end{bmatrix} \times \begin{bmatrix}\textbf{Heating value}\\ \textbf{of kg of pyrolytic oil}\end{bmatrix}$$

Results and Discussions

The significant differences between the experimental works, in terms of pyrolysis product yields and their distribution over whole range of temperature, are attributed to the specific characteristics of each experimental system, including of reactor type and size, feed particle size and vapor residence time (Islam et al., 2010).

The results of the work done of Islam et al. is adopted in this study, where a fixed-bed fire-tube heating pyrolysis reactor was designed to pyrolyse tire wastes under N2 atmosphere. The results of their work are plotted in Figure (3) and Figure (4). It is obvious that the optimum temperature and feed size of the maximum pyrolytic liquid of 51.5 wt% are 4 cm3 and 475°C.The quantity of the expected pyrolysis liquid is calculated based on this value. The results are summarized in Figure (4). As the pyrolysis process converts more than the half quantity of scrap tires to liquid oil at optimum conditions of temperature and feed size, the specific heating value of the end product oil is reported by an experimental research works of 40 MJ/kg run by(Islam et al., 2010).

For one year of 2020, the ideal output energy that can be obtained from pyrolytic oil is 310.5 kW which represents about 0.52% of the country requirements of electrical energy. The results can be forecasted for the next ten years since the national population growth rate is 1.8% and every two citizens will consume one tire per year.

The production capacity of pyrolytic oil can be boosted yearly accompanying the linear raise in the local population. At the end of next decade, about 300 ton/year of oil is extracted from scrap tire. This means a quantity of recoverable energy of 380 kW.

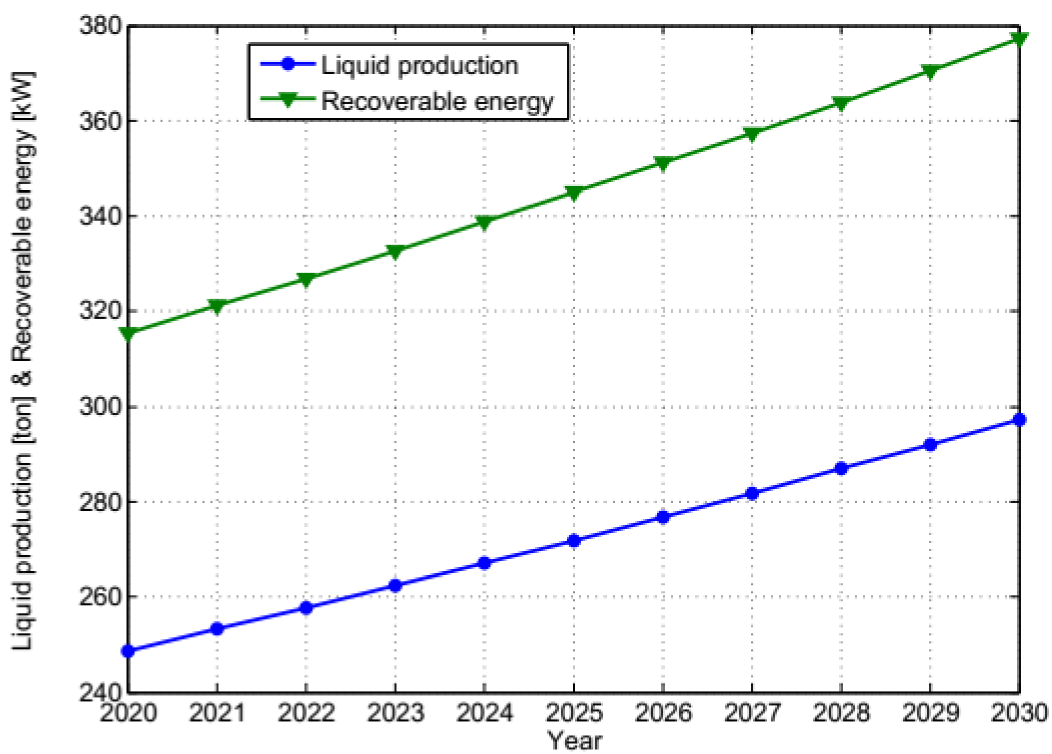


Figure (4): Fuel Production and Recoverable Energy from Pyrolysis of Tires.

Conclusions

The pyrolysis of scrap tires were discussed. A number of previous experimental research works that investigated the optimum conditions of the pyrolysis process were reviewed. Almost all published literatures aimed to maximize the liquid product due to its potential as an alternative fuel for conventional diesel. Temperature, feed size and vapor residence time were found to be the most important factors that influence the product yields.

A case study of Jumayel city, Libya, were considered for searching the pyrolysis of scrap tires as an alternative route for tire landfill. The theoretical calculations proved that a significant amount of energy as liquid and gaseous fuel can be recovered from the expired tires.

The researchers call for more research effort, experimental in particular, on the local and national level to explore production capacity, economic profitability and the environmental hazardous.

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