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Fabrication and Performance Test of a Cold Model of Fire Tube with Fixed Heating Pyrolysis System

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ABSTRACT
Among various methods of thermochemical conversion of organic solid wastes into bio-crude, a fixed bed pyrolysis system has attained much attention. In this study, one cylindrical cold model fixed bed reactor has been constructed from a Plexi glass pipe. A gas distributor of Plexiglass sheet with 218 holes has been fabricated. In this study, the required air pressure and flow were measured to escape the pyrolytic char from the cylindrical reactor. The actual pyrolytic char makes the Plexiglass reactor and the laboratory dirty. Thus, a pulls husk of size range 3-5mm have been used as bed material. The working fluid was supplied from an air compressor. The airflow rate and char ejection pressure for the beds of different heights were measured. From the experimental results, a mathematical model has been developed. The results obtained by the cylindrical model are compared with those from the mathematical model.

Keywords: Pyrolytic char, Fixed bed reactor, Exhaust port, Distributor plate, Reactor feeder, Rig

1. Introduction

An increasing environmental issue for modern civilization, particularly in developing countries, is the removal of solid tire wastages from human activities. These solid organic wastages are not biodegradable. Landfilling is one common form of disposal. Due to the risk of unintended fires and the high-emission rate of dangerous gases, a land filling is a potential threat. Besides, alternative approaches are often used for tire-recycling with major disadvantages and/or limitations. Such as retreat, reclaim, incineration, grinding, etc [1].

Pyrolysis process for solid tire disposals has sought a concerning amount of attention since there might still be a chance to optimize the process conditions to manufacture highly energized- concentrated gas, Char, or even liquids. Moreover, the liquid by-product can be kept in storage until further efficient utilization and requirement. Pyrolysis is mainly based on the decomposition of tire rubber at 300-900°c in a chemically inactive atmosphere. Mainly 3 types of products are acquired from the aforementioned sources (char, tire-rubber, and gas). Liquids from tire-pyrolysis (a mixture of aromatics, paraffin waxes, and olefins) have been experimentally found to have a high amount of Gross Calorific Value or GCV (ranging between 41-44 MJ/kg), making them a suitable alternative for typically used liquid fuels [1-9]. Besides being used as fuels, they have enough possibility to be a valuable source of light aromatic organic compounds. Namely- Benzene, Xylene, and Toluene, or otherly known as BTX altogether. These products hold greater market value than raw oils [1-3,7,10,11]. Limonene has very fast-growing and wide-ranging commercial uses, including the production of industrial solvents, Adhesives and resins, as a dye dispersant, as a pigment in cleaning materials and as an eco-friendly solvent. [6-8, 12]. It is very abundant in beauty products and is used as a flaming solvent for heating. Moreover, the biological role of limonene, including its therapeutic chemotherapy activity against rat mammary cancer, has recently been studied. [6] Using vacuum distillations, Stanciulescu and Ikura[13, 14] isolated the limonene-enriched fraction and reacted it with methanol to generate limonene ethers to improve the marketability of tire-pyrolysis liquids. The extraction of limonene from tire-derived pyrolysis liquids was thoroughly explored by the former study groups [6-8, 12] using different techniques. Pyrolytic char can be used as a solid fuel or as a precursor for activated carbon processing. [1, 7, 9 and 15]. Pyrolytic Carbon Black (CBp) is another possible significant end-use, functioning as a bitumen filler used in road construction. It was investigated by Roy et al [8].Also, the main characteristics of active carbons extracted from used tires were further studied by (Roy et al)[8] alongside Zabaniotou and Stavropoulos[16] & Zabaniotou et al[17]. Their findings indicated that, in comparison to conventional commercially available active carbons (areas about 1100 m2/g), this active carbon obtained from the above sources, has higher surface areas. Some of the previous research groups [1, 3, 7, 10, and 18] investigated the composition of the developed pyrolysis gas fraction and reported that it comprises.

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Quite a few varied experimental methods have been used to manufacture liquid materials from vehicle-tyre waste, using pyrolysis technologies. They include- fixed-bed reactors [2, 3, 7, 10, 19-28, 30], fluidized-bed pyrolysis systems [5, 29, 31], vacuum pyrolysis units [6, 8, 32-35], spout-bed reactors [36] etc covering from experimental to industrial level facilities. Many scientific papers [2, 3, 7, 19, 21, 23, 27, 28, 33, 37-39] on the effect of reactor temperature on product yields and product composition have been worked out. But very few studies [5, 9] on the impact of feed size and vapor residence time on the pyrolysis regime of tire waste have been published in scientific publications.

Based on all these researches, some points were particularly focused. Such as designing and fabricating the cold model of a fixed-bed fire-tube heating pyrolysis system, determining the suitable pressure to eject the char from the reactor, and suitable flow of air to release the char from the reactor. Besides all, developing a mathematical model is another big issue.

2. Methodology

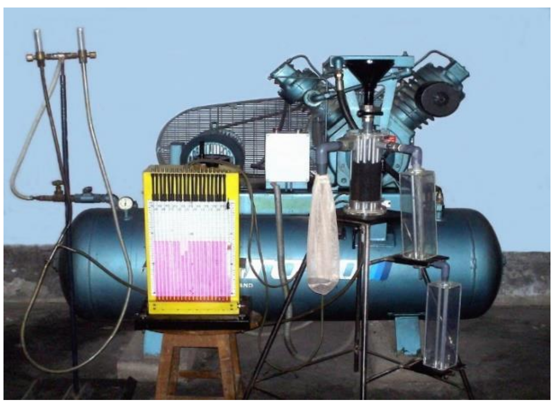

Fig.1 Photograph of the full setup

Fig.2 Photograph of the experimental setup

The model of a fire-tube heating pyrolysis system with a fixed bed consists of one reactor chamber. The inside diameter of the chamber is 10cm. The height of the reactor is 31cm. The reactor is fabricated from a 5mm thick Plexiglass pipe. The gas distributor separates the reactor into two chambers. The distributor plate supports the pull husk in the reactor chamber and provides uniform air distribution. The distributor plate of diameter 10cm with 218 holes, is fabricated from a 5mm thick Plexi glass plate. The distributor plate with such holes works quite well in promoting particle circulation in the bed and in preventing backflows of particles to the air plenum. The diameter of each hole is 2mm. The spacing and design of holes are created in such a way that they may prevent the back flow of fluidized beds. In this study, the reactor is provided with 8 aluminum pipes of 1.2cm in diameter throughout the reactor. This is done because, in actual setup, the fire tubes make a certain effect on the flow or removal of char from the reactor. At the top of the reactor chamber, the opening is made to emit fluidizing gas. This type of opening helps the char to exit efficiently and quickly from the reactor. The fluidizing gas is dry air, supplied from a compressor, euro 30 of model E3-G100. The capacity of the compressor was 400 liters with a maximum pressure of 20 bars. The air from the compressor reached the pull husk bed through the entrance pipe and distributor plate to the reactor. During fluidization, the pressure in the char bed was higher than the atmospheric pressure. Two pipes of inside diameter 4mm, is fitted at 1.5cm above and below the distributor plate. They are also connected to a multi-tube manometer for measuring pressure drop. The pressure drops across the bed. At different heights and amount of char is measured through the manometer which has multi tubes. A pitot-static tube is attached at the entrance path of the compressed air to measure the air velocity at the entrance of the reactor. The airflow rate is also measured from the reading of the pitot-static tube. Water is used as the manometric fluid in a multi-tube manometer.

The actual char of pyrolyzed scrap tire makes the Plexi-glass reactor and the laboratory room dirty. So, the pull husk of definite particle sizes has been used as bed material instead of pyrolyzed scrap tire. The density of pulls husk is almost 70% of scrap tire char. The pull husk is first sieved to get the desired grain size of the pull husk. To increase the density of pull husk, it is colored with oil paint and mixed with carbon powders. After drying under the sun, the density of the pull husk becomes almost 95% of pyrolyzed scrap tire char. The average particle size of pulls husk is taken about 4mm and bulk density is about 342 kg/m3 Where the bulk density of pyrolyzed scrap tire is about 360 kg/m3. This prepared pulls husk was used as bed material in this study.

At first, a certain weight of the bed material is taken by measuring with a weight balance. Then it is poured into the reactor chamber through the reactor feeder. Furthermore, all the valves attached with the setup are closed and a collector bag is placed at the exit way of the char. After that, the char-height inside the reactor is measured. The manometer and the air compressor are attached with the setup by rubber tubes. Then compressed air is passed through the distributor plate to the reactor. The airflow rate from the air compressor is controlled by the valve. For a certain interval of airflow rate, the pressure below and above of the distributor plate is measured from the multi- tube manometer in terms of cm of water. The velocity head is also measured from the manometer with multi tubes in terms of cm of water. Again by increasing the airflow rate, the reading of pressure and velocity head is noted. Then the readings are calculated to obtain air pressure and air velocity by carrying out the same procedure for different weights of char bed. The manometer reading at the beginning and end of char-ejection from the reactor is marked for further calculation. The time required for the ejection of all the char from the reactor at a constant valve opening is also recorded

3. Results & Discussion:

The results obtained from the experiment were quantified at different steps and for different weights. The flow velocity was controlled by the controlled valve at a certain interval. The related pressure developed in the reactor chamber was recorded for the different air flow velocity. These velocity and pressure readings were plotted for the different height and the following curves were obtained. Completing the process, the pressure difference was recorded for different air flow velocity for an empty condition of the reactor vessel. This experiment was done for calculating the required excess pressure to flow up the char from the reactor chamber. Total time was recorded for the complete removal of char for the constant valve opening**.**

For char weight 375 gm, it was obtained from the calculated data taken during the experiment that the char starts to escape the reactor at about the pressure head of 8.3cm to 8.5 cm of water and at pressure head of 11cm to 13.5cm of water the char inside the reactor is fully escaped. The other pressure values for different char weights were given in appendix. From the calculated data it was obtained that it takes about 7% to 9% extra pressure of weight to completely remove the char from the reactor. The time required for complete removal of char from the reactor at constant valve openings are as follows:

- For 375gm char 67.3 seconds
- For 337.5gm char 51.96 seconds
- For 300gm char 39.65 seconds
- For 262.5gm char 28.05 seconds

The pressure required for the complete removal of char from the reactor chamber at const valve openings are as follows:

- For 375gm char 8.5 to 13.6 cm of water
- For 337.5gm char 8 to 12 cm of water
- For 300gm char 7.4 to 10.6 cm of water
- For 262.5gm char 6.8 to 9.4 cm of water

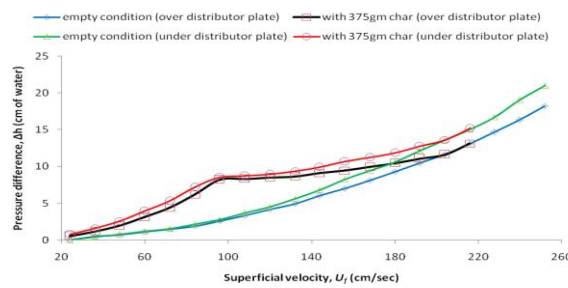

Fig.3 U_f verses Δh curve (comparison between empty condition and 375gm of char over and under the distributor plate)

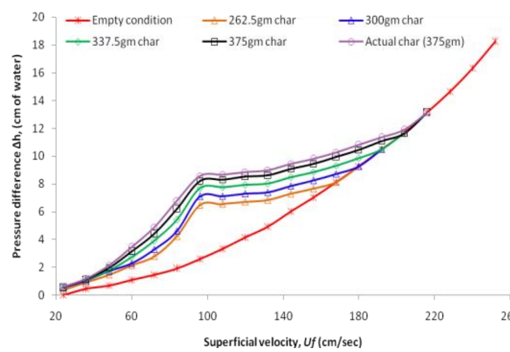

Fig.4 U_f verses Δh curve for all char weight obtained under the distributor plate

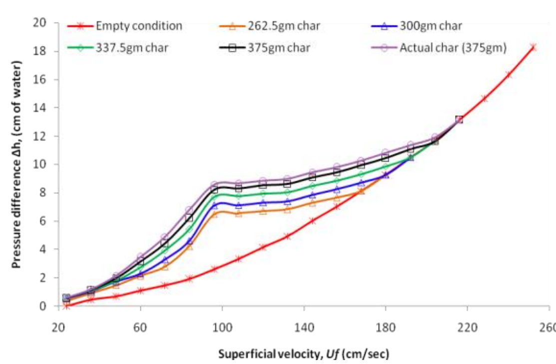

Fig.5 U_f verses Δh curve for all char weight obtained over the distributor plate

This is an experiment with the heating pyrolysis method of a cold model fire tube. The superficial velocity vs. pressure difference curves are seen in Figures 3, 4 and 5. Typically, if a gas is moved upwards at a low flow rate through a bed of granular particles, the gas percolates between stationary particles through the void spaces. With a raise in the surface gas velocity, defined as the gas volume flow rate per unit cross-sectional area of the empty container holding the bed, particles move apart and others vibrate and move in limited regions, causing the bed to spread and increasing the pressure around the bed column P. All particles are trapped at another higher point of velocity by the moving gas energy that has been applied. The frictional force between the particles and the gas balances their respective particle weight at this point. The vertical portion of the compressive force disappears between the adjacent particles; the pressure differential is proportional to the weight of the gas and the particles in the segment. The superficial gas velocity through the column of the bed, responsible for this state is called the minimum superficial velocity U_f and its value depends on the properties of the gas and the char particles.

At gas velocity just above U_f, particles start to jump at the top of the char bed. At higher superficial gas velocity, U_f all particles in the bed are in motion, and increasing the gas velocity leads to particles moving in a more rapid independent motion. Increasing gas velocity further will only cause incremental increase in ΔP. More vigorous vibration of char particles can be observed. Eventually at very high gas velocity, the terminal velocity, U_f the particles are released, at which the particles will be entrained by upward force of the flowing gas.

From figure 3 it is observed that at lower air flow rate, both the pressure and superficial velocity inside the chamber is very low. But if the pressure is increased the superficial velocity and pressure drop both starts to rise. For empty condition, the pressure drop across the char bed increases comparatively slowly than filled up condition. This is occurred due to friction of char particles inside the reactor chamber. At the point, when char starts to eject the reactor the pressure of air is about 8 to 9 percent greater than the char weight pressure. As more and more char is ejected from the reactor the percentage of extra pressure is decreased. At just before the complete ejection of char from the reactor, the extra pressure becomes about 0.5 to 1 percent of the char pressure weight. After complete ejection of char, the superficial velocity versus pressure drop curve for 375gm char becomes completely equal to the curve for empty condition. The pressure drop value for over and under distributor plate varies due the resistance of air flow through the distributor plate. Pressure drop under the plate is slightly greater than the pressure drops over the distributor plate.

From figure 4 and 5 it is observed that for different weights of char the pressure drop is different. But the nature of the curves for different char weight is almost same. It almost same for the pressure drop verses superficial velocity curves for over distributor plate shown in figure 5 but varies in the values of pressure drop.

4. Conclusion

This thesis explores the performance test of a cold model of a pyrolysis method of fixed-bed fire-tube heating. In this experiment, the suitable pressure and air flowrate has been determined for ejection of char for different weights. The extra pressure required to lift up and eject the char is also calculated in terms of percentage of weight. The results of this experiment can be summaries as follows:

The time required for complete removal of char from the reactor at constant valve openings are as follows:

- For 375gm char 67.3 seconds
- For 337.5gm char 51.96 seconds
- For 300gm char 39.65 seconds
- For 262.5gm char 28.05 seconds

The pressure required for the complete removal of char from the reactor chamber at const. valve openings are as follows:

- For 375gm char 8.5 to 13.6 cm of water (about 9% extra pressure of weight)
- For 337.5gm char 8 to 12 cm of water (about 8.5% extra pressure of weight)
- For 300gm char 7.4 to 10.6 cm of water (about 8% extra pressure of weight)
- For 262.5gm char 6.8 to 9.4 cm of water (about 7.5% extra pressure of weight)

The char starts to eject from the chamber at about 96 cm/sec for all char weight.

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