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Improvement of the Pyrolysis System by Integrating Solar Energy Based Preheating System

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Abstract:
***Background**:Gasification and pyrolysis are some examples of thermo-chemical conversion processes that have proven to be a viable option for utilizing renewable energy. In conventional pyrolysis process, feed material in the reactor is heated using biomass or electric run heater. Which, in turn, causes excess energy consumption and production of greenhouse gases (GHG). Solar assisted pyrolysis would be one of the solutions to overcome this heating problem of the pyrolytic reactor.*

***Materials and Methods**: A redesigned pyrolysis system with a solar energy-based pre-heating mechanism was studied in this work. The feasibility of incorporating solar energy into a pyrolysis system has been examined independently for both transparent and opaque reactors. The modified systems' results were compared to those of a traditional pyrolysis system.*

***Results**: In comparison to the standard pyrolysis system, the solar assisted system has lower fuel costs, energy usage, and GHG output. Under the current energy crisis, this process as a supplement to fossil fuels requires increased attention.*

***Conclusion:**In terms of energy consumption, pollution, and heating expenses, the technique proved to be feasible. Nearly 38% less conventional energy was used in the case of the transparent solar preheater system. As a result, the cost and emissions were lowered by the same amount.*

***Key Word**: Pyrolysis; Solar energy; Thermo-chemical conversion; Greenhouse Gas; Energy crisis.*

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I. Introduction

Two of the most important current issues of today's world are global warming and dwindling energy supply [1]. Plants, microbes, animal origin waste, forestry, agriculture, and biodegradable materials from industrial and municipal waste are among the organic components that make up bioenergy [2]. If these bio energies are wasted, they end up in landfills, resulting in the squandering of a large number of lands. Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, and Ash are all acquired by examining biomass, according to the literature [3]. However, even if only 5% of this total trash is used for energy generation, it can contribute to the world's total energy consumption of 26%. As a result, 5% of total trash is over 3.5 billion tons, which is comparable to 6 billion tons of oil, or around 26% of global energy use [4]. However, even if only 5% of this total trash is used for energy generation, it can contribute to the world's total energy consumption of 26%. There are several waste management systems, but the most important waste management method may be the thermochemical conversion process of gasification or pyrolysis to turn waste into energy. Pyrolysis is a popular process for extracting renewable energy, such as bio-oil, from many types of bio mass, such as agricultural wastes, forest leftovers, and municipal garbage, utilizing sun radiation. Pyrolysis is a thermal degradation of organic components in biomass wastes in the absence of oxygen at a temperature of around 5000°C [5]. Despite the fact that pyrolysis is still in its early stages in the current energy picture, it has been given special attention since it can convert biomass directly into solid, liquid, and gaseous products by thermal decomposition in the absence of oxygen [6].Large amounts of heat cannot be created in the pyrolysis process without activating the reactor [7].Furthermore, this process heating accounts for a significant portion of the overall operating cost. Various numerical models have been developed to improve the pyrolysis system by using the pre-heat method [8] [9] Additionally, the degree of environmental impact is determined by the type of biomass heating used. Pyrolysis systems use conventional fuels and electricity for both internal and external heating, resulting in the production of hazardous gases. The reactor heated by biomass burning produces a significant amount of CO_2, CH_4, and N_2O. As a result, solar energy can reduce both the cost of process heating and the negative impact on the environment[10, 11, 12]. The pyrolysis process, however, cannot be sustained using only solar energy since a tremendous amount of heat cannot be generated using only solar heating. However, if combined heating from solar and charcoal firings is provided, it will be more efficient [13]. Because thermal gasification and pyrolysis are endothermic reactions, heat must be supplied throughout the process. This heat can be provided simultaneously by solar energy and the combustion of by-products, or by using a fuel such as 30% biomass, fossil fuels, or other sources. In addition, the persistent gases created by pyrolysis are affected by the heating temperature and the feed materials used. The flow diagram of a typical pyrolysis process is shown in Figure 1. As a result, heating the pyrolysis reactor using green and sustainable solar energy will be a good way to reduce pollution from the solar heating system. Thermochemical conversions such as pyrolysis of biomass, such as tire waste, to produce liquid fuel and gas can benefit greatly from concentrated sun thermal energy. This is a cost-effective and carbon-free method. Despite several theoretical studies on solar pyrolysis, no actual studies have been published in the literature [14]. The goal of this study is to overcome the aforementioned difficulties by establishing a solar-powered method that can use solar energy to generate electricity utilizing wastages as fuel. An enhanced pyrolysis system was devised and built in this study, which included a solar energy-based pre-heating mechanism for the feed materials. The feasibility of incorporating solar energy into a pyrolysis system has been examined independently for both transparent and opaque reactors.

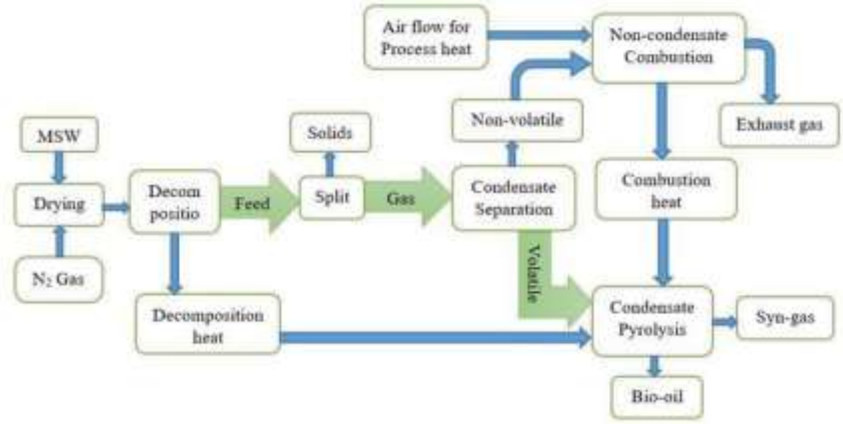


Figure 1: Flow diagram of a typical pyrolysis process

II. Material And Methods

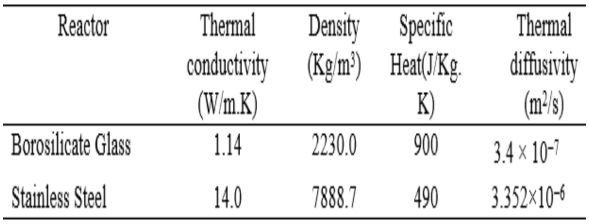
Composition of Solid Tire Waste, Char and Their Elemental Analysis:A waste tire had been utilized as the raw materials to use as feedstock for the pyrolysis. The tires were collected from the nearby garage at Rajshahi University of Engineering & Technology (RUET), Rajshahi, Bangladesh. In order to maintain the uniformity of the components in the representative samples of the tire, same brand tires were chopped cross-section wise into four different sizes, such as (1.00×1.00×0.75)cm; (1.00×1.75×0.75)cm; (2.00×1.00×0.75)cm and (2.00×1.50×0.75)cm. These little fragments could be thought of as the sample's representative. They are made entirely of textile fabrics and do not contain any steel cables. The samples were thoroughly cleansed to remove any mud or extraneous elements before being loaded into the reactor.

Finding sufficient information about the many qualities of solid tires is necessary and crucial. Table 1[16] shows the proximate and elemental analyses of solid waste tires with increased calorific value.

Table 1: Proximate and elemental analysis of solid waste tires

Proximate analysis	(Wt %)	Elemental analysis	(Wt %)
Moisture	0.82	Carbon (C)	80.30
Volatile	62.70	Hydrogen (H)	7.18
Fixed carbon	32.31	Nitrogen (N)	0.50
Ash	4.17	Oxygen (O)	8.33
H.C.V (MJ/Kg)	33.30	Others	3.69

Table 2: Properties of the reactor materials [15]



Reactor	Thermal conductivity (W/m.K)	Density (Kg/m³)	Specific Heat(J/Kg. K)	Thermal diffusivity (m²/s)
Borosilicate Glass	1.14	2230.0	900	3.4×10^{-7}
Stainless Steel	14.0	7888.7	490	3.352×10^{-6}

Transparent and Opaque Reactor Materials: The reactor is one of the most important parts of the pyrolysis process, accounting for 10-15% of the total pyrolysis cost [3]. The borosilicate glass reactor is transparent. The opaque reactor is built of AISI 340 stainless steel. Table 2 depicts the parameters of transparent and opaque reactor materials.

Cost of Heating System: The correct cost of a pyrolysis plant's heating system includes capital expenses, fixed costs, and ongoing costs such as fuel, maintenance, and labor. The actual cost analysis with these characteristics is not possible to compare with fast pyrolysis because our comparison is at the laboratory level. As a result, just the cost of fuel is considered in both circumstances while heating the reactor.

The overall cost of heating charcoal for an optimal yield condition in one cycle is projected to be around 0.2432 USD. Solar heating, on the other hand, lowers the fuel cost per cycle to 0.1520 USD. As a result, it saves roughly 1.544 kg of charcoal at a cost of 0.0914 USD per cycle, or 37.58 percent of the overall cost. Though bio-oil production on a small scale is relatively expensive, bulk manufacturing will lower costs by utilizing a large amount of solar energy. If total solar rapid pyrolysis is truly attainable, then fuel costs will be reduced to zero. As a result, including a solar heating system with pyrolysis could be a potential strategy for reducing heating costs of pyrolysis process.

Experimental Set-up and Procedure: Because of the corrosive character of pyrolysis liquid, particularly that obtained from biomass, and the high working temperature of the process, stainless steel of grades AISI 340 and ASTM A240 was chosen as the material for the system's main component. The major constructions were completed in the outside shops.

For quick pyrolysis to occur, the fixed bed reactor is built with a vapor residence period of less than 5 seconds. The length of the condenser is chosen to meet certain requirements, such as temperature, vapor and water mass flow rates. For the ease of manufacturing, a cylindrical reactor made of stainless-steel pipe has been explored for the system. The reactor's design is shown in Figure 2.

Figure 2: Opaque reactor with condenser

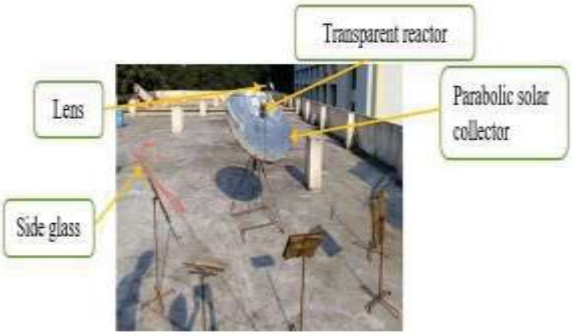


Figure 3: Photograph of solar pre-heating consists all the three heating elements for transparent reactor.

Another key component of the experimental setup is the condenser. The vapor product from the reactor was routed through a water-cooled counter flow condenser to cool it down for liquid and non-condensable gaseous yields. Various operational arguments also influence its dimension. The reactor, together with the feed material, was placed in the combustion bed after being preheated with solar radiation. To obtain the needed temperature, charcoal was employed for burning at this point. As a result, a sheet metal combustion bed was built to conduct subsequent experiments. Before designing, the dimensions of other units such as connecting tubes and condensers were taken into account to ensure that they could be readily positioned and had a sufficient height. Solar preheating is the sole purpose of the parabolic solar collector, side glasses, and lenses. The side glasses reflect the sun's rays, which fall on the transparent reactor. The reactor is positioned in the parabolic solar collector's central focus. As a result, the reactor receives a significant amount of heat. Three sun heating devices, including the lens, side glass, and parabolic solar collector, are used to heat the reactors. To determine the temperature increase caused by each heating element, each heating element is tested separately. Concentrated solar energy is highly effective for high biomass conversion and fast heating rates. Using side glasses raises the temperature by roughly 55°C. The parabolic solar collector is properly positioned for proper concentrating in accordance with the sun's movement. When utilizing a parabolic solar collector, the temperature rises by roughly 97°C. Figure 3 is a photograph of solar pre-heating for the transparent reactor, which includes all three heating elements. Using three heating sources, the temperature rose to around 115°C. The feed material from the transparent reactor is moved to the opaque reactor and inserted into the charcoal combustion bed after it has been preheated. The opaque reactor is positioned into the charcoal combustion bed after being preheated by the parabolic solar collector, as shown in Fig. 4. For flowing water, the water pipe is connected to the condenser. The blower's airline is connected to the bed, supplying air for proper charcoal burning. To keep the blower running at a constant pace, an electric setup with bulbs is used. As a result, the apparatus for heating the charcoal combustion bed was assembled.

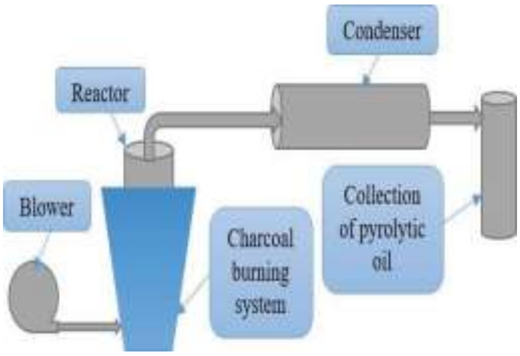


Figure 5: Obtained product yields by solar pyrolysis

Figure 4:Schematic diagram of charcoal heating

III. Result

Obtained Product Yield: After each cycle of tire pyrolysis, three common products are recovered: oil, char, and gas. The system was tested multiple times. The char that was recovered from the reactor had no odor, but the created gas, as well as the liquid, had a much stronger odor than the char. The results of the experiment are shown in Figure 5.

From the Fig. 5, it is observed that for every 100gm feed material, obtained liquid was about (40.1±1.65) gm, char was almost (38.55±1.37) gm and gas was around (21.35±2.76) gm. Amount of liquid obtained is higher than that of the non- condensable gas and char. However, a slight variation may occur due to the measuring error and faulty apparatus.

Temperature Rise with Time by Single Heating Element: Three heating elements were used to pre-heat the reactor during solar pre-heating. Figure 6 shows the temperature rise of the reactor over time as a function of the separate heating elements.

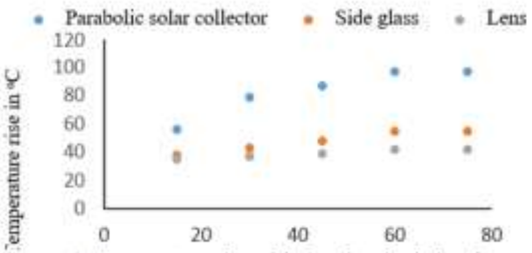


Figure 6: Temperature rise with time by single heating element for transparent reactor (TR)

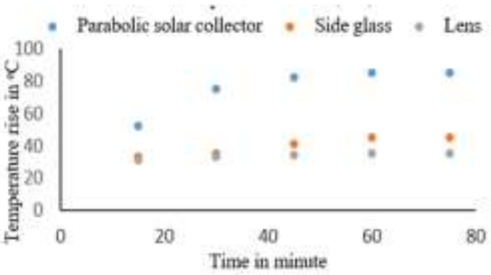


Figure 7: Temperature rise with time by single heating element for opaque reactor (OR).

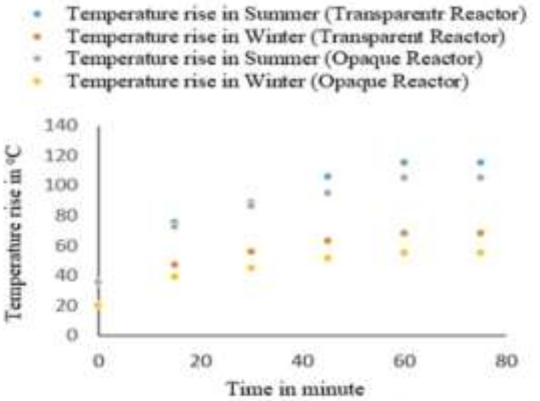


Figure 8: Temperature rise with time by combination of three heating element (TR and OR).

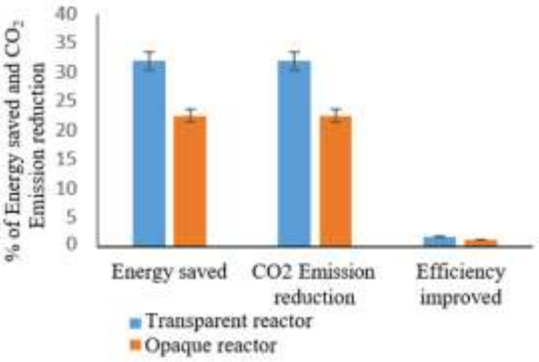


Figure 9: Percentage of energy saved and CO_2 emissions reduction for TR and OR

The temperature rises by the parabolic solar collector are higher than the other two parts, as shown in Fig. 6. The temperature increases for transparent reactors using the parabolic solar collector, side glass, and lens were up to 97^0C, 55^0C, and 42^0C, respectively. In all three cases, the temperature increases fast for the first 15 to

25 minutes, then progressively slows. The driving causes that result in this form of curve trend include variations in climatic conditions such as sudden cloud in the sky, cold wind blows, and decentralization of focus for solar movement.

The temperature spikes caused by the parabolic solar collector are higher than those caused by the other two elements, as shown in Fig. 7. For the parabolic solar collector, side glass, and lens, the temperature rises to 850°C, 450°C, and 350°C, respectively. In all three cases, the temperature increases fast for the first 15 to 25 minutes, then gradually slows down. The temperature rise is, however, lower for all three heating components than for the clear reactor.

Temperature Rise with Time by Combination of Three Heating Elements: Three heating elements were used to pre-heat the reactor during solar pre-heating. The temperature rises faster in the summer than it does in the winter. Figure 8 depicts a comparison of the temperature rise in summer and winter of the transparent reactor (TR) and the opaque reactor (OR) with respect to time, as measured by all heating devices combined.

The combination of three heating elements for transparent reactors raises temperature up to 115^{0}C in summer and up to 68^{0}C in winter, as shown in Fig. 8. Because of the greenhouse effect, the temperature in the transparent reactor is higher. It is the primary reason of the transparent reactor's temperature rise. Because the sun's rays of longer wavelengths are trapped inside the transparent reactor, the temperature rises.

According to Fig.8, the opaque reactor's temperature rises to 105^{0}C in summer and 55^{0}C in winter when three heating elements are used, which is lower than the transparent reactor in both circumstances.

Effect of Energy Saving and Reduction of Carbon Dioxide Emissions:

Energy Saving:

Percentage of Energy saved, by using solar assisted preheating system=(B–Æ) (*100%)

B

Where, A= Amount of Input energy while doing pyrolysis, reactor is preheated by solar energy (kJ)

B= Amount of Input energy while Pyrolysis is occurred without preheating the reactor by solar energy (kJ)

Emission of Carbon Dioxide Gas for Burning Coal:

Percentage of CO_2 emission reduction= $(X/Y) \times 100\%$

Where, X= Amount of CO_2 produced without using solar energy (kg)

Y= Amount of CO_2 produced using solar energy for preheating the reactor (kg)

By using the above equations, the amount of energy saved and amount of percentage of CO_2 emission reduction was calculated in this study. However, the average value of the percentage of energy saved and CO_2 emission reduction for the TR and OR is presented in Fig. 9

IV. Discussion

From this study, it can be concluded that the temperature rises by the parabolic solar collector are higher than the lens and the side glass for both transparent and opaque reactors.Also, highest temperature can be obtained from transparent reactor at summer and the lowest temperature is obtained from the opaque reactor during winter. Transparent reactor saved energy and reduced the CO_2 emission by 35% whereas the opaque reactor achieved this efficiency by 25%.

V. Conclusion

In this work, a unique way of incorporating a solar preheating system into a typical pyrolysis system was devised. The strategy proved to be feasible in terms of energy usage, pollution, and heating costs. In the case of the clear solar preheater system, nearly 38% less conventional energy was consumed. As a result, the same amount of cost and emission was reduced. In addition, the pyrolysis system produced a significant amount of liquid yield. More research is needed to determine the practicality of this novel strategy to incorporating renewable energy into a traditional pyrolysis system.

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