

Temperature Profile of Produced Gas in Oil Palm Biomass Fluidized Bed Gasifier: Effect of Fibre/Shell Composition Ratio

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Abstract

Malaysia is known to be one of the largest palm oil producers and also generates huge amounts of oil palm biomass, which is mainly treated as bio waste. One of the efficient methods to recycle this potential oil palm biomass could be gasification technology. Gasification is a process involving conversion of solid carbonaceous fuel into combustible gas using directly heated biomass. From processing of Fresh Fruit Bunch (FFB) (a biomass example), Empty Fruit Bunch (EFB) fibre, shell etc. are produced. In this study, a laboratory scale fluidized bed was developed, an appropriate fibre/shell composition ratio was studied and analysis on profiles of gas produced in the oil palm biomass fluidized bed gasifier was conducted. The effects of fibre/shell composition ratio and rate of reaction on temperature profiles were investigated. Temperature reaction rate and calorific value of oil palm biomass with gas compositions were also analyzed.

Keywords: Composition ratio; Oil palm biomass; Gasification; Fluidized bed gasifier; Temperature profiles; Empty fruit bunch

Introduction

With the progress of strong economic growth and revolutionary development, the demands for energy are ever increasing. Presently, one of the major challenges that the developed/developing countries are facing is the ample supply of energy. To date, various alternatives energy sources (e.g. biofuel, biogas etc.) have been investigated to find sustainable solutions to ever increasing energy demands [1, 2]. In Malaysia, the oil palm biomass can be a major potential source for energy production. It is a new renewable source of energy, which could serve 5% of total energy consumption in Malaysia [3-7]. The gasification process is one of the most simple, cleanest and efficient method for the production of useful gases from low or negative-value carbon-based feedstock such as coal, petroleum coke and high sulfur fuel oil that would otherwise be disposed as waste [8-11]. Nowadays, Gasification is becoming a more interesting and efficient energy-conversion technology for a wide variety of oil palm biomass fuels. The large scale deployment of efficient technology along with interventions to enhance the sustainable supply of oil palm biomass fuels can transform the energy supply situation in rural areas. It has gained as a potential technique to become the growth engine for rural development in the country. The understanding of new methodology during gasification is a fundamental importance, for the optimal design of oil palm biomass fluidized bed gasifier [12-14].

The temperature often plays important roles in the behavior of produced liquids and semi-liquids. Kanagaratnam et al. observed that the oil-binding capacity of palm oil based shortening (a semi-liquid) was affected by the temperature [15]. Likewise, the effects of various compositional factors such as, air temperature, moisture content, conditions in gasifying chamber etc. on the gas production had also been studied. Schoeters et al. developed a fluidized bed gasifier with beds moving in parallel to each other [16]. The fluidized bed gasifier is more suited for low density and non free flowing material. They also investigated the effect of variables, such as air factor, volumetric throughput, steam and oxygen addition and feedstock properties on the gasifier performance (gas quality, thermal efficiency). Boateng et al. [17] employed fluidized bed gasification of rice hull had approved the method of gasifying using Fluidized Bed Gasifier (FBG) significantly.

Their method used steam as reaction in the FBG where the heating value was found to be between 11.1-12.1 MJm⁻³ at the respective reactor temperature of 700-800°C, varied between 35-59% MC of rice hull. Azali et al. [12] suggested gasification technology for palm oil mill in comparison to the existing system that is using boiler. Gasification system converts a gas from combustion and uses this syngas direct to generator or engine gas to generate electricity. Similar function is found in boiler where it generates steam for turbine to generate electricity. Azali studied the gasification system for fuel treatment in which moisture content in oil palm biomass poses a major obstacle [18]. Figure 1 shows a flowchart of gasification developed in oil palm industry, while Figure 2 describes flow process of fibre and shell treatment before being used as fuel.

Materials and Methods

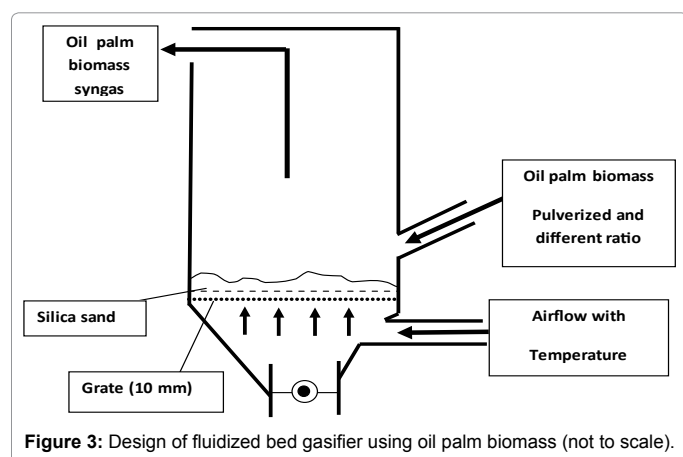
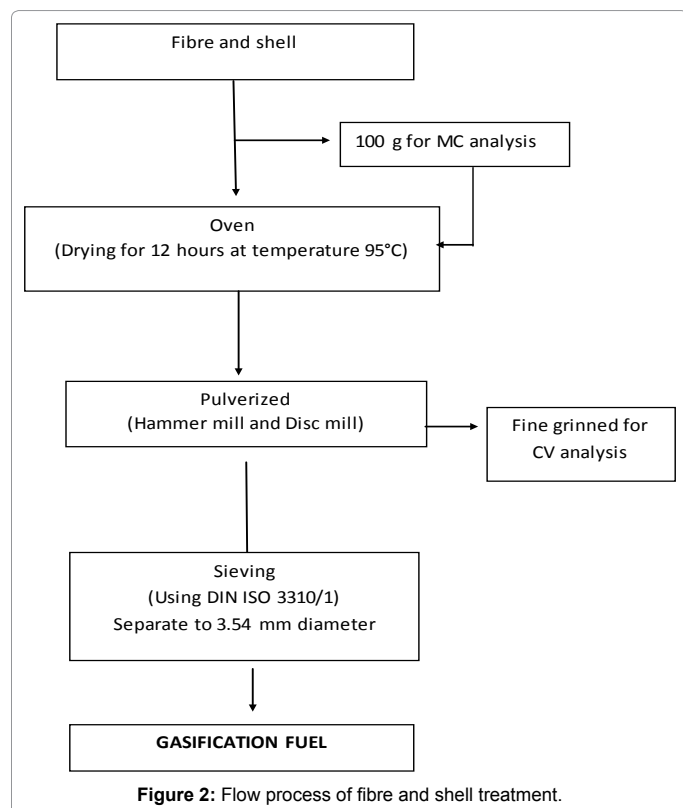
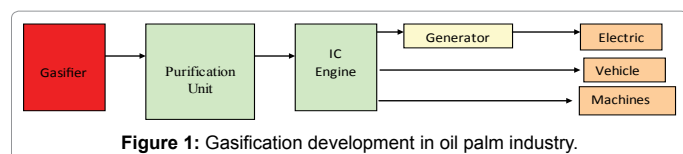
Figure 3 represents a basic diagram of oil palm biomass fluidized bed gasifier where the oil palm biomass flows into gasifying chamber at different ratios. The gasifier was made of stainless steel pipe and the total high of gasifier was 850 mm with an internal diameter of 50 mm. Prior to each experiment, the gasifier was charged with 20 g of silica beads as the bed material to obtain better temperature distribution, to stabilize the fluidization and prevent coking inside the reactor. The solenoid valve was turned on and a pre-heated air flow passed through the bed and the reactor when the temperatures in the bed and in the gasification zone reached the desired temperature. Flow of fuel was set-up at 20 kg per hour with screw conveyer as a feeder. In this

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experiment, the baseline data was first obtained for gasifying of oil palm biomass. In addition, gasifying with different ratios of fibre and shell were carried out to investigate their gasification characteristics in comparison of mixer, air flow and gas produced. The fibres in the EFB have various lengths and on each fibre, the diameter varies from one end to another where the largest diameter is located around the middle. The usual diameter varies in between 0.4 to 0.7 mm. It had tensile strength of 50-300 MPa, Young's modulus of 6-18 GPa and moisture content of around 15%. On the other hand, the EFB shell

comprises 24-26% lignin, 22-25% cellulose, 24-27% hemicelluloses and 8-10% moisture. The calorific value of the shell is also higher than that of EFB fibre. Gasification process were carried out for the different ratio of oil palm biomass of 80% fibre and 20% shell, 60% fibre and 40% shell, 60% shell and 40% fibre and 80% shell and 20% fibre. In gasifying process, excess air flow was varied from 1-2 m/s at the interval of one hour for each oil palm biomass. For each excess air condition, a 4 kW heater was used to pre heat air at 400°C where the total airflow at inlet was maintained by an air damper. Fuel feeding was performed by a screw conveyor with a setting speed at 2 rpm. The gasifying tests were operated at the bed temperature 950°C, air velocity in the range of 1-2 m/s and at atmospheric pressure.

Results and Discussion

Calorific value of oil palm biomass (fibre and shell)

The properties of oil palm biomass such as percentage of mixing ratio, temperature behavior, air velocity and gas production as well as variable of operating parameters were determined. In addition, calorific value analysis of the oil palm biomass, whose heating profile of different mixture ratio was tested during gasification. The experiments were divided into four types of oil palm biomass mixture (fibre and shell):

1. 80% fibre and 20% shell
2. 60% fibre and 40% shell
3. 60% shell and 40% fibre
4. 80% shell and 20% fibre

Prior to delivering the oil palm biomass into the gasifier chamber, some sample was taken to measure its Calorific Value (CV). Table 1 presents a summary of calorific value of oil palm biomass used in this study. This table shows that the oil palm biomass fuels with the lowest CV is 80% fibre and 20% shell to yield an average of 18.82 MJ per kg and the highest CV of 19.38 MJ per kg for 80% shell and 20% fibre. The data of CV of oil palm biomass are shown as follows:

The fibre had CV of 18.5 MJ/kg, while shell had calorific CV of 20.72 MJ/kg. 1 kg of biomass was used for calculating CV of each ratio of biomass. The methods of calculation are given below:

$$1. \text{ 80\% Fibre and 20\% Shell} = 800\text{g}/1000\text{g} \times 18.5 \text{ MJ/kg} + 200\text{g}/1000\text{g} \times 20.72\text{MJ/kg}$$

$$\text{Net CV} = 18.944 \text{ MJ/kg}$$

$$2. \text{ 60\% Fibre and 40\% Shell} = 600\text{g}/1000\text{g} \times 18.5 \text{ MJ/kg} + 400\text{g}/1000\text{g} \times 20.72\text{MJ/kg}$$

$$\text{Net CV} = 19.388\text{MJ/kg}$$

$$3. \text{ 60\% Shell and 40\% Fibre} = 600\text{g}/1000\text{g} \times 20.72 \text{ MJ/kg} + 400\text{g}/1000\text{g} \times 18.5\text{MJ/kg}$$

$$\text{Net CV} = 19.832\text{MJ/kg}$$

$$4. \text{ 80\% Shell and 20\% Fibre} = 800\text{g}/1000\text{g} \times 20.72 \text{ MJ/kg} + 200\text{g}/1000\text{g} \times 18.5\text{MJ/kg}$$

$$\text{Net CV} = 20.27\text{MJ/kg}$$

Figure 4 shows a plot of average experimental and theoretical CV value. A difference of 1-5% was observed between theoretical and experimental values, which may be due to imperfections in the raw material. This is consistent with the study done by Eris [19], who

Sample	80% Fibre and 20% Shell kJ kg ⁻¹	60% Fibre and 40% Shell kJ kg ⁻¹	60% Shell and 40% Fibre kJ kg ⁻¹	20% Fibre and 80% shell kJ kg ⁻¹
1	18679	18769	18973	18978
2	18367	20956	18723	19034
3	19897	18453	19002	19005
4	18532	19689	18976	19023
5	18145	18671	18790	18996
6	20342	18438	18923	21996
7	17753	18578	21025	19909
8	17894	18365	18881	18907
9	19923	17980	18845	19021
10	18678	18679	19006	19013
Average	18821	18857.8	19114.4	19388.2

Table 1: Data of Calorific Value (CV) Recorded by Calorimeter.

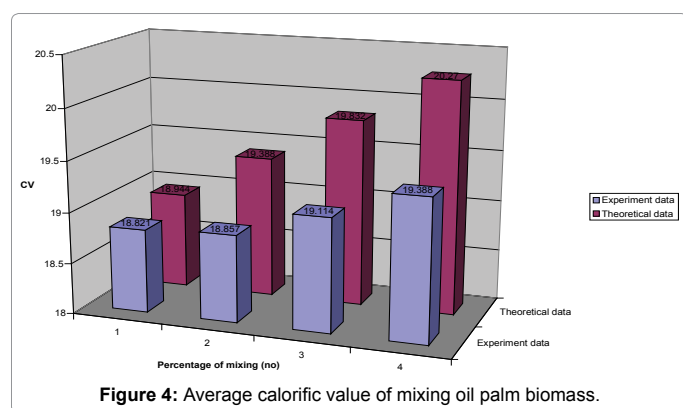


Figure 4: Average calorific value of mixing oil palm biomass.

found that fibre had a CV of 13.57 MJ/kg and shell had a CV of 16.37 MJ/kg. From the experiment, Moisture Content (MC) of oil palm biomass was also controlled such that $\leq 15\%$ dry basis. Brammer and Bridgwater claimed that the moisture content delivered to gasification system should be minimized hence a drying stage is required [20]. The drying process carried out should be maximized at the expense of heat exported. Bain [21] as well as Brammer and Bridgwater [20] reported that drying of a biomass material means removing water from the solids to reduce moisture content to an acceptably low value. They also mentioned that the combustion of biomass in the range 79% combustion efficiency could be obtained using the dried biomass. The above-mentioned literature proposed that the moisture content must be removed effectively from biomass and this has been done for this research.

Effect of temperature

When oil palm biomass was delivering into the gasifier, a strong flame was initially observed leaving the outlet chamber. After five minutes, the flames disappeared. The observation of this work is in agreement with the work of Azlina [22]. In her work, she reported that the reduction of temperature occurred when the oil palm biomass was fed into the combustion chamber. Figures 8-14 show the temperature versus times curves for fuel feed of 20 kg/hour under steady state conditions for different fibre shell ratios. The air flow speed was maintained up to 1 m/s during the process.

The results of this study are in good agreement with the results of Van Paasen and Kiel [23] during their work on tar formation in a fluidized bed gasifier where the temperature range selected was between 500-800°C. Figure 5 depicts that for the case of 80% fibre and 20% shell

during the feeding of fuel, the curve increased linearly with time at the temperature range of 450-780°C. Then, at the temperature range of 650-700°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was observed for 15 minutes, and subsequent collection and measurements of synn gas produced.

From Figure 6, it was shown that for the case of 60% fibre and 40% shell during the feeding of fuel, the curve increased linearly with time at the temperature range of 500-780°C. Then, at the temperature range of 700-780°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was observed for 18 minutes. From Figure 7, it was obvious that for the case of 60% shell and 40% fibre during the feeding of fuel, the curve increased linearly with time at the temperature range of 550-810°C. Then, at the temperature range of 740-810°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was observed for 30 minutes.

The trend revealed by Figure 8 indicated that for the case of 80% shell and 20% fibre during the feeding of fuel, the curve increased linearly with time at the temperature range of 550-850°C. Then, at the temperature range of 770-850°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was observed for 30 minutes. Figures 9-12 show the curves for temperature vs. time for different fibres and shell ratios at air flow rate of 2 m/s. From Figure 9, for the case of 80% fibre and 20% shell during the feeding of fuel, the curve increased linearly with time at the temperature range of 470-760°C. Then, at the temperature range of 670-760°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was observed for 25 minutes.

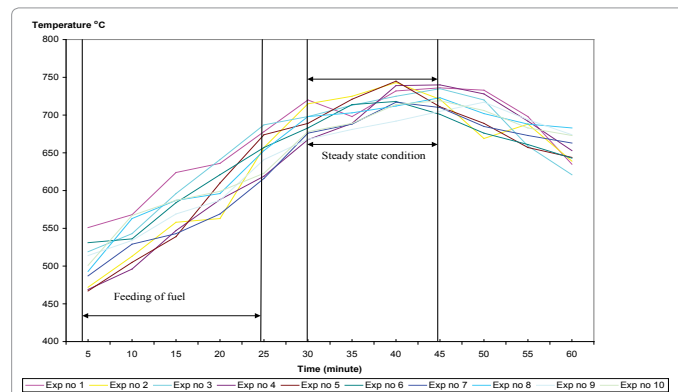


Figure 5: Temperature pattern for mixture of 80% fibre and 20% shell at air flow rate of 1 m/s.

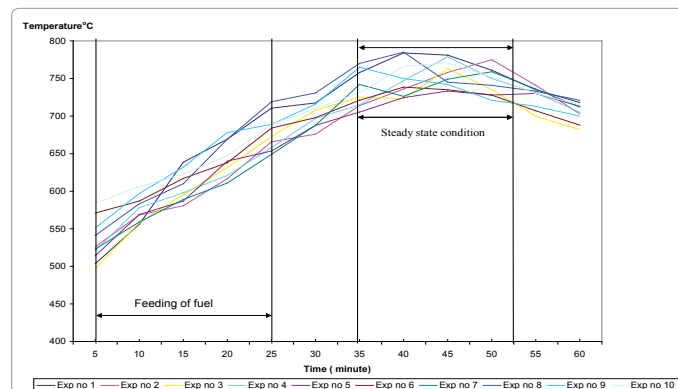
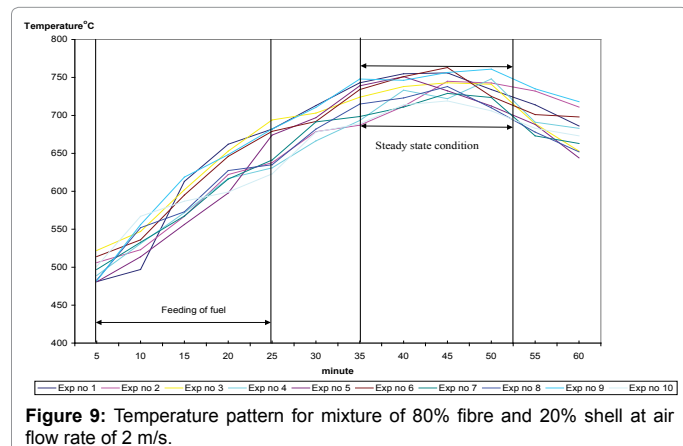
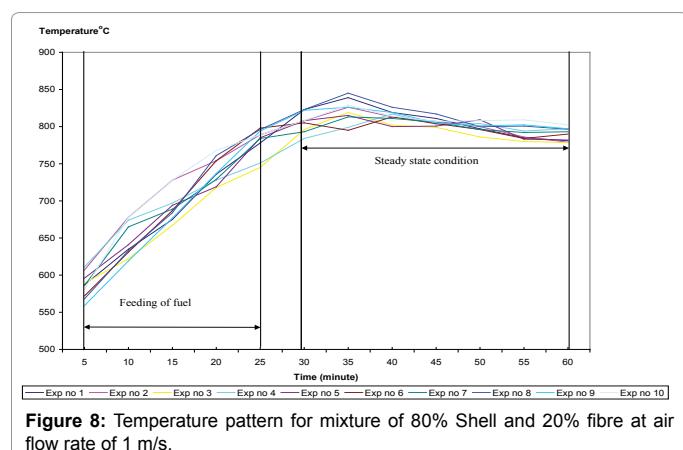
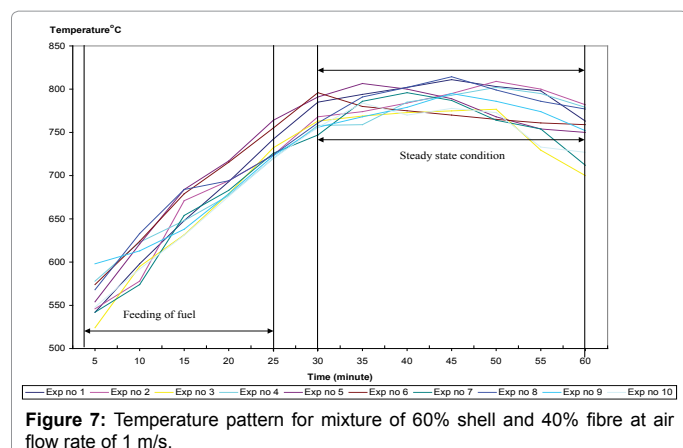


Figure 6: Temperature pattern for mixture of 60% fibre and 40% shell at air flow rate of 1 m/s.



For the case of 60% fibre and 40% shell in Figure 10, during the feeding of fuel, the curve increased linearly with time at the temperature range of 510-760°C. Then, at the temperature range of 680-760°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was observed for 15 minutes. The results of Figure 11 depicts that for the case of 60% shell and 40% fibre during the feeding of fuel, the curve increased linearly with time at the temperature range of 540-810°C. Then, at the temperature range of 730-810°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was observed for 30 minutes. From Figure 12, it was observed that for the case of 80% shell and 20% fibre during the feeding of fuel, the curve increased linearly with time at the temperature range of 550-850°C. Then, at the temperature range

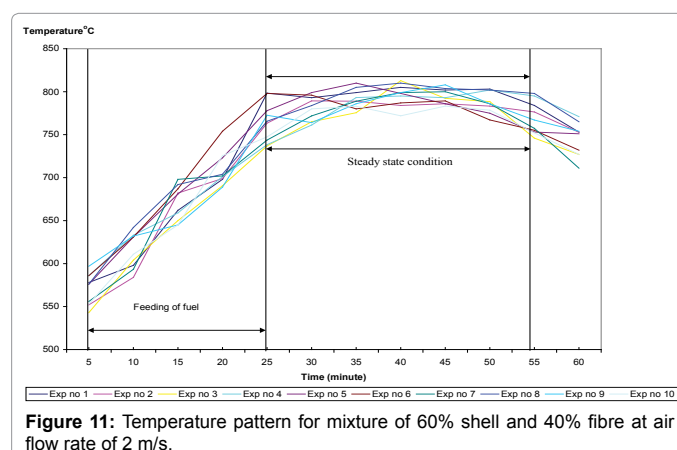
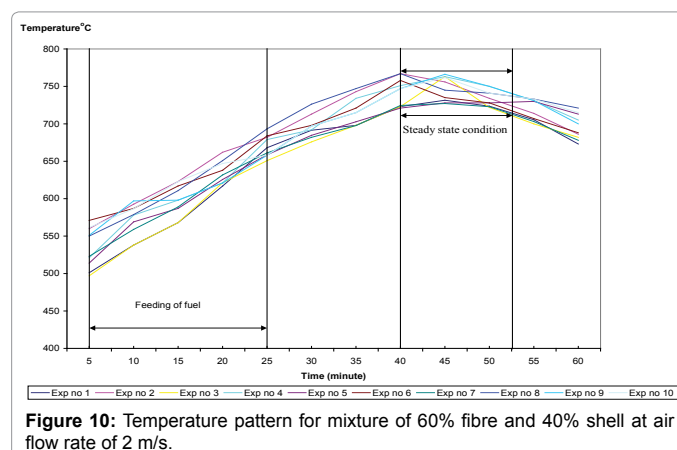
of 750-850°C, the steady state (state with no fluctuate of value $\leq 10\%$) condition was achieved for 30 minutes.

Marcelo et al. [24] used biomass, such as sugar-cane bagasse, rice husk, sawdust and elephant grass (*Pennisetum purpureum*) for their gasifier and they achieved 750°C, which is similar to this work on oil palm biomass. In this study, the longest period of steady state condition of 30 minutes occurs when using 80% shell and 20% fibre at airflow of 1 m/s. This result also indicates that complete gasification was achieved because the output temperature $\geq 700^\circ\text{C}$. Figure 13 shows the detailed temperature of versus time for all conditions at 1 m/s airflow rate whilst in Figure 14 shows results for airflow rate of 2 m/s. From both figures, a temperature difference of 1-5% between experimental and simulation results were obtained. This is in good agreement and consistent with literature [25].

Conclusions

The experiments were carried out by mutually varying the fibre/shell composition ratio from 20 to 80%. The overall findings of this study are concluded as below:

- The highest calorific value (19.38 MJ/kg) was achieved from the composition of 80% shell and 20% fibre while, the lowest calorific value (18.82 MJ/kg) was achieved from the composition of 80% fibre and 20% shell.
- Composition of 80% fibre and 20% shell contributed the temperature range of 470-760°C. At the air flow rate of 1 m/s the steady state (i.e. the state with no fluctuation of value $\leq 10\%$)



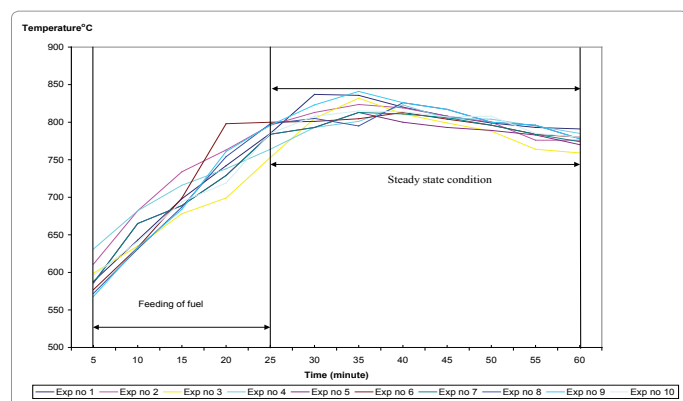


Figure 12: Temperature pattern for mixture of 80% shell and 20% fibre at air flow rate of 2 m/s.

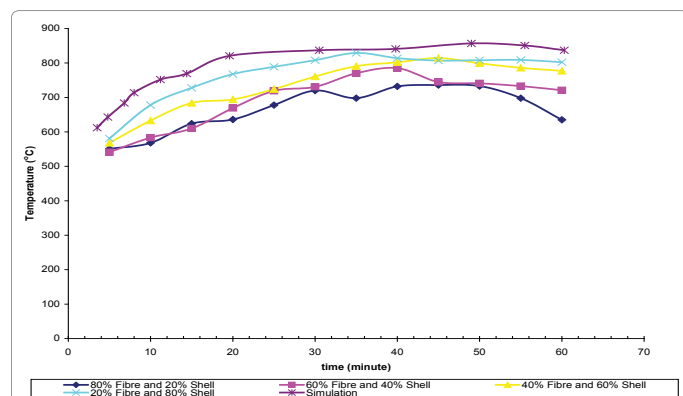


Figure 13: Temperature pattern of experiment and simulation at air flow rate of 1 m/s.

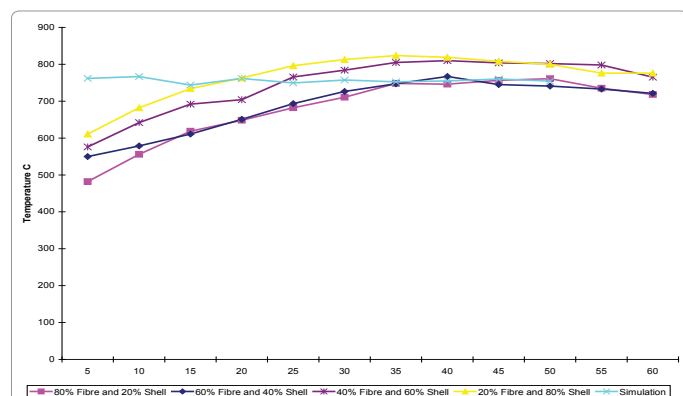


Figure 14: Temperature pattern of experiment and simulation at air flow rate of 2 m/s.

condition was observed for 15 minutes at the temperature range of 670-760°C, and at the air flow rate of 2 m/s the steady state condition was observed for 25 minutes at the temperature range of 680-770°C.

- Composition of 60% fibre and 40% shell contributed temperature range of 500-780°C. At the air flow rate of 1 m/s the steady state (i.e. the state with no fluctuation of value $\leq 10\%$) condition was observed for 18 minutes at the temperature range of 690-780°C, and at the air flow rate of 2 m/s the steady state condition was observed for 15 minutes at the temperature range of 680-760°C.

- Composition of 60% shell and 40% fibre contributed temperature range of 540-810°C. At the air flow rate of 1 m/s the steady state (i.e. the state with no fluctuation of value $\leq 10\%$) condition was observed for 30 minutes at the temperature range of 740-810°C, and at the air flow rate of 2 m/s the steady state condition was observed for 30 minutes at the temperature range of 730-810°C.
- Composition of 80% shell and 20% fibre contributed temperature range of 560-840°C. At the air flow rate of 1 m/s the steady state (i.e. the state with no fluctuation of value $\leq 10\%$) condition was observed for 30 minutes at the temperature range of 770-840°C, and at the air flow rate of 2 m/s the steady state condition was observed for 30 minutes at the temperature range of 760-840°C.

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