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STUDY ON FREEBOARD TEMPERATURE PROFILE DURING COMBUSTION OF RICE HUSK IN A FLUIDISED BED COMBUSTOR

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ABSTRACT

In this paper, the temperature profile while firing rice husk in a fluidized bed combustor was investigated. The experiment was carried out in a 210 mm I.D. non insulated fluidized bed combustor with a height of 2000 mm. The experiments were carried out in two sets; firstly without any secondary burner and secondly with one and two secondary burners in the freeboard region and its effect on temperature was studied. The results without any secondary burner showed that the temperature reduces sharply along the height of the combustor with fluctuation in freeboard temperature. The reason was heat loss to surrounding due to non insulation of the fluidized bed combustor and run off flue gas. However, improvement or almost steady freeboard temperature profile was observed with addition of one and two secondary burners in the freeboard region. In addition to this, the high temperature (around 700 °C) could help in burning off the carbon in the rice husk ash during elutriation from fluidized bed. Hence, freeboard region could be made as secondary combustion zone in obtaining high quality white siliceous ash.

Key Words: Rice husk, Combustion, Fluidized bed combustor, Freeboard temperature

1.0 INTRODUCTION

The fluidized bed technology is capable of producing amorphous rice husk ash with very low carbon content (< 2%) at a very rapid reaction time (< 2 min) [1]. This has led to extensive research work [2 – 8] on combustion characteristics of rice husk in a fluidized bed technology during past decades. In addition to this, due to turbulent nature of the bed in the fluidized bed, the heat transfer rates are very high resulting in good combustion efficiency. Hence, the combustion temperature should be kept low, typically in the range of 600 – 800 °C compared to other technology. The lower range of operating temperature in a fluidized bed is advantageous to prevent the crystallization of silica in the ash. However, the heat loss, which is particularly significant in non-insulated combustor, resulted in the decreased temperature profile with respect to the height of the combustor. Ideally, whereby heat loss is negligible, the temperatures in the combustor should increase with the height of the combustor as the density of hot gases are lower, and thereby have the tendency to rise to the top of the combustor. Moreover, the residence time of the rice husk ash particle in the combustor is shorter. Thus, the temperature required to burn off the carbon totally in the freeboard region was insufficient.

To overcome this problem, use of secondary burners in order to increase the temperatures at the freeboard region of fluidised bed combustors was necessary due to the inherent heat loss to the surroundings. Maintaining high temperatures (not above 700 °C) along the freeboard region of the combustor is crucial in enabling the oxidation of residual carbon in the fly ash particles as they are being carried towards the cyclone. However, much emphasis is not given to this factor, as can be observed from published literatures on rice husk combustion in fluidised bed combustors, except for Huang [7]. Although using electrical heating element instead of secondary burner, these researchers

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somehow realised the significance of maintaining high temperatures at the entire height of the combustor instead of just at the bed region. Such measure ensures that the temperature in the freeboard region remained high for effective oxidation of carbon in the fly ash.

The purpose of this study was to investigate the freeboard temperatures profile during combustion of rice husk in a fluidised bed combustor. The freeboard temperatures in the combustor are to be elevated through the presence of secondary LPG (Liquified Petroleum Gas) burners at different locations at the freeboard region. The difference in rice husk combustion characteristics will be determined in terms of temperature profiles with and without secondary burners in the combustor.

2.0 COMBUSTION PROCESS IN THE FLUIDIZED BED COMBUSTOR

As soon as the rice husk enters the hot fluidised bed combustor, drying and to a certain extent some devolatilisation takes place instantaneously. In general, the combustion process of high-volatile materials such as rice husk in the fluidised bed proceeds at three distinct stages, namely:-

i) *Primary stage*: Drying and the minimal amount of devolatilisation take place due to the available heat provided by the hot sand bed for the endothermic reactions. Some char burning in the hot bubbling bed also takes place due to the high temperature to initiate oxidation of carbon. Approximately 60 – 70% of the combustion reaction to liberate ash is expected to take place in the bed.

ii) *Secondary stage*: Majority burning of the evolved volatiles and some oxidation of unburnt carbon in the ash particles take place, as they are being entrained towards the cyclone. If sufficient freeboard height is available, the remaining 20 – 40% of the combustion reaction takes place in the freeboard area.

iii) *Tertiary stage*: Burning of the residual volatile gas and carbon in the ash takes place in the cyclone.

The hot bubbling bed provides a very conducive environment for the combustion reaction to occur due to the presence of key elements necessary to achieve good combustion. They are:-

i) Reactants - The fluidising air provides the necessary oxidant (oxygen) on a continuous basis to the fresh, incoming rice husk feed.

ii) Temperature - The sand bed acts as a 'thermal flywheel' to store and transfer the heat evolved during the combustion process to initiate reaction of the fresh feed, thereby ensuring that there is always sufficient temperature for the combustion reaction.

iii) Turbulence - The rise of bubble swarms and their subsequent eruption at the bed surface creates turbulence in the bed, thereby resulting in good mixing. As such, the transport of heat and mass on a micro-level in the bed is enhanced.

iv) Retention time- The eruption of bubbles at the bed surface tends to 'engulf' the feed materials, after which they moved downwards towards the distributor along with the movement of the sand. The continuous bubbling action of the bed tends to recirculate the feed materials in the bed for a certain period of time, thereby increasing the contact time amongst the reactants and the heat source.

Although majority of the combustion reaction is expected to take place in the sand bed, provision of sufficient freeboard height is necessary especially when burning low-density materials such as rice husk. Such provision ensures that any incomplete burning of the evolved volatiles and char could proceed in the freeboard region. In addition, combustion of some portion of the low-density feed materials which tends to be elutriated upon entry into the combustor could still take place. For such purpose, it is of prime importance to maintain enough high temperature at the freeboard region. However, high heat loss to the surroundings in a non-insulated combustor results in a decreasing temperature profile along the height of the combustor, as opposed to the increasing temperature profile in a properly-insulated combustor. Thus, to maintain the required high temperature at the freeboard region, auxiliary burners are necessary to offset the heat loss.

3.0 EXPERIMENTAL

The combustion of rice husk was carried out in a fluidised bed combustor having the dimensions of 210 mm (inner diameter) and 2000 mm (height). The schematic diagram of the experimental set-up is shown in Figure 1. The distributor was a perforated plate with orifice diameter of 2 mm and a total orifice area of 1.5%. Commercial silica sand of size 250 – 595 μm (mean diameter 340 μm) was used as the inert bed media. A high pressure blower was used to supply the necessary airflow and all airflows were metered using rotameters prior to entry into the fluidised bed combustor. A detailed start-up procedure and other experimental information can be found in recent literature [1]. The burner used Liquid Petroleum Gas (LPG) bottles obtained from local Malaysian Petroleum Company named, Petronas Berhad.

The temperatures in combustor were monitored using six type-K thermocouples located at different heights along the combustor, all of which were hooked to a data acquisition system (TC-08, PICO Technology, U.K.) and finally to Computer for continuous temperature recording. The specification of this temperature data logger is given in Table 1. However, the resolution and accuracy of the product depends upon the thermocouple type and the temperature range. The temperature range supported by this type of data logger system for type-K thermocouple was -270 to 1370 °C. Nevertheless, the temperature range of the present study in a fluidized bed combustor was from 500 to 800 °C. Hence, the effect of temperature range on data logger accuracy can be neglected.

Table 1 Specifications of TC-08 temperature data logger system

Temperature accuracy	The sum of ± 0.2 % and ± 0.5 °C
Voltage accuracy	The sum of ± 0.2 % and ± 10 μV
Temperature reading rate	Up to 10 readings per second
Themrocouple types	B, E, J, K, N, R, S, T
Power requirements	No additional power required
Environment conditions	0 to 50 °C, 25 to 75 % humidity

The freeboard temperature profile during combustion of rice husk was investigated by first conducting the experiment without the presence of any secondary burner (Case Study I). Then, the same experiment was repeated with the inclusion of a simple secondary burner (non-premixed type) located 479 mm above the distributor plate (Case

Study II). Further, the effect of increasing the freeboard temperature further through the inclusion of one or more secondary burners (Case Study III and IV, respectively) were investigated using the optimum set of determined operating parameters [9]. The locations of the secondary burners and thermocouple are shown in Figure 2 while the major operating parameters were summarised in Table 2. However, it should be noted that present investigation was done in a non-insulted fluidized bed combustor.

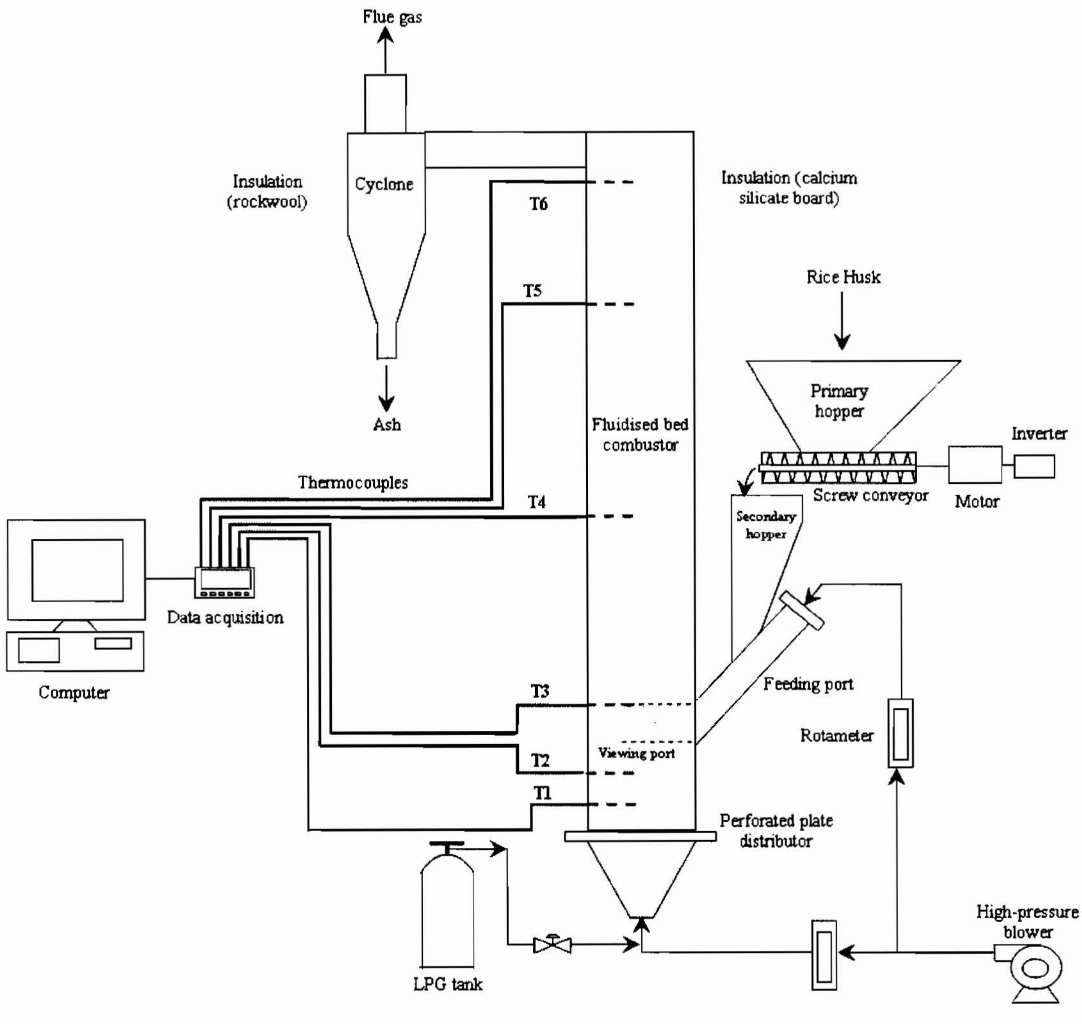
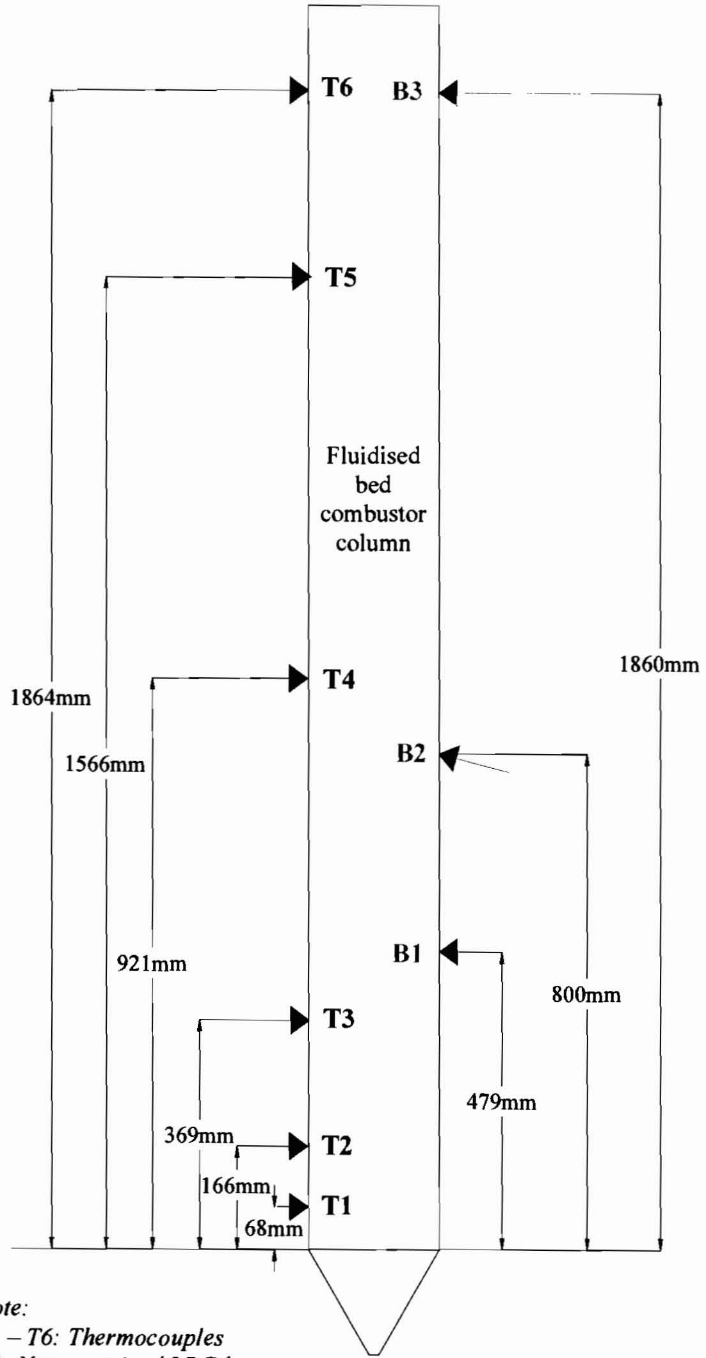


Figure 1 Schematic diagram of the fluidised bed combustor system



Note:
T1 – T6: Thermocouples
B1: Non-premixed LPG burner
B2: Premixed LPG burner c/w secondary air (tilted upwards at 15° from horizontal)
B3: Premixed LPG burner c/w with secondary air (facing cyclone ducting)

Figure 2 Exact locations of the thermocouples and secondary burners in a fluidised bed combustor

Table 2 Major operating parameters for Case Studies I – IV

Parameter	Case I	Case II	Case III	Case IV
Presence of Secondary LPG Burner	None	Yes (1 unit non-premixed type, B1)	Yes (1 unit non-premixed type, B1)	Yes (2 units premixed type complete with individual secondary air, B2 and B3)
Primary air feed @ 30 °C (LPM)	300	300	200	200
Rice husk feed rate (g/min)	110.8	110.8	40	40
Average bed temperature (°C)	725	765	666	636
Bed velocity @ bed temp. (m/s)	0.48	0.49	0.30	0.29
Operating U_{mf}	5.28	5.49	3.31	3.21
Primary air factor	0.81	0.81	1.49	1.49
Burning characteristics	Unstable burning of rice husk due to flame-quenching; primary LPG was fed intermittently to maintain bed temperature at 750°C	Stable and sustainable burning without primary LPG. Freeboard temperature (T3 and T4) maintained at 700 – 800°C	Minimal primary LPG required to sustain bed temperature (due to insufficient heat released at current feeding rate)	Minimal primary LPG required to sustain bed temperature (due to insufficient heat released at current feeding rate)

4.0 RESULTS AND DISCUSSIONS

4.1 Temperature profile and combustion characteristics

The temperature profiles during the combustion of rice husk for case studies I – IV are shown in Figures 3 to 5. Figure 3 shows the temperature profile without any secondary burner in a freeboard region of a fluidized bed combustor, while Figure 4 and Figure 5 depict the temperature profile with one and two secondary burners respectively. Meanwhile, results of the statistical analysis on the bed temperatures for all four experiments are depicted in Figure 6.

From Figure 6, it was observed that the fluctuations (as indicated by the value of standard deviation) in bed temperature (T1) was decreased with the presence of more secondary burners. This could be attributed to the generation of free radicals and compounds by the secondary burners acting as pilot flame, as noted by Luan and Chou [10]. In their studies on the gasification of rice husk/coal in the presence of a pilot flame in a modified fluidised bed, they concluded that the pilot flame supplied many free radicals, thus making the pyrolysis and combustion of rice husk more efficient in the lower temperature range. This subsequently led to a more stable temperature profile with less fluctuation as observed in the current experimental study.

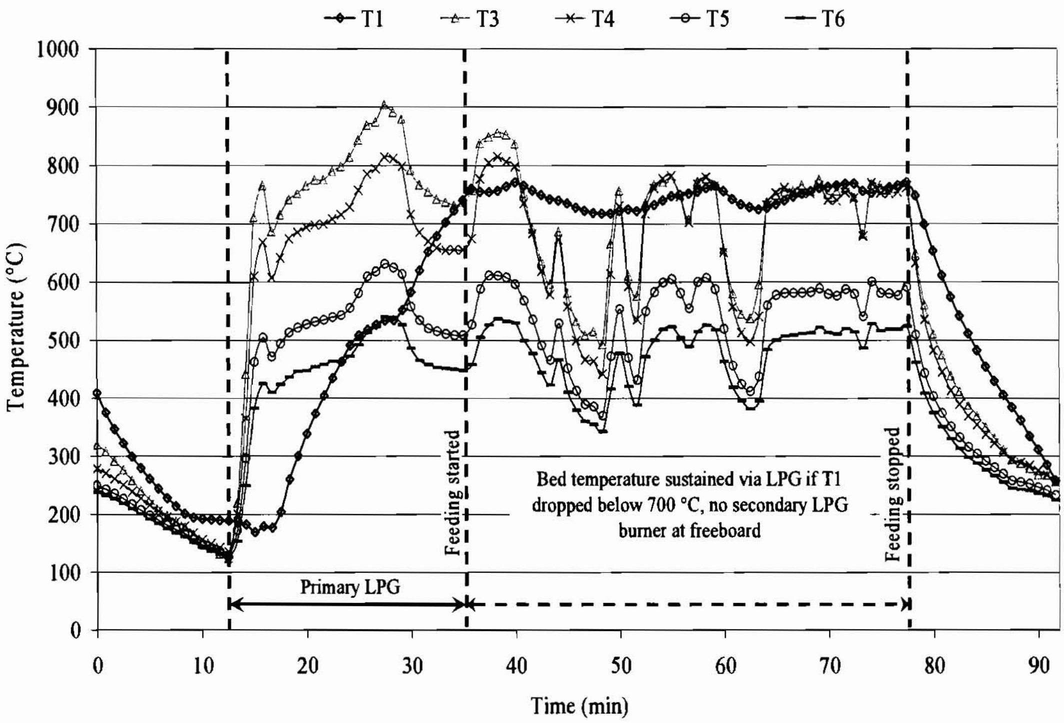


Figure 3 Temperature profiles during rice husk combustion without any secondary burner in a freeboard region

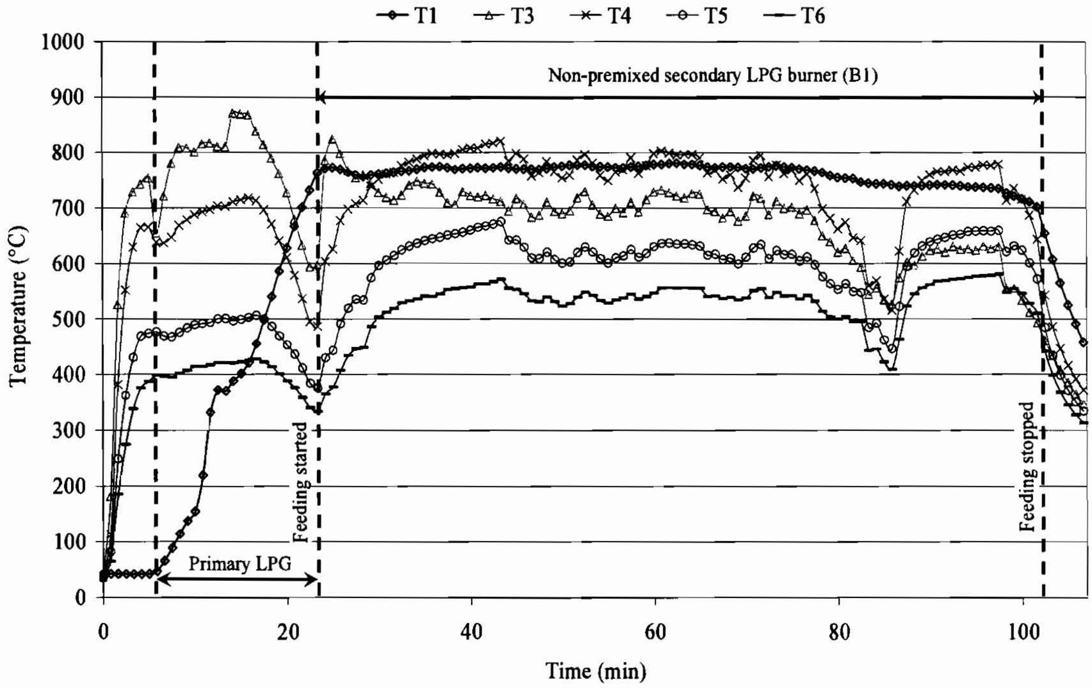


Figure 4 Temperature profiles during rice husk combustion with one secondary burner (B1) in a freeboard region

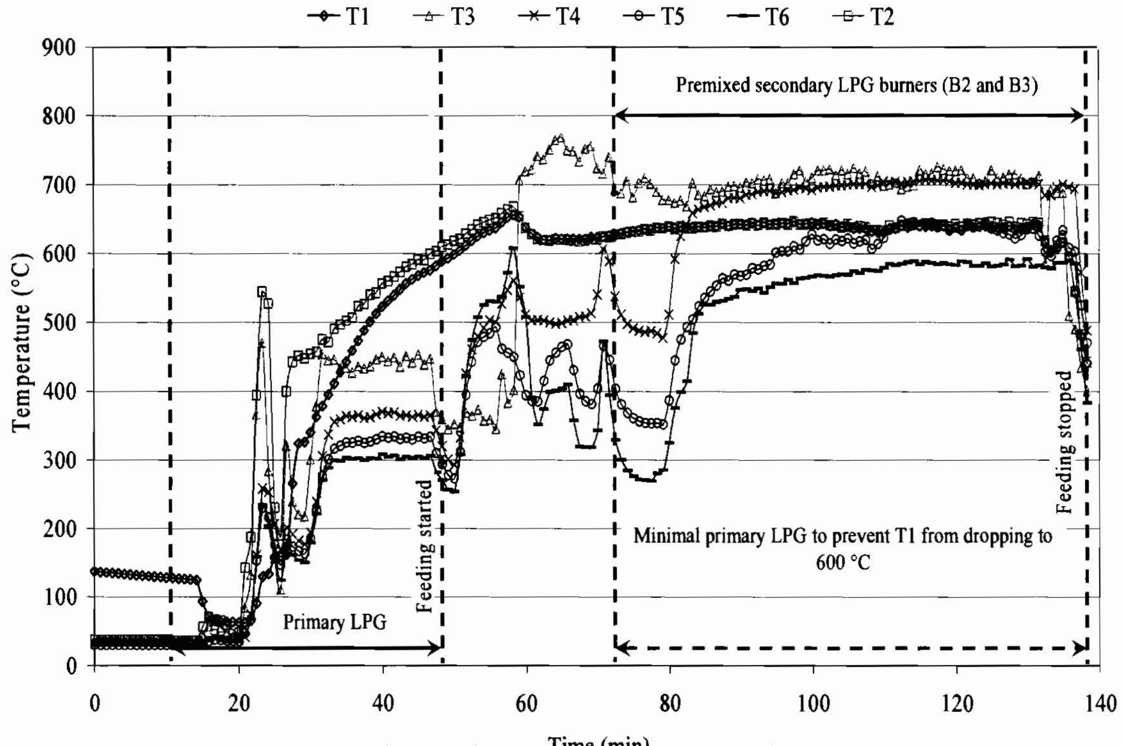


Figure 5 Temperature profiles during rice husk combustion with two secondary burners (B2 and B3) in a freeboard region.

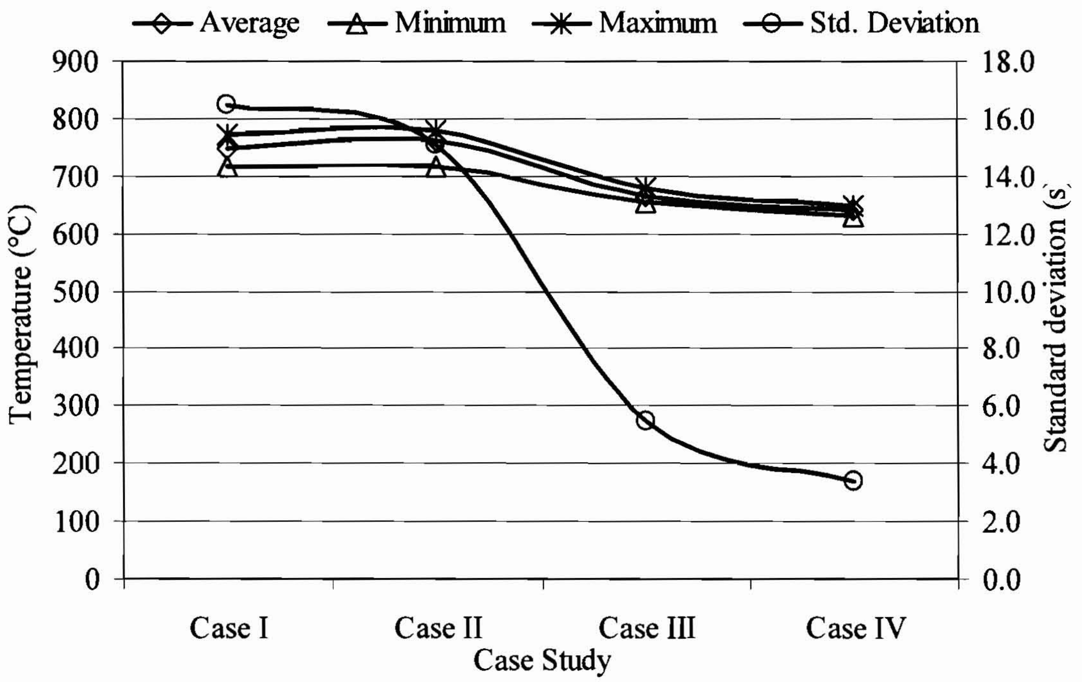


Figure 6 Statistical analysis on the bed temperatures (T1) for Case I - IV

The presence of free radicals generated by the secondary burner also explained why the combustion process in Case II is autogenous as opposed to Case I, since the operating parameters for both case studies were similar (except for the presence of a secondary burner (B1) in the former). In the former case, as soon as the rice husk feed entered the combustor, the free radicals generated by the secondary burner aided in igniting the rice husk particles, including the evolved volatile gases. Thereafter, these burning rice husk particles proceeded towards the bed region, thus increasing the bed temperature to as much as 40 °C compared to the case without the presence of the secondary burner B1. The phenomenon of ignition of rice husk feed and their evolved volatiles by the free radicals could be further proven by the temperature profile of thermocouple T3, located 369 mm above the distributor plate. As the feed entry port was located at 365 mm above the distributor plate, the temperature profile of T3 acted as an indicator as to whether the rice husk particles were ignited upon entry into the fluidised bed combustor. In Case I, the temperature profile of T3 (Figure 3) displayed great fluctuations (as much as ± 370 °C), indicating the occasional catching of flame by the rice husk upon their entry into the combustor. On the other hand, the temperature profile of T3 for Case II (Figure 4) showed minimal fluctuations (less than ± 30 °C) throughout the experiment, which indicated that the rice husk feed was steadily ignited and burned upon entry into the combustor, hence raising the temperature at this region to a steady average of 770 °C.

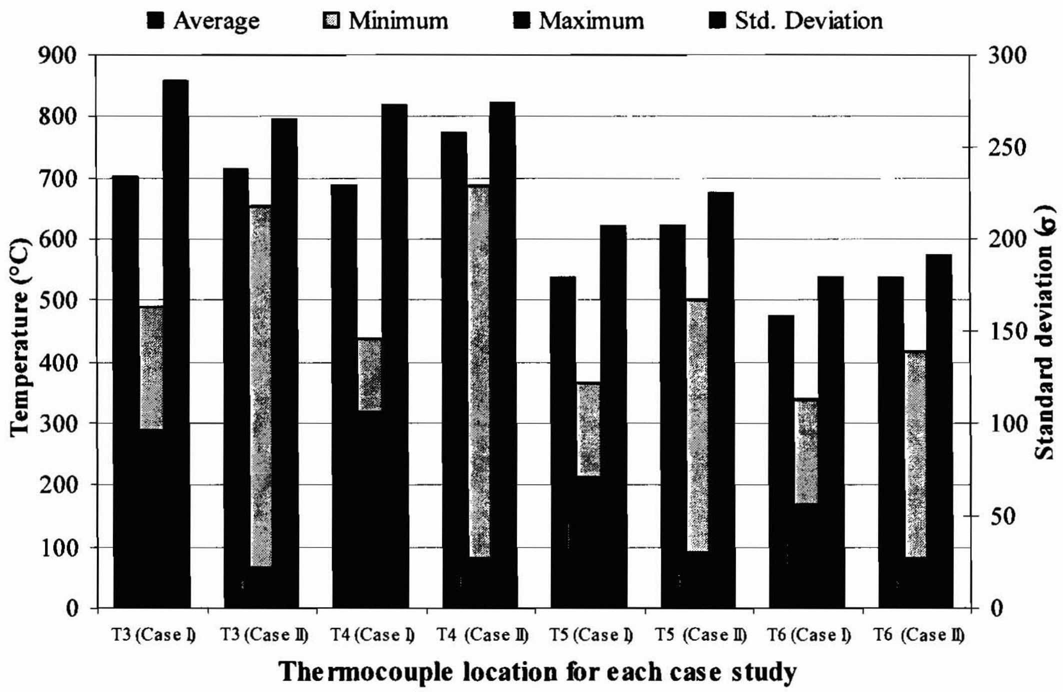


Figure 7 Statistical analysis on temperature profiles of T3 – T6 for Case Study I and II

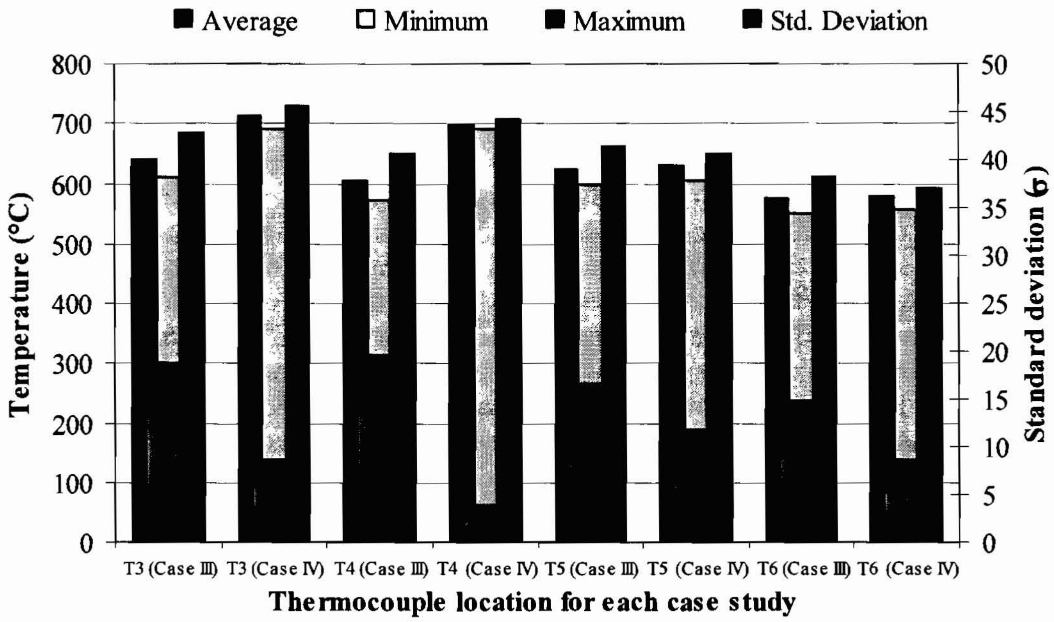


Figure 8 Statistical analysis on temperature profiles of T3 – T6 for Case Study III and IV

The statistical analysis for temperatures at T3 to T6 for case studies I and II is shown in Figure 7. In general, it could be concluded that the freeboard temperatures (T3 to T6) in Case II was higher compared to Case I and showed lesser fluctuations (as indicated by the lower values of standard deviation) primarily due to the presence of the secondary burner in Case II. As such, the presence of such burner actually improved the combustion characteristics by maintaining a stable and higher temperature profile in the freeboard region when all other parameters were held constant.

Likewise, the statistical analysis for temperatures at T3 to T6 for case studies III and IV is shown in Figure 8. In general, the analysis reflected the similar findings as in case studies I and II, whereby in this case, the presence of more secondary burners resulted in higher temperature profile with less fluctuations.

Another reason might be the release and burning of volatile matter form rice husk upon the entrance in fluidized bed combustor. The temperature at the rice husk entrance in case studies II to IV was enough high to overcome the primary stage burning and directly switch to secondary stage burning as described in Section 2. It was likely that minimal amount of volatile matter was released in case study I and the fluctuation increases as newer rice husk are fed into combustor. Nonetheless, the operating conditions during rice husk combustion cannot be neglected. The fluidizing velocity for case studies III and IV was lower compared to case studies I and II. The lower fluidizing velocity enables the penetration of rice husk particle towards the bed region [1]. Previous studies [7-8] revealed similar results for the effect of fluidizing velocity on temperature profiles of the fluidized bed combustor while firing rice husk.

Hence, it could be concluded that the presence of secondary burner improved the combustion process by generating free radicals to ignite the feed materials, thereby resulting in a steady temperature profile with lesser fluctuations. These effects were enhanced with the presence of more secondary burners. This might also aid in obtaining higher quality of siliceous rice husk ash with less carbon content due to increase temperature profile in the freeboard region acting as secondary combustion zone.

5.0 CONCLUSIONS

From the current study, it could be concluded that the presence of secondary burners improved the temperature profile in the freeboard region of the fluidised bed combustor. This stable and uniform temperature profiles in the combustor might be due to the continuous generation of free radicals from the flame of the secondary burners to continually ignite the fresh incoming rice husk and the evolved volatile gases. This was supported by statistical analysis of freeboard temperature profile which revealed that the deviation was lower in the cases where secondary burner was installed. However, release of volatile matter at the feeding point in combustor and fluidizing velocity also plays a role in freeboard temperature profile. Secondary burners not only help in increasing the freeboard temperature and maintaining it, but also aids in obtaining high quality of siliceous ash with less carbon content by acting as secondary combustion zone.

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