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Investigation on Rice Husk Combustion in a Fluidized Bed with Longitudinal Vortex Generators

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Abstract. Effects of wavy-ribbed surface chamber on combustion temperature/efficiency and exhaust gas behaviours in a fluidized bed combustor were investigated. In the experiments, the five wavy-rib pairs were placed at the bottom chamber for inducing longitudinal vortex flow which enhanced the fuel and fluid/combustion-air mixing in the top chamber for giving better combustion efficiency. The experiments were examined at five percent excess airs of EA = 15%, 30%, 45%, 60%, and 75% and were tested at the constant air mass flow rate of 95 kg/hr. From experimental results, it can be showed that a fluidized bed combustor with wavy-ribbed surface chamber can be promoted the high combustion efficient for all test runs especially at the percent excess airs of EA = 75%.

1. Introduction

In general, paddy or rice is one of the mostly produced crops throughout the world. The rice husk is the outer cover of the rice grain and is in the form of husk/hull. At about 20% by weight of the paddy harvested is generated as a waste, known as rice husk. For an efficient method, the rice husk can be converted to a useful form of energy to meet the thermal and mechanical energy requirements in the locality. Due to its low energy density, husk transport over a short distance between the originating mill and utilization site can be economical and competitive. Therefore, an attempt to energy recovery from this rice husk waste by efficient combustion techniques may be worthwhile. Vortex generator is one of the efficiency device that applied in the vortex combustor or vortexing fluidized bed combustor by using rice husk as the fuel [1-5]. Zhang and Nieh [6] reported the isothermal flow and reacting gas flow and the gas-particle slip motion in the vortex combustor. They found that the gas flow in the vortex combustor with a coaxial center tube and multiple air injection was behaved with swirling, developing, and recirculating features. Zhang et al. [7] studied the behaviors of emissions, the fuel concentration distribution and combustion of trapped vortex combustor under different swirl fields and fuel injection modes. They found that a vertical double vortex structure can be formed in the cavity under various conditions while the air velocity of cavity inlet, the spray cone angle, and Sauter mean diameter of kerosene droplets had different effects on the liquid and gaseous fuel concentrations. Sirisomboon and Laowthong [8] studied the heat transfer coefficient characteristics in a twin-cyclonic



swirling fluidized-bed combustor fitted with a conical shape bed. Influences of the combustor geometry and operating parameters (silica sand as bed material at different particle diameters and swirl number of 2.76, and 2.98) were also reported. They result showed that the radial profile of heat transfer coefficient was highest at the center of the combustor while the heat transfer coefficient in the bed region was comparable to the value in freeboard region though about 5-12% higher. Li et al. [9] carried out the combustion efficiency of a trapped vortex combustor at various strut lengths. They showed that lean blowout (LBO), combustion performance and ignition depend to a great extent upon the length of the strut. The longer struts performed prominent advantages in terms of ignition and LBO, whereas the shorter ones perform rather poorly. Cao et al. [10] predicted the in-bed combustion fraction (combustion and pollutant emissions characteristics) in a vortexing fluidized-bed combustor using Response surface methodology (RSM). They showed that primary gas ratio, particle size, and fuel type significantly affect the combustion fraction while the in-bed combustion fraction increases with increasing particle size, and decreases with increasing primary gas ratio and the ratio of volatile to fixed carbon. Wu et al. [11] used the Large Eddy Simulation (LES) to study the isothermal and incompressible turbulent swirling flows in a model gas turbine combustion chamber geometry. Influences of the outlet geometry contraction (contraction ratio) on the vortex breakdown structure and the processing vortex core in the chamber were also reported. In their studied, the swirling flow was created using a swirler with 15 guide vanes. They indicated that the contraction ratio increases as a result of the change of the structure of the center recirculation zone.

The aim of this report is to examine the combustion temperature/efficiency and exhaust gas behaviors in a fluidized bed combustor with wavy-ribbed surface chamber using rice husk as the fuel. Five pair of wavy-rib were fixed at the bottom chamber for creating strong longitudinal vortex of fuel and air for better combustion in the top region. This work also investigation the effect of percent excess air on the combustion temperature distribution, exhaust gas and combustion efficiency are also tested.

2. Combustor and experimental setup

2.1. Fluidized bed combustor

A fluidized bed combustor with wavy-ribbed surface chamber setup is designed to investigate the effect of longitudinal vortex generators on combustion temperature distribution, exhaust gas and combustion efficiency. Fig. 1 demonstrated a 2-D schematic of the bed test rig. The fluidized bed combustor is made of 6 mm thick, 310 stainless steel cylinder of 200 mm (D) in diameter, 2100 mm in bed height (H) and 2400 mm in total height, which the bottom wall was fixed with five pairs of wavy-rib. The wavy-ribs were constructed at the bottom chamber with 5 modules of converging-diverging nozzles and each module had a throat diameter of 100 mm (d) and height of 200 mm (h). The chamber was insulated with 40 mm thick brick and covered by 1 mm thick galvanized steel. A dual distributor plate was fixed at the bottom chamber which included the main distributor plate for feeding the primary air and the secondary distributor plate for feeding the rice husk. In the experiments, the combustion temperatures inside the bed/chamber were monitored at eleven axial stations namely, $x/D = 2.0, 3.0, 4.0, 5.0, 6.0, 6.75, 7.5, 8.5, 9.5, 10.5, 11.5$ and the exit and radial stations namely $r/R = 0.235, 0.4$ and 0.5 , respectively. A schematic diagram of the combustor and experimental setups used in this investigation is demonstrated in figure 1 and 2.

2.2. Procedure

The air was separated in to two parts; primary and secondary air. The primary is used to be fluidizing and secondary air for feeding rice husk. The flow rates of airs were measured by orifice plate and manometer. Rice husk form hopper was feed by screw feeder and quantity of rice husk controlled by motor and inverter. Startup process was commenced by heating up the FBC with LPG torch inserted at the bottom chamber. Rice husk particles were fed through a screw feeder into the chamber from bottom of the main distributor plate with secondary air injection and the combustion occurs primarily

in the bottom chamber. Then, hot combustion gas ascends to the wavy-ribbed surface chamber and then to the top chamber before leaving through the exhaust tube. The highly turbulent gas around the wavy-ribbed surface chamber induces a central recirculation zone near the wavy-ribbed surface chamber that helps to increase the strongly mixing rate between air and fuel particles and to prolong residence time of husk particle in this chamber. In addition, the combined effects of centrifugal, gravitational and fluid drag forces give rise to fuel particles to be trapped along the height of the combustor. As rice husk particles are burned they continually reduce in mass and size until completely burned out. The majority of ash particles become light and small enough to be entrained by the flue gas and exit the combustor as fly ash.

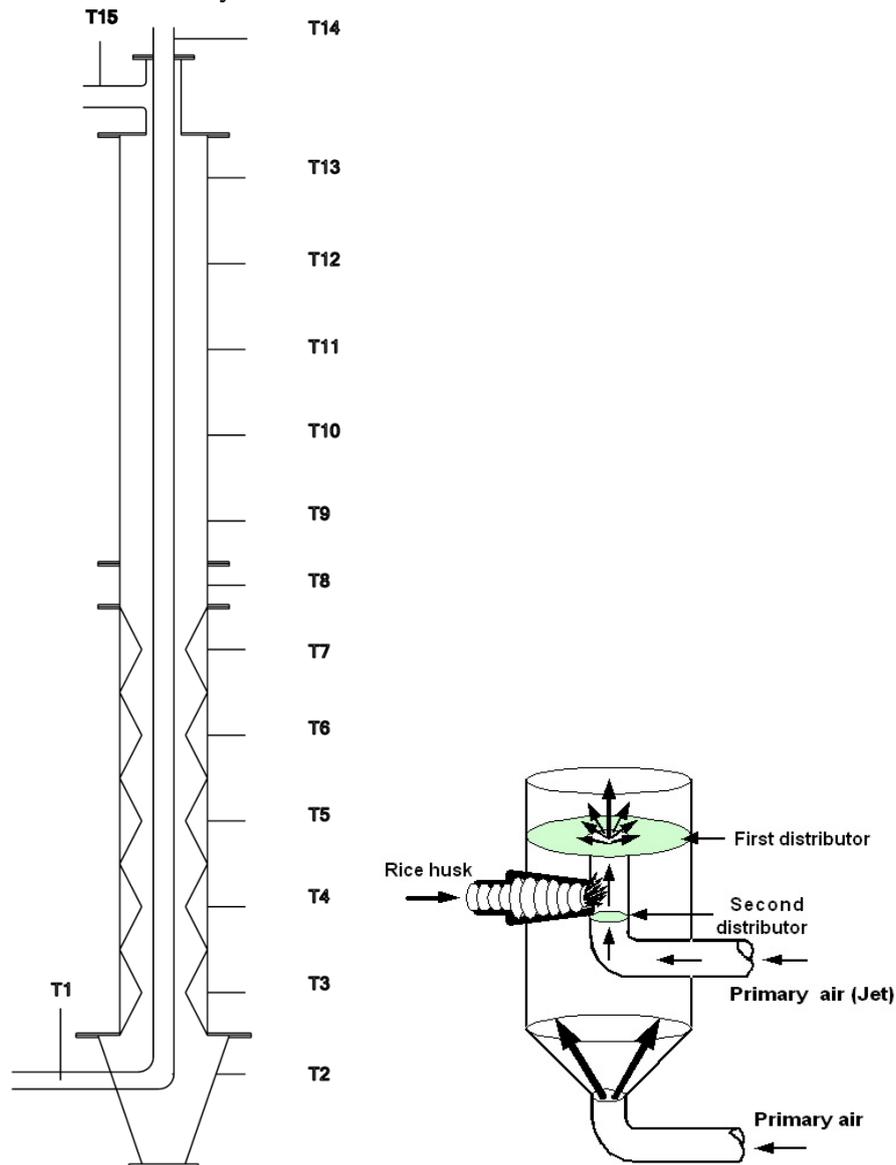


Figure 1. 2-D schematic of fluidized bed combustor with wavy-ribbed surface chamber and a dual distributor plate.

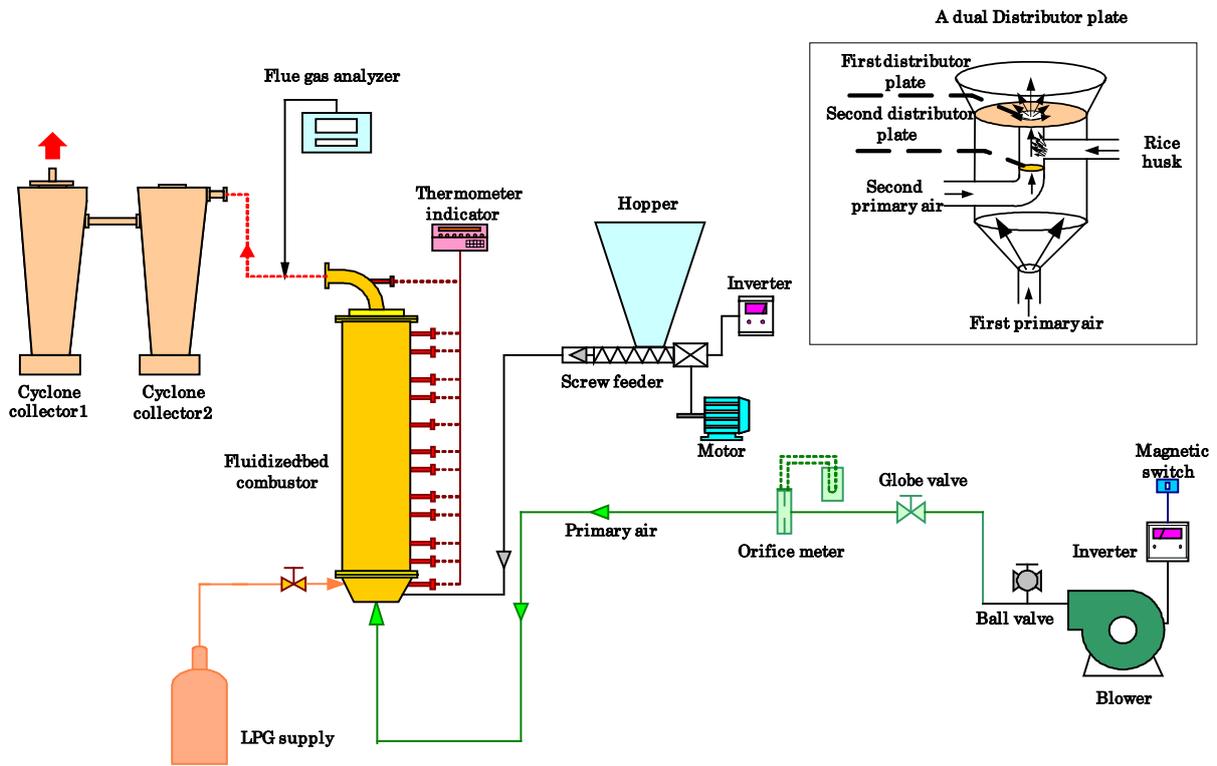
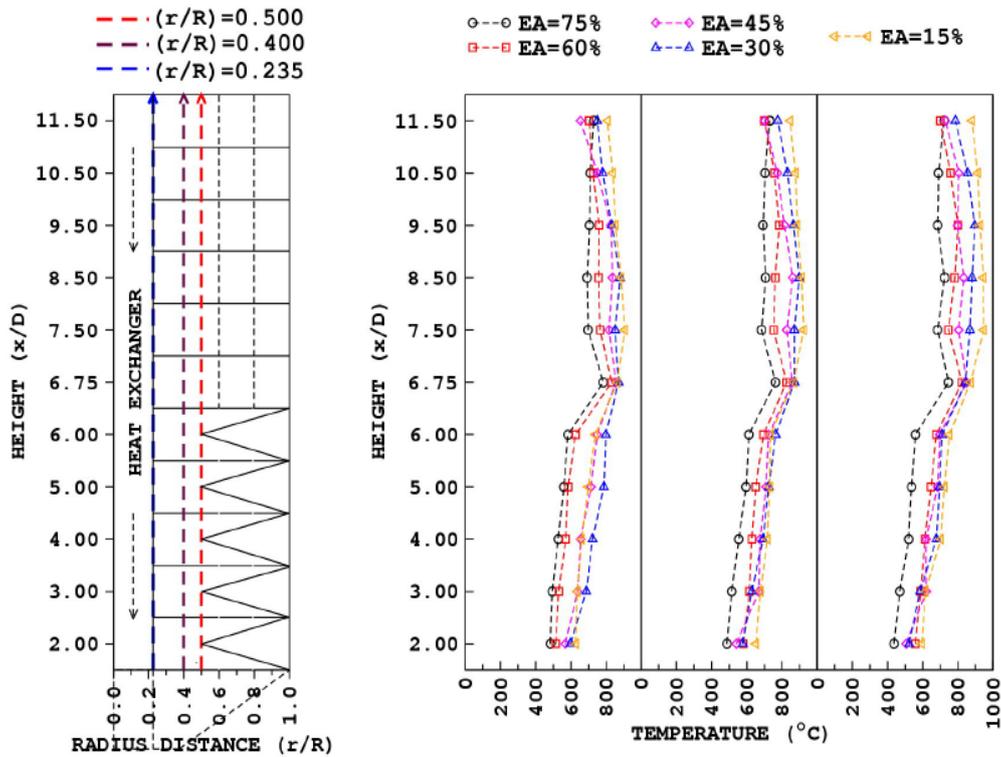
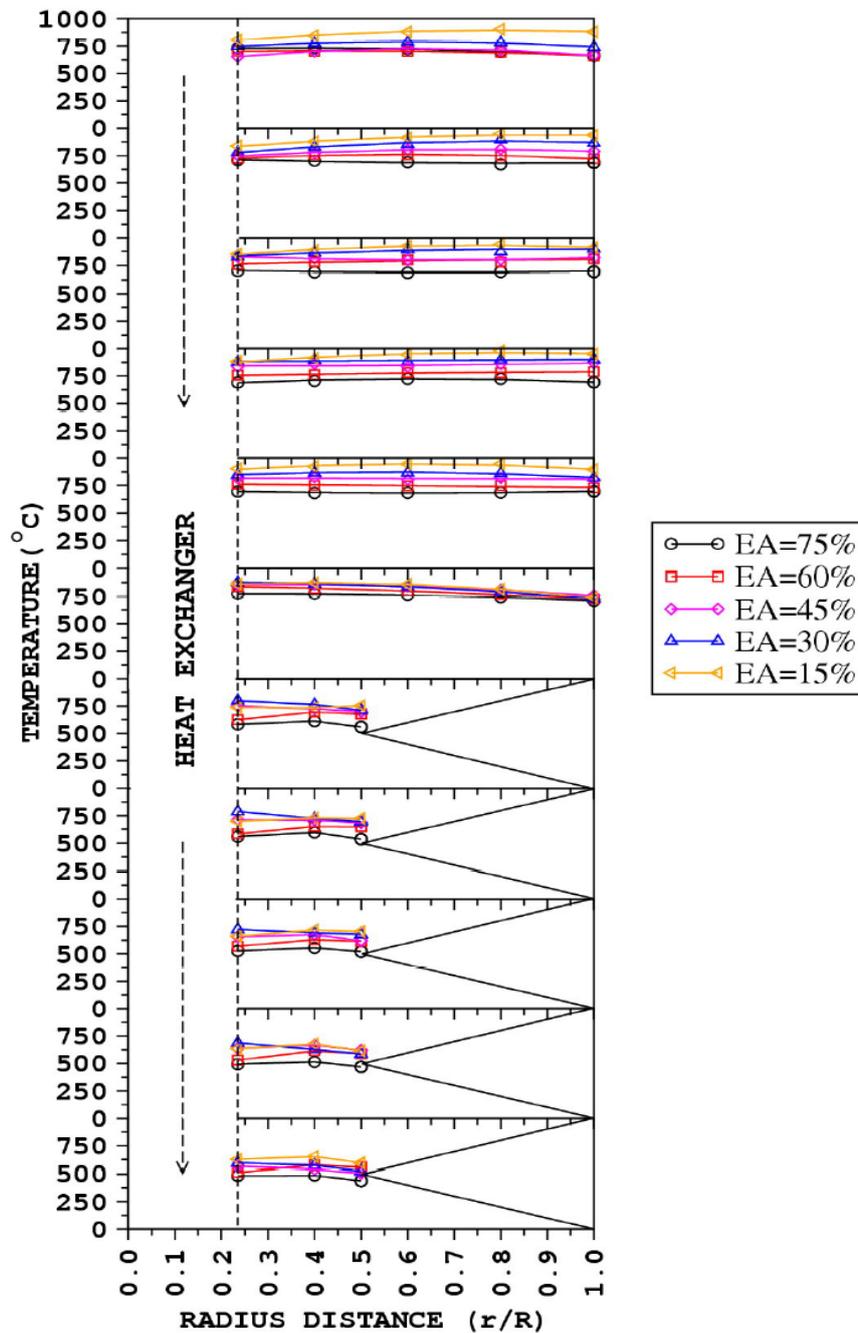


Figure 2. Diagram of a fluidized bed combustor with wavy-ribbed surface chamber facility.



(a) radial combustion temperature profiles



(b) axial combustion temperature profiles

Figure 3. Combustion temperature profiles in a fluidized bed combustor with wavy-ribbed surface chamber at five different percent excess airs of EA = 15%, 30%, 45%, 60%, and 75%.

3. Combustion results

Figure 3 shown the axial/radial combustion temperature profiles in a fluidized bed combustor with wavy-ribbed surface chamber at five different percent excess airs of EA = 15%, 30%, 45%, 60%, and 75%. It is observed that the behavior of combustion temperature profiles at percent excess airs of EA = 15%, is same to other percent excess airs but combustion temperature profiles is slightly higher at the top chamber due to the less heat loss to the excess air and high particle residence time which help to increase combustion temperature inside a fluidized bed combustor. The highest combustion

temperature zone is visible in the middle region and near the top chamber wall of combustion zone while the highest percent excess air of EA = 75% provided the minimum combustion temperature profile.

Figure 4 demonstrated the combustion results of the combustion efficiency and exhaust gas (NO and CO) from a fluidized bed combustor with wavy-ribbed surface chamber at five different percent excess air of EA = 15%, 30%, 45%, 60%, and 75%. It is interesting to find that the combustion efficiency and NO are increased substantially at the higher percent excess air (EA) especially at excess air of EA = 75%. On the other hand, the emission gas of CO is reduced by increasing the percent excess air (EA) examined. It is showed that the combustion efficiency level is enhanced with the increasing of the excess air (EA) due to the abrupt change of area size of the internal combustion chamber or wavy-ribbed surface chamber helps to enhance the high level of stronger longitudinal vortex affecting the air turbulence intensity and the considerable increase of the state of turbulence and completing combustion.

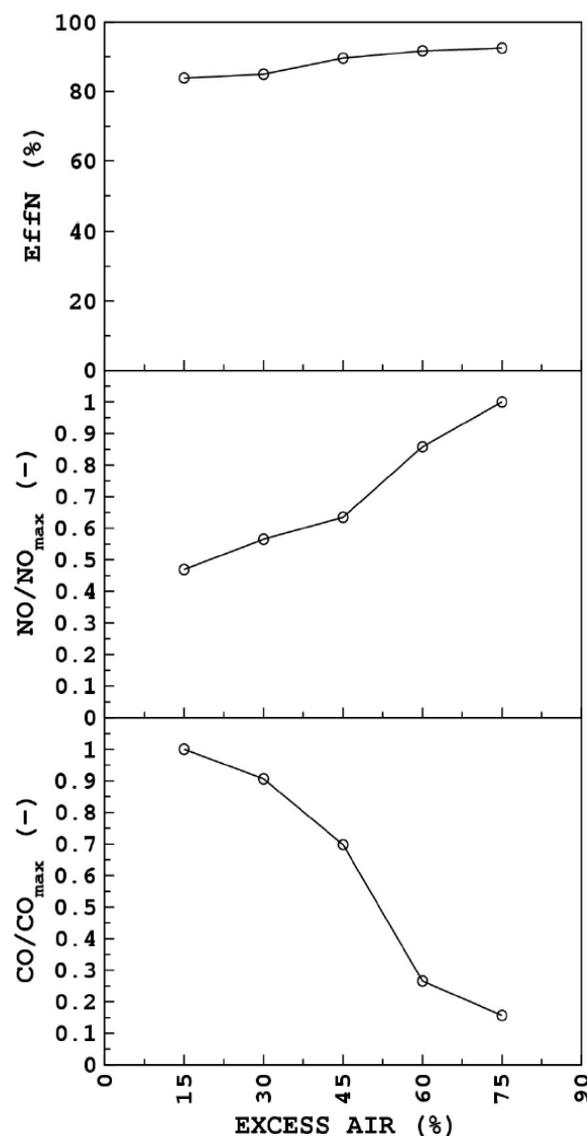


Figure 4. Combustion efficiency and exhaust gas in a fluidized bed combustor with wavy-ribbed surface chamber at five different percent excess air of EA = 15%, 30%, 45%, 60%, and 75%.

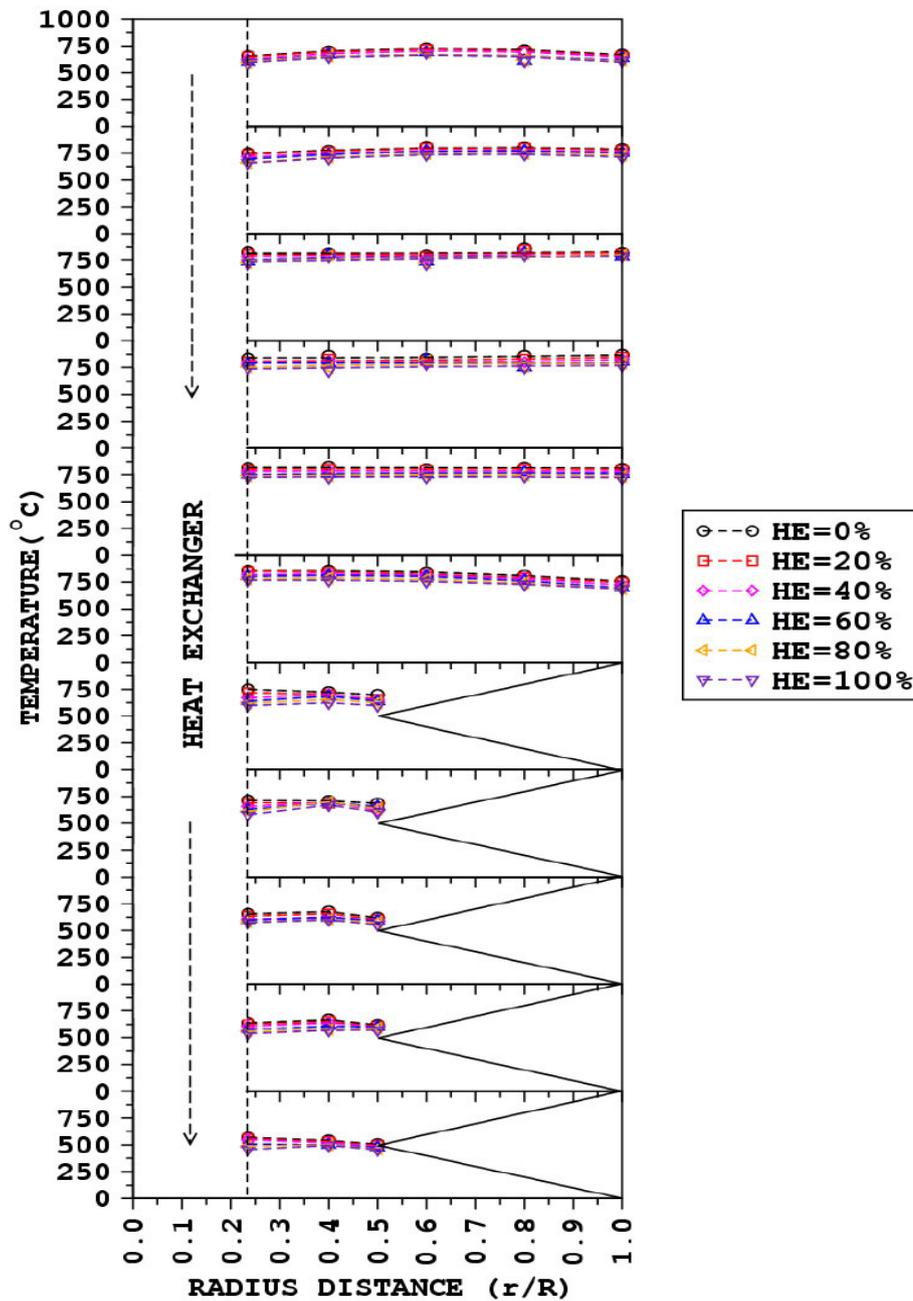


Figure 5. Combustion temperature profiles in a fluidized bed combustor with wavy-ribbed surface chamber at different heat exchanger air mass flow rates.

From figure 5, it is depicted that the radial temperature profiles (r/R) for all axial locations generally are nearly uniform for different six heat exchanger air mass flow rates to the total of primary air at the bottom chamber of 0%, 20%, 40%, 60%, 80%, and 100%. The characteristic of combustion temperature distribution with heat exchanger at the core bed is slightly lower for the high air mass flow rate especially for the 20% of the air mass flow rate.

4. Conclusion

The paper presents an investigation on rice husk combustion behaviours in a fluidized bed combustor with wavy-ribbed surface chamber which used as longitudinal vortex flows in the bed. The fluidized

bed combustor with wavy-ribbed surface chamber performs a stronger intensity of longitudinal vortex flow and stronger turbulence lead to more complete combustion in the chamber due to stronger mixing between air and fuel particles, and then energy released can occur considerably with the highest temperature. They found that the highest temperature inside the combustor is found at percent excess air of 15%. For all combustion results, use of percent excess airs of EA = 15%, 30%, 45%, 60%, and 75% results in significant improvement of combustion temperatures and combustion efficiency.

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