https://doi.org/10.51459/futajeet.2021.15.2.161

Journal of Engineering and Engineering Technology

EXPERIMENTAL STUDY ON BED-TO-TUBE HEAT TRANSFER COEFFICIENTS IN BUBBLING FLUIDIZED BED

Adewole, B. Z.
Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria

ARTICLE HISTORY
Received: 28-07-20
Accepted: 12-07-21

KEYWORDS:
Fluidized bed, Co-firing, Coal, Coconut shell, Bed-to-tube, Heat transfer

ABSTRACT

The overall bed-to-tube heat transfer coefficients of the blends of Lafia-obi coal and coconut shells have been investigated in a bubbling fluidized bed combustor. Experiments were performed at five different particle sizes of coal (5, 10, 15, 20 and 25 mm) and five different particle sizes of coconut shells (2, 6, 10,14 and 18 mm) for different blend proportions of 10%, 20%, 30%, 40% and 50%. Results obtained showed that the overall bed-to-tube heat transfer coefficient decreased with increasing coconut shell particle size in the blends. Combined effects of high radiation from large particle size of coal (25 mm) and high convection heat from small particle size of coconut shell (2 mm) at blend proportion of 10 and 50% produced the maximum bed-to-tube heat transfer coefficient. Due to the importance of heat exchange in the fluidized bed, it is observed that the contribution of biomass co-firing with coal is significant, hence, co-firing at optimal particle size and biomass blend ratio is imperative for achieving higher bed-to-tube heat transfer in the fluidized bed boiler.

Correspondence: *bzadewole@oauife.edu.ng*

1.0 INTRODUCTION

Design of a fluidized bed boiler is largely depended on bed hydrodynamics and heat transfer characteristics. For this reason, emphasis has been given to the mechanism of heat transfer and the effect of operating parameters on the heat transfer process in the fluidized bed combustor (Basu, 2006; Molerus, 1977). This is with a view to improving the design and operation of a fluidized bed boilers. The heat transfer in the fluidized bed usually includes several sub-processes (Basu, 2006, Basu and Cheng, 1996): heat transfer between solid particles and fluidizing medium and heat transfer between bubbles and solid particles. Heat transfer between solid particles and fluidizing medium includes heat transfer between the gas and solid particles in emulsion phase while heat transfer between bubbles and solid particles includes: heat transfer between the bed and the surfaces (walls or immersed surfaces) *Kim et al.*, (2003); and heat transfer inside the solid particles (Molerus, 1977).

Mechanisms by which heat is transferred from the fluidized bed to immersed surfaces virtually involve all known heat transfer mechanisms (Abdelmotalib *et al.,* 2015). Due to the different physical nature of heat transfer mechanisms between the fluidized

https://doi.org/10.51459/futajeet.2021.15.2.161

bed and immersed surfaces, with the change in flow, geometrical and physical parameters of the bed, great differences in heat transfer intensity occur. The heat transfer process also depends on numerous physical properties of particles and gas (Asere, 1992) and physical and geometrical characteristics of the heat transfer surface and the fluidized bed (Oka, 2004).

Heat transfer due to particle size can be transferred through the action of bubble or emulsion phase (gas-particle suspension). Heat transfer due to action of bubble is small and sometimes negligible. This is due to small contact area between the particles and the wall (Basu, 2006). In comparison with emulsion phase heat transfer, large amount of heat is transferred through conduction between a thin layer of gas and particles. Studies on gas-particles heat transfer showed that the heat transfer coefficient was very low for Group C particles (very fine particles less than 30 µm) and decreases with increasing particle size for Group A (30-100 µm) and B (100-650 µm) particles. (Basu, 2006; Chao *et al.,* 2015; Kalita *et al.,* 2013). In case of a very large particles greater than 650 µm (Group D), heat-transfer coefficient increased moderately with increasing particle size (Abdelmotalib *et al.,* 2015).

In co-firing study, there are limited studies on heat transfer process of co-fired fuels in the fluidized bed. In these limited studies, parameters such as suspension density, biomass share, secondary air ratio, type and size of heat transfer surfaces are usually investigated (Chinsuwan and Dutta, 2009; Sun et al., 2013) and found to enhanced heat transfer in fluidized bed (Sun et al., 2013; Chao et al., 2015; Abdelmotalib et al. 2015). In this study, effect of particle size of biomass, particle size of biomass/coal mix and biomass blend ratios were investigated on bed-to-tube heat transfer coefficient in the fluidized bed.

2.0 MATERIALS AND METHOD

2.1. Materials and selection criteria

Fuels selected for the study were Lafia-Obi coal and coconut shell. Popoola (2011) reported extensively on Lafia-Obi coal deposits in Nigeria. Lafia-Obi coal deposit which is in the Middle Benue Trough is geologically, the oldest coal deposit in Nigeria and it is believed to be Turonian – Coniacian in age (Obaje, 2009; Obaje *et al*., 1994). It has an estimated inferred resource of 33 million tonnes (Popoola, 2011). 36 Lafia-Obi coal seams have been identified and 22 million tonnes proven reserves have been reported (Agbu, 2007; Sambo, 2008). Lafia-Obi coal is reported to have lowest moisture content, lowest volatile matter and highest fixed carbon of all Nigerian coal investigated (Popoola, 2011). It is also reported to have high sulphur and ash content (Fatoye and Gideon, 2013) and high calorific value of between 31,391-35,576 kJ/kg (Popoola and Asere, 2010). Lafia-Obi coal for the present study was obtained from Lafia-Obi coal mine located in the town of Lafia, Nasarawa state.

Coconut is a multifunction plant and it has a lot of economic, environmental and technological benefits. As at 2018, Food and Agricultural Organization, estimated the annual production of coconut in Nigeria to be 265,000 mega tonnes (FAO, 2018). Coconut shell is obtained from coconut palm tree. It has a heating value of 20,647 kJ/kg, moisture

https://doi.org/10.51459/futajeet.2021.15.2.161

content of 12.22% and ash content of 3.47% respectively (Jekayinfa and Omisakin, 2005; Jejayinfa and Scholz, 2007). Coconut shells are commonly burned and abandon in the past but nowadays, they are valuable fuel for energy production. Hence, its selection for the study. The quantity considered for the study was procured from the local sellers within Ile-Ife Metropolis, Osun state.

2.2. Fuel Analysis of Coal and Biomass Samples

The proximate and ultimate analyses of fuels on as-receive basis were determined following the procedure of the America Society for Testing Materials (ASTM) Standards and by Rutherford Backscattering Spectrometry (RBS) respectively. The results of test are presented in section 3.1.

2.3. Experimental rig

The experimental rig is a laboratory scale, bubbling fluidized bed combustor (Figure 1). The major components of the combustor consist of furnace, distributor plate and water tubes. The combustor was lagged to prevent wall heat losses and ash drain was introduced to maintain a steady operation. The bed characteristics were determined and presented in Table 1.

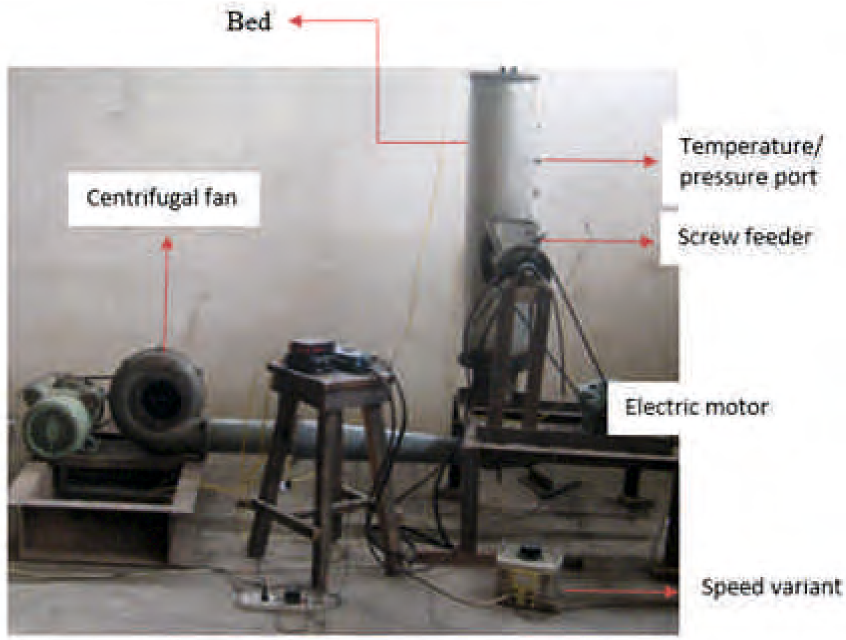


Figure 1. Photograph of the experimental rig

2.4. Experimental procedure

Experiments were performed in a laboratory scale atmospheric fluidized bed combustor of 1.03 MW thermal input (Fig. 1). Lafia-Obi coal and coconut shell particles sizes were pre-mixed thoroughly before combustion. The fuel mixture at different biomass blend ratio (BBRs) were fed and fired separately in the fluidized bed combustor. The combustion was done at a fluidization velocity of 0.57 m/s and fuel feed rate of 0.5 kg/s. Table 2 shows blend parameters for Lafia-obi coal/coconut shells blends at a fixed fuel flow rate of 0.5 kg/s. Six (6) sheathed Type-K, Ni/Cr

https://doi.org/10.51459/futajeet.2021.15.2.161

Table 1: Bed Characteristics

Bed Parameters	Values
Furnace diameter	0.15 m
Furnace height	1 m
Freeboard height	0.9 m
Bed height	0.1m
Furnace Insulation thickness	0.077 m
Transport disengaging height (TDH)	0.9 m
Distributor pressure drop	3 kPa
Bed voidage	0.6
Pressure drop through the bed	10.2 kPa
Number of orifices	836
Orifice pitch	0.035 m
Grate heat released	1.56 MW/m^3

thermocouple were installed and position on the riser at 0.15, 0.3, 0.45, 0.6. 0.75 and 0.9 m to measure the bed temperature, the freeboard temperature and the outer wall temperature of the fluidized bed rig along the height of the combustor. A heat exchanger tube constructed from mild steel with outer diameter of 21 mm, inner diameter of 20 mm and 774 mm long was installed in the freeboard part of the combustor at a height of 226 mm above the distributor plate. Water was supplied to the heat transfer tube by gravity, through rotameters at 1 litre/s.

The temperature of water at the inlet and at outlet of the heat exchanger were measured with sheathed Type-K, Ni/Cr, 1.6 mm mineral

Table 2: Blend parameters of Lafia-obi coal and coconut shells based on a fixed fuel flow rate

Fuel blends	Mass		Fuel flow rate	Co-firing share	
	M_c (kg)	M_b (kg)	$\dot{m}_{mixture}$ (kg/s)	P_c (%)	P_b (%)
Base (coal)	0.5	0	0.5	100	0
COAL/CNS	0.45	0.05	0.5	90	10
	0.40	0.10	0.5	80	20
	0.35	0.15	0.5	70	30
	0.30	0.20	0.5	60	40
	0.25	0.25	0.5	50	50

https://doi.org/10.51459/futajeet.2021.15.2.161

Table 3: Experimental operating conditions

Properties	Values
Fuel feed rate (kg/s)	0.5
Minimum fluidization velocity (m/s)	0.191
Fluidization velocity (m/s)	0.57
Coal particle size:(mm)	5, 10, 15, 20 and 25
Biomass particle size:(mm)	2, 6, 10, 14 and 18
Bed material (um)	Silica sand (450 um)
Co- firing ratio (%)	10, 20, 30, 40, and 50
Bed temperature (°C)	700-1200
Bed pressure (kPa)	10.2

insulated thermocouples. The wall temperature of the heat exchanger were also measured at different height of 0.3, 0.45, 0.6, 0.75 and 0.9 m respectively using sheathed Type-K, Ni/Cr thermocouple. Table 3 shows the operating conditions for the experiment. All thermocouples were logged into a data logger to obtain temperature data.

The burnt particles and flue gases release heat through convection and radiation to the heat exchanger and the space around it in the fluidized bed. Hot flue gases leave the furnace through the exit region to the atmosphere and the ash accumulated in the bed was drained occasionally through the ash drain.

2.4. Heat Transfer Coefficient

Heat transfer to the heat transfer tube in the fluidized bed combustor is the sum of convective and radiative heat and it was determined by equation (1), according to Basu (2006).

$$h = h_{conv} + h_{rad} = 900(1-\varepsilon)\frac{kg}{dt}\left[\frac{UdtP_p}{u}\ \frac{u^2}{{d_p}^3 p_g^2 g}\right]^{0.326} P_r^{0.3} \quad + \frac{Kg}{dt}\left[\frac{\sigma\left(T_b^4 - T_w^4\right)}{\frac{1}{e_b}+\frac{1}{e_w}-1(T_b - T_w)}\right] \qquad (1)$$

where ε is the void fraction in the bed, U is the fluidization velocity, P_p is the particle density, d_p is the particle diameter, p_g is the gas density, g is the acceleration due to gravity, u is the dynamic viscosity of air, P_r is the Prandlt number, k_g is the thermal conductivity of gas (26.3×10^3 w/m.k), d_t is the outer diameter of heat transfer tube, T_b is the bed temperature, T_w is the water temperature, e_b is the emissivity of the bed (0.8), e_w is the emissivity of the tube surface (0.85) and σ is Stefan-Boltzmann constant (5.67×10^{-11} kw/k^4m^2). Emissivity of the bed (silica sand) and that of the tube wall were obtained from Singh (2014).

2.4.1 Bed-to-tube heat transfer coefficients

Bed-to-tube heat transfer coefficient was calculated by equation (2), Basu (2006).

https://doi.org/10.51459/futajeet.2021.15.2.161

$$h_{tube} = \frac{1}{\frac{d_t ln\left(\frac{d_t}{d_i}\right)}{2k_m} + \frac{1}{h_0}} \quad (2)$$

here, d_t is the outer diameter of the tube (m), d_i is the inner diameter of the tube (m), K_m is the thermal conductivity of the heat transfer tube (54 w/m. k), h_o (h_{conv} + h_{rad}) is the outside heat transfer coefficient, h_i is the inside heat transfer coefficient. Table 4 shows heat transfer parameters used in the study.

Table 4: Heat Transfer Parameters

Particle size:	$d_p = \frac{1}{\sum \frac{x}{d_m}}$
Bed voidage:	$\varepsilon = 1 - \frac{\Delta P_b}{H(\rho_p - \rho_g)g}$
Suspension density:	$\rho_{sus} = \rho_p (1 - \varepsilon) + \varepsilon \rho_g$
Fuel density:	$d\rho = \frac{m}{v}$
Minimum fluidization velocity:	$Re_{mf} = \frac{U_{mf} d_p \rho_g}{\mu} = C_1^2 + C_2 Ar]^{0.5} - C_1$
Archimedes number:	Ar = $A_r = \frac{\rho_g(\rho_p - \rho_g) g d_p^3}{\mu}$
Fluidization velocity:	$3U_{mf}$
Parandtl number:	Pr = $\frac{\mu Cp}{k}$

Overall heat transfer coefficients in the fluidized bed: $h_o = h_{cond} + h_{conv} + h_{rad}$

$$h_o = h_{conv} + h_{rad} = 900(1-\varepsilon)\frac{kg}{dt}\left[\frac{UdtP_p}{u}\ \frac{u^2}{{d_p}^3 p_g^2 g}\right]^{0.326} P_r^{0.3} + \frac{Kg}{dt}\left[\frac{\sigma(T_b^4 - T_W^4)}{\frac{1}{e_b}+\frac{1}{e_W} - 1(T_b - T_w)}\right]$$

Bed-to-tube heat transfer coefficients: $htube = \frac{1}{\frac{d_t ln\left(\frac{d_t}{d_i}\right)}{2k_m} + \frac{1}{h_0}}$

3. RESULTS AND DISCUSSION

3.1. Overall Bed-to-tube Heat Transfer Coefficients

Table 4 presents the proximate and ultimate analysis of both Lafia-Obi coal and coconut shell. The fixed carbon and moisture content in Lafia-Obi coal are higher compare to coconut shell. However, coconut shell is richer in volatile matter and ash content. The percentage composition of carbon, nitrogen and sulphur is higher in coal compare to coconut shell while the contents of hydrogen and oxygen are higher in coconut shell.

3.1.1 Effect of co-firing different particle size of coconut shell with coal

Figure 2(a) and 2(b) represent the plots of the variation of the overall bed-to-tube heat transfer coefficient for different particle sizes of coal and coconut shells in coal blends at 30% BBR. The plots show a decreasing trend for the overall bed-to-tube heat transfer coefficients with increasing particle sizes of coal in Figure 2a and increasing particle size of coconut shells in coal blends as shown in Figure 2b. Results here shows that the overall bed-to-tube heat transfer coefficient is high for

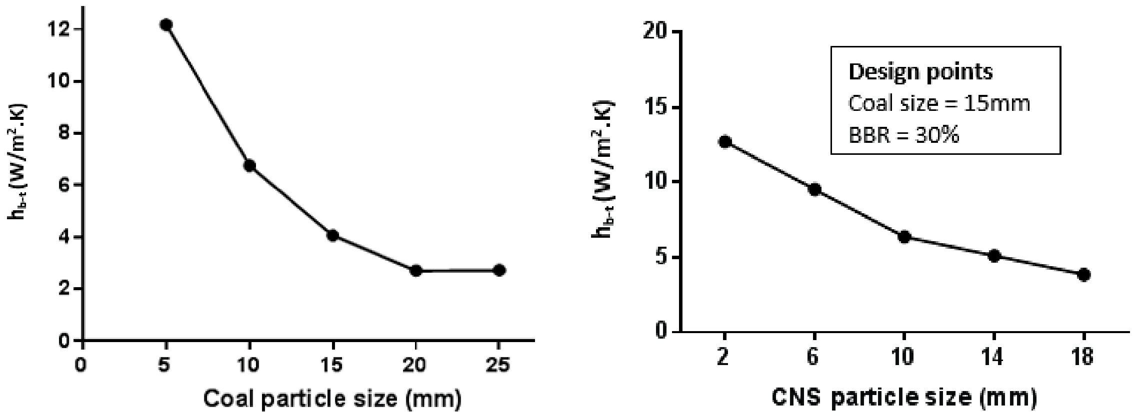
https://doi.org/10.51459/futajeet.2021.15.2.161

Table 4: Proximate and Ultimate Analysis of Fuel Samples

	Lafia-obi Coal (LOC)	**Coconut shell (CNS)**
Proximate analysis (wt.%) (dry)		
Moisture	9.5	8.5
Ash	20.18	28.82
Volatile matter	27.12	47.8
Fixed carbon	43.20	14.89
Ultimate analysis (wt.%) (dry)		
Carbon	72.12	59.2
Hydrogen	5.61	6.21
Oxygen	24.18	39.3
Nitrogen	2.10	1.29
Sulphur	1.34	0.26
Sodium	0.02	0.14
Magnesium	0.20	0.14
Silicon	0.0011	0.04
Phosphorus	0.017	0.15
Chlorine	-	0.67
Potassium	0.037	1.03
Calcium	0.91	0.47
Iron	1.11	0.012

small particle sizes of coal and coconut shells and low for large particle sizes. Similar results were reported by Chao et al, (2015). On the effect of cofiring different particle sizes of biomass (coconut shells) with coal on heat transfer coefficient, coal particle size was kept constant at 15 mm while coconut shell particle size was varied from 2 to 18 mm in steps of 4 mm at 30% cofiring ratio as shown in Figure 2b. It was observed that the overall bed-to-tube heat transfer coefficient decreases as CNS particle size increases in the blend. Highest value of 12.67 W/m^2. K was obtained when 2 mm CNS particle size was cofired with coal. In comparison with the value obtained for 100% Lafia-Obi coal combustion for 15 mm (4.068 W/m^2. K), the overall bed-to-tube heat transfer coefficients increased by 8.60 W/m^2. K. The reason for higher value of overall bed-to-tube heat transfer coefficient at small biomass particle sizes could be due to an increasing convection heat emanated from small particle size of coconut shell. Co-firing 2 mm coconut shells with 15 mm coal increased the overall bed-to-tube heat transfer coefficients above the value for 100% coal by 67%. The result here indicates that the overall bed-to-tube heat transfer coefficients increase significantly due to the contribution from the convective components of biomass particles

https://doi.org/10.51459/futajeet.2021.15.2.161



(a) (b)

Figure 2: Variation of overall bed-to-tube heat transfer coefficient with (a) Coal particle size (b) CNS particle sizes in coal/CNS blends

in the coal/biomass blends. Similar observation was reported by Basu (2006) and Chao et al., (2015). According to Abdelmotalib *et al,* (2015), study on radiative heat transfer coefficient is usually neglected because of its little contribution to the overall bed-to-tube heat transfer coefficient.

3.1.2 Effect of blend ratio of Coal/CNS mix on overall bed-to-tube heat transfer coefficient

Figure 3 shows the effect of blend ratios of Coal/CNS mix on the overall bed-to-tube heat transfer coefficient in the fluidized bed. It was observed that the overall bed-to-tube heat transfer coefficients decreased slightly with increasing coconut shell percentage in the blend. This could be attributed to the increase in moisture and ash content of coconut shell as its percentage increases in the blend.

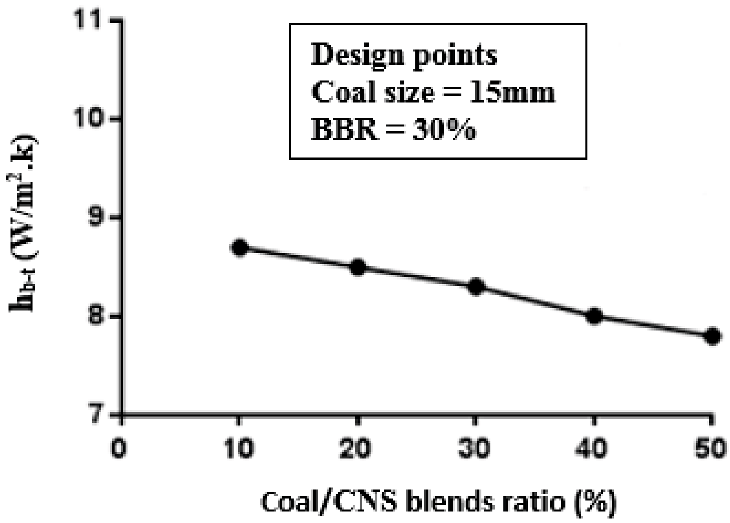


Figure 3: Effect of blend ratios of Coal/CNS mix on bed-to-tube heat transfer coefficient

https://doi.org/10.51459/futajeet.2021.15.2.161

3.1.3. Interaction of biomass blend ratio and particle size of fuel mix on bed-to-tube heat transfer coefficients

Table 5 shows an interaction effect of BBRs and particle size of Coal/CNS mix on the overall bed-to-tube heat transfer coefficient in the fluidized bed combustor. Co-combustion of 25 mm coal and 2 mm CNS at 10% BBRs produced the maximum overall bed-to-tube heat transfer coefficient of 21.168 W/m^2. K. This is due to the combined effects of higher radiative heat from 25 mm coal and higher convective heat from 2 mm coconut shells. Overall bed-to-tube heat transfer coefficient obtained from the combustion of 25 mm coal was 3 W/m^2. K. (Figure 2a). Co-combustion of 25 mm coal and 2 mm CNS at 10% BBRs increased this overall bed-to-tube heat transfer coefficient to 21.17 W/m^2.K. This produced 79% increase in the value of the overall bed-to-tube heat transfer coefficient obtained from the combustion of coal only. Likewise, co-combustion of 25 mm coal and 2 mm coconut shell also produced higher bed-to-tube heat transfer coefficient of 16.88 W/m^2.K, at 50% BBR, leading to 73.3% increase in the value obtained from coal only. This is also due to higher volatile combustion in coconut shell at 50% BBR coupled with high radiative heat from the combustion 25 mm particle size of coal. It could be concluded from the above

Table 5: Interaction Effects of BBRs and Particle Size of Coal/CNS mix on Bed-to-Tube Heat Transfer Coefficients

BBRs	Coal particle size (mm)	Biomass particle size (mm)	h_{tube} (W/m^2.k)		
			100% Coal	Coal/CNS blends	% increase
10	5	2	12.2	19.18	36.4
	25	18	4.44	4.13	n/s
	25	2	4.44	21.17	79.0
20	15	10	4.07	6.52	37.6
30	10	10	6.76	7.67	11.7
	15	10	4.07	6.36	36.0
	20	10	2.63	5.98	56.0
	15	6	4.07	3.81	n/s
40	15	10	4.07	6.15	33.8
50	5	2	12.2	19.77	38.3
	25	2	4.44	16.88	73.70
	5	18	12.2	2.47	n/s
	25	18	4.44	4.01	n/s

n/s- not significant

https://doi.org/10.51459/futajeet.2021.15.2.161

results that the combination of large particle size of coal and small particle size of biomass at 10 and 50% BBR could enhance the overall bed-to tube heat transfer coefficient in the fluidized bed.

4.0 CONCLUSION

Due to the importance of heat exchange in the fluidized bed, it is important to understand the effect of operating parameters on the heat transfer process for proper design of fluidized bed combustors. This study confirmed the influence of coal/CNS blend ratio and particle size of coal/CNS mix on the heat exchange between the bed and the tube. The bed-to-tube heat transfer coefficient decreased with increasing CNS particle size and biomass percentage in the blend. The combined effects of high radiation from large particle size of coal (25 mm) and high convection heat from small particle size of coconut shell (2 mm) at biomass percentage of 10 and 50% BBR enhanced significantly, the overall bed-to-tube heat transfer coefficient. The study concluded that biomass co-firing at optimal particle size and biomass blend ratio is imperative for achieving higher bed-to-tube heat transfer in the fluidized bed boiler.

REFERENCES

Abdelmotalib, H. M., Mahmoud, A.M.Y., Ali, A. H., Suk, B. Y., Ik-Tae, I. (2015). Heat transfer process in gas–solid fluidized bed combustors: A review. *International Journal of Heat and Mass Transfer 89: 567–575.*

Agbu, O. (2007). The iron and steel industry and Nigeria's industrialization. V.R.F Series: 418

Asere, A. A. (1992). Some characteristics of large coal combustion in fluidized bed, J.N.S. Egnrs. 27(1): 58-67.

Basu, P. and Cheng, L. (1996). Heat transfer in a pressurized circulating fluidized bed, *International Journal of Heat and Mass Transfer,* 39: 2711-2722.

Basu, P. (2006). Combustion and Gasification in Fluidized Bed, Taylor and Francis Group, Abingdon, United Kingdom, Pp. 57-97, 208-332.

Chinsuwan, A. Dutta, P. (2009). An experimental investigation of the effect of longitudinal fin orientation on heat transfer in membrane water wall tubes in a circulating fluidized bed, *International Journal of Heat and Mass Transfer,* 52: 1552-1560.

Chao, J., Lu, J., Yang, H., Zhang, M., Liu, Q. (2015). Experimental study on the heat transfer coefficient between a freely moving sphere and a fluidized bed of small particles. *International Journal of Heat and Mass Transfer*, 80: 115-125

Fatoye, F. B. and Gideon, Y. B. (2013). Appraisal of the Economic Geology of Nigerian Coal Resources, *Journal of Environment and Earth Science*, 3 (11): 25-31.

Food and Agriculture Organization (2012). FAO statistics, FAO statistics division. http://www. faostats.fao.org.

Hamada, M. Abdelmotalib, Mahmoud, A. M., Youssef, A. A., Hassan, S.B.Y., Ik-Tae I. (2015). Heat transfer process in gas–solid fluidized bed combustors: A review. *International Journal of Heat*

https://doi.org/10.51459/futajeet.2021.15.2.161

and Mass Transfer, 89: 567–575

Jekayinfa, S. O. and Scholz, V. (2007). Assessment of availability and cost of energetically usable crop residues in Nigeria, Paper Presented at the Conference on International Agricultural Research for Development, University of Kassel- Witzenhausen and University of Gottingen, Germany, October 9-11.

Jekayinfa, S. O., Omisakin, O., S. (2005). The Energy Potentials of some Agricultural Wastes as Local Fuel Materials in Nigeria". *Agricultural Engineering International*, 7(5): 1-10.

Kalita, P., Saha, U.K., and Mahanta, P. (2013). Effect of biomass blending on hydrodynamics and heat transfer behaviour in a pressurized circulating fluidized bed unit, *International Journal of Heat and Mass Transfer*, 60:531–541.

Kim, S. W., Ahn, J. Y., Jun, S. D. and Lee D. H. (2003). Heat transfer and bubble characteristics in a fluidized bed with immersed horizontal tube bundle, *International Journal of Heat and Mass Transfer*, 46(3): 399–409.

Molerus, O. (1997). Particle-to-gas heat transfer in particle beds at Peclet numbers, *Powder Technology,* 90:47–51.

Obaje, N. G., Ligouis, B. and Abba, S. I. (1994). Petrographic Composition and Depositional Environments of Cretaceous Coals and Coal Measures in the Middle Benue Trough of Nigeria. *International Journal of Coal Geology*, 26: 233 – 260.

Obaje, N. G. (2009). *Geology and Mineral Resources of Nigeria*, Springer, Dordrecht Heidelberg, New York, USA, pp. 221.

Oka, S. N. (2004). *Fluidized Bed Combustion,* Mercel Dekker Inc., New York, USA, Pp. 147-195

Popoola, O.T. and Asere, A. A. (2010). Emission and combustion characteristics of Lafia-Obi coal in fluidized bed combustor. *Advanced Materials Research,* 824: 318-326.

Popoola, (2011). Investigation of the behavior of Lafia-Obi coal in a fluidized bed combustion chamber. Unpublished M.Sc. Dissertation, Obafemi Awolowo University, Ile-Ife. Nigeria.

Sambo, A. S. (2008). The Place of Coal in the Nigeria Electricity Generation Scheme. A keynote address at the inauguration of the President of Nigeria Society of Engineers, International conference Centre, Abuja, Nigeria.

Singh, R. I. (2014). Study of fluidized bed combustion power plant using agric residues. *Applied Thermal Engineering*, 71: 616-626.

Sun, P., Hui, S., Gao., Z., Zhou, Q., Tan., H., Zhao, Q. and Xu, T. (2013). Experimental investigation on the combustion and heat transfer characteristics of wide size biomass co-firing in 0.2 MW circulating fluidized bed, *Applied Thermal Engineering*, 52: 284-292.