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Co-combustion of Low-rank Coal and Palm Shell in Fluidized Bed Boiler (Study on Generated Steam Characteristics)

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Abstract

Co-combustion of Aceh low-rank coal and palm shell in Fluidized Bed Boiler (FBB) was studied by using ASPEN Plus Process Simulator. In this simulation, combustion was treated as the chemical reaction equilibrium in which the flue gas composition evaluated by minimization of Gibbs free energy. For the fuel ratio (coal/palm shell) 1:1, and air to fuel ratio 5.2 kg/kg, the number of generated steam was 4.3 kg/kg of fuel. Boiler efficiency and steam temperature were 66% and 450^{o}C, respectively. At these conditions, combustion efficiency reached up to 90%.

Keywords: *low-rank coal, palm shell, fluidized bed boiler, combustion.*

1 INTRODUCTION

It is recognized that combustion of fossil fuels currently dominates world energy production, and will continue to dominate in the near future. Among fossil fuels, coal has the highest potential as one of future energy sources in the world [1]. Although a part of coals is used for power generation in large scale utility boilers and gasifiers, the amount of coals utilized as a fuel in both middle and small scale industrial boilers is still large in the developing countries.

The direct combustion of coals, especially low-rank coals with high ash, high sulfur and high nitrogen contents in industrial boiler causes more serious pollution. On the other hand, a large amount of biomass (agriculture and forestry wastes) is also being discarded in these countries. As well known, the biomass is renewable and slightly clean fuel and CO_2-neutral energy source [2]. In order to enhance effective utilization of low-rank coals and biomass on technologies suitable for burning this class of fuels, among the others, fluidized bed combustion (FBC) has been indicated as one of the most promising ones [3-5]. This is because of its flexibility, high combustion efficiency and low environmental impact. However, a number of operational problems mostly related to air to fuel ratio, chemical conversion and ash (fouling, slugging, bed agglomeration and so forth).

It is well known that combustion is a chemical reaction between a fuel and oxygen which is accompanied by the production of gaseous. If the combustion is completed at this stage by assuming that all the fuel is burned to completion. Strictly speaking, this means that after a long period of time a chemical equilibrium has been reached, but in the present context it is sufficiently accurate to say that complete combustion has been achieved when no further reaction take place-all carbon in the fuel appears in the flue gases as CO_2 and all the hydrogen in the fuel is burned to water (H_2O) [6].

In fact, it is difficult to achieve the complete combustion since to bring together the fuel and air (as the reactants) in the correct proportion is not easily. The present study addressed to elucidate the effect of carbon and hydrogen conversions, air to fuel ratio on combustion behavior and heat recovery efficiency. It is also to examine the effect of boiler feed water rate on boiler steam generation by using ASPEN Plus Simulator. Low-rank coal and palm shell used in this study come from Aceh Province with the characteristics as listed in Table 1.

Table 1. Proximate and ultimate analyses data for Aceh Province low-rank coal and palm shell

Parameter	Sample		Standard method
	Coal	Palm shell	
Proximate:			
- Moisture in air dried (% adb)	5.83	4.30	ASTM D.3173
- Ash (% adb)	5.40	2.63	ASTM D.3174
- Volatile matter (% adb)	46.00	73.65	ASTM D.3175
- Fixed carbon (% adb)	42.77	19.42	ASTM D.3172
Ultimate (% adb):			
- Carbon (% adb)	60.65	29.32	ASTM D.3178
- Hydrogen (% adb)	5.75	5.88	ASTM D.3179
- Nitrogen (% adb)	0.48	0.30	ASTM D.3179
- Total Sulfur (% adb)	0.38	0.13	ASTM D.4239
- Oxygen (% adb)	27.34	61.74	ASTM D.3176
Calorific value (cal/gr adb)	5904	4865	ASTM D.5865

2 COMBUSTION IN ASPEN PLUS SIMULATOR

Modeling and simulation involved combustion of single low-rank coal; single biomass and co-combustion of coal-biomass were performed using ASPEN Plus, a commercial process simulator. In this simulator, decomposition and combustion processes took place in the Decomposer and Burner (represent by Yields and Gibbs Reactors, respectively). Decomposition is addressed to decompose the fuel into its elements because the Gibbs Reactor does not know the conventional species such as coal or palm shell. Energy for decomposition is supplied automatically from heat of combustion by connecting the Yields and Gibbs Reactors using an energy line as shown by dashed line in Figure 1. In addition to the decomposer and burner, other installed main process units are separator, boiler and economizer.

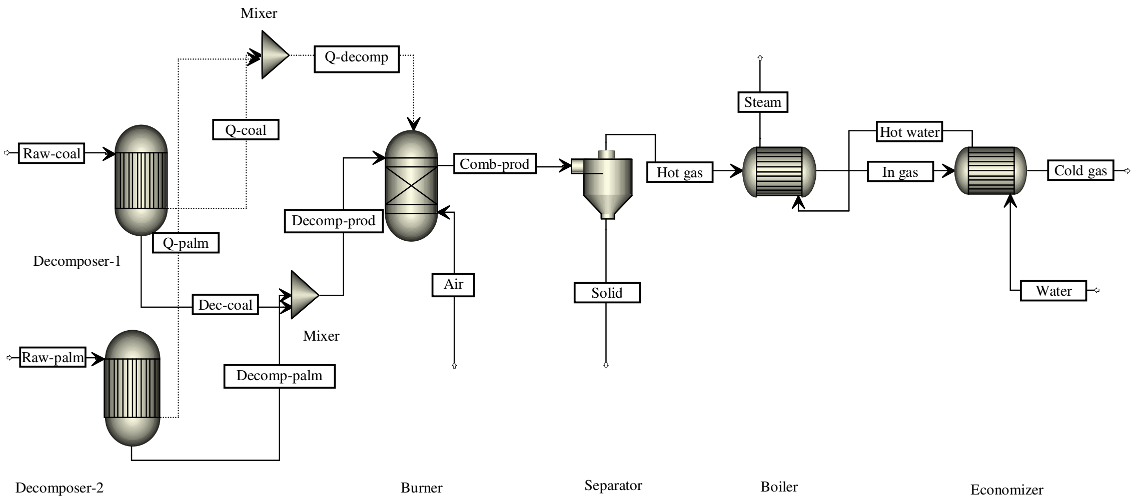

Figure 1. Flow sheet of combustion process

Some specifications are required before running the simulation such as:

1. Coal, biomass and ash are included non-conventional component consequently it is necessary to determine their enthalpy and density. Calculation methods used are HCOALGEN and DCOALIGT with option code approach.
2. Global stream class and stream properties.
3. Inlet condition of air: temperature, pressure and composition
4. Inlet condition of coal and/or biomass: temperature, pressure, flow rate, proximate and ultimate data.
5. Operating conditions of reactor, separator, boiler and economizer involve temperature, pressure and heat duty.

The composition of the flue gas in combustion process was evaluated by minimization of the Gibbs free energy:

$$\frac{\Delta G}{RT} = \frac{\Delta G^0 - \Delta H^0}{RT_0} + \frac{\Delta H^0}{RT} + \frac{1}{T}\int_{T_0}^{T} \frac{\Delta C_p}{R} dT - \int_{T_0}^{T} \frac{\Delta C_p}{R}\frac{dT}{T} \quad (1)$$

$$\Delta G = -RT \ln K \quad (2)$$

$$\prod_i (y_i \phi_i)^{v_i} = \left(\frac{P}{P^0}\right)^{-v} K \quad (3)$$

Fugacity coefficient in the model was estimated using Peng-Robinson equation of state:

$$\ln \phi_i = \frac{B_i}{B}(Z-1) - \ln(Z-B) + \frac{A}{4{,}828B}\left[\frac{B_i}{B} - \frac{2}{a\alpha}\sum_j y_j (a\alpha)_{ij}\right] \ln\left[\frac{Z + 2{,}414B}{Z - 0{,}41B}\right] \quad (4)$$

where ΔG = Gibbs free energy (J/mol)
ΔH = enthalpy (J/mol)
T = temperature (K)
R = gas constant (J/mol K)
C_p = heat capacity (J/mol K)

K	= equilibrium constant
y_i	= equilibrium composition of species i
ϕ_i	= fugacity coefficient of species i
v_i	= coefficient of stoichiometry
P	= pressure (atm)
a, A, B, α	= constants of Peng-Robinson equation of state.

3 RESULTS AND DISCUSSION

3.1 Effect of Air to Fuel Ratio on Combustion Product

There are two important parameters for simulation of the combustion process. Firstly, the ideal proportion, in which the fuel combine with oxygen are used as a basis for finding the correct air supply rate for a fuel. Secondly, knowledge of the expected composition of the combustion product is useful during the design. The flue gas composition is essential information if the flue gas system is to be corrected designed.

The simulation was conducted at first for single coal and palm shell combustion in order to observe the air to fuel ratio effect from 4.5 - 15.5 kg/kg in which temperature and pressure of inlet air were 25^{o}C and 1 atm. As shown in Figures 2 and 3, the combustion product gases of single coal and palm shell depend on air to fuel ratio. CO_2 reached up to maximum when the air to coal ratio about 5.5 - 6.7 kg/kg. At this point the observed CO was low.

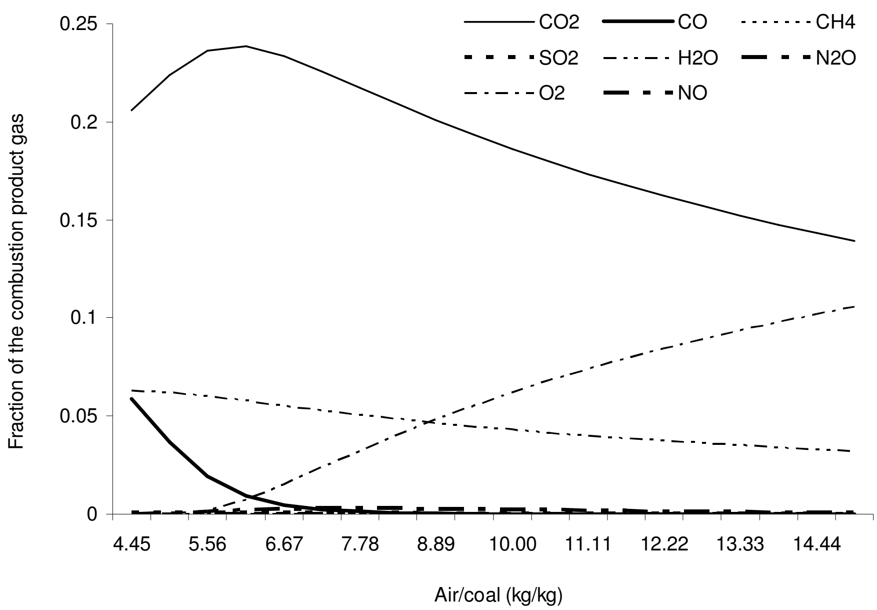

Figure 2. Effect of air to coal ratio on combustion characteristics

In the case of palm shell combustion as shown in Figure 3 the maximum of CO_2 product appeared when the air supply about 2.5 - 3.8 kg/kg. At this time CO was also small. This may caused the combustion process is started to drive off the volatile matter from the coal and palm shell. The volatiles will then rise through the bed, partly reacting with the hot carbonaceous material. At the combustion process proceeds, the volatile matter decreases until there is only the carbonaceous residue left, which burns with the intense emission. At that time the conversion of carbon to carbon dioxide falls away as the reduction to carbon monoxide proceeds.

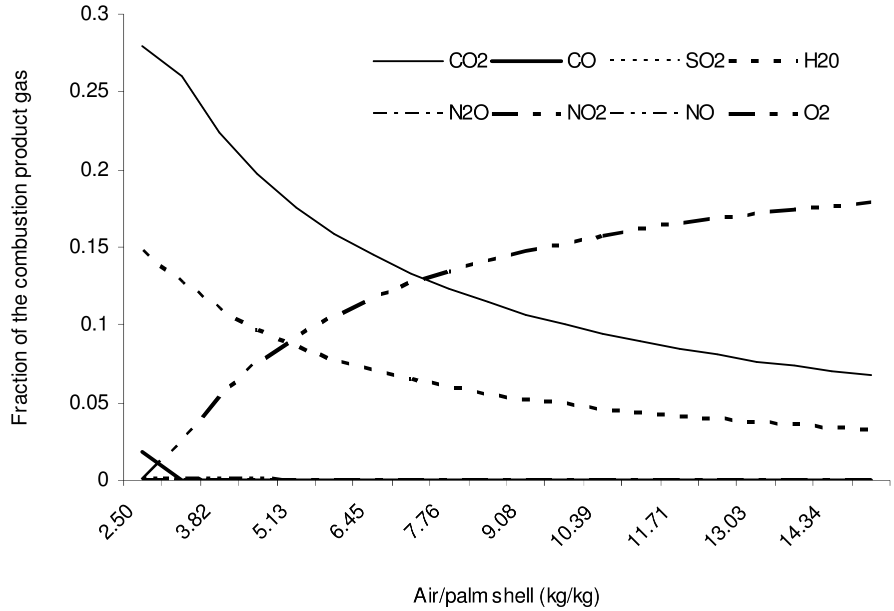

Figure 3. Effect of air to palm shell ratio on combustion characteristics

From the above discussion, it is suggested that for Aceh low-rank coal combustion in FBC the air supply is about 5.5 - 6.7 kg/kg of coal. On the other hand, for palm shell fuel air supply is about 2.5 - 3.8 kg/kg of coal.

3.2 Effect of Air to Fuel Ratio on Combustion Efficiency

There is very important to discuss relating the effect of air to fuel ratio on combustion efficiency. The factors which affect in regard combustion efficiency as a two component system. The first component, the burner, has the task of converting the chemical energy in the fuel into thermal energy in the flame as efficiently as possible. To bring this about, there should be no unburned fuel in the flue gas and the fuel should be burned at an air to fuel ratio as close to the stoichiometric value as possible.

The effect of air to fuel ratio on combustion efficiency in single coal combustion is shown in Figure 4. Carbon and hydrogen conversion efficiencies lied between 87 - 97% and 97 - 99%, respectively, while thermal conversion efficiency was around 87 - 88% when the adjusted air to coal ratio was 5.5 - 6.7 kg/kg.

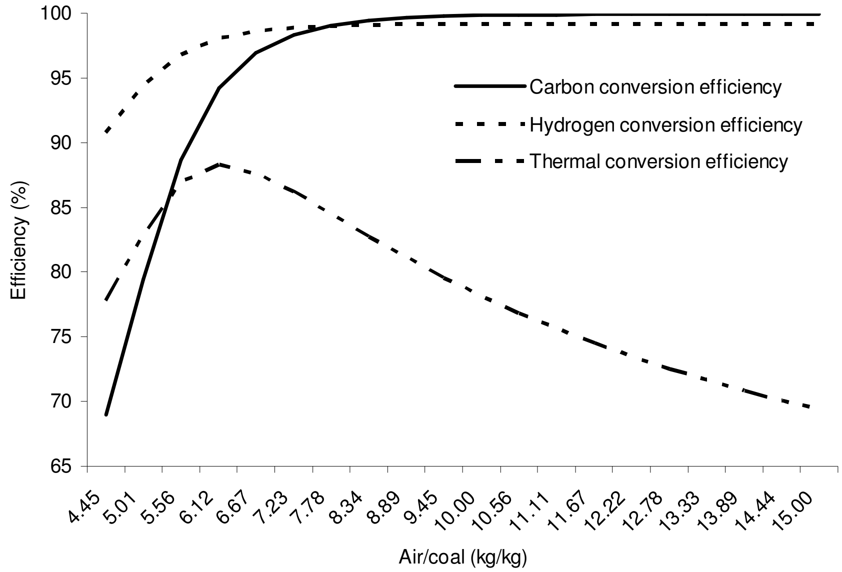

Figure 4. Effect of air to coal ratio on combustion efficiency

In the case of single palm shell combustion, the effect of air to fuel ratio on combustion efficiency was almost exhibit the same pattern with the single coal combustion, but the thermal conversion efficiency was much lower than its carbon and hydrogen conversion efficiencies. Thermal efficiency in this case was only about 43 - 47% when the air to palm shell ratio set up from 2.5 to 3.8 kg/kg, whereas the carbon and hydrogen conversion efficiencies significantly touched the level of 99%. Moreover, the thermal efficiency for coal combustion was higher than that of palm shell combustion. This is may caused calorific value of coal is higher than that of palm shell.

3.3 Effect of Biomass Composition on Co-combustion Efficiency

Co-combustion in this context is defined as the firing of palm shell (biomass) and coal together in fluidized bed combustor. The burning of biomass and coal mixture has a positive impact both on the environment and the economics of power generation. The emission of SO_2 and NO_X were reduced in most co-combustion test. The CO_2 net production was also inherently lower, because biomass is considered CO_2-neutral. In addition, total fuel cost can be reduced in some case if the biomass processing cost (transportation, grinding) are lower, on energy base, than the coal processing coast on energy base.

In this simulation tried to elucidate the effect of biomass content on co-combustion efficiency. The palm shell content was selected about 50% to total fuel. The effect of air to fuel ratio on co-combustion efficiency is shown in Figure 5. The thermal efficiency reached up to 86% when the air to fuel ratio about 5.2 kg/kg, while the carbon and hydrogen conversion efficiencies located between 96 - 98%. This thermal efficiency is spectacularly close to the thermal efficiency of single coal combustion that shown in Figure 4. Based on this fact, it is recommended that the practical co-combustion of coal-palm shell process should be designed at the fuel composition 1:1.

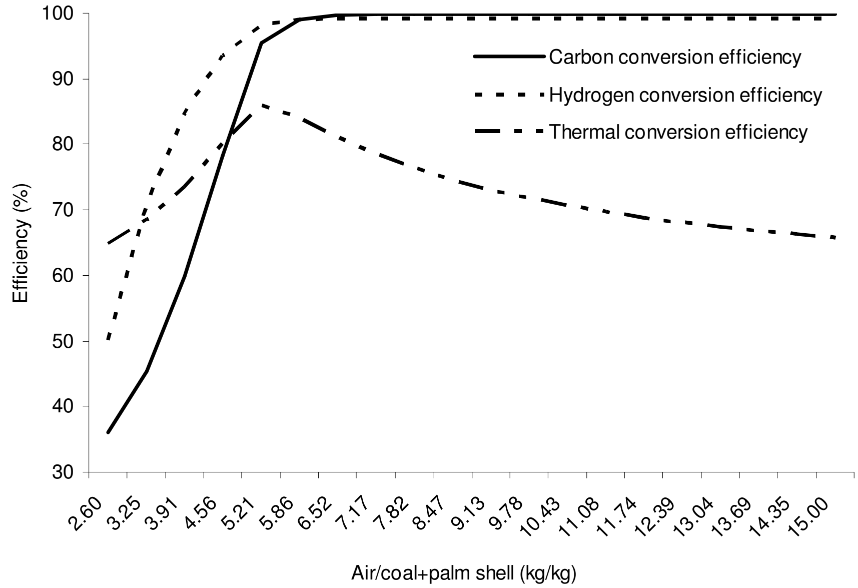

Figure 5. Effect of air palm shell-coal ratio on combustion efficiency

3.4 Effect of Boiler Feed Water Flow Rate on Steam Generation

Boiler is the portion of the steam generator where saturated liquid is converted to saturated steam, although it may be difficult to separate it, physically, from the economizer [5]. The economizer is the heat exchanger that raises temperature of the water leaving the highest-pressure feed water heater to the saturation temperature corresponding to the boiler pressure. In this work, the effect of boiler feed water flow rate on steam generation characteristics were also investigated both for single fuel combustion and co-combustion. Figures 6, 7 and 8 show that the steam temperature is influenced by boiler feed water flow rate.

If in the application we use the circulating fluidized bed boiler made in Jiangxii Jianglian Energy, Shanghai Boiler Works from China, the specifications of produced steam are 450^{o}C (723 K) and 3,82 MPa with the temperature of boiler feed water of 105^{o}C. These steam specifications satisfy for condensing steam turbine made in Hangzhou Steam Turbine China with the capacity of 6 MW. In single coal combustion, such kind of target steam was achieved at the average of boiler feed water flow rate of 12.54 kg/h or 6.27 kg of steam/kg of coal. Vertical solid block in Figure 6 describes the area at where the typical of steam is produced. In this simulation, temperature of economizer outlet gas (temperature of cold gas) can be maintained at 378 K (105^{o}C).

The same phenomenon to single coal combustion is also demonstrated by single palm shell combustion in which the steam temperature is affected by boiler feed water flow rate. The average of boiler feed water flow rate at where the 450^{o}C steam generated was 4.5 kg/h or 2.25 kg of steam/kg of palm shell. A very advantage fact is exhibited here where the temperature of economizer outlet gas can be lowered to a range of 361- 349 K (88 – 76^{o}C) as presented in Figure 7. This is much lower than temperature of cold gas in single coal combustion. Vertical solid block represent the same meaning.

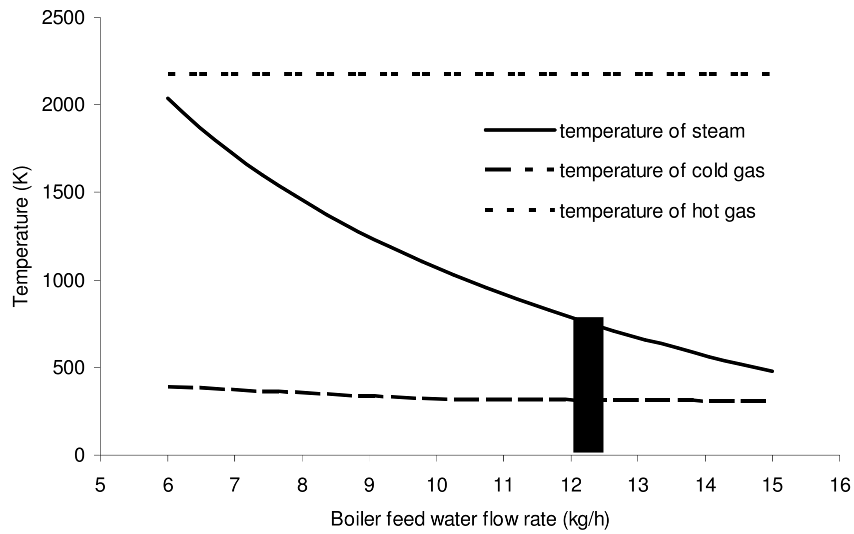

Figure 6. Effect of boiler feed water flow rate on steam temperature for single coal combustion

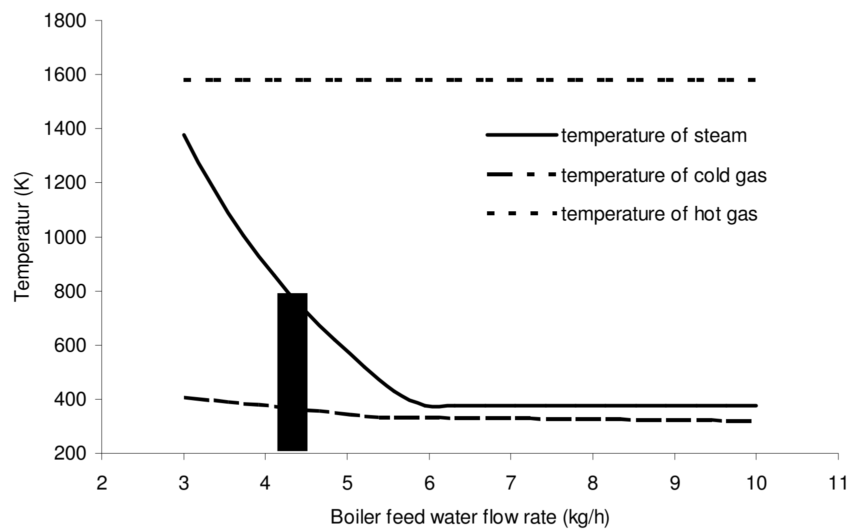

Figure 7. Effect of boiler feed water flow rate on steam temperature for single palm shell combustion

By utilization as maximum as possible the energy content in flue gas, the average number of generated steam was up to 8.6 kg/h or 4,3 kg of steam/kg of fuel. In Figure 8, it is clearly seen that cold gas temperature was only 324 K (51^{o}C). This cold gas temperature is very safe to waste to the atmosphere. Boiler efficiency and steam temperature were 66% and 450^{o}C, respectively. At these conditions, average combustion efficiency about 90%.

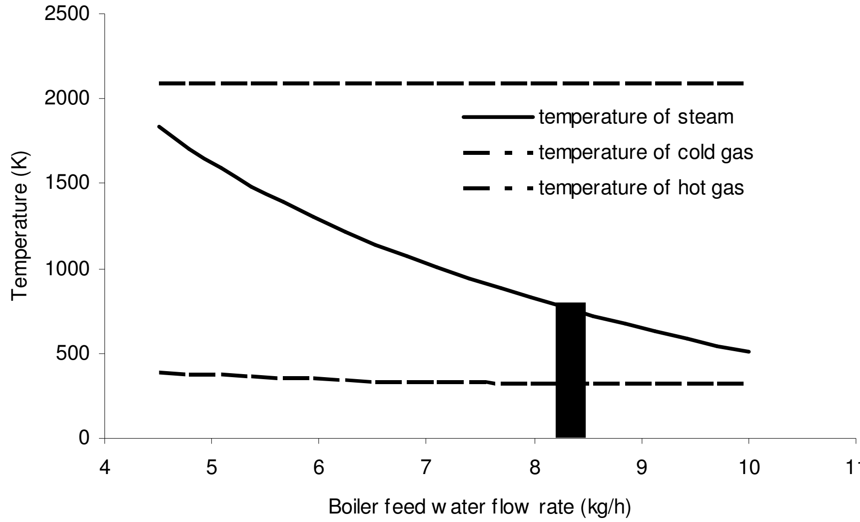

Figure 8. Effect of boiler feed water flow rate on steam temperature for co-combustion

4 CONCLUSIONS

Study on generated steam characteristics of co-combustion of low-rank coal and palm shell in fluidized bed boiler were carried out by using ASPEN Plus Simulator. It is finally conclude that:

1. Combustion characteristics of coal and palm shell depend on air to fuel ratio. For the fuel composition (coal/palm shell) 50:50, and air to fuel ratio 5.2 kg/kg, the number of generated steam was 4.3 kg/kg of fuel.
2. Thermal efficiency for single coal combustion was higher than that of single palm shell combustion. This is may caused by calorific value of coal is higher than that of palm shell. In single coal combustion the average combustion efficiency was 90%, while in single palm shell combustion was only 50%.
3. Generated steam temperature was affected by boiler feed water flow rate. It is shown that the steam temperature decreased by the increase of the boiler feed water flow rate.

5 ACKNOWLEDGEMENTS

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