VOL. 12, NO. 10, MAY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

CO-COMBUSTION MODELING OF RICE HUSK AND PLASTIC BAG AS ENERGY SOURCE IN INDONESIA

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ABSTRACT

This study was conducted to obtain a model combustion characteristics of rice husk and plastic bags as a energy source. The characteristics modeling using Autodesk Mechanical Desktop, Gambit, and Ansys - Fluent software. Maximum temperature of gas in the grate bed was obtained of about 1,710 K, in the furnace of about 1,670 K, and the average temperature in the furnace of about 1,086 K. The flue gas CO_2, CO, and H_2O in the furnace was obtained maximum of about 0.336% (3,360 ppm), 0.305% (3,050 ppm), and 0.132% (1,320 ppm), respectively. It was concluded that the co-combustion characteristics model of RH_{90} + PB_{10} produces temperature that meets the needs of a trap on the boiler and flue gas produces a small that is safe for the environment. Thus, it can be the basis for the development of utilization as fuel in the power plant.

Keywords: Co-combustion, modeling, rice husk, plastic bag, energy source.

INTRODUCTION

Electrification ratio in Indonesia is still low, has reached an average of 72%. Even still there are four provinces, only around 20 - 40% (PT PLN - Persero, 2010). This shows the electric energy supply in Indonesia is still lacking. Rural communities there are still about 28% who do not use electric energy for everyday purposes. In urban areas also still frequent rolling blackouts. This is due to lack of power while electricity for the society and industry is increasing every year. In addition, fossil energy sources are a major source of power generation in Indonesia tend to be reduced drastic and cause environmental impacts. While the potential of rice husk and plastic waste in Indonesia is produced each year and has not been used as a source of energy, even still wasted as environmental pollution. Results of previous studies show Indonesia has a great potential of rice husk (RH) is about 13 294 × 106 tons, 13 151 × 106 tons, 13 809 × 106 tons in 2010, 2011, 2013 with an energy potential of approximately 51.696 GWh, 51.144 GWh, 53.702 GWh, respectively (Anshar *et al.*, 2014). This potential can be utilized as fuel in the power plant as well as the results of studies in Thailand (Madhiyanon *et al.*, 2009) and in India (Kapur *et al.*, 1996).

In addition, the potential of municipal solid waste (MSW) and plastic solid waste (PSW) are also available on each province produced every day in urban areas (Anshar *et al.*, 2015c, 2015b). This potential is wasted as waste that pollutes the environment. This study was conducted to obtain characteristics model of co-combustion of rice husks and plastic bags as an alternative energy source at the power plant in Indonesia. Modeling results are expected to contribute to further research and for policy-makers in the development and the waste as a source of electric energy in Indonesia.

GEOMETRY MODEL OF FURNACE AND BOUNDARY CONDITION

This modeling using the boundary condition namely: fuel feed rate of about 6,575 kg/h at 298 K, the overall air/fuel stoichiometric ratio of about 0.84, the primary water about 6 kg/s at 453 K, the secondary air 1 and 2 of about 3.2 kg/s at temperatures around 453 K. Geometry of the furnace and the type of boundary condition are used: inlet velocity, mass flow inlet, wall and outflow. Meshing is made with a quad element, pave type, size interval, spacing about 0:05. A total mesh consists of about 28,875 nodes and 28,434 elements to generate proper combustion models. Geometry models of furnaces are used for small power plants i.e. 7.5 × 5.7 × 12 m is presented in Figure-1. Co-combustion modeling of RH and plastic bags (PB) performed with a ratio between 90% of RH and 10% of PB (RH_{90}+PB_{10}). Testing the calorific value (CV) is performed by using a bomb calorimeter by standard procedure ASTM D.5865. Proximate analysis was carried out under the standard procedure ASTM D 3172 - 3175 and ISO 565. While, the ultimate analysis was performed under the standard procedure ASTM D 3176, ASTM D 4239, and ASTM D 5373. This method is in line with previous studies studies (Maiti *et al.*, 2006 ; Patel and Kumar, 2009). Furnace geometry is obtained by using Autodesk Mechanical Desktop software. Furnace geometry is obtained by using Autodesk Mechanical Desktop software. Mashing is done with Gambit software, and modeling co-combustion (RH_{90}+PB_{10}) was performed using Ansys - Fluent software. Boundary condition is determined based on the capacity output of energy that will be generated by reference to some previous study (Kær, 2004; Kær, 2005; Husain *et al.*, 2006; Yin *et al.*, 2012; Shin *et al.*, 2013; Anshar *et al.*, 2015a).

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TRANSPORT AND COMBUSTION REACTION EQUATIONS

Biomass combustion on grate bed furnace is basically divided into two parts, namely in-grate bed and over-grate bed combustion. In biomass combustion on the grate bed furnace occurred heat and mass exchange between the solid phase and the gas phase. The change of the solid phase into the gas phase occurs in grate bed due to the combustion while the gas phase occurs in over grate bed combustion chamber as a result of combustion. Scheme numerically solving the combustion process is obtained by using a computer program (Yang *et al.*, 2007; Yu *et al.*, 2010). The conservation equations for solid phase and gas phase in grate bed are as follows:

Continuity equation:

$$\frac{\partial \rho_{sb}}{\partial t} + U_b \frac{\partial \rho_{sb}}{\partial x} + \frac{\partial (\rho_{sb} V_s)}{\partial y} = -S_s \quad (1)$$

Energy equation:

$$\frac{\partial(\rho_{sb}H_s)}{\partial t} + U_b\frac{\partial(\rho_{sb}H_s)}{\partial x} + \frac{\partial(\rho_{sb}V_sH_s)}{\partial y} = \frac{\partial}{\partial x}\left(\lambda_s\frac{\partial T_s}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_s\frac{\partial T_s}{\partial y}\right) - S_a h_s^{'}(T_s - T_g) + \sum \Delta h_k \quad (2)$$

Species equation:

$$\frac{\partial(\rho_{sb}Y_{si})}{\partial t} + U_b\frac{\partial(\rho_{sb}Y_{si})}{\partial x} + \frac{\partial(\rho_{sb}V_sY_{si})}{\partial y} = \frac{\partial}{\partial x}\left(D_s\frac{\partial(\rho_{sb}Y_{si})}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_s\frac{\partial(\rho_{sb}Y_{si})}{\partial y}\right) - S_{si} \quad (3)$$

The resultant conservation equations for gas phase in grate bed as follows:
Continuity equation:

$$\frac{\partial(\phi\rho_g)}{\partial t} + \frac{\partial(\phi\rho_g U_g)}{\partial x} + \frac{\partial(\phi\rho_g V_g)}{\partial y} = S_s \quad (4)$$

Energy equation:

$$\frac{\partial(\phi\rho_g H_g)}{\partial t} + \frac{\partial(\phi\rho_g U_g H_g)}{\partial x} + \frac{\partial(\phi\rho_g V_g H_g)}{\partial y} = \frac{\partial}{\partial x}\left(\lambda_g\frac{\partial T_g}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_g\frac{\partial T_g}{\partial y}\right) + S_a h_s^{'}(T_s - T_g) + \Sigma \Delta h_k \quad (5)$$

Species equation:

$$\frac{\partial(\phi\rho_g Y_{gj})}{\partial t} + \frac{\partial(\phi\rho_g U_g Y_{gj})}{\partial x} + \frac{\partial(\phi\rho_g V_g Y_{gj})}{\partial y} = \frac{\partial}{\partial x}\left(D_g\frac{\partial(\phi\rho_g Y_{gj})}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_g\frac{\partial(\phi\rho_g Y_{gj})}{\partial y}\right) + S_{sj} + S_{gj} \quad (6)$$

Where D = mass diffusion coefficients, m^2/s, H = enthalpy, J/kg, hs = convective mass transfer coefficient between solid and gas, m/s, h's = convective heat transfer coefficient between solid and gas, W/m^2 K, Δ_{hk} = heat effect for kth process or reaction, W/m^3, S = mass source term, kg/m^3 s, Sa = particle surface area, m^2, t = time, s, T= temperature, K, U= horizontal velocity, m/s, V = vertical velocity, m/s, x= co-ordinate in the direction of grate length, m, X = solid mass loss fraction, mass fraction of pollutants, y = co-ordinate in the direction of bed height, m, Y= mass fraction of species, ρ = density, kg/m^3, λ = thermal conductivity, W/m K^{-1}, ϕ = void fraction in the bed,. Ss = mass loss rate from solid (Ss = Revp+ RV + RC), kg/ m^3 s, k= kinetic rate of reactions. Subscripts b = bed, g = gas, i= species in solid, i.e., moisture, volatile matter, fixed carbon and ash, j = species in gas, i.e., O_2, CO_2, CO, NH3, NO, N_2, H_2, CH_4 and H_2O, s = solid, sb = bulk density,

RESULTS AND DISCUSSIONS

Input data of co-combustion modeling

Input data for co-combustion modeling of RH_{90}+PB_{10} and RH is to use the result data of proximate and ultimate analysis, as presented in Table-1. In this case, RH modeling performed as a comparison of co-combustion modeling of RH_{90}+PB_{10}.. The analysis showed the addition of approximately 10% PB in the RH increase the calorific value (CV), volatile matter (VM), carbon (C), water vapor (H2O). In addition, the lower the moisture content (MC), fixed carbon (FC), oxygen (O), nitrogen (N), and ash. This means that the co-combustion RH_{90}+PB_{10} can improve fuel quality of RH.

Table-1. Proximate and ultimate analysis of RH_{90}+$PB_{10}$and RH.

Modeling parameter input	RH_{90}+PB_{10}	RH
CV (kJ/kg)	18,847	13,442
FC (%)	13.62	14.81
VM (%)	58.65	55.62
MC (%)	9.68	10.46
C (%)	42.21	39.28
H (%)	5.82	5.08
O (%)	33.45	35.81
N (%)	0.38	0.64
S (%)	0.09	0.08
Ash (%)	18.05	19.11

Co-combustion modeling results of RH_{90}+PB_{10} in grate bed furnace showed that the co-combustion provide a significant influence on several of co-combustion parameter. In this case, increase gas temperature (Tg), increase the combustion gas velocity (Vg), and increase the total energy in the fuel input. Overall air fuel ratio (AFR) stoichiomertri decreases which means less air needs, but solid gasification efficiency is complete

(100%). Some parameters of co-combustion modeling results of RH_{90}+PB_{10} has similarities with the modeling parameters result of RH, but differ significantly in temperature, total energy input, and overall AFR. Modeling parameter result are presented in Table-2.

Table-2. Modeling parameter results of RH_{90}+PB_{10} and RH on grate bed furnace.

Modeling parameter results	RH_{90}+PB_{10}	RH
Teotitical air (Nm^3/kg waste	3.73	3.23
Total primary air (Nm^3/min)	296.19	296.19
Final carbon in solid (% mass)	8.4e-096	8.4e-096
Solid gasification efficiency (%)	100	100
Moisture evaporated (kg/hr)	638.26	694.99
Volatile released (kg/hr)	3,495.4	3,584.3
Total mass loss (kg/hr)	5,018.1	5,259.8
Tg max.(K)	1,710	1,680
Tg Average (K)	1,186	1,138
Tg exit (K)	1100	950
Vg (m/s)	9	8.51
Overall AFR	0.726	0.837
Fuel input (kg/h)	6,575.35	6,575.35
Energy in fuel input (MWt)	34.42	24.55

Co-combustion modeling of RH_{90}+PB_{10} and temperature distribution in the grate bed furnace is presented in Figure-2. In this case, the combustion process began to take place at a distance of 0.4 m from the fuel input, but the burning began to stabilize in the range of 0.8 - 6.2 m with a temperature of about 969 – 1,710 K. After that, the temperature began to decrease until it reaches temperatures of 454 K, which occurs the decrease in temperature of bottom ash.

Figure-3 shows the combustion start occurs at a distance of 0.4 m from the fuel input where CO, CO_2, H_2O increase and fluctuate. At a distance of 2.3 m, H_2O to zero, which means all the water content in RH_{90}+PB_{10} turn into gas phase. At a distance of 3.7 m, CO and CO_2 to zero. In these conditions RH_{90}+PB_{10} already burn completely so as not to form more CO_2, CO, and H_2O. In these conditions the CO and CO_2 reaches zero, while O_2 drastically increase reaching normal condition (21%). On top of the bed (over-bed) combustion temperature distribution is very uneven due to the gases do not burn completely.

In addition, Figure-4 shows the mass loss rate, volatile release, moisture evaporation, and char burning rate occurred fluctuation start at a distance of 0.4 m to 1.87 m from the fuel inlet. Volatile release is proportional to the mass loss rate, which release volatile increases when the mass loss rate increases. This suggests that volatile release occurs due to the mass loss caused by the heating and combustion processes. The maximum value of mass loss rate and the volatile release reached 827.7 kg / m2 h at a distance of about 1.8 m from the fuel inlet. At a distance of 0.4 -1.87 m, moisture evaporation process also occurs. After the evaporation of moisture, volatile release, and the mass loss rate is over, there will be a process maximal char burning rate at 0.4-3.7 m area until the end.

In these conditions, volatile release dramatically decreases until it reaches zero, while the char burning rate reaches zero at a distance of 3.7 m from the fuel inlet. The process of burning rice husk and plastic bag in the bed take place starting at a distance of approximately 0.4 m to 7.66 m. Co-combustion model characteristics of rice husk and the plastic bag has similarities with the characteristics model of previous studies (Ryu *et al*., 2005; Yang *et al*., 2007), although the value of each variable is different because differences in input data and boundary conditions in the combustion process.

Figure-5 shows the characteristics of the combustion gas and gas temperature in the furnace. Gases of combustion in the grate bed followed the combustion in the furnace by adding secondary air so that gases of combustion burn completely before exiting the furnace. The maximum temperature at the base of the furnace is about 1670 K and 1100 K furnace exit. At the base of the furnace obtain CO maximum of about 0.305% (3050 ppm), CO_2 maximum of about 0.336% (3360 ppm), and H_2O maximum of about 0.132% (1320 ppm). These conditions indicate that the co-combustion RH_{90}+PB_{10} meet feasibility as fuel in the power plant because it produces gas temperature that meets the needs of the boiler and exhaust gas are small so no impact on the environment.

Co-combustion modeling result of RH_{90}+PB_{10} in grate bed furnace show that co-combustion of RH_{90}+PB_{10} provide a significant influence on several combustion parameters. In this case, increase of maximum gas temperature, average temperature, exit temperature, increase the combustion gas velocity, and increase the total energy in the fuel input. However, moisture evaporated, volatile released, and total mass loss decrease. This shows that the water content in the fuel RH_{90} + PB_{10} is smaller than the water content of the RH. Thus, the combustion air requirements (AFR stoichiomertri) in the fuel RH_{90} + PB_{10} are reduced.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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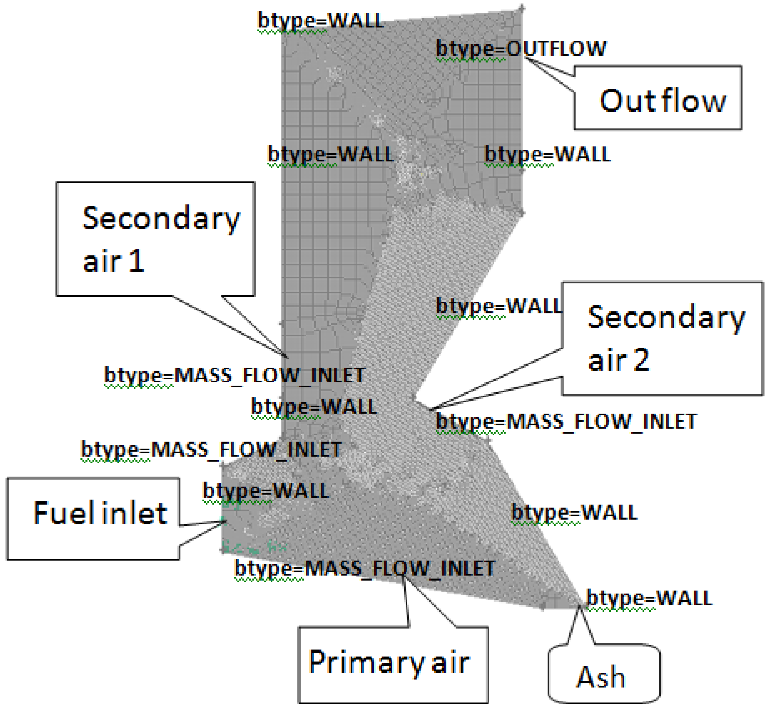

Figure-1. Geometry of grate bed furnace.

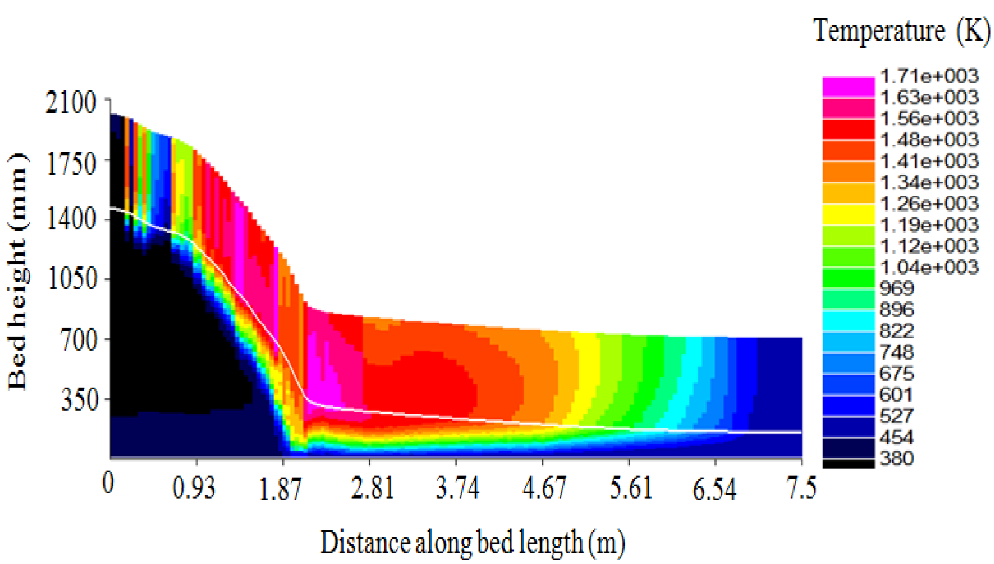

Figure-2. Gas temperature characteristic of RH_{90}+PB_{10} in grate bed.

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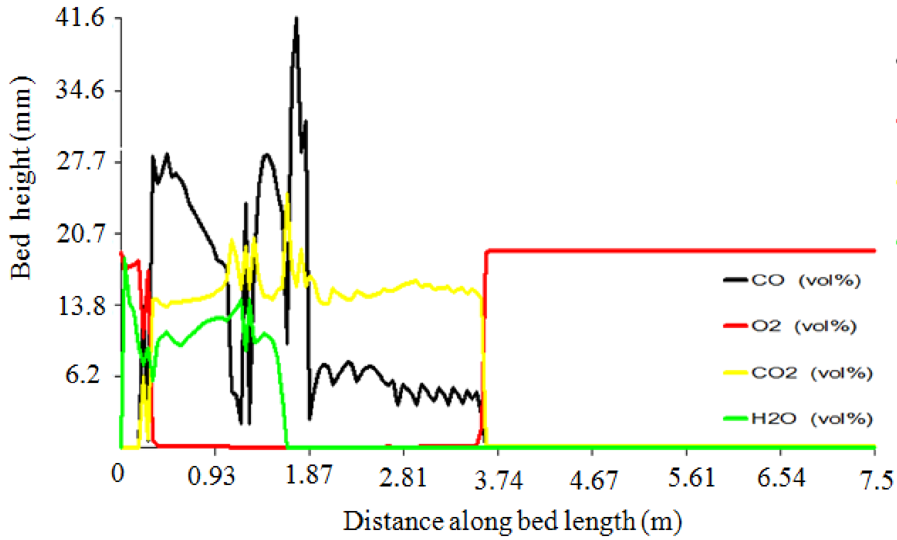

Figure-3. Profile of CO, CO_2, O_2, and H_2O of RH_{90}+PB_{10} at the top bed.

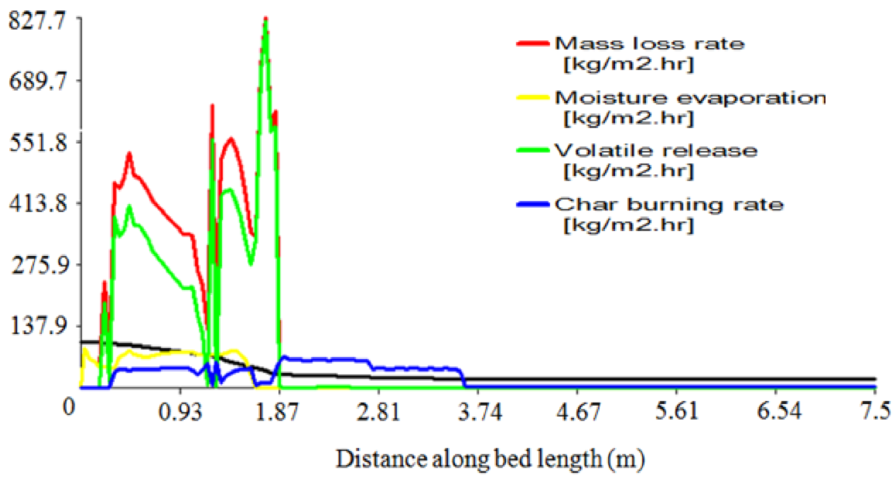

Figure-4. Profile of combustion gas of RH_{90}+PB_{10} at the top bed.

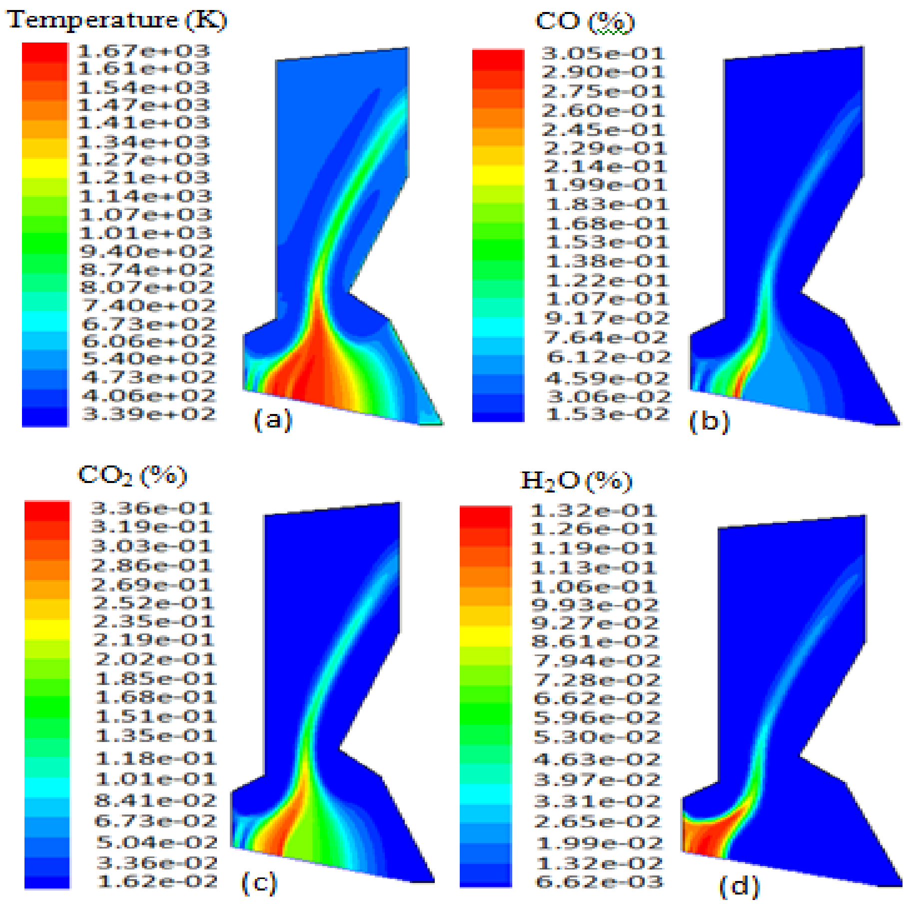

Figure-5. Contours of of RH_{90}+PB_{10}: a) Static temperature (K); b) CO (%); c) CO_2 (%); d) H_2O (%).

CONCLUSIONS

Co-combustion model characteristics of RH_{90}+ PB_{10} meet feasibility as fuel in the power plant because it produces gas temperature that meets the needs of the boiler temperature. In addition, the exhaust gas is low. Maximum temperature on the grate bed of about 1710 K, the maximum temperature in the furnace gas of about 1670 K, and the average temperature of about 1086 K. The flue gas CO_2, CO, and H_2O in the furnace obtained maximum of about 0.336% (3360 ppm), 0.305% (3050 ppm), and 0.132% (1320 ppm), respectively. Thus, it can be a reference for the development of utilization as fuel in the power plant in Indonesia.

ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Higher Education Malaysia for the RU Grant, Vot 05H25 and Research Management Centre, UTM for the financial and management support. Also, the authors would like to thank the Ministry of Higher Education of Republic of Indonesia, which has provided funding for the development of Research in Indonesia.

REFERENCES

Anshar M, Ani FN, Kader AS. 2015a. Combustion Characteristics Modeling of Rice Husk as Fuel for Power Plant in Indonesia. Applied Mechanics and Materials, Trans Tech Publications, Switzerland, 695, pp.815-819.

Anshar M, Ani FN, Kader AS. (2015b). The Energy Potential Of Municipal Solid Waste For Power Generation In Indonesia. Jurnal Mekanikal, 37, pp.42 - 54.

Anshar M, Ani FN, Kader AS. 2015c. The Potential Energy of Plastic Solid Waste as Alternative Fuel for Power Plants in Indonesia. Applied Mechanics and Materials, Trans Tech Publications, Switzerland, 699, pp. 595-600.

Anshar M, Kader AS, Ani FN. 2014. The Utilization Potential of Rice Husk as an Alternative Energy Source for Power Plants in Indonesia. Advanced Materials Research, Trans Tech Publications, Switzerland, 845, pp. 494-498.

Husain A, Ani FN, Sulaiman N, Adnan. MF. 2006. Combustion modelling of an industrial municipal waste combustor in Malaysia. International Journal of Environmental Studie, 63, pp.313-329.

Kær SK. 2004. Numerical modelling of a straw-fired grate boiler. Fuel, 83, pp. 1183-1190.

Kær SK. 2005. Straw combustion on slow-moving grates a comparison of model predictions with experimental data. Biomass and Bioenergy, 28, pp. 307–320.

Kapur T, Kandpal TC, Garg HP. 1996. Electricity generation from rice husk in Indian rice mills: Potential and financial viability. Biomass and Bioenergy, 10, pp. 393-403.

Anshar M, Ani FN, Kader AS. 2015a. Combustion Characteristics Modeling of Rice Husk as Fuel for Power Plant in Indonesia. Applied Mechanics and Materials, Trans Tech Publications, Switzerland, 695, pp.815-819.

Anshar M, Ani FN, Kader AS. 2015b. The Energy Potential Of Municipal Solid Waste For Power Generation In Indonesia. Jurnal Mekanikal, 37, pp. 42 - 54.

Anshar M, Ani FN, Kader AS. 2015c. The Potential Energy of Plastic Solid Waste as Alternative Fuel for Power Plants in Indonesia. Applied Mechanics and Materials, Trans Tech Publications, Switzerland, 699, pp. 595-600.

Anshar M, Kader AS, Ani FN. 2014. The Utilization Potential of Rice Husk as an Alternative Energy Source for Power Plants in Indonesia. Advanced Materials Research, Trans Tech Publications, Switzerland, 845, pp. 494-498.

Husain A, Ani FN, Sulaiman N, Adnan. MF. 2006. Combustion modelling of an industrial municipal waste combustor in Malaysia. International Journal of Environmental Studies, 63, pp. 313-329.

Kær SK. 2004. Numerical modelling of a straw-fired grate boiler. Fuel, 83, pp.1183-1190.

Kær SK. 2005. Straw combustion on slow-moving grates a comparison of model predictions with experimental data. Biomass and Bioenergy, 28, pp. 307-320.

Kapur T, Kandpal TC, Garg HP. 1996. Electricity generation from rice husk in Indian rice mills: Potential and financial viability. Biomass and Bioenergy, 10, pp. 393-403.

Madhiyanon T, Sathitruangsak P, Soponronnarit S. 2009. Co-combustion of rice husk with coal in a cyclonic fluidized-bed combustor (ψ-FBC). Fuel, 88, pp. 132-138.

Maiti S, Dey S, Purakayastha S, Ghosh B. 2006. Physical and thermochemical characterization of rice husk char as a potential biomass energy source. Bioresource Technology, 97, pp. 2065-2070.

Patel SK, Kumar M. 2009. Electrical Power Generation Potential of Paddy Waste.

PT PLN- Persero. 2010. Power Supply Business Plan PT PLN (Persero) 2010-2019, Indonesia.

Ryu C, Yang Y-B, Yamauchi H, Nasserzadeh V, Swithenbank J. 2005. Integrated FLIC/FLUENT Modelling of Large Scale MSW Incineration Plants. Sheffield University Waste Incineration Centre, Department of Chemical and Process Engineering, Mappin Street, Sheffield, S1 3JD.

Shin D, Ryu CK, Choi S. 2013. Computational Fluid Dynamics Evaluation of Good Combustion Performance in Waste Incinerators [Accessed 15.12.2013]. Mechanical Engineering Department, Korea Advanced Institute of Science and Technology, Taejon, Korea.

Yang YB, Newman R, Sharifi V, Swithenbank J, Ariss J. 2007. Mathematical modelling of straw combustion in a 38 MWe power plant furnace and effect of operating conditions. Fuel, 86, pp. 129-142.

Yin C, Rosendahl L, Clausen S, Hvid SL. 2012. Characterizing and modeling of an 88 MW grate-fired boiler burning wheat straw: Experience and lessons. Energy, 41, pp. 473-482.

Yu Z, Ma X, Liao Y. 2010. Mathematical modeling of combustion in a grate-fired boiler burning straw and effect of operating conditions under air- and oxygen-enriched atmospheres. Renewable Energy, 35, pp. 895-903.