Combustion of producer gas from gasification of south Sumatera lignite coal using CFD simulation

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Abstract. The production of gases from lignite coal gasification is one of alternative fuel for the boiler or gas turbine. The prediction of temperature distribution inside the burner is important for the application and optimization of the producer gas. This research aims to provide the information about the influence of excess air on the temperature distribution and combustion product in the non-premixed burner. The process was carried out using producer gas from lignite coal gasification of BA 59 was produced by the updraft gasifier which is located on Energy Conversion Laboratory Mechanical Engineering Department Universitas Sriwijaya. The excess air used in the combustion process were respectively 10%, 30% and 50%. CFD Simulations was performed in this work using two-dimensional model of the burner. The result of the simulation showed an increase of excess air, a reduction in the gas burner temperature and the composition of gas (carbon dioxide, nitric oxide and water vapor).

1 Introduction

The decreasing of crude oil as the energy sources has been followed by the increasing of the energy needs, so the needs of an alternative energy source to replace the crude oil is very crucial. Coal is one of the alternative energy to replace the crude oil. The utilization of coal in the direct combustion method will cause a problem in the pollution and a low efficiency of energy conversion. Gasification is one of the technology that can convert coal to be combustible gas with the low pollution [1-2] and high of the efficiency [2-3]. Indonesia is one of the largest coal-producing country in the world that have coal reserves about 3% from the world coal reserve [4] whereas about 57% of the reserve is the lignite coal [5]. South Sumatera is one of the largest coal suppliers in Indonesia. One of the coal product that not utilized maximally is the lignite coal (South Sumatera lignite coal called as BA 59).

The combustible gas produced from its gasification can be used for application on boiler, gas turbine, and dryer [6]. Its for the coal application, it needs an appropriate gas burner to reach the temperature distribution as expected. The method can be used to predict the temperature distribution inside the gas burner is simulation using computational fluid dynamics. Several simulations has been done by several researchers. Previous authors [7] has simulated the combustion of producer gas from the biomass gasification using computational fluid dynamics (CFD). The result of study shows the highest temperature is about 1367 °C. Other researchers [8] has simulated the combustion of producer gas from biomass gasification, the result shows the highest temperature in the combustion chamber about 1300 °K to 1700 °K. The combustion of producer gas in gas burner for applying in gas turbine is reported by [9]. The result of the work showed that the highest temperature of combustion was about 1500 °K [9].

Another work have performed by [10], they simulated the combustion of producer gas from gasification of wood chip and turkey feather. The result showed that the highest temperature can reach to 2000 °K and 1500 °K [10]. The combustion of producer gas from coconut shell gasification at swirl gas burner has simulated by [11], the result shows the application of swirl will increase the combustion temperature. The highest temperature reached about 1173 °K [11]. The result of the researchers showed the combustion temperature of the producer gas is effected by the fuel of the gasification process and the gas burner design with the temperature range of 1200 °K to 2000 °K. However, none of the previous studies used the application of CFD on the production of gases from lignite coal gasification. The objective of this research is to obtain the effect of excess air on the temperature distribution and the combustion products in the non-premixed burner using CFD simulation.

2 Producer gas composition

Producer gas used in the simulation is the BA 59 that produced from coal gasification from South Sumatera, Indonesia using updraft gasifier at Energy Conversion Laboratory Mechanical Engineering Department.
Sriwijaya University. The gas composition shows in Table 1.

**Table 1. Producer gas composition**

<table>
<thead>
<tr>
<th>Species</th>
<th>%(Vol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>29.54</td>
</tr>
<tr>
<td>H₂</td>
<td>12.07</td>
</tr>
<tr>
<td>CH₄</td>
<td>3.4</td>
</tr>
<tr>
<td>CO₂</td>
<td>8.11</td>
</tr>
<tr>
<td>O₂</td>
<td>1.3</td>
</tr>
<tr>
<td>N₂</td>
<td>45.58</td>
</tr>
</tbody>
</table>

3 Governing equation

Combustion process of the producer gas at the stoichiometry condition define by the equation below

\[
\text{producer gas} + 0.26305 (\text{O}_2 + 3.76 \text{N}_2) \rightarrow 0.4105 \text{CO}_2 + 0.1887 \text{H}_2\text{O} + 1.4449 \text{N}_2
\]

(1)

Combustion of producer gas in gas burner involved fluid flow and chemical reaction. Mass and momentum equation are used to drive the fluid flow.

**Mass Conservation Equation**

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m
\]

(2)

**Momentum Conservation Equation**

\[
\frac{\partial}{\partial t} (\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla P + \nabla \vec{T} + \rho \vec{g} + \vec{F}
\]

(3)

The distribution temperature inside gas burner is solved by energy conservation equation.

\[
\frac{\partial}{\partial t} (\rho E) + \nabla \cdot (\rho \vec{v} E) = \nabla \cdot (k_{\text{eff}} \nabla T) - \sum_i h_i \vec{f}_i + (\vec{T}_{\text{eff}} \vec{v}) + S_h
\]

(4)

Species movement in the gas burner is solved using the species transport equation

\[
\frac{\partial}{\partial t} (\rho \vec{Y}_i) + \nabla \cdot (\rho \vec{v} \vec{Y}_i) = -\nabla \vec{f}_i + R_i + S_i
\]

(5)

The combustion process depend on the turbulence. K-Epsilon Standard equation is used to solve turbulence process using combustion.

\[
\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho u_i \mu) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \rho \frac{\partial \mu}{\partial \rho} \right) \frac{\partial k}{\partial x_j} \right] + \Sigma_i h_i \vec{f}_i + \rho \vec{e} - Y_M + S_k
\]

(6)

The interaction between chemical reaction and turbulence in side of the gas burner are solved using the model has developed by Magnussen and Hjertager. The reaction rate will be produced by the smallest value between equation 7 and 8.

\[
R_{r, r} = v'_{r, r} M_{w,r} \rho \frac{e_{r}}{k} \min \left( \frac{Y_R}{v'_{r, R} M_{w,R}} \right)
\]

(7)

\[
R_{r, r} = v'_{r, r} M_{w,r} \rho \frac{e_{r}}{k} \frac{\Sigma \rho v_p}{\Sigma \lambda_j v'_{r, j} M_{w,j}}
\]

(8)

The mechanism of NOx production in side gas burner are modeled on thermal and prompt mechanism.

**Thermal NOx mechanism**

\[
\begin{align*}
0 + \text{N}_2 & = \text{N} + \text{NO} \\
\text{N} + \text{O}_2 & = \text{O} \text{N} + \text{NO} \\
\text{N} + \text{OH} & = \text{H} + \text{N} \text{O}
\end{align*}
\]

(9-11)

**Prompt NOx mechanism**

\[
\begin{align*}
\text{CH} + \text{N}_2 & = \text{HCN} + \text{N} \\
\text{N} + \text{O}_2 & = \text{NO} + \text{O} \\
\text{HCN} + \text{OH} & = \text{CN} + \text{H}_2\text{O} \\
\text{CN} + \text{O}_2 & = \text{NO} + \text{CO}
\end{align*}
\]

(12-15)

Thermal and Prompt NOx transport are derived by equation below.

\[
\frac{\partial}{\partial t} (\rho Y_{NO}) + \nabla \cdot (\rho \vec{v} Y_{NO}) = \nabla \cdot (\rho D \nabla Y_{NO}) + S_{NO}
\]

(16)

4 CFD Modeling

The combustion process was conducted in non premixed gas burner with the diameter of 45 cm and length of 180 cm [12]. The nozzle for injecting the producer gas diameter of 1 cm [12]. The schematic of the gas is presented burner in Fig 1.

![Fig.1. The scheme of gas burner](image-url)
The boundary condition for the simulation is presented in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity of Producer gas</td>
<td>Excess air of 0%</td>
<td>80 m/s</td>
</tr>
<tr>
<td>Velocity of air</td>
<td>Excess air 0%</td>
<td>0.052 m/s</td>
</tr>
<tr>
<td>Velocity of air</td>
<td>Excess air 10%</td>
<td>0.057 m/s</td>
</tr>
<tr>
<td>Velocity of air</td>
<td>Excess air 30%</td>
<td>0.067 m/s</td>
</tr>
<tr>
<td>Velocity of air</td>
<td>Excess air 50%</td>
<td>0.077 m/s</td>
</tr>
<tr>
<td>Inlet temperature of</td>
<td>Excess air of</td>
<td>300 °K</td>
</tr>
<tr>
<td>Producer gas</td>
<td>0%;10%;30%;50%</td>
<td></td>
</tr>
<tr>
<td>Inlet temperature of air</td>
<td>Excess air of</td>
<td>300 °K</td>
</tr>
<tr>
<td></td>
<td>0%;10%;30%;50%</td>
<td></td>
</tr>
</tbody>
</table>

5 Result and Discussion

5.1 Temperature Distribution

The simulation result shows the increasing of excess air from 0 to 50% will reduce the temperature distribution in gas burner as shown in Fig 4. The increasing amount of air caused the increasing amount of nitrogen. This is due to nitrogen absorb the heat from combustion and reduce the temperature in gas burner. This result is similar with the study as reported by [13-14]. The highest temperature was about 1910 °K. The temperature was decreased about 100 °K for increasing of the excess air from 0% until 50%.

In the visualization can be shown clearly the reduction of temperature distribution in the gas burner as shown in figure 5-8. The reduction zone of the yellow contour which describe the higher temperature, otherwise increasing of the green zone which describe the lower temperature zone.
5.2 Carbon dioxide (CO₂) distribution

From the simulation, it showed that the excess air was increased with the decreased of the concentration distribution of CO₂ in gas burner as shown in Fig 9. This condition was occurred due to the increasing of air which is not followed by the increasing of carbon content in combustion process when the fuel flow rate is set constant. The result showed the same trend with the result has been reported by [15].

![Fig. 9. Carbon dioxide distribution on middle of gas burner at radial distance with difference excess air.](image)

The decreasing of CO₂ distribution in gas burner is shown clearly in Fig. 10-13. The area of highest temperature (brown color) shown a decrease as the increase of the excess air. The maximum of CO₂ mass fraction concentration could be reached to 28%. The increasing of excess air from 0-50% caused a decrease in mass fraction concentration about 3%.

![Fig.10. Carbon dioxide distribution in gas burner on excess air of 0%.](image)

![Fig.11. Carbon dioxide distribution in gas burner on excess air of 10%.](image)

![Fig.12. Carbon dioxide distribution in gas burner on excess air of 30%.](image)

![Fig.13. Carbon dioxide distribution in gas burner on excess air of 50%.](image)

5.3 Water vapor (H₂O) distribution

The simulation result shows the increasing of excess air will decrease the distribution of H₂O in gas burner as shown in Fig 14, it is caused by the increasing of excess air was not followed by the increasing of H₂ (constant of fuel flow rate).

![Fig. 14. Water vapor distribution on middle of gas burner at radial distance with difference excess air.](image)

The decreasing of H₂O distribution in gas burner is shown clearly in Fig 15-18. The area of highest temperature (brown color) shown a decrease as the increase of excess air. The maximum of H₂O mass fraction concentration could be reached to 5%. The increasing of excess air from 0%-50% caused a decrease in mass fraction concentration about 0.6 %.
5.4 Nitric Oxide (NO) distribution

From the simulation process, it is shown an increase in excess air will cause a decrease in NO distribution in gas burner as shown in Fig. 19. It is caused by the increasing of excess air which is followed by the decreasing of temperature in gas burner as shown in Fig. 4. The reaction 9–15 is decreased by the decreasing of temperature. This result has similarity to the simulation that has been reported by [16].
Fig. 23. Nitric oxide distribution in gas burner on excess air of 50%

6 Conclusion

From the simulation, a number of conclusions could be taken as follows:

- The highest temperature can be reached by the combustion of producer gas from gasification of BA 59 coal at non premixed gas burner is 1910 °K. The highest mass fraction concentration of CO₂ about 28%, and the highest mass fraction concentration of NO about 5.37 x 10⁻³ %.
- The increase of excess air on combustion process from 0%-50% will cause the decreasing of temperature, CO₂, H₂O, and NO distribution in side gas burner

References