Numerical Investigation for the Plasma Coal Gasifier of 150kW and 1400kW

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1. Introduction

Integrated coal gasification combined cycle (IGCC) has gained a lot of interest because they can produce cleaner gaseous fuels such as hydrogen, carbon monoxide and methane. Therefore, the National Fusion Research Institute (NFRI) plant has been investigating the application of their plasma technology to gasify coal. It is a fusion plasma technology for better efficiency of low-carbon fuels [1]. They recently completed experiment for the gasifier of 150kwe, and are currently trying experiment for the gasifier of 1.4MWe. They have tried to design the gasifier that has cold gases of a higher efficiency. However it is considerably complicated and expensive that performance of gasifier is experimentally studied, because it is difficult to measure or control gases of very high temperature. So this study has verification of simulation for the gasifier of 150kWe and focuses on prediction of performance for the gasifier of 1.4MWe with a computational fluid dynamics (CFD) method. It is possible to predict flow patterns, tracks of particles, combustion characteristics, temperature distributions and chemical distributions using the commercial CFD solver ANSYS/FLUENT.

2. Methods and Results

2.1 Numerical methods

Figure 1 shows characteristics for analysis of the plasma coal gasifier. The three-dimensional flows in gasifier includes in the turbulence, dispersion, mixing, chemical physical reaction of gases, devolatilization of the coal particles, volatile matter and char partial combustion etc. In addition, the heat transfer occurs by convection and radiation. So this steady stated CFD analysis is performed with gas-phase and char reaction models, turbulence models, discrete phase models (DPM) and thermal radiation models [1]. Table Ⅰ shows numerical model used in FLUENT code [2].

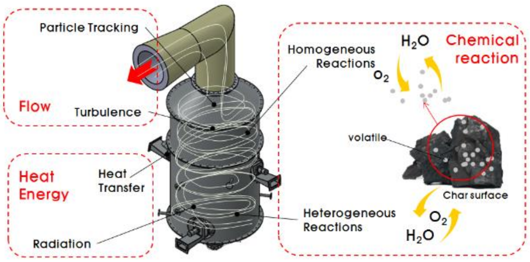

Fig.1. View of gasifier and general characteristics

Table Ⅰ Numerical models used in FLUENT

Analysis system	- Three-dimensional, steady stated flows - Mass, velocity (x, y, z), temperature, thermal radiation, and turbulence equation
Physical model	- Turbulence: Realizable k-ε model - Particle: DPM (with random walk model) - Radiation: P1 thermal radiation model
Chemical model	- Char gasification: Multiple surface reaction model - Finite-rate/eddy-dissipation model

The physical gasification of coal is evaporation and devolatilization by heating coal. Namely, the coal particle is divided into the char, volatiles and moistures.

$$Coal \rightarrow Volatile\,(V) + Char(C_{(s)}) + Moisture \quad (1)$$

Then, homogeneous reactions of volatiles and heterogeneous reactions of char take place. The kinetic rate expressions for global reactions for both heterogeneous and homogeneous reactions are given by relationship as [3, 4, 5]:

$$k = AT^{\beta} e^{-Ea/RT} \quad (2)$$

The char gasification reactions take place at surface of char particles. The heterogeneous reactions are modeled by multiple surface reaction mechanism [6]. The chemical reactions in the gas-solid interaction include reaction of a char particle with oxygen, steam and carbon dioxide and the major products are hydrogen and carbon monoxide [7]. Then, the gas phase reactions are the reaction of oxidant and product that generated from char reaction and devolatilization of the entrained flow. The turbulence chemistry interaction is modeled using a finite rate/eddy dissipation model, a built in module in FLUENT [6, 8].The gasification reactions are given as follows [3].

$$C_{(S)} + 0.5O_2 \rightarrow CO \quad (3)$$

$$C_{(S)} + CO_2 \rightarrow 2CO \quad (4)$$

$$C_{(S)} + H_2O \rightarrow CO + H_2 \quad (5)$$

$$vol + xO_2 \rightarrow yCO_2 + zH_2O + wH_2 \quad (6)$$

$$vol \rightarrow aCO + bCO_2 + cH_2 + dH_2O + eCH_4 + fN_2 \quad (7)$$

$$CH_4 + 0.5O_2 \rightarrow CO + 2H_2 \quad (8)$$

$$H_2 + 0.5O_2 \rightarrow H_2O \quad (9)$$

$$CO + 0.5O_2 \rightarrow CO_2 \quad (10)$$

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \quad (11)$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \quad (12)$$

2.2 Geometry and mesh

Fig.2 shows the internal flow field in gasifier of 150kWe and 1.4MWe. Coal is transported with the feeding gas through the torch, and oxidant is injected through tangential ports. The gasifier of 150kWe has 3 torch at the upper and lower of reactor, and the gasifier of 1.4MWe has 8 torches. Torch supplies not only coal but also steam and heat. There are tangential ports in tangential direction of torch, respectively. In addition, some air is supplied through the view ports.

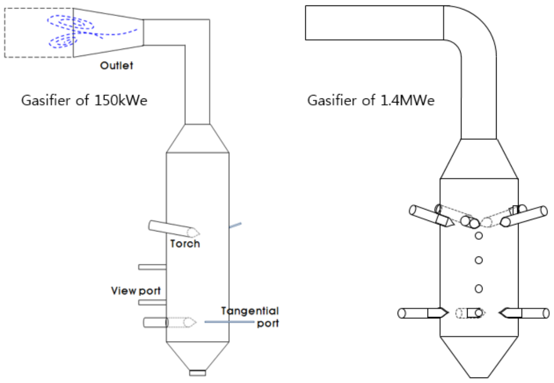

Fig.2. Views of the internal flow field for CFD modeling

Fig.3 and Fig.4 are grids of the gasifier of 150kWe and 1.4MWe, respectively. The total number of cells is approximately 1.5 and 1.1 million in the each internal flow field. The shape of the cells is tetrahedrons as body fitted grids. These have inflated boundary on the walls of gasifier. The number of inflated layers is 5. Each torch and ports has finer grids

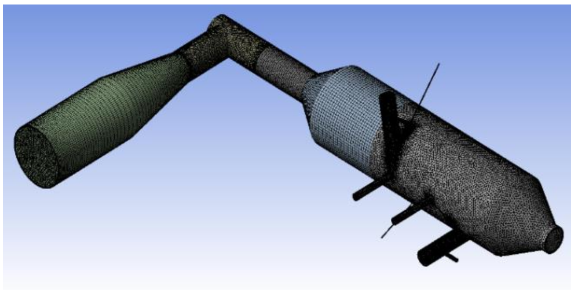

Fig.3. Mesh for gasifier of 150kWe

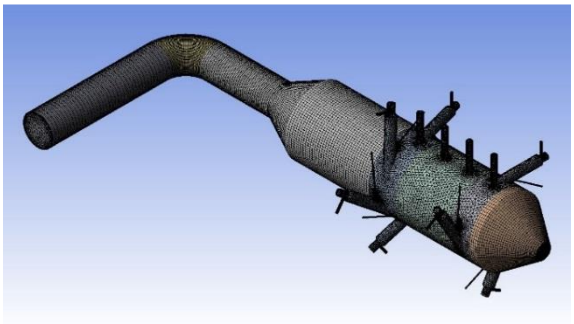

Fig.4. Mesh for gasifier of 1.4MWe

2.3. Operating conditions

Table Ⅱ show proximate analysis, ultimate analysis and measurement result of the calorific value for Indonesia lower coal burnt used in NFRI. A diameter (D_{coal}) of the coal particles is less than 70 ㎛ in their experiments, and is assumed to have a uniform particle size of 50 ㎛ for this analysis. Then the coal combustion and char gasification reaction are assumed to take place only in surface of the coal particles. The coal volatile include all gases such as hydrogen, methane, nitrogen etc. The chemical equation coefficients for volatiles according to each coals is in table Ⅲ.

Table Ⅱ Design for Indonesia lower coal

%		150kWe	1.4MWe
Proximate analysis	Moisture	24.44	24.40
	Fixed carbon	35.91	35.91
	Volatile	33.31	33.31
	Ash	0.35	6.35
Ultimate analysis	C	52.47	52.47
	H	4.66	4.66
	O	16.08	16.58
	N	0.01	0.01
	S	0.10	0.10
	Ash	-	-
Coal HHV (kcal/kg)		4,774	4,474

Table Ⅲ Design for Indonesia lower coal

$vol + xO_2 \rightarrow yCO_2 + zH_2O + wH_2$		
	150kWe	1.4MWe
x	0.050	0.420
y	1.540	0.030
z	1.080	1.430
w	0.577	0.583
$vol \rightarrow aCO + bCO_2 + cH_2 + dH_2O + eCH_4 + fN_2$		
	150kWe	1.4MWe
a	0.35058	0.02775
b	0.07985	0.60773
c	0.49111	0.00250
d	0.03973	2.3e-14
e	0.82957	0.82700
f	0.05170	0.58293

Oxidant is oxygen and steam, and a feeding gas is air. Table Ⅳ shows inlet conditions varied according to injection amount of oxidant, coal and feeding gas in gasifier of 150kWe and 1.4MWe. The injection power is for devolatilization of coal. The heat loss is only assumed in the exhaust duct of the 150kWe gasifier.

Table Ⅳ Design for Indonesia lower coal

	Injection location		
Cole(kg/s)	Torch	125	890
Steam(kg/s)	Torch/Upper ports	88	610
Oxygen(lpm)	Lower ports	1000	6900
Air (lpm)	Torch/View ports	1610	11200
Power(kW)	Torch	100	800

2.4 Analysis results for gasifier of 150kWe

Fig. 5~6 show contours of each species mole fractions. Most of carbon dioxide is generated by reaction $CO + 0.5O_2 \rightarrow CO_2$ (carbon monoxide is oxidized) at bottom of reactor. So a small quantity of carbon monoxide generated in end of torch is almost oxidized, and most of carbon monoxide is regenerated by char reaction with carbon dioxide or steam in reactor. The mole fraction of carbon monoxide especially increases over 20% at exhaust duct. The hydrogen is generated by the reduction reaction of steam at torch and maintained to end of exhaust duct.

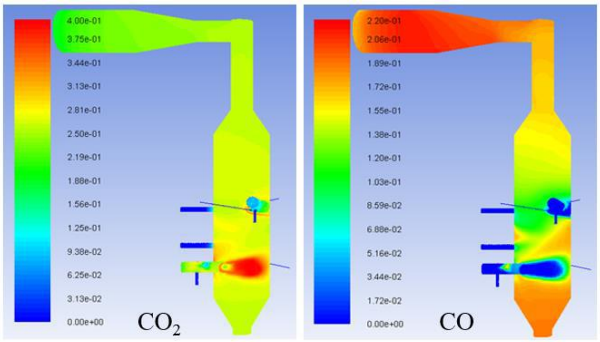

Fig.5. Contour of mole fraction of CO_2 and COfor150kWe

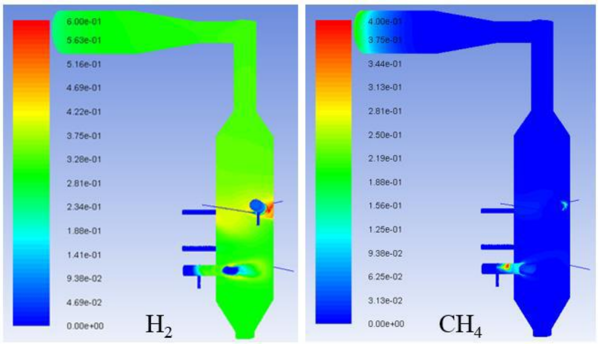

Fig.6. Contour of mole fraction of H_2 and CH_4for150kWe

The results at outlet are summarized in table Ⅴ. The cold gas efficiency of CFD analysis is 74.849%. Most of species mole fractions is not only similar to experiment results, but the cold gas efficiency and carbon exchange rate is similar to experiment results for gasifier of 150kWe.

Table Ⅴ Results of experiment and simulation for the 150kWe

	Mole fraction (%)			Carbon exchange rate (%)	Cold gas efficiency (%)
	H2	CO	CO2		
Exp.	29.80	24.50	19.50	113.45	74.80
CFD	30.17	20.74	23.79	110.19	78.85

2.5Analysis results for gasifier of 1.4MWe

Fig.7~9 show contours of temperature and each species mole fractions. The injection coal and gas is pumped into gasifier as room temperature, and is heated from torches. The heat separate into chars and volatiles. The chars and volatile is combusted with oxygen injected from lower tangential ports. Therefore, lower region of reactor has very high temperature that is over locally approximately 2500℃ and concentration of carbon dioxide. This generated carbon dioxide has reduction reaction with steam from upper torches and tangential ports, and becomes carbon monoxide. The hydrogen is sharply generated in upper region of reactor due to char reaction with carbon dioxide that is from lower region of reactor. The methane is generated in upper region of reactor, but is under 1% at outlet duct because is mostly used for chemical reactions. Otherwise, the nitrogen stay steady in all region.

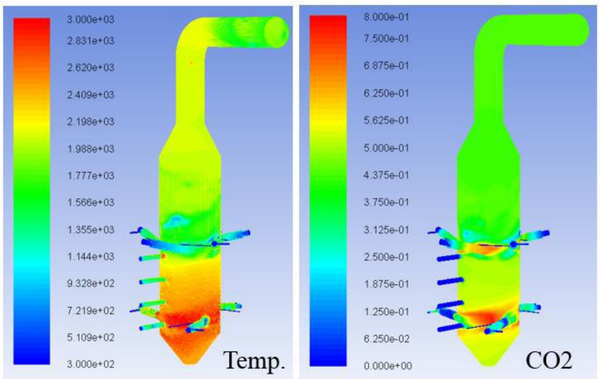

Fig.7. Contour of mole fraction of CO_2 and COfor150kWe

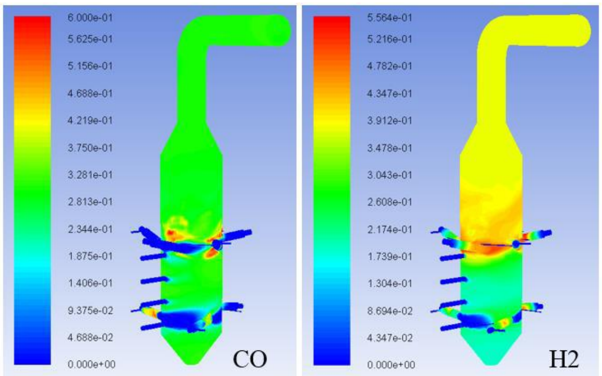

Fig.8. Contour of mole fraction of CO_2 and COfor150kWe

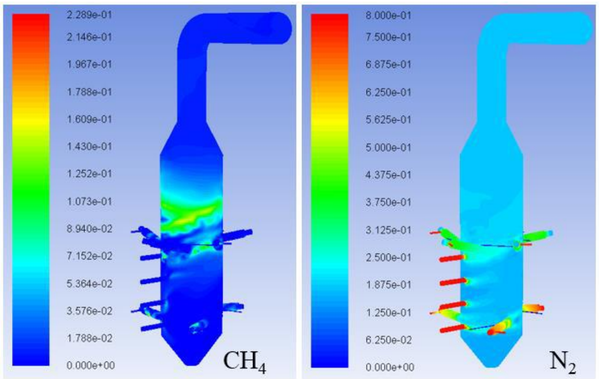

Fig.8. Contour of mole fraction of CO_2 and COfor150kWe

The results at outlet are summarized in table Ⅵ and Ⅶ. The cold gas efficiency is 98.451%.

Table Ⅵ Mole and mass fraction for gasifier of 1.4MWe

%	H2	CO	CO2	CH4	N2
Mole fraction	36.70	20.98	20.39	0.91	21.30
Mass fraction	3.03	44.13	28.49	0.85	23.50

Table Ⅶ Results of simulation for gasifier of 1.4MWe

Mass flow rate (kg/sec)	0.72
Temperature at outlet (K)	2007.69
Carbon exchange rate (%)	108.002
Cold gas efficiency (%)	98.451

3. Conclusions

This study has numerical investigation for the phenomena of coal gasification for coal gasifier of 150kWe and 1.4MWe at experiment operating conditions. This study has verification of simulation for the gasifier of 150kWe, and predicts performance for the gasifier of 1.4MWe. The gasifier of 1.4MWe will have a cold gas of higher efficiency than gasifier of 150kWe because can generate many hydrogen gas. So this gasification has the potential to become cornerstone technology in many hydrogen industries.

ACKNOWLEDGEMENT

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