Numerical Simulation of the Effect of Particle Size Distribution on Fluidized Bed Gasifier

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Abstract. The rapid development of technology and industrialization has confronted humanity with two important problems: the depletion of fossil energy resources and environmental damage. This study aims to determine the effect of the particle size distribution of the bed on the composition of the produced syngas which has the potential to replace fossil fuels. The particle bed used is silica sand with 4 variations of particle size distribution with a diameter of 600-1000 µm. The results of this study indicate that the larger the particle size distribution of the bed can reduce the temperature distribution and composition of the syngas produced. The highest temperature distribution was found in the 1st particle size distribution variation of 1060.23 K. The highest syngas composition was found in the 3rd particle size distribution variation of 2.21% CH4, 19.68% CO, 6.21% CO2, and 18.51% H2The highest syngas composition was found in the 3rd particle size distribution variation of 2.21% CH_4, 19.68% CO, 6.21% CO2, and 18.51% H_2. The lowest temperature distribution was obtained in the 3rd particle size distribution variation of 1057.77 K. The lowest syngas composition was found in the 4th particle size distribution 1.99% CH_4, 17.71% CO, 5.63% CO_2, and 16.66% H_2.

1 Introduction

The rapid development of technology and industrialization has faced mankind with two major concerns: depletion of fossil energy resources and deterioration of the environment. Fossil fuels are the most common energy sources used in the world. It has been reported that over 80% of the energy consumption counts for fossil fuels [1]. However, there are some crucial problems associated with such fuel sources. Fossil fuels emit significant amounts of pollutants such as CO_2, NO_2, and SOx into the atmosphere [2]. Combustion of fossil fuels produces large amounts of CO_2 which is considered for its greenhouse effect and promotion of global warming [1]. Besides, energy consumption has increased 17-fold in the last century, and with the present rate of energy consumption, it is estimated that the world's oil reservoir will be diminished by 2050. Meanwhile, the cost of fossil fuel is globally increasing [2], [3].

Among all of the renewable resources, biomass is the only renewable source of carbon that can be converted to solid, liquid, and gaseous products through various conversion processes [4]. Currently, biomass is the fourth largest source of energy in the world after coal, petroleum, and natural gas and provides about 14% of the world's energy consumption [3]. Biomass wastes are mostly burnt in the open air or dumped which generates pollutants including dust, acid rain gases such as NO_2 and SOx, and large amounts of methane which is a more potent greenhouse gas than CO_2. Therefore, in developed countries, there is a growing trend toward the use of biomass-based energies [1]. These technologies which use waste or plant matter to produce energy, emit less greenhouse gas than fossil fuels and are cost-wise competitive with conventional energy resources [5].

As an alternative approach, numerical simulation has emerged as a powerful tool for studying solid reactive two-phase flows, as it offers the possibility to study detailed local information (e.g., temperature and concentration) about the fluidized bed. From a numerical perspective, the flow of gas-solid reactions can be solved in an Euler-Lagrange framework based on the method used to track the motion of the solid. In an Euler–Lagrangian system, each particle is tracked with position, velocity, and temperature information that is updated over time, providing the ability to approximate solid-state particle-scale information. However, tracing each particle's trajectory increases the required computational resources. According to the collision behavior processing method, high-precision numerical flow simulation combined with the discrete element method (CFD-DEM) and multiphase particle cell (MP-PIC) evaluates particle collision events with the soft-sphere collision model and particle normal stresses. Several numerical reports on the gasification of biomass in bubbling fluidized beds have been made, after which many valuable results have been obtained.

Computational fluid dynamics (CFD) technology, together with rapidly growing computing power, offers an efficient alternative method for studying fluidized bed gasification processes. The CFD model of fluidized bed

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gasification problems can provide qualitative and quantitative profiles such as pressure, solid volume fraction, temperature, species distribution, and pollutant emission [6]. Therefore, Barracuda VR, software with the application of the multi-phase method of particles in cells (MP-PIC) specially designed for CPFD (computational particle fluid dynamics) simulations, is the software of choice with the Eulerian-Lagrangian approach [7].

Win et al. [8] conducted an experimental study on the gas characteristics of the fluidized bed gasifier. This study aims to determine the performance and characteristics of RPF and wood pellet products so that the relationship between ER and temperature, LHV, gas composition, and tar concentration is obtained. Biomass from wood pellets with a diameter of 6 mm and Refuse Paper and Plastic Fuel (RPF) with a diameter of 10 mm were tested in a Fluidized Bed Gasifier (FBG). With temperatures ranging from 700-940oC and Equivalence Ratio (ER) varying between 0.3-0.5. The bed material is silica sand and the reactor used is 3 m high and 0.2 m in diameter. The results obtained from the gas composition showed that the concentration tendencies varied for CO, H 2, and hydrocarbon gas products, depending on the type of feedstock, while the same trend was observed for the concentrations of CH4 and tar. Through the ER range, the LHV of product gas for RPF and wood pellets is 3.4 – 5.9 MJ/Nm3. The tar concentration decreased to 2.5 - 14.0 g/Nm3-dry when the ER was increased.

T. Basmoen et al. [9] conducted an experimental and computational study on the gasification of biomass in fluidized beds. This study aimed to investigate the effect of the air-to-biomass ratio on the composition of the gas produced by the high-energy components H_2, CH_4, and CO. The experiment was carried out with wood chip biomass with dimensions of 5-12 mm in width and 1-5 mm in thickness in a pilot-scale gasification reactor with a height of 1.63 m and a diameter of 0.084 m. The results indicate that an air-to-biomass ratio of less than one gives the most suitable gas composition. In the fluidized bed gasifier, bed material is used to improve the fluidization quality. Experiments were carried out in a cold bed model to study the fluidization properties of the bed material. the minimum fluidization velocity is predicted based on the pressure drop in the bed.

Zhou et al. [10] Conducted a study on a multiphase particle-in-cell approach to explore the effect of particle size distribution (PSD) on the gas yield of the biomass gasification process. The impact of PSD width on gas production and mole fraction of gas species combined with gas temperature was investigated. The study used biomass particles with a diameter of 250 µm to 350 µm a reactor with a cylinder height of 500 mm and a diameter of 50 mm and silica sand as bed material. The results showed that increasing the width of the PSD increases the total gas yield, the mole concentration of combustible gases (CH4, CO, and H2), and also the carbon conversion efficiency, which indicates the effect of increasing the width of the PSD on improving the gasification performance. The axial distribution of the large mole fraction of the combustible gas and O2 is distributed in the aqueous and solid regions, respectively.

Reschmeier et al. [11] Conducted an experimental study of the kinetics of wood charcoal gasification in a fluidized bed. This study describes gravimetric measurements directly applied to a fluidized bed with 6 mm wood pellet charcoal samples and wood cubes measuring 10-40 mm to measure “pseudo kinetics” directly. The 100 mm diameter reactor sits on balance with a platform size of 800x600 mm filled with quartz sand. The parameters studied in this study were particle size, product gas (hydrogen) in the gasification medium, wood species, and differences in CO/steam gasification. The results are presented as Arrhenius diagrams and half-value period diagrams. The most important parameters are temperature and product gas (hydrogen) in the gasifying agent. The half-period values for gasification of charcoal from wood cubes (10 mm 40 mm) with 100% steam at atmospheric pressure lie between 1000 s at 1023 K and 300 s at 1173 K. For 6 mm wood pellet charcoal, the half-period values lie between 1900 s at 1023 K and 250 s at 1173 K.

2 Research Methodology

2.1 Diagram Flowchart

Fig. 1. Research flow chart

This study uses numerical simulation methods with variations in particle size distribution. In this simulation, chemical reactions from gasification are involved so that the gas produced from the gasification process can be analyzed. The research steps carried out can be seen in Figure 1 with detailed steps explained in the points below:

1. Literature Review
   This research was done with the literature study and reading journals from various previous studies related to the simulation of fluidized bed gasifiers.
2. Reactor Design Making

Design only the gasifier reactor part in the fluidized bed gasifier, all of these parts are made according to their original size using SolidWorks 2017 software. Figure 2 provides the gasifier reactor design in centimeters.

3. Gridding
The grid used is a uniform grid of 77000 grids, modifications are made to the biomass feeder input section so that the cross-sectional shape corresponds to the original shape. According to a study conducted by Bandara et al., [12]. the number of grids does not affect the minimum fluidization velocity. However, grid size has a large effect on the bubble size and consequently on the hydrodynamics of the layer, where the larger the number of grids, the larger the bubbles.
4. Setup Global Settings
Begins by entering the general settings, namely the acceleration of gravity of 9.81 m/s2 or - 9.81 m/s2 according to the geometric axis.
5. Setup Base Materials
Import all the materials involved in the simulation, including chemical compounds contained in the biomass.
6. Setup Particles
Defined the particles involved in the simulation, the nature of the interactions between the particles and the reactor wall, and the interactions between the particles. The variation of silica sand that has been determined is then put into the reactor with operating temperature conditions in the gasifier reactor. This is done with the assumption that the conditions in the reactor are sufficient for the gasification reaction to occur so that the simulation process carried out is not too long. Biomass is also loaded into the screw feeder but under normal conditions.

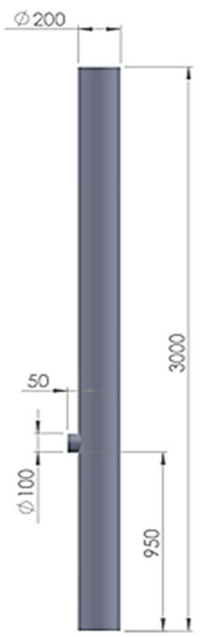

Fig. 2. Gasifier reactor design in centimeters

7. Setup Particle Size Distribution
The distribution can be specified as a cumulative distribution or a frequency distribution. the cumulative distribution shows the percentage by weight of particles that are less than or equal to the size specified in the row. the cumulative distribution shows the first row must have a cumulative value of 0 and the last row must have a cumulative value of 100.
In this study, 4 variations of the particle size distribution were used using different cumulative distributions which can be seen in Table 1.
8. Setup Initial Conditions
Determine the initial conditions of the fluids involved. The fluid used is air, the airspeed is "0m/s", the air temperature is set at 1073K, and the pressure is one atmosphere that contains 78% N_2 and 22% O_2. Then the initial conditions of the particles involved namely silica sand and determined the height of the bed, as well as the condition of the particle temperature, which is 350℃ according to the experimental conditions.
9. Setup Boundary Conditions
The process includes Pressure BCs and Flow BCs to regulate the inlet or outlet of particles or fluid flow.
Pressure BCs are defined as the boundary conditions under which the pressure through the fluid and particles can move out or into the domain.
The flow of BCs is defined as the open location for the fluid in the domain where the fluid can pass through the inflow or outflow to determine the bottom.
The screw feeder biomass mass flow rate is set according to the experimental data, namely 0.011 kg/s.
10. Finding the Minimum Fluidization Velocity (Umf)
The success parameter used by Fluidized Bed Gasifier is the formation of bubbles through the fluidization process. The superficial velocity was adjusted to the experimental conditions of 1.0 m/s
11. Chemistry Setup
This simulation involves a gasification chemical reaction to identify the gas produced. The chemical reaction equation and the reaction rate are entered into the chemistry menu.
12. Setup Time Controls
Setting the time controls for the simulation is used to determine the simulation running time, which is 60 seconds.
13. Setup Data Output
Setting the output data on the simulation serves to determine the data that appears after the running process is complete. The data output is flux planes, general mesh view (GMV), and transient points.
Flux planes are imaginary planes that are placed across a channel. The data that can be displayed from the flux plane is the fluid flow rate, the total mass of the flowing fluid, the particle flow rate, the total mass of the flowing particles, and the total energy carried by the fluid and particles.
General Mesh View (GMV) stores calculation data whose results will be displayed in a visual form.

Transient points are sensors that can be installed at points throughout the existing grid. Several transient points are installed to retrieve data on pressure, fluid temperature, particle temperature, and gas mass fraction.

14. Running 1 Step
    Running 1 step is used to see the check setup generated during 1 step of the simulation process.
15. Error
    Checking whether the results of running 1 step are true or false.
16. Running Total
    After seeing the results of running 1 step correctly, a running total is carried out to get the expected data according to the previous settings.
17. Post-processing and Analysis
    The plot manager is an integrated plotting system in a Virtual reactor, where the output data can be monitored periodically from the graph feature, and all plotting is stored in the project file.

Table 1. Cumulative presentation of particle size distribution variations

Particle size distribution variation 1		Particle size distribution variation 2	
Cumulative (%)	Diameter (%)	Cumulative (%)	Diameter (%)
0	600	0	600
22.5	630	3.1	630
48.8	670	11.2	670
59.8	690	17.8	690
67.8	710	29.8	710
75.9	780	57.9	780
87	870	73.9	870
88.8	900	76.8	900
93.7	960	84.7	960
97.1	990	93.8	990
100	1000	100	1000
Particle size distribution variation 3		Particle size distribution variation 4	
Cumulative (%)	Diameter (%)	Cumulative (%)	Diameter (%)
0	600	0	600
16.5	630	3.5	630
38.8	670	8.8	670
48.8	690	11.8	690
54.8	710	14.8	710
67.9	780	24.9	780
73.7	870	39.7	870
75.8	900	45.9	900
81.7	960	61.7	960
88.8	990	78.8	990
100	1000	100	1000

2.2 Research Tools

The hardware specifications of the PC and the software used are shown in Table 2.

Table 2. Hardware and software specifications used

Hardware specifications	
Processor	AMDF Ryzen 7 5700X 8-Core (16 CPUs) 3.4 GHz
Memory	32768 MB RAM
VGA Card	NVIDIA GeForce RTX 3060
GPU Memory	12143 MB
Operating System	Windows 10 Pro 64-bit
Software specification	
Barracuda VR 17.1.0	Fluidized bed fasifier particle and fluid simulation
SolidWorks 2017	Fluid domain creation

3 Result and Discussion

3.1 Grid Verification

Setting the grid is the first task in creating a Virtual Reactor model because the grid has many roles that make it truly the basis of simulation. In this study, a grid verification has been carried out by conducting experiments using several grids, namely the number of grids 45000, 77000, and 90000 by simulating for 10 seconds and only seeing the pressure during the simulation process. Figure 3 presents the verification of the grid.

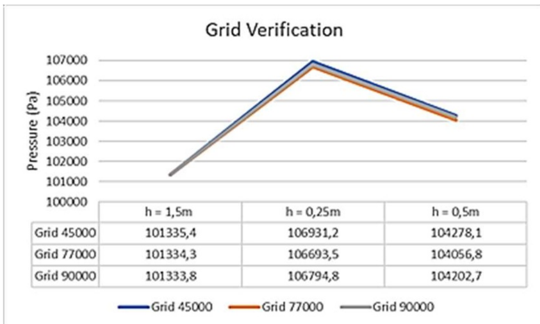

Fig. 3. Grid verifications

Figure 3 shows that Grid 45000 produces an average pressure at a bed height of 0,25m of 106931,2Pa, a height of 0,5m of 104278,1 Pa, and a height of 1,5m of 101335,4 Pa. The simulation process runs for 1 hour and 56 minutes.

The 77000 grid produces an average pressure at a bed height of 0,25m of 106693,5 Pa, a height of 0,5m of

104056,8 Pa, and a height of 1,5m of 101334,3 Pa. The simulation process runs for 3 hours and 20 minutes.

The 90000 grid produces an average pressure at a bed height of 0.25m of 106794,8 Pa, a height of 0.5m of 104202,7 Pa, and a height of 1,5m of 101333,8 Pa. The simulation process runs for 3 hours and 47 minutes.

It can be concluded that the greater the number of grids used, the longer the simulation process takes and does not result in a significant change in pressure. In addition, according to research conducted by Bandara et al., the number of grids does not affect the minimum fluidization velocity. However, the size of the grid has a large effect on the size of the bubbles and consequently on the hydrodynamics of the bed, where the greater the number of grids, the larger the bubbles.

3.2 Hydrodynamic Characteristics of Bed Gasifier

During the simulation process, there is the movement of silica sand in the gasifier which is the effect of pushing air from below. Figure 4 – Figure 7 shows the four phenomena of variations in the particle size distribution.

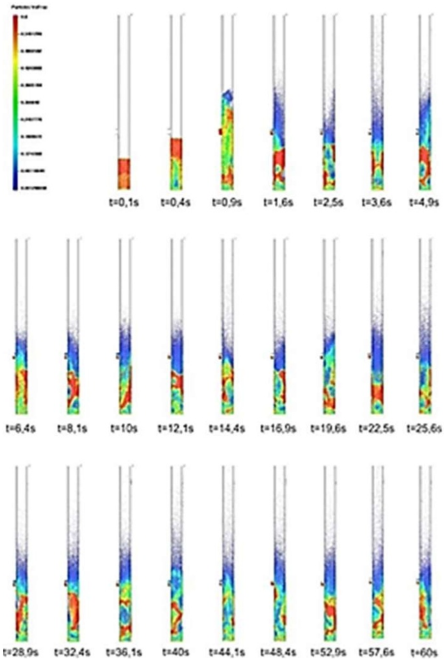

Fig. 4. Particle size distribution variation 1

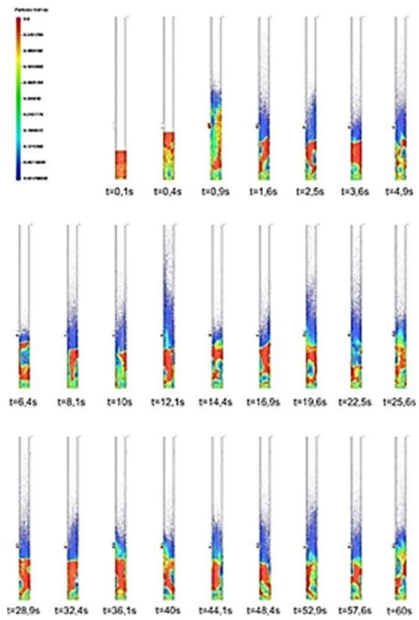

Fig. 5. Particle size distribution variation 2

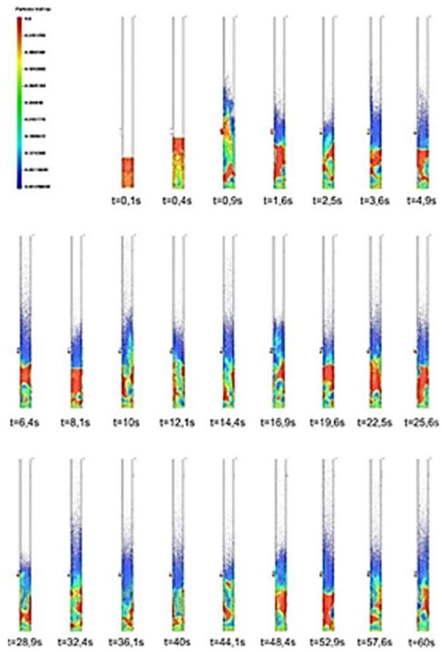

Fig. 6. Particle size distribution variation 3

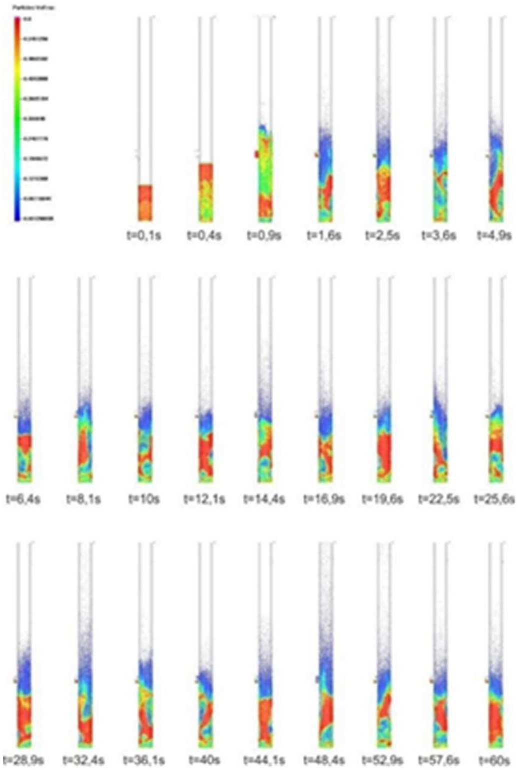

Fig. 7. Particle size distribution variation 4

From Figure 4 – Figure 7 it can be seen that the particle size distribution of the four variations does not show a significant difference in particle movement. At 0.1 seconds, the bed particles have started to react but are still a solid bed at rest. at 0.4 seconds it starts to increase compared to before and green particles start to appear indicating the presence of air.

At 0.9 seconds the particles of the bed have been pushed up due to the great air force from below. For variation 1, the particles experience the highest thrust because the particle size distribution is relatively small. For variation 4 the particles experience a high thrust but the particles fall back because the particle size distribution is larger. while for variations 2 and 3 the particles experience high impetus and form slugging in the middle of the solid bed formed due to the uniform particle size.

At 1.6 to 60 seconds of four variations, a large burst of air occurs which can eject particles above the surface layer. In that second, constant slugging occurs because the air velocity coming out from the bottom is higher than the minimum fluidization velocity.

Changes in the particle size distribution of the bed can slow down the movement of the bed particles. This is due to the creation of larger cavities/gaps between the bed particles so that the air entering the gasifier is not fully fluidized.

3.3 Distribution of Temperature Gasifier

Inside the gasifier, various gasification reactions occur to produce syngas. The existence of this reaction causes a temperature difference along the gasifier. The distribution of the temperature inside the gasifier can be used as information to predict the reactions that occur at points along the gasifier. In this discussion, all the data presented is taken by calculating the average value of each variation at 50 to 60 seconds during the simulation, because under these conditions the ongoing gasification process is assumed to be in a steady condition. The distribution of temperature differences in all parts of the Fluidized Bed Gasifier for each variation of the particle size distribution can be seen in Figure 8 which was taken at 60 seconds.

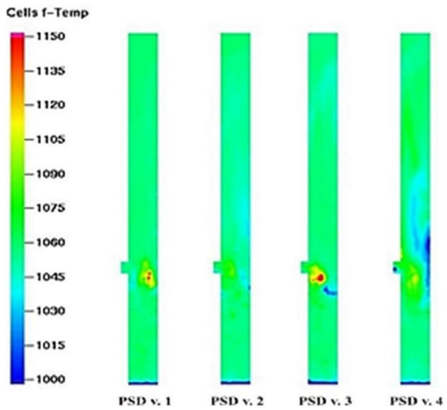

Fig. 8. Gasifier temperature distribution to variations in particle size distribution

In Figure 5 for Particle Size Distribution variation 1 at the bottom of the gasifier (height 0.5 m) the temperature is 1061.32 K, in the middle of the gasifier (height 1.5 m) the temperature is 1060.77 K, and at the top of the gasifier (height 2.75 m), the temperature is 1059.30 K.

In Figure 6 for Particle Size Distribution variation 2 at the bottom of the gasifier (height 0.5 m) the temperature is 1059.23 K, in the middle of the gasifier (height 1.5 m) the temperature is 1060.24 K, and at the top of the gasifier (height 2.75 m), the temperature is 1057.75 K.

In Figure 6 for Particle Size Distribution variation 3 at the bottom of the gasifier (height 0.5 m) the temperature is 1060.31 K, in the middle of the gasifier (height 1.5 m) the temperature is 1058.79 K, and at the top of the gasifier (height 2.75 m), the temperature is 1056.61 K.

In Figure 7 for Particle Size Distribution variation 4 at the bottom of the gasifier (height 0.5 m) the temperature is 1058.82 K, in the middle of the gasifier (height 1.5 m) the temperature is 1062.24 K, and at the top of the gasifier (height 2.75 m), the temperature is 1058.13 K.

The greater the percentage of bed particle size distribution to the gasifier height, the lower the gasifier temperature. This is predicted to occur when the heat transfer of combustion products is absorbed into the bed particles, due to the increased surface area of the bed particles that are created so that the gas temperature decreases while the bed particle temperature increases.

3.4 Characteristic of Syngas

3.4.1 Composition of Syngas

Syngas resulting from gasification will go up so that they will be detected by the sensor that has been installed before. The syngas detected by the sensor are in the form of H_2, CO, CH_4, and CO_2 gas.

Changes in the value of the particle size distribution in the gasifier result in significant changes to the gas produced. When the value of the particle size distribution from variation 1 to variation 2 resulted in gas H_2, CO, and CH_4 not changing with a composition of 17.64% H_2, 18.73% CO, 2.11% CH_4, and CO_2 decreased in composition from 6.17% to 5.76%.

In the particle size distribution, variation 2 becomes variation 3 resulting in H_2 gas increasing from 17.62% to 18.51%, CO increasing from 18.73% to 19.68%, CH_4 increasing from 2.11% to 2.21%, and CO_2 increased from 5.76% to 6.21%.

While in the particle size distribution variation 3 to 4 resulted in H_2 gas decreasing from 18.51% to16.66%, CO decreasing from 19.68% to 17.71%, CH_4 decreasing from 2.21% to 1.99%, and CO_2 decreasing from 6.21% to 5.63%.

Changes in the molar fraction of the gas produced at the top of the gasifier during the simulation process can be seen in Figure 10.

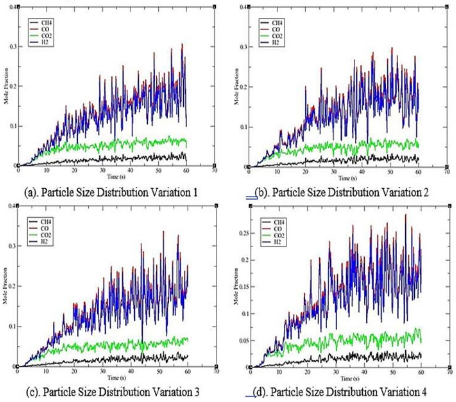

Fig. 9. Syngas composition to variation of particle size distribution

Here, a diagram of changes in the composition of the syngas at the top of the gasifier will be shown for each variation of the particle size distribution. Changes in syngas composition can be seen in Figure 7.

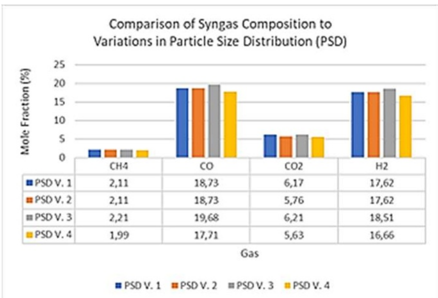

Fig. 10. Comparison of syngas composition to variations in particle size distribution

3.4.2 Distribution of Syngas

Of the gases that appear in the wood pellet gasification process, three gases can be utilized because they are gases that have a high calorific value and can still be burned, namely H_2, CO, and CH_4. The presence of these three gases is also a measure of the success of a gasification process.

Hydrogen gas produced in the gasification process is obtained from the reaction of steam gasification and water gas shift. Hydrogen is also obtained from the content in the biomass through the devolatilization process. Figure 8 shows the distribution of hydrogen throughout the Fluidized Bed Gasifier on the particle size distribution for each variation taken at 60 seconds during the simulation.

CO gas is a product of incomplete combustion reactions and has a high calorific value. Figure 9 shows the distribution of CO throughout the Fluidized.

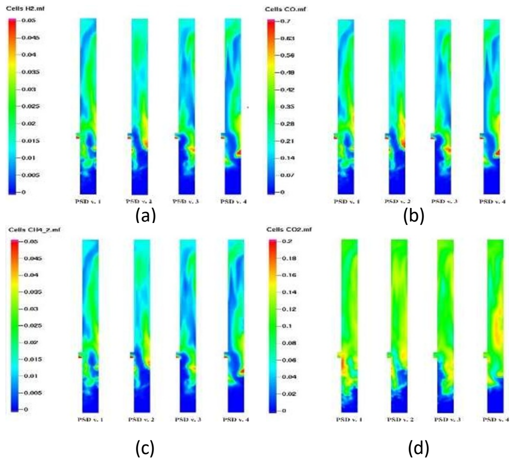

Fig. 11. Distribution of syngas bed gasifier on the particle size distribution of each variation

The methanation reaction converts carbon and hydrogen into methane or CH_4. Methane itself is a gas that can be burned so that it can be used as fuel. Figure 10 shows the distribution of CH_4 throughout the Fluidized Bed Gasifier on the particle size distribution of each variation.

The amount of CO_2 gas also needs to be measured because it affects the quality of gas as a result of gasification. CO_2 is a gas resulting from the complete combustion reaction of carbon and oxygen. The amount of CO_2 in the gasification process must be kept to a minimum because this gas cannot be used further and can reduce the quality of the syngas. Figure 11 shows the distribution of CO_2 throughout the Fluidized Bed Gasifier on the distribution of particle sizes for each variation.

3.4.3 LHV (Low Heating Value)

LHV (Low Heating Value) is the calorific value obtained from burning fuel without taking into account the heat of steam condensation (water produced from combustion in the form of gas/steam). The formula for calculating LHV is written as follows:

From the equation above, we can find the LHV for each variation in the particle size distribution used.

$$LHV = \left(11{,}76\,x\,(\%CO)\right) + \left(11{,}882\,x\,(\%H_2)\right) + \left(37{,}024\,x\,(\%CH_4)\right) = (MJ/Nm^3)$$

The resulting LHV for each variation of the particle size distribution can be seen in Figure 12.

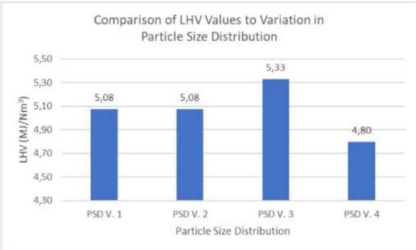

Fig. 12. Comparison of LHV values to variation in particle size distribution

It can be seen in the picture above that it can be concluded that the highest LHV was obtained when the particle size distribution of the 3rd variation was 5.33 MJ/Nm^3.

3.5 Comparison of Syngas Composition Experimental with Simulation Method

This modelling needs to be verified by validating experimental case study data and compared with simulation results. The results of research from Win et al. 2019, with the dimensions of the gasifier reactor, are 3 m high, and 0.2 m in diameter from wood pellet biomass with a diameter of 6 mm and a length of 5 -25 mm as compared is the result of syngas in a simulation with a particle size distribution of variation 3. The following is a comparison of data from experiments and simulations.

As seen in Figure 13, there are differences in the results between the simulation and the experiment. The composition of the CH_4 mole fraction in the simulation has almost the same results as the experiment, namely the composition of the CH_4 mole fraction of 2.21% for the simulation and 2.3% CH_4 for the experiment, while the mole fractions of CO and H_2 from the simulation results are higher than the experiment, namely, the composition value CO mole fraction 19.68%, H_2 18.51% for the simulation method and CO 10.8%, H_2 7.3% for the experimental method, for the CO_2 mole fraction the simulation results were lower than the experiment with a CO_2 composition of 6.21% for simulation and 15.8% CO_2 for the experiment.

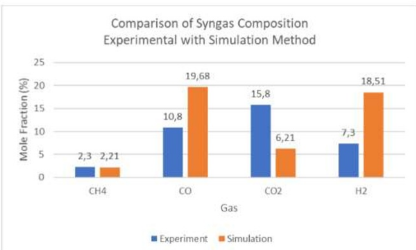

Fig. 13. Comparison of syngas experimental with simulation method

The factor causing the difference in results between the simulation and the experiment is the difference in the duration of the gasification process between the simulation method and the experiment. Another factor is the difference in the use of equations to calculate volatiles between the simulation and experimental methods.

4 Conclusion

Numerical simulation methods for the effect of particle size distribution on gasifier fluidized beds with variations in the cumulative percentage of particle size distribution have been successfully carried out, and the resulting data are in agreement with experimental data from study literature journals. The simulation results can be concluded that the greater the percentage of bed particle size distribution, the gasifier temperature distribution, syngas composition, and the resulting syngas distribution decreases. Changes in the particle size distribution of the bed can slow down the movement of the bed particles. This is due to the creation of larger cavities/gaps between the bed particles so that the air entering the gasifier is not fully fluidized. The highest temperature distribution is found in the particle size distribution variation 1 with an average temperature distribution of 1060.23K. The lowest temperature distribution is obtained in the particle size distribution variation 3 with an average temperature distribution of 1057.77 K. The highest syngas composition is on the third variation of particle size distribution with syngas composition of 2.21% CH_4, 19.68% CO, 6.21% CO_2, and 18.51% H_2. The lowest syngas composition was found in the 4th variation of particle size distribution with syngas composition of 1.99% CH_4,17.71% CO, 5.63% CO_2, and 16.66% H_2. and the highest distribution of syngas with CH_4, CO, CO_2, and H_2 gases is at an altitude of 2.75 m.

References

1 J. C. Escobar, E. S. Lora, O. J. Venturini, E. E. Yáñez, E. F. Castillo, and O. Almazan, "Biofuels: Environment, technology, and food security," *Renew. Sustain. Energy Rev.*,**13**, 6–7, pp. 1275–1287 (2009)

2 A. Demirbas, "Progress and recent trends in biofuels," *Prog. Energy Combust. Sci.*,**33** , no. 1, pp. 1–18 (2007)

3 R. C. Saxena, D. K. Adhikari, and H. B. Goyal, "Biomass-based energy fuel through biochemical routes: A review," *Renew. Sustain. Energy Rev.*, **13**, no. 1, pp. 167–178 (2009)

4 A. Demirbas, "Biofuels sources, biofuel policy, biofuel economy, and global biofuel projections," *EnergyConvers. Manag.*, **49**, no. 8, pp. 2106–2116, (2008)

5 Z. A. B. Z. Alauddin, P. Lahijani, M. Mohammadi, and A. R. Mohamed, "Gasification of lignocellulosic biomass in fluidized beds for renewable energy development: A review," *Renewable and Sustainable Energy Reviews*, **14**, no. 9. (2010)

6 Kemas Ridhuan, Dwi Irawan, Yulita Zanaria and Fendi Firmansyah, "The Influence of Biomass type in pyrolysis combustion on the characteristic and

efficiency of the biodory-Liquid smoke Produced", Vol.20, No 1 (2019)

7 Nur Aklis, Tri Agung Rohmat, Harwin Saptoadi and Jayan Sentanuhady, "Performance and Behaviors of coconut Shell-Air Dual Fluidized Bed Gasification in the CPFD Simulation with Initial Temperature Variation", Vol.12, No 1 (2022)

8 S. Kraft, F. Kirnbauer, and H. Hofbauer, "CPFD simulations of an industrial-sized dual fluidized bed steam gasification system of biomass with 8 MW fuel input," *Appl. Energy*, **190**, no. pp. 408-20,2017 (2017)

9 A. Lunzer, S. Kraft, S. Müller, and H. Hofbauer, "CPFD simulation of a dual fluidized bed cold flow model," *Biomass Convers. Biorefinery*, vol. **11**, no. 1, pp. 189–203, (2021)

10 M. M. Win, M. Asari, R. Hayakawa, H. Hosoda, J. Yano, and S. ichi Sakai, "Characteristics of gas from the fluidized bed gasification of refuse paper and plastic fuel (RPF) and wood biomass," *Waste Manag.*, **87**, pp. 173–182 (2019)

11 T. Basmoen *et al.*, "Experimental and computational studies on biomass gasification in fluidized beds," *Int. J. Energy Prod. Manag.*, **4**, no. 2, pp. 168–177 (2019)

12 T. Zhou, S. Yang, Y. Wei, J. Hu, and H. Wang, "Impact of wide particle size distribution on the gasification performance of biomass in a bubbling fluidized bed gasifier," *Renew. Energy*, vol. **148**, no. xxxx, pp. 534–547, (2020)

13 R. Reschmeier and J. Karl, "Experimental study of wood char gasification kinetics in fluidized beds," *Biomass and Bioenergy*, vol. **85**, pp. 288–299 (2016)