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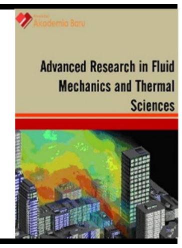

The Effect of Single and Double Air Inlets on Swirling Flow in a Reactor of a Fluidized Bed Gasifier

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ABSTRACT

In this work, the effect of single and double air inlets on swirling flow in a reactor of fluidized bed gasifier was studied numerically. The reactor diameter (D) was 20 cm, and the reactor length was 7.5D. The geometry of the reactor bottom was conical. In order to generate swirling flow in the reactor, the air inlet pipe with inner diameter of 46.8 mm was assembled tangentially to the bottom of the reactor. The comparison of the effect of single and double air inlets were studied based on the same mass flow rate. A 3-D numerical model of the reactor was created using a commercial software of ANSYS Ver.15.0 (Fluent). The results showed that swirling flow at the bottom of the reactor for the case of double inlets was more uniform than that of single inlets. Therefore, double air inlets were applied to design and fabricate a swirling fluidized bed gasifier.

1. Introduction

Gasification is a chemical process that converts carbonaceous materials like biomass into useful convenient gaseous fuel, which include chemical compound such as carbon monoxide, hydrogen and carbon dioxide using incomplete combustion [1]. The gasification consists of four different steps i.e. (1) drying, (2) pyrolysis or devolatilization, (3) combustion or oxidation and (4) gasification or reduction. There are various types of gasifiers as reported by Waeneck [2]: 1) Fixed-bed gasifier, 2) Entrained flow gasifier, and 3) Fluidized bed gasifier. In the case of a fluidized bed gasifier, the fuel is gasified in a bed of small particles that fluidized by a suitable gasification medium such as air or steam [3]. Fluidized bed technology can be useful for gasification and pyrolysis. It has more advantages [4, 5] for example: accepting for fuel size variation (less than 6 mm), uniform temperature profile of reactor and compact construction. Moreover, it can use for high flexibility in accepting solid, liquid, gaseous fuels even with low calorific value for waste and high moisture

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content for biomass. The fluidized bed reactors are divided in bubbling fluidized beds (Figure 1(a)) and circulating fluidized beds (Figure 1(b)). Bubbling beds operate at relatively low gas velocities (typically below 1 m/s), while the circulating fluidized beds operate at higher gas velocities (typically 3-10 m/s) [6].

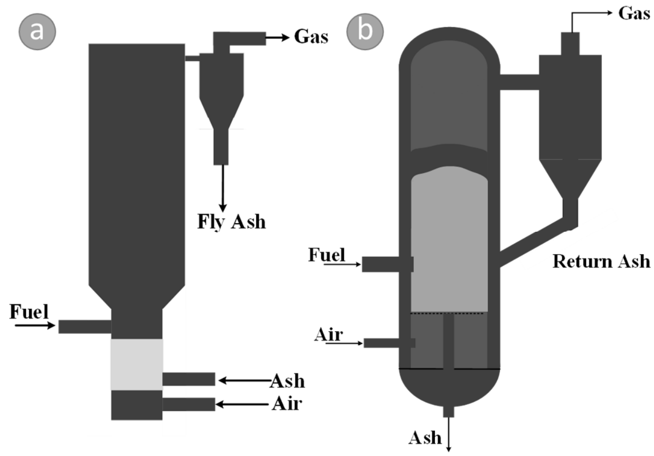


Fig. 1. Several types of Fluidized bed gasifier reactors, (a) Bubbling fluidized bed (b) Circulating fluidized bed

Kim *et al*., [7] used a laboratory scale fluidized bed reactor to produce bio-oil from pyrolysis process. The solid materials used were jatropha seed shell cake (JSC), palm kernel shell (PKS) and empty palm fruit bunches (EFB), as waste from palm and jatropha oil industries. The results showed that the oil yield of JSC was higher than those of PKS and EFB.

Ramírez *et al*., [8] design of a 70-kW fluidized bed gasifier for rice husk as feedstock. The inner diameter of reactor was 0.3 m and the height of reactor was 3 m. This work presented that it is advantageous for preliminary estimate of the equivalence ratio, low heating value, volumetric yield, gas power and cold efficiency obtained in the experimental gasification test.

Benedikt *et al*., [9] presents experimental results with a new generation of a 100 kW dual fluidized bed steam gasification in pilot plant with calcite as bed material, converting wood and lignite in separate test runs into product gas. The results are compared to experiments with the same fuels with olivine as bed material and the previous generation of the gasification pilot plant.

Kumar *et al*., [10] studies gas–solids flow in combustion coal of circulating fluidized bed by using CFD model. The size of 5 mm feedstock was chosen and fluidizing velocity of inlet was 4-6 m/s. For analysis, the variation in mean feedstock diameter and superficial velocity, does affect the temperature, pressure and turbulence kinetic energy in different mean fractions in the combustion zone.

Liu *et al*., [11] simulated biomass gasification of three-dimension CFD of circulating fluidized bed reactor by using steady state model, and simulation results were compared to experimental data. The effects of turbulence models, radiation model, water−gas shift reaction, and equivalence ratio (ER) were investigated to present a reliable understanding of feedstock gasification in a Circulating Fluidized Bed (CFB) reactor.

Murgia *et al*., [12] has developed CFD model to compare and simulate the gasification process within an air-blown updraft coal gasifier. Updraft fixed bed gasification processes are characterized by complex behaviour, since they involve different space and time dependent sub-processes where coal preheating, drying, devolatilization and char reactions take place. Simplified models, such as non-dimensional ones, useful for preliminary gross mass and energy balance are unable to correctly simulate the overall gasification phenomena and more sophisticated approaches are required.

Bockelie *et al.*, [13] described a CFD based modelling tool for entrained flow coal gasifiers. The model contains sub-models to properly model the reaction kinetics of coal gasification at high pressure, high solids loading and slagging walls. Comparisons between values predicted by CFD model and modelling studies performed by other research groups have shown good agreement.

In this work, swirling fluidized bed gasifier was being designed and fabricated for a small scale. In order to accelerate fuel-air reaction, a reactor generating swirling flow was designed. In order to design tangential connection between air inlet and the bottom of the reactor to generate swirling flow, computational fluid dynamics (CFD) was adopted. In preliminary study, the effect of single and double air inlets on swirling flow in the reactor was examined.

2. Experimental setup

The diagram of experimental setup of fluidized bed gasifier is shown in Figure 2. The blower accelerated the air which flow through the orifice flow meter for measuring the mass flow rate. The flow rate of air was controlled by adjusting rotating speed of blower with an inverter. The air inlet pipe with inner diameter of 46.8 mm and length of 300 mm were connected tangentially to the bottom of the reactor. The biomass is fed with a constant flow rate to the reactor by using screw conveyor while the flow rate of air was varied according to required Equivalent Ratio (ER). Inside the reactor, biomass was burned with limited air for getting incomplete combustion. Syngas was sent to the cyclone for particle filtration and then discharged from pipe outlet.

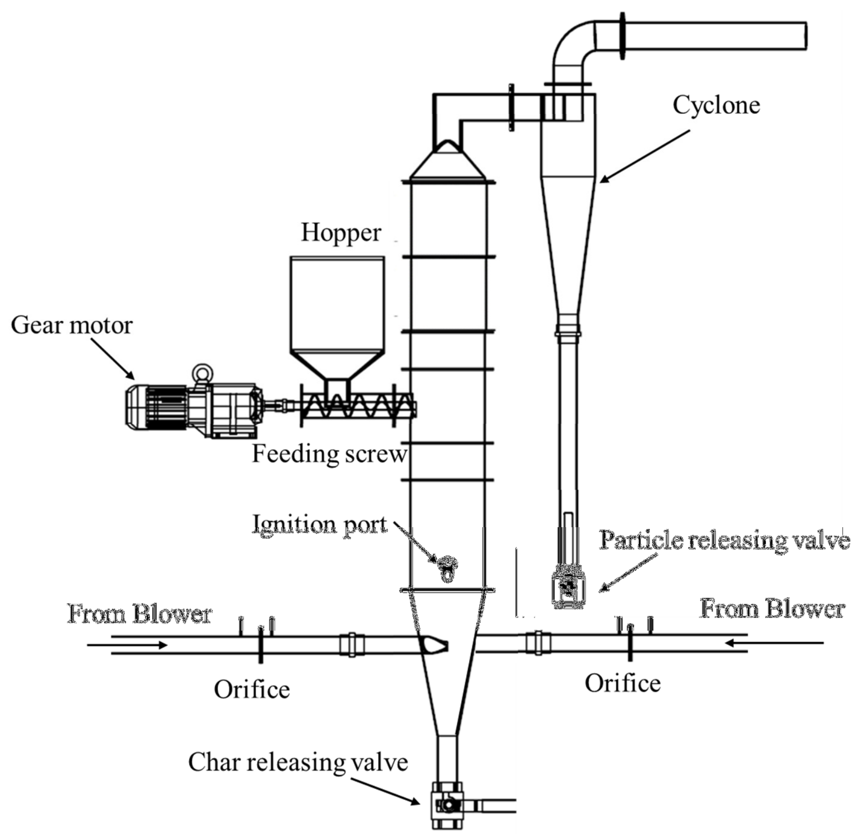


Fig. 2. Diagram of experimental setup of the swirl fluidized bed gasifier

3. Numerical simulation design

3.1 Computational model and boundary conditions

From aforementioned experimental set up of fluidized bed gasifier, the effect of single and double air inlets on swirling flow in the reactor was designed using CFD software. The schematic diagram of creating swirling flow in the reactor with single and double air inlets is shown in Figure 3. To simulate air flow in this work, the commercial CFD software, ANSYS Ver. 15.0 (Fluent) was adopted. The *3-D* numerical model was created as shown in Figure 4. The main domain was reactor of fluidized bed gasifier with diameter of 20 cm and length of 150 cm. The configuration of the bottom part of the reactor was divergent geometry. The air inlet with a diameter of 4.64 cm and a length of 30 cm was tangentially assembled to the divergent part of the reactor. The position of the connection was 15-cm height from the bottom end. The air outlet with diameter of diameter 7.5 cm was located at the top of the reactor. The details of boundary conditions were summarized in Table 1. Since the comparison of the effect of single and double air inlets based on the same mass flow rate, the uniform entering velocity at the inlet was 4 m/s for single air inlet and 2 m/s for double air inlet. Since the effect of single and double air inlets on swirling flow in the reactor of a fluidized bed gasifier was focussed, the simulation was done only for flow characteristics without combustion.

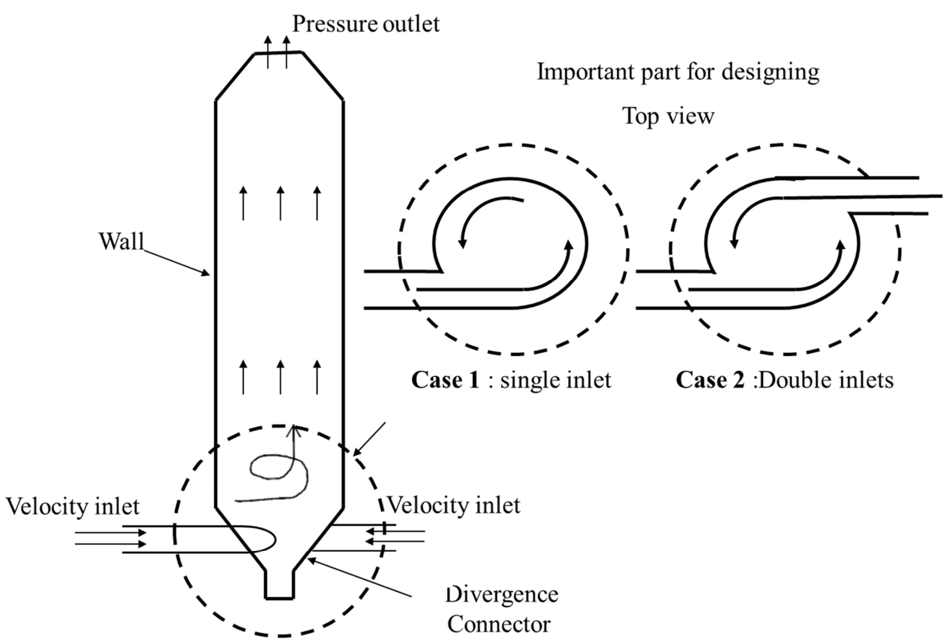


Fig. 3. Numerical domain of swirl reactor of fluidized bed gasifier

Table 1
The details of boundary conditions

Boundary condition	Define
Air inlet	Velocity inlet
Air outlet	Pressure outlet
Surfaces of reactor	Wall

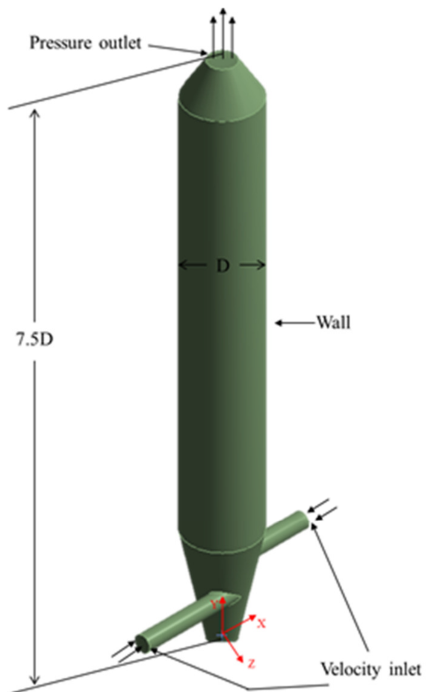


Fig. 4. Computational model and boundary conditions

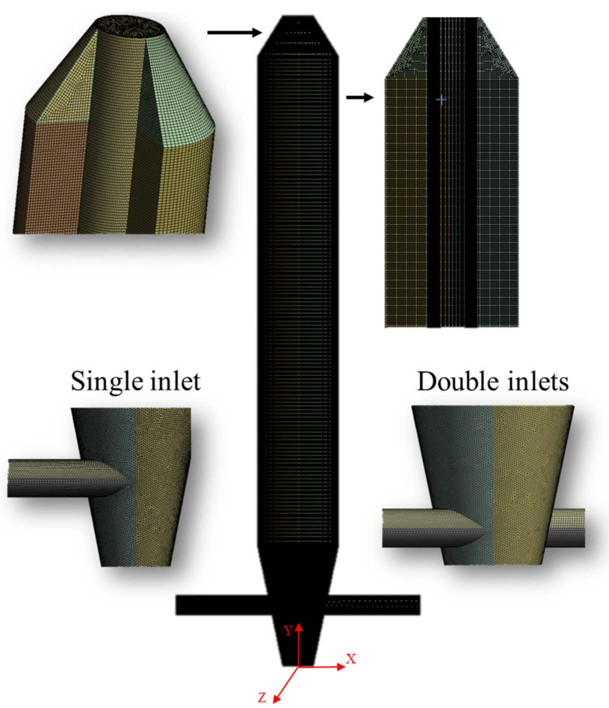


Fig. 5. Generated rectangular grid for the numerical mode

3.2 Grid generation and grid dependency

The rectangular grid was mainly applied in this numerical model. The internal generating grid is shown in Figure 5. The generated grids in region having high velocity gradient as in area of divergence air inlet of reactor are finely controlled. The numbers of generated grids are varied to achieve an accurate solution by considering low computation cost. The number of generated grid was varied to achieve an accurate solution by considering the effects of grid dependency. The numbers of element were varied in the rage of 0.10 – 3.54 million elements. The tangential velocity in the direction of X-axis at 15 cm from the bottom end was plotted with varying element number as shown in Figure 6. It showed that the effect element number on tangential velocity profile was saturated at the element number of 1.71 and 3.54 million elements. Here, to minimize computational task, the 1.71 million elements was selected to run the numerical simulation in this study.

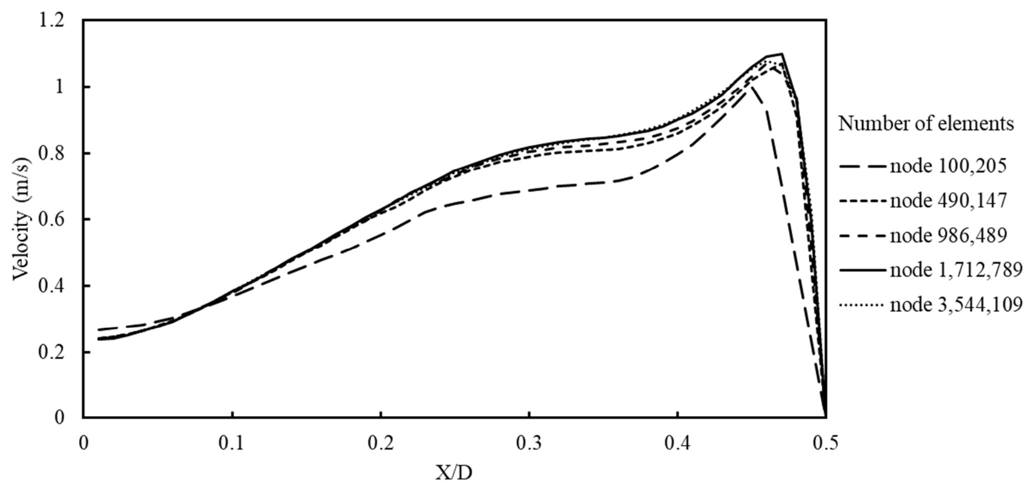


Fig. 6. The tangential velocity in the direction of X-axis at Y/D=0.75 (Air inlet)

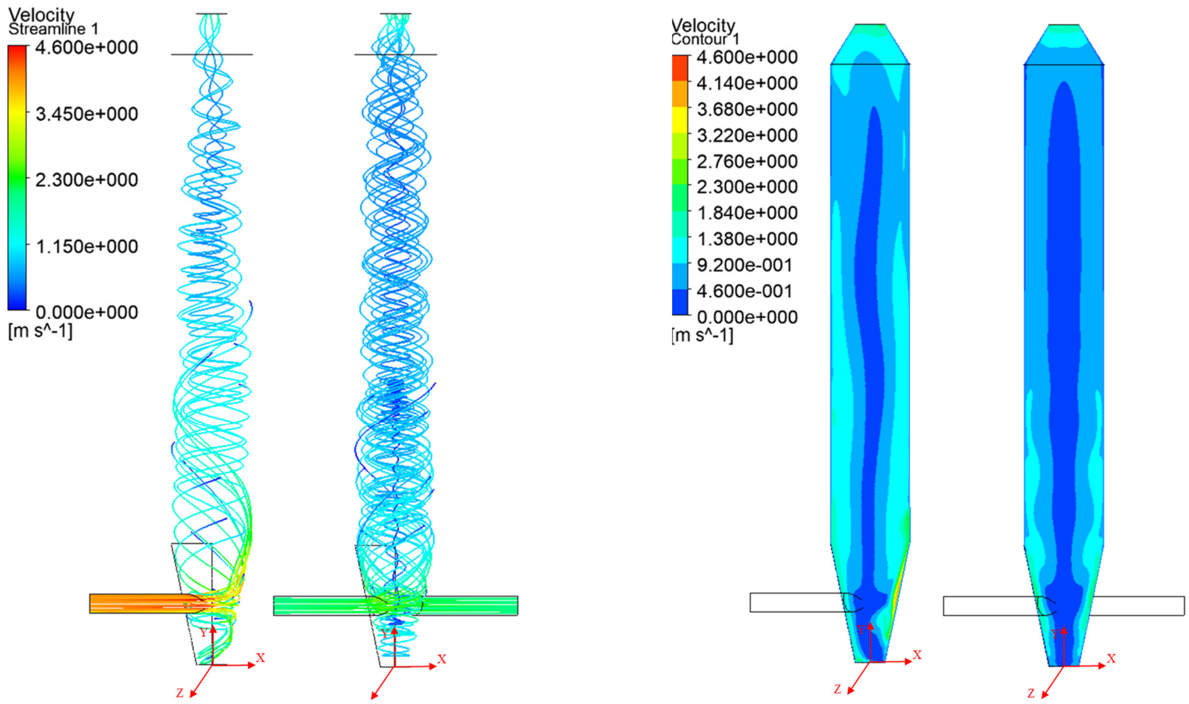
3.3 Calculation method and algorithm

Computations were conducted by solving Reynolds averaged continuity and Navier-Stokes equations under existing boundary conditions. A k-epsilon turbulence model has been adopted in solving many numerical simulation problem [14]. It excellently predicted the solutions of internal flow with moderate computation cost. The SIMPLE algorithm [15] is used with second order upwind scheme for pressure and momentum and first order upwind scheme for turbulent kinetic energy and turbulent dissipation rate. The convergence of iterative solution is insured when the residual of all the variables is less than the specified values. The specified value is 1×10^{-4} for continuity and momentum equations

4. Results and Discussions

4.1 Simulations result

Streamlines and contours of velocity in the reactor of single inlet and double inlets are shown in Figure 7. Noted that the comparison of the effect of single and double air inlets based on the same mass flow rate; the entering velocity at the inlet was 4 m/s for single inlet and 2 m/s for double inlet. Air entering from inlet pipe into the reactor turned around along conical surface of the reactor to develop swirling flow. The results show that the development of swirling flow for the case of double inlet was faster than the case of single inlet. The swirling flow for the case of double inlets was more uniform (In term of symmetry) than that of single inlet. This can be notified by uniformity of the velocity contours as shown in Figure 8.



(a) single inlet (b) double inlets (c) single inlet (d) double inlets

Fig. 7. The streamlines (left) and the contours (right) of velocity in the reactor

The velocity vectors and the u-component velocity (X-axis) profiles in the reactor at different levels of the reactor height are shown in the Figure 8 - 12. At the level of air inlet (Y/D=0.75) as shown in Figure 8, the magnitude of velocity for the case of single air inlet was the highest in -X-axis, and velocity profile was asymmetry. It was contrast to the case of double air inlet that the vectors and velocity profiles were symmetry in X-axis. At the reactor height of Y/D=1.25 (Figure 9), the magnitude of velocity for both single and double inlets become lower when compared to those the case of Y/D=0.75 (Figure 8), and the velocity profiles in X-axis approached symmetry for the case of single air inlet. Afterwards, the velocity profiles for single air inlet at Y/D=1.5 (Figure 10) became symmetry in X-axis. Moreover, the profiles of both single and double was almost the same at Y/D=5 (Figure 12).

This show obviously that the effect of the number of air inlet at the reaction zone (Figure 8) could generate symmetry swirling flow for the case of double air inlet and asymmetry swirling flow for the case of single air inlet. In the reactor of experimental apparatus, particles of feedstock are fed and dropped at the reaction zone in the reactor. Uniformity in term of interaction between fuel particle and oxidizer (air) is required to perform homogenous thermo-chemical reaction. From this results can be suggested that applying double air inlets in the reactor of fluidized-bed gasifier is suitable.

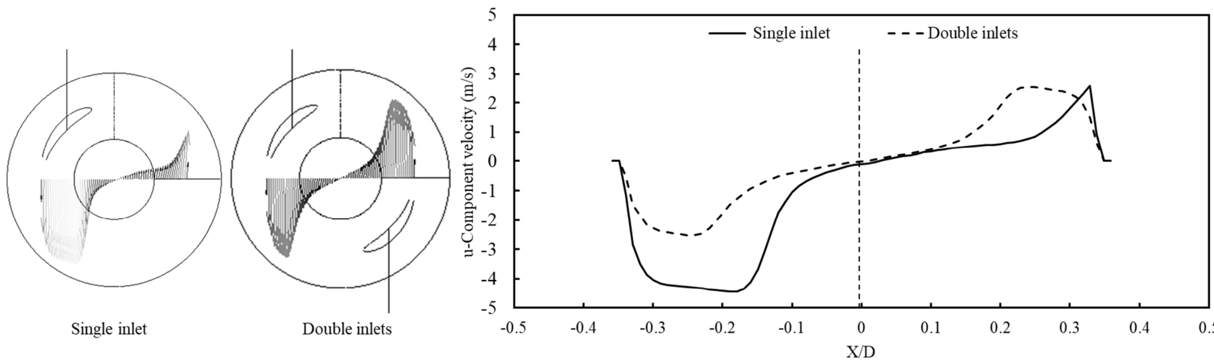


Fig. 8. Velocity vectors (left) and velocity profiles (right) in the reactor at Y/D= 0.75

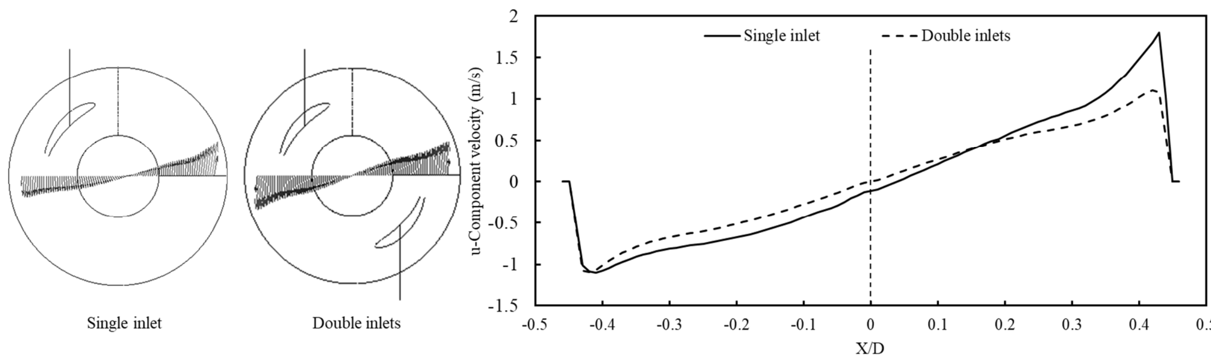


Fig. 9. Velocity vectors (left) and velocity profiles (right) in the reactor at Y/D= 1.25

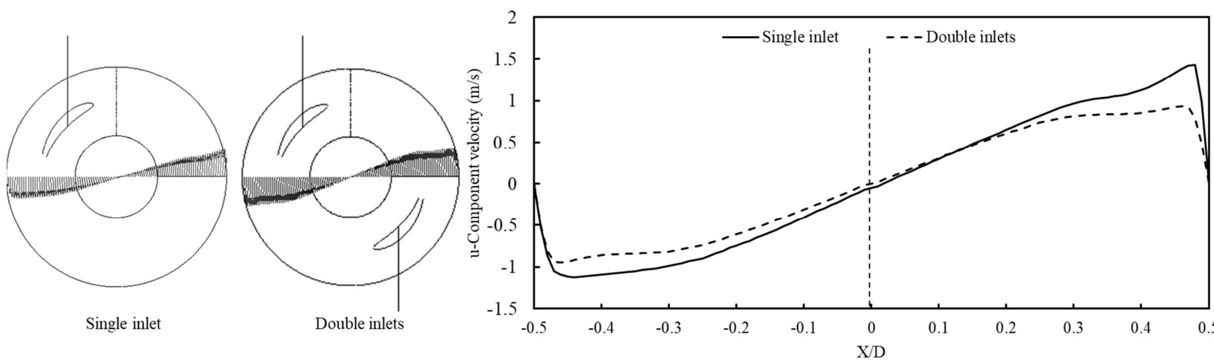


Fig. 10. Velocity vectors (left) and velocity profiles (right) in the reactor at Y/D= 1.5

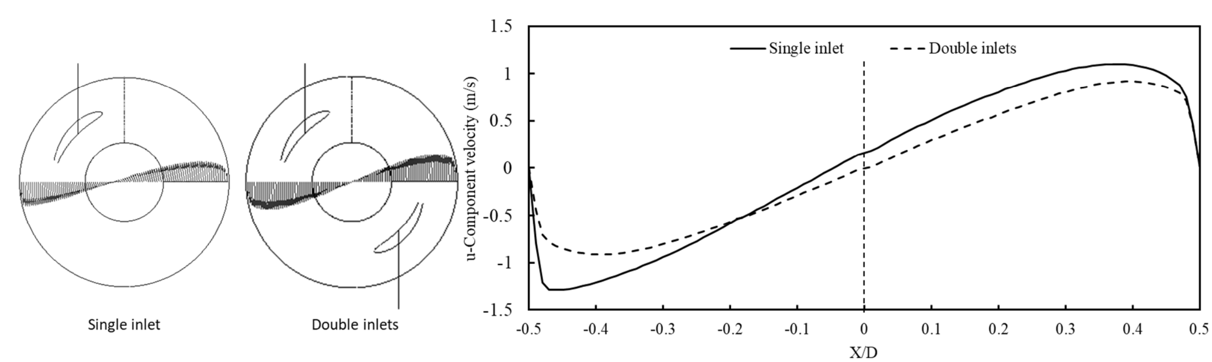


Fig. 11. Velocity vectors (left) and velocity profiles (right) in the reactor at Y/D= 3

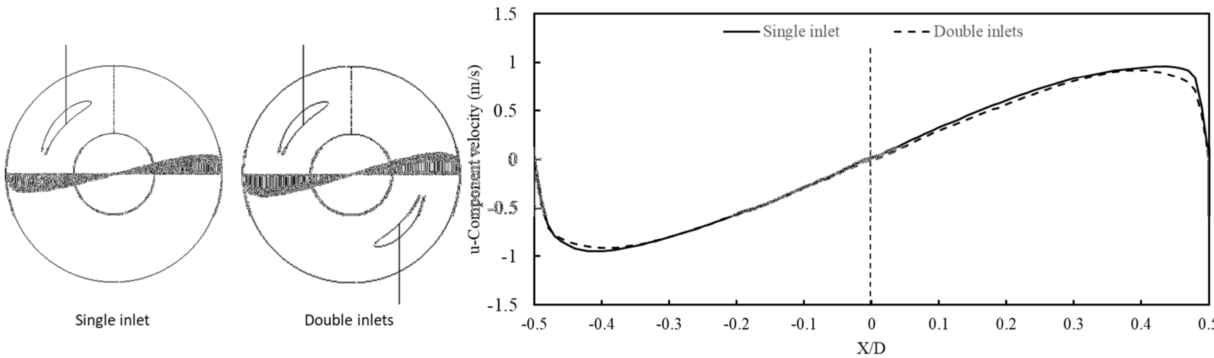


Fig. 12. Velocity vectors (left) and velocity profiles (right) in the reactor at Y/D= 5

4.2 Experimental test

A mini pilot scale of swirl fluidized bed gasifier was successfully designed and fabricated in related our work. Double air inlets which was simulate in this study were applied in the reactor gasifier in those work . The position of applying double air inlets in the reactor is shown in Figure 13 at the point h. The results showed that a production of combustible syngas can be operated continuously for eight hours without shut down or malfunction.

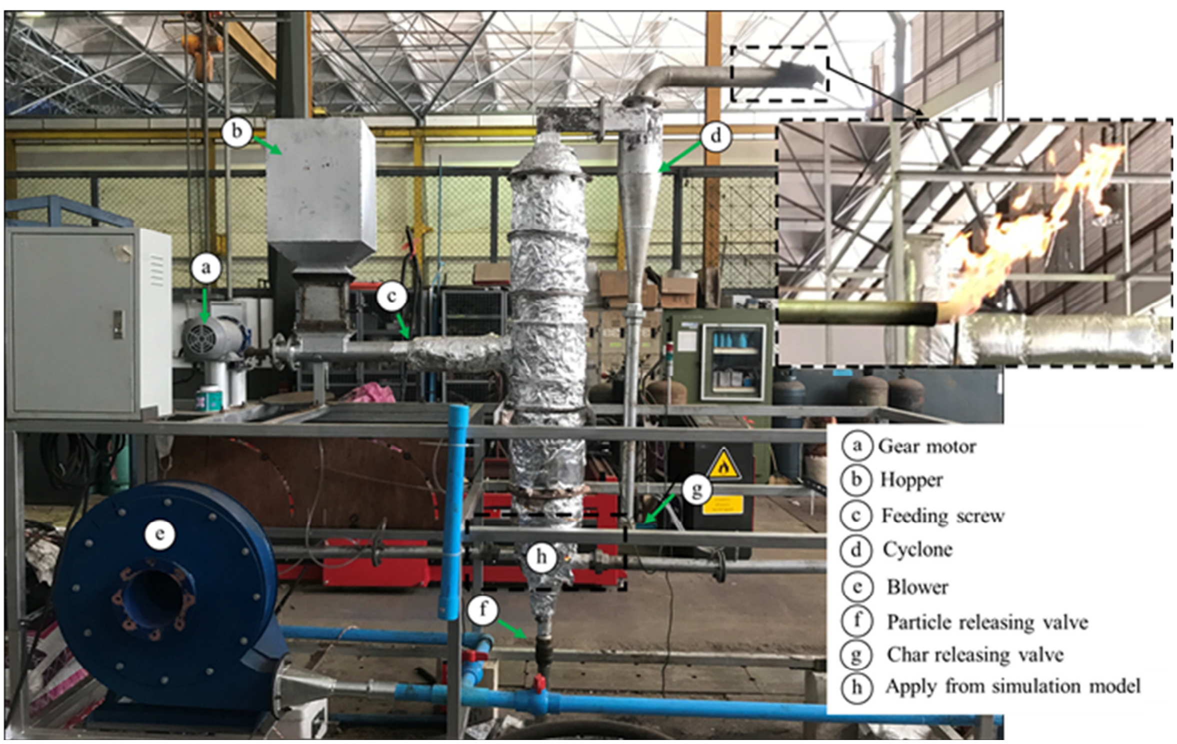


Fig. 13. Photo of mini pilot swirl fluidized-bed gasifier system

5. Conclusions

The effect of single and double air inlets for applying in the reactor of swirl fluidized bed gasifier was studied numerically. A 3-D numerical model of the reactor was created using commercial software, ANSYS Ver.15.0 (Fluent). The comparison of the effect of single and double air inlets were based on the same mass flow rate. The results showed that the effect of the number of air inlet at the reaction zone of the reactor can generate symmetry swirling flow for the case of double air inlet and asymmetry swirling flow for the case of single air inlet. Therefore, double air inlets were chosen to apply in the real reactor of swirl fluidized bed gasifier.

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