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Effect of bluff body and swirl plate on performance of pulverized biomass combustion in a laboratory-scale furnace

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Abstract. Investigation on 300 kW biomass burning rate on pre-chamber type of pulverized biomass burner has been presented in this paper. Two modification techniques known as bluff body and swirler (second swirl plate) were applied to enhance burning rate of 1 mm of biomass particles. Firstly, bluff body unit with horseshoes-liked in shape was located at the outlet port feeding fuel-primary air mixture and creating turbulent flow path. Secondly, in addition to already existing 1st-staged swirler, the second swirl plate, was then applied and expected to create more swirling flow of the secondary air. By comparing between experimental and simulation schemes, it was found that the simulation gave higher degree of combustion than suggested by experiment. The technology on second swirl plate could work out on simulation but experiment as it led to unstable flame. On the other hand, better result was found in case of bluff body. It could generate sufficient turbulent flow thus enabling stable combustion within a pre-chamber resulting in high burning temperature, high emission of volatile and also high consumption rate of O_2. On pollutant aspect, CO and NOx were found lower and higher, respectively, on the unit with bluff body comparing to its counterpart.

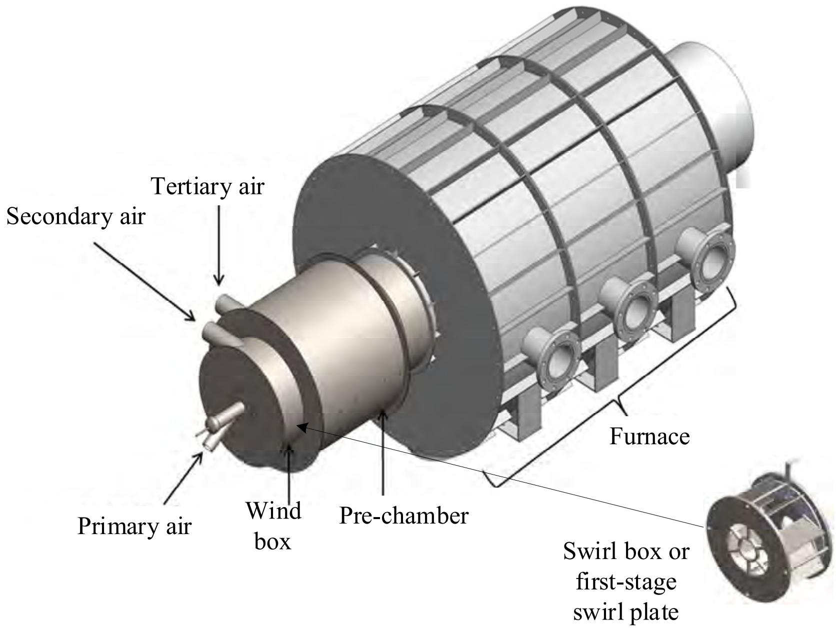
1. Introduction

Combustion of pulverized biomass fuel using an in-house designed industrial burner has been investigated at KMITL for recent years. This paper presents the recent development which was in continuation with the previous work [1]. In his study, the inlet guide vane was successfully adopted as a swirl generator for combustion of relatively finer particle. However, it was required that the specific energy consumption was to be reduced during the fuel preparation process, resulting in courser size distribution of the particle. The aim of this work was to investigate the effect of modifications done on the geometry at the inlet of the burner when firing the particle with this relatively larger size distribution.

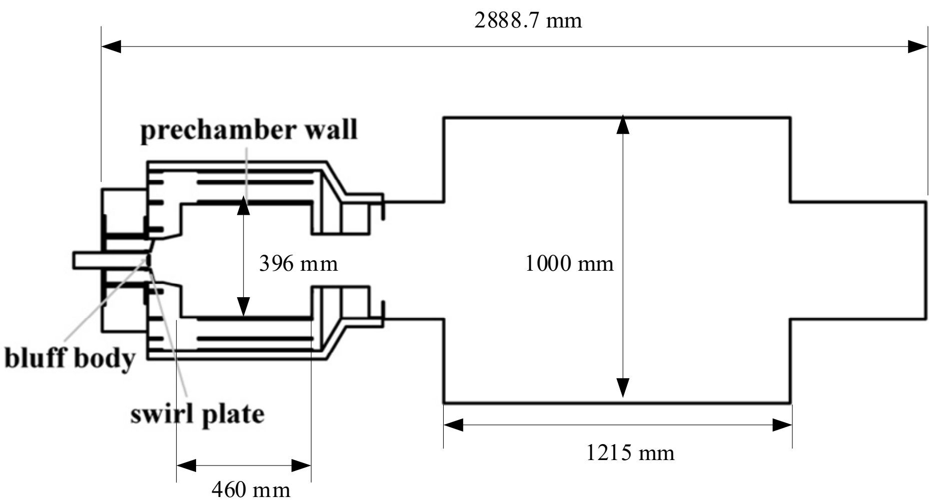
Increment of swirl number of a secondary air has been one of the widely-adopted technique when adjustment of the burner is required in order to enhance the strength of the internal recirculation flow at the near burner region [2-5]. This technique could slow down the incoming particle to a greater degree by increasing a reverse drag force and also bringing hot product from downstream closer to the burner tip for continuous ignition. Despite of its ease of use, such modification was prone to high secondary air pressure build-up and, at certain circumstance, led to local flame extinction due to excessive shearing strain between the hot gas and the incoming air [6]. Alternatively, application of a bluff body is generally seen in many industrial burners, the technique is also named as an adjustable inlet port or annular port

[7-8] where the central bluff body or "spool" can be inserted inside the central inlet port. The primary air and fuel are fed into the combustion chamber with adjustable annular inlet area, according to the position of the bluff body. By doing so the annular gap can be adjusted in response to different firing rate. The area next to bluff body, generally called the wake region, is the location of the relatively slower flow. The flame could be stabilized in this region.

The effect on combustion performance from two major tasks of modifications were investigated. One was on placement of additional secondary air swirler locating next to the inlet guide vane, and the other was on placement of a horseshoe-liked bluff body at the burner tip of the primary air inlet.



(a)



(b)

Figure. 1 (a) Biomass burner with pre-chamber and (b) its cross section

2. Methodology and Apparatus

2.1 *Burner*

Without additional modification, the burner (combustor) has been designed having 2 main parts, Pre-chamber and Furnace. Unlike other pulverized burners, the pre-chamber was constructed aiming to create recirculation itself which results in stabilization of flame. On the first-stage of pre-chamber, there is a swirl box having 100^o of angle to the normal plane. There are 3 inlet ports of air as illustrated in Figure 1. Primary air is produced to carry the biomass particle moving into the combustion zone. The secondary air is fed through the swirl plate to promote swirl flow and enhance resident time, while the tertiary one is not only served as an air jacket of pre-chamber but also an oxidizer for second stage of combustion.

As mentioned earlier, the 2 modification tasks have been made for a comparison on combustion performance, second-swirl plate and Bluff body. They were expected to provide larger recirculation area. The second swirl plate was located beyond swirl box at the exit port of secondary air towards combustion zone. It has 6 guide vanes with 60^o of angle correlated with 1.16 of swirl number considering to be in intensive range of swirl flow. Alternatively, the bluff body was located at primary exit port which carried both primary air and biomass particles. It is horseshoe-like in shape with 0.42 of blockage ratio.

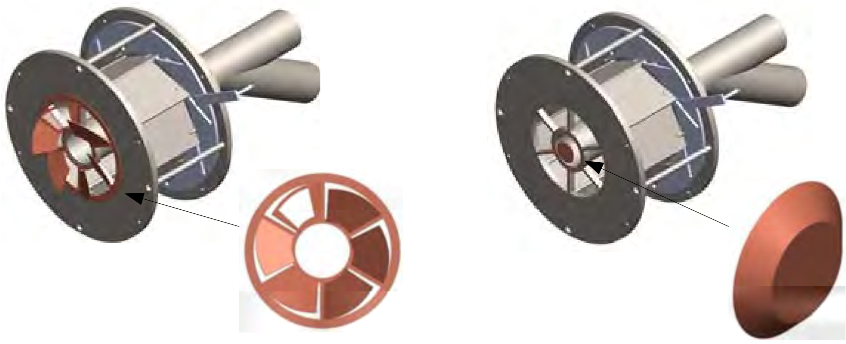


Figure 2. location of a.) second-swirl plate and b.) Bluff body

2.2 *Condition*

Both experiment and simulation were conducted under the same condition for an in-depth investigation on interaction mechanism. The burner was operated at 300 kW of fuel flow rate with 15% excess air. The portion of air was selected ensuring the greatest combustion performance, as indicated in Table 1. Wood pellet made from rubber wood was grinded with 1mm of sieve diameter giving the size distribution of particle as seen in Table 2. Moreover, the study cases are provided in Table 3.

Table 1. Condition for Experiment and Simulation

Parameters	value
Fuel flow rate, kg/s	0.0186
Primary air, kg/s	0.017 (15% of total air)
Secondary air, kg/s	0.075 (50% of total air)
Tertiary air, kg/s	0.023 (25% of total air)

Table 2 Size distribution on biomass particle obtained from 1mm of sieve diameter

Particle size (s), μm	% by mass
$425 \le s \le 1000$	35.8
$355 \le s < 425$	9.4
$300 \le s < 355$	9.8
$180 \le s < 300$	18.4
$150 \le s < 180$	9.4
$75 \le s < 150$	8.1
$s < 75$	9.2

Table 3 Comparison cases

Case	Details
Case I	Without modification
Case II	With Bluff body
Case III	With Second swirl plate
Case IV	With both Second swirl plate and Bluff body

2.3 *Experiment set-up*

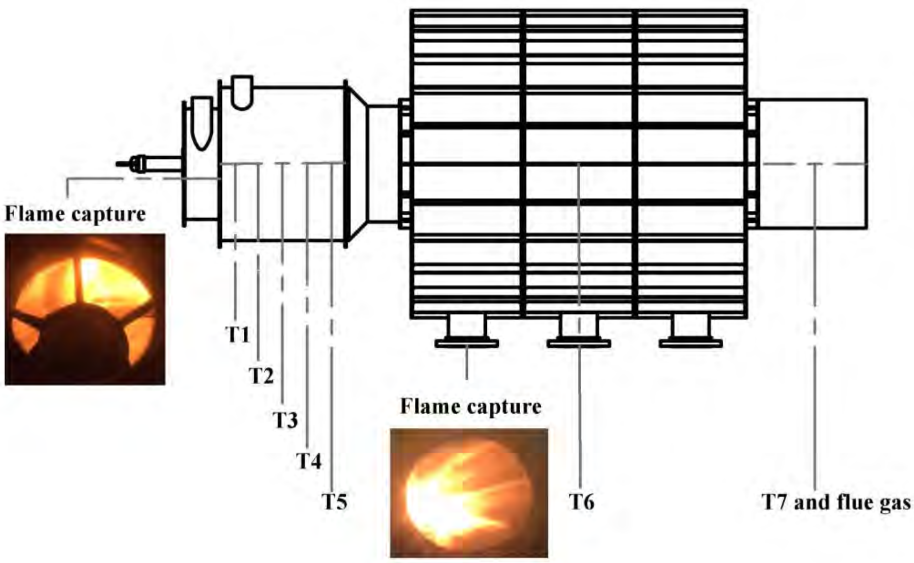


Figure 3 Measurement and location

To assess the combustion performance, temperature distribution, flame image and flue gas compositions were brought into consideration. Thermocouple type K had been installed along centerline of combustion chamber and collected the data with data logger (accuracy of thermocouple is $\pm 1°C$). On the last section of chamber, CO and NO_x emission was collected by flue gas analyzer (accuracy of $\pm 5\,ppm$ and $\pm 4\,ppm$, respectively).

Experiment started with preparation process where fuel had to be grinded with 1mm of sieve size diameter before transferring into combustion chamber with primary air. The pilot burner using LPG was turned on to raise the temperature approaching ignition level of biomass. When high level of temperature was attained, operators would turn off LPG flow rate and let the burner making continuous ignition by itself. The aforementioned data would be collected when combustion turned into steady state at 300 kW of heat input.

2.4 *Simulation set-up*

The 3D simulation was made on ANSYS Fluent 12.0 software to investigate the mechanism in the combustion chamber by solving the discretized equations governing fluid flow, solid particle motions, heat and mass transfer in combustion chamber. For the mathematical model, the details are in Table 4. Discussion on models adopted in this work has already been given elsewhere [3], [6].

Table 4 Simulation model

Model	Details
Turbulent	Standard $k-\varepsilon$
Radiative heat transfer	Discrete Ordinates (DO)
Absorption coefficient	WSGGM
Combustion on gas phase	Eddy-dissipation
Char Oxidation	Kinetic/diffusion – limited rate

Model validation was done comparing to the result of previous work [1], which the base case condition (case I) was selected to compare at 300 kW of heat input. Apart from inlet condition in Table1, the other two important condition were also considered to obtain the proper result. Wall chamber was served as an adiabatic wall, while the furnace's stack was set as outlet pressure in order to create the negative pressure inside the furnace.

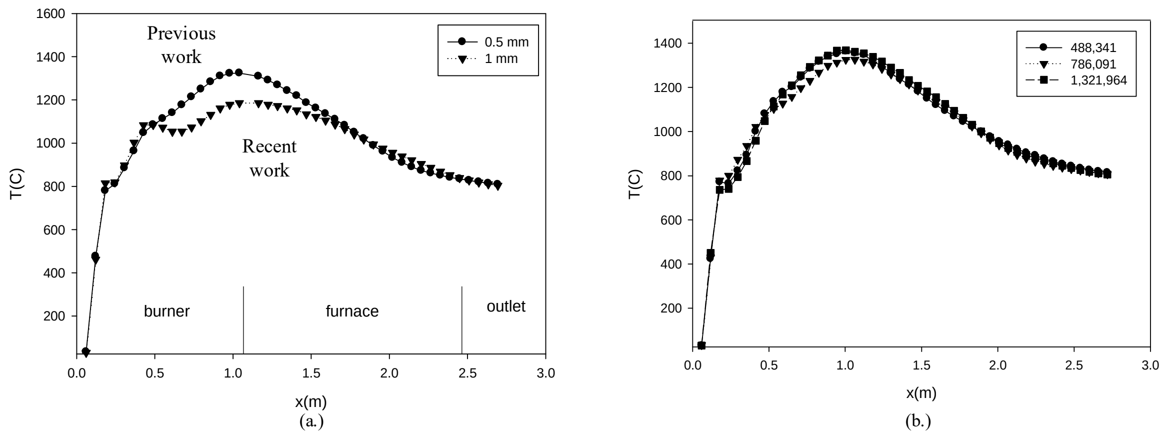
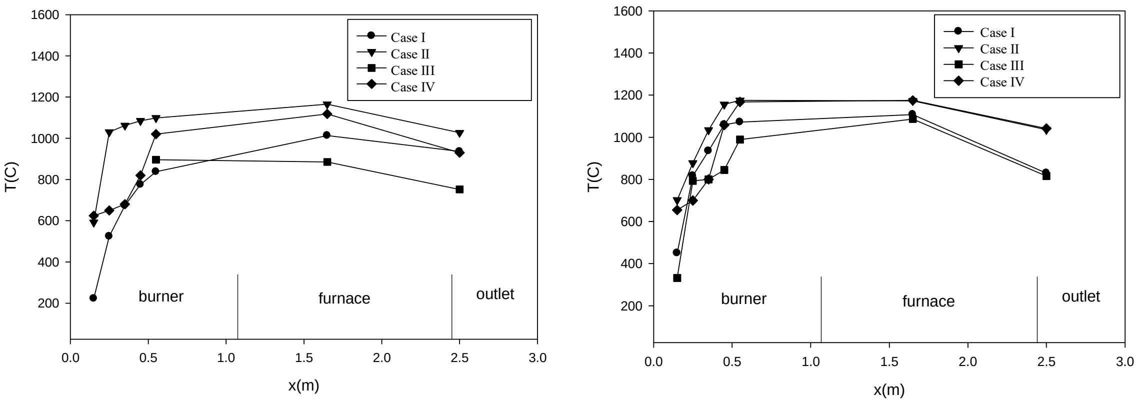


Figure 4 (a.) Effect of particle size on axial temperature profile and (b.) Grid independence result

3. Result and Discussion

As far as accuracy on simulation has been concerned, validation and grid independence were done with previous work on the biomass burner unit. As mentioned in introduction, the simulation and experiment of previous work was delivered for 0.5mm of sieve size diameter, while the result of 1mm of diameter was given to compare. The results are indicated in Figure 4 a). As expected, temperature distribution on recent work was lower than previous one due to larger particle size. By the large one, surface area contacting to oxidizer of particle was small so that the reaction rate was in lower level comparing to 0.5mm. By considering grid independence result, 786,091 of meshes was chosen, see Fig.4b.



(a.) (b.)

Figure 5 Axial temperature along centerline of burner from (a.) experiment and (b.) simulation

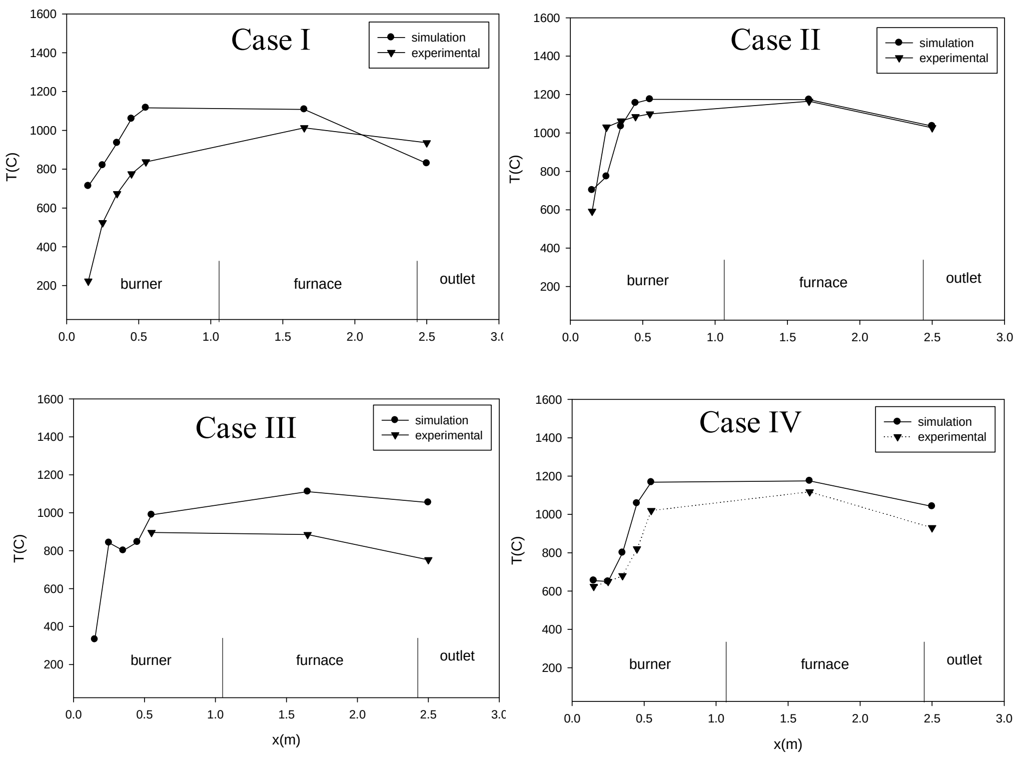


Figure 6 Comparison of Experiment and Simulation

Figure 5, the temperature distributions along centreline of burner are shown. Both experimental and simulation results were agreed that the burner with bluff body (case II) gave highest temperature level along the centreline in both pre-chamber and furnace zones. Case IV provided the second place as far as temperature level was concerned. Case I exhibited delayed combustion as evidenced by relatively much lower measured temperature in the pre-chamber zone. Simulation of this particular condition did not exhibit well the temperature distribution in the pre-combustion zone, as significant discrepancies in those values can be observed. The finding would be similar for Case III, where significant difference in temperature distribution was also found. It is reasonable to say that the experiment and simulation are in good agreement only for Case II and IV where the bluff body was installed, see Figure 6.

The contour of temperature for all cases are given in Figure 7. By comparing between experimental and simulation cases in Figure 6, the temperature along the chamber from experiment was indicated lower with every single case. As expected, there was no heat loss transferring through the wall by mean of simulation set-up (adiabatic wall), thus the accumulation of heat was found.

The biomass particle has been tracked and shown in Figure 7. It was evidently confirmed that the significant distribution of biomass paths was found in the unit with bluff body. When the particle impinged the bluff body with the momentum received from primary air, the flow was enforced to diverge and resulted in large scale of vortex behind bluff body unit. The bluff body not only acted as flame stabilizer but also gave intensive turbulent flow so that heat and mass transfer was enhanced. The high flue gas temperature continuously recirculated toward a low-pressure region behind bluff body. Since the high temperature in pre-chamber was achieved, large amount of volatile was liberated causing in self ignition on the other particles.

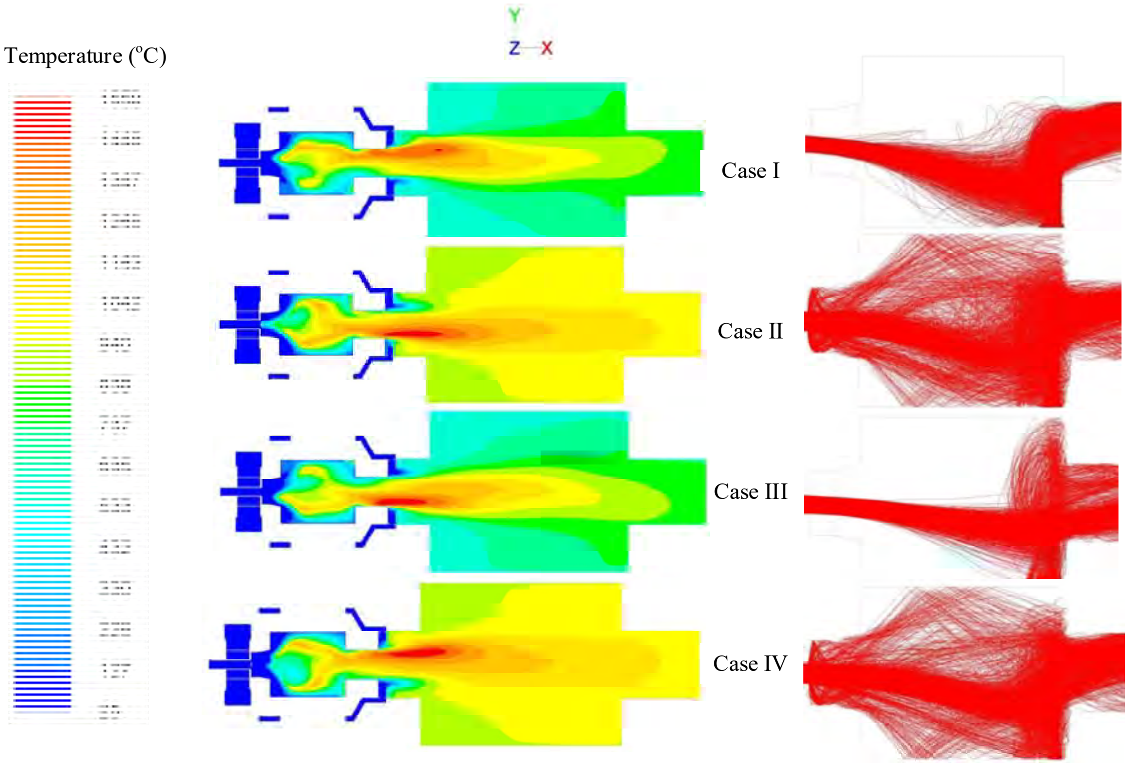


Figure 7 Temperature Contour from simulation and Particle tracking in Pre-chamber

(a.)

(b.)

Figure 8 the shade of flame on burner with (a.) bluff body and (b.) second swirl plate

On the other hand, small region of high temperature was found in case with swirl plate (case I and case III). This was confirmed by shooting path of particle associated with small recirculation region. The flame could not remain stabilized at the exit of swirl plate, while the peak temperature was observed at the end of pre-chamber. Moreover, during experiment, flame extinction was frequently observed when the pilot burner was forced to shut down. It was clearly seen that this kind of modification burner could not raise the temperature to the satisfactory level. The flame in Figure 8 is illustrated when the burner was operated with bluff body and the second swirl plate. Moreover, it was conformably seen that the shade of flame was observed illuminated in case of bluff body corresponding with high temperature level found in Figure 5 and 7. While the unit consisted of second swirl plate perform less severity of reaction and finally quenched.

Since the emission has been a concerned issue, CO concentration from experiment result is shown in Figure 9. The low level of CO emission was found on bluff body unit and it was accepted by the industrial standard. While the concentration on case I and case IV was produced in high level because the reaction zone was shifted toward downstream. On contrary, NO_x emission of bluff body modification unit was investigated highest due to strong heat radiation inside pre-chamber. By the way, both pollutant should be brought in consideration before making production for industrial scale.

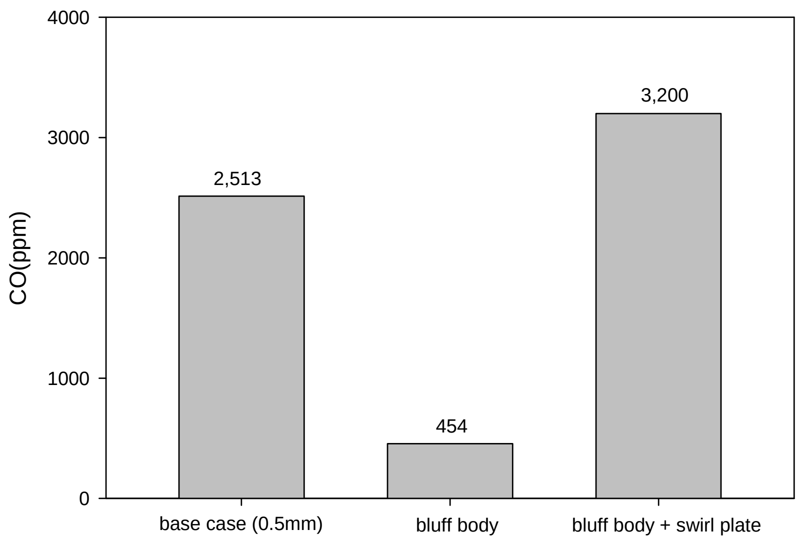


Figure 9 CO concentration from both experiment and simulation

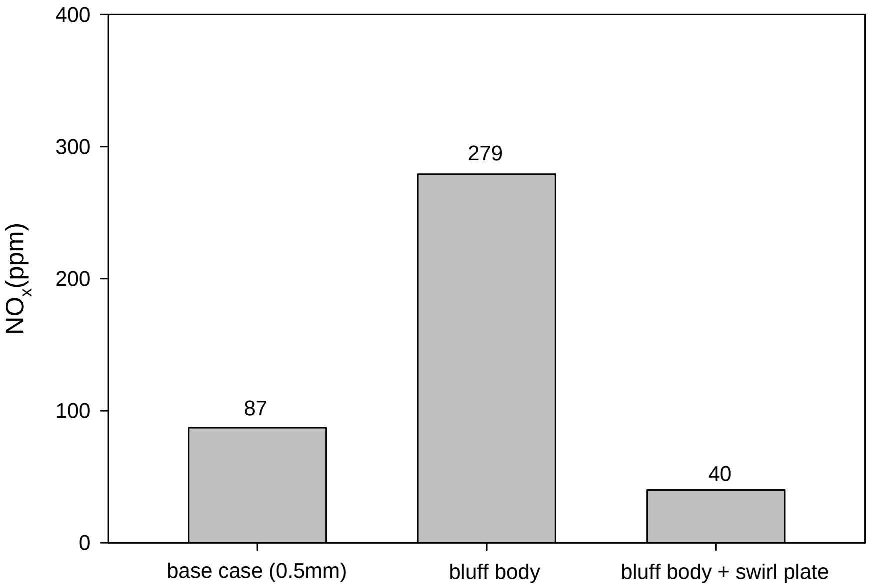


Figure 9 NO_x concentration

4. Conclusion

Effects on combustion performances between 2 major tasks of modification, bluff body and second swirl plate were conducted on both experiment and simulation. These modifications were done on pulverized biomass burner operated at 300 kW of heat input which was a maximum capacity on previous version of this burner. Both results from experiment and simulation were agreed that the burner with bluff body gave higher distribution of temperature in pre-chamber, due to scattering of particle impinging on bluff body unit, while the flame was investigate shifting to downstream in case of second swirl installation.

Acknowledgement

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