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The CFD Simulation of Cyclone Separator without and with the Counter-cone in the Gasification Process

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Abstract. The performance of cyclone separator as the ash trapper in the gasification system was studied through the Computational Fluid Dynamic (CFD) using the finite volume method. The ash trapper system is important part due to the effect on the gasification process, in particular on the quality of Syngas (Synthesis Gas). Therefore, the aim of this study is to find the suitable of the cyclone separator in the gasification apparatus that can separate the syngas and particulates. The CFD simulation was performed to determine the effect of adding the counter-cone in the cyclone separator to the trend of the efficiency of ash separation, speed profile, and pressure drop in the gasification process. The Reynold Stress Model (RSM) was employed for the for swirl flows modelling accuracy. The efficiency of ash separation was predicted by using the flow velocity in the cyclone separator and the pressure drop in the vortex finder. Discrete Phase Model (DPM)-one-way coupling was used to predict the efficiency of collection. The results of this simulation show that by adding the counter-cone in the cyclone separator increasing the number of particulates trapped and the distribution efficiency of particle diameter. The cyclone separator with the counter-cone can trap the particle diameter less than 1 micro meter (μm) while the cyclone separator without the counter-cone cannot.

1. Introduction

In the laboratory of Mechanical Engineering Education, Universitas Sebelas Maret (UNS) was developed the small-scale gasifier for study the energy recovery of palm starch waste at home industry center in Jawa Tengan province. The palm starch waste has processed as the RDF 5 (Refuse Derived Fuel) by pelletization process. The RDF 5 of palm starch waste was used as the biomass fuel in the gasifier. However, the Syngas quality (gasification product of RDF 5 of palm starch waste) by using the small-scale gasifier in the laboratory of Mechanical Engineering Education shown the impurity. This is due to the other products of gasification process such as tars, particulates (char-ash and soot) and water content of gas. Therefore, the aim of this study is to find the suitable of the cyclone separator in the gasification apparatus that can separate the syngas and particulates.

Gasification is an old technology that still exists today. This technology was developed in France and England in 1798, and 1920 gasification technology crossed the Atlantic (United States) and successfully supplied gas to the resident in American towns [1]. In Indonesia during the Dutch occupation period, gasification technology was developed to produce city gas in several big cities such as Jakarta, Bogor, Bandung, Semarang, and Surabaya. However, the gas factories ceased operating in the early 1970s due to the low price of natural gas compared to gasified synthetic gas. Currently, natural gas prices are increasing steadily due to declining natural gas reserves. Therefore, the gasification technology is being developed again as the alternative solution. The gasification was designed as the gas production from coal and biomass. Recently, there has been increased interest in biomass as a renewable energy source. In the last few years, some individuals and groups have built versions of small downdraft gasifiers and have operated them as demonstration units.

In this study focuses on the purification system of Syngas from particulates (char-ash and soot) that proper with the characteristic of palm starch waste by using the cyclone separators. Cyclones separator is a device to separate the particulates from the gas though the centrifugal force. This device is widely used in industry where there is a need to remove particles from a gas stream due to the simple design and low costs investment. The operating principle of the cyclone in gasification system i.e. the gas consists of particles enters tangentially into cyclone and forcing the flow into a spiral movement. The centrifugal force appears because of circular flow throws the particulates toward the wall of the cyclone and finally, the particles fall into a hopper located underneath [2]. However, the deficiency of cyclone separator is difficulty trapped the particle diameter lower than 10 microns [3] or low separation efficiency [4].

An additional element in the form of a counter-cone was employed to increasing the separation effectiveness of cyclone separator. This counter-cone is suitable for all type of cyclones. Counter-cone also called a *Chinese hat, a vortex stabilizer or an apex cone* [5]. The investigation of the effect of apex cone shape (40^0-80^0 range) on fine particle classification by experiment and CFD studies [6]. They reported that the effect of the apex cone angle on particle separation performance decreases under high inlet velocity conditions, because most particles are moving in the area away from the apex cone. The CFD calculation of large cyclone equipped with a counter-cone in large coal-fired boilers application [7]. This study used the Reynolds-averaged Navier–Stokes equations with the Reynolds Stress Turbulence model (RSM) in the analysis. He concluded that placing the counter-cone below the conical part is more beneficial, as it helps increase separation efficiency. The possibility of optimizing the structure of cyclone separators through the application of an additional compartment in the form of a counter-cone [5]. This study was applied in cement clinker burning. He reported that application of a counter-cone in each of the studied geometrical variants led to an increase in solid particle separation and the apex angle of the counter-cone also plays a significant role. Apex angle of counter-cone in cyclone separators of cement clinker burning should be 85^0 [5]. The apex angle 120^0 of counter-cone in coal-fired boilers application [7].

Therefore, to improve the quality of Syngas from the particulates impurity in gasification process of palm starch waste, counter-cone could be applied to the cyclone separator. This study has compared the separation efficiency of cyclone separator without (existing cyclone separator in the laboratory of Mechanical Engineering Education-UNS) and with counter-cone through the Computational Fluid Dynamic (CFD) method. The efficiency of particulate separation was predicted by using the flow velocity in the cyclone separator and the pressure drop in the vortex finder. The input parameter of simulation was used the gasification experimental data from the palm starch waste gasification in laboratory of Mechanical Engineering Education-UNS. By using the numerical simulation, the efficiency of cyclone separator without and with counter-cone was investigated. The results of this simulation will be used as the basic design of replacement the existing cyclone separator in the laboratory of Mechanical Engineering Education-UNS).

2. Numerical model description

This study simulated the three type of geometry (A, B and C) of the cyclone separator. Geometry A is geometry cyclone separator without counter-cone (existing cyclone separator type in the laboratory of Mechanical Engineering Education-UNS) (Fig. 1). Geometry B is cyclone separator with counter-cone and apex angle 90^0 (Fig. 2). Geometry C is cyclone separator with counter-cone and apex angle 120^0

(Fig. 3). The properties of the solid body of cyclone shown in Table 1. The study was conducted based on CFD using the finite volume method with the Ansys Fluent 16.2 Academic package.

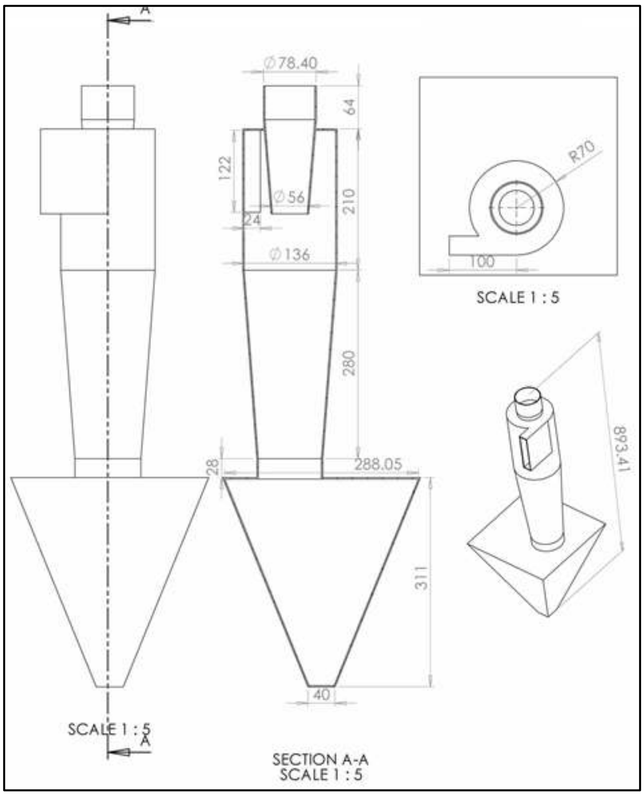

Figure 1. Cyclone separator without counter-cone (Geometry A)

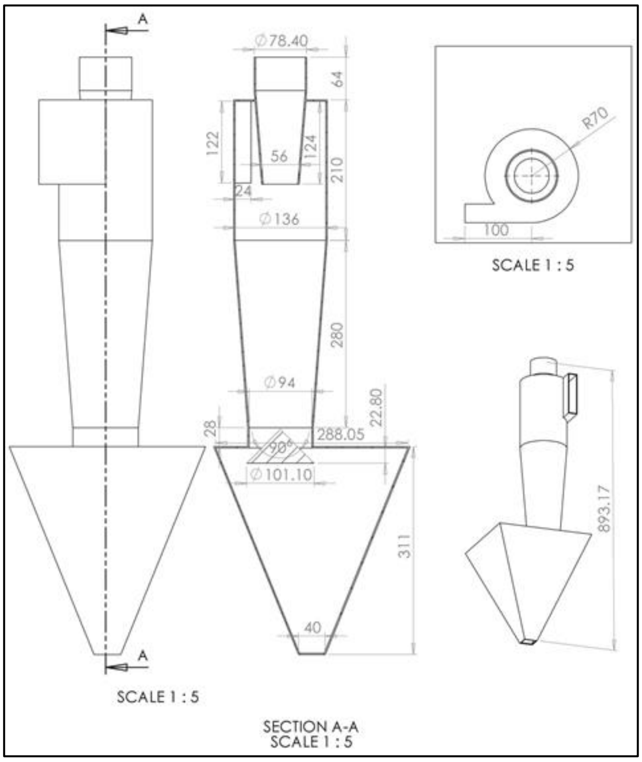

Figure 2. Cyclone separator with counter-cone 90^0 (Geometry B)

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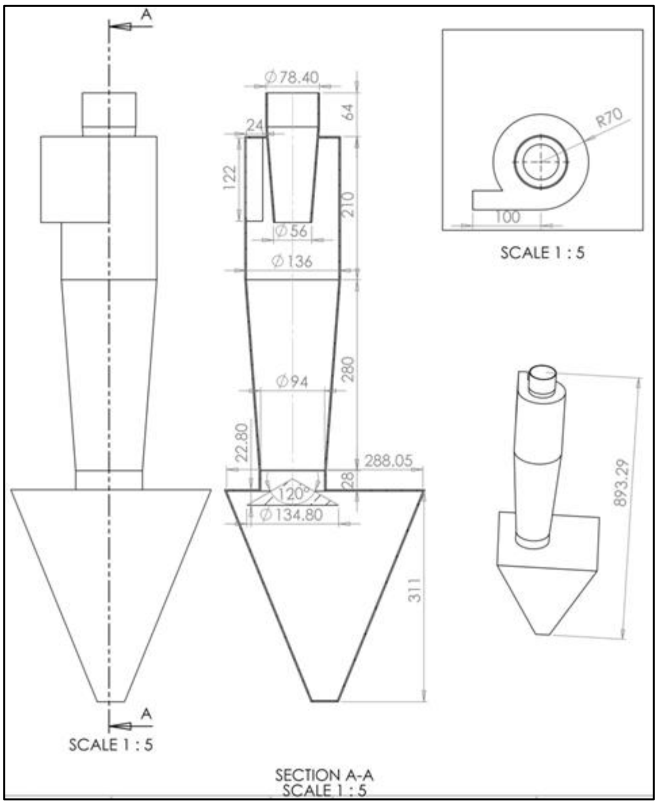


Figure 3. Cyclone separator with counter-cone 120^0 (Geometry C)

Table 1. The properties of the solid body of cyclone

Properties	**Unit**
Thickness	2 mm
Roughness	0.046
Density	1643 kg/m^3

2.1. Experiment data of palm starch waste gasification

The input parameter of simulation was used the gasification experimental data from the palm starch waste gasification in laboratory of Mechanical Engineering Education-UNS. The detail of properties of the gas (Syngas) and the properties of ash solid was shown in Table 2 and 3.

Table 2. The detail of properties of gas (Syngas)

Gas properties	**unit**
Act. Vol. flowrate (Q)	0.1434 m^3/s
Velocity of gas	48.95 *m/s*
Density	0.1116 kg/m^3
CP (dynamic viscosity)	2.612 x10^{-5} *kg/ms*
Thermal conductivity	0.2641 *W/mK*
CSt (kinematic viscosity)	2.341 x10^{-4} m^2/s
Temperature	330,4 *K*
Specific heat	3.524 *Kj/mole kg C*

Table 3. The properties of ash solid

Gas properties	unit
Velocity of ash solid	48.95 *m/s*
Density	1643 kg/m^3
Particle diameter	-
Number of particle	-

2.2. CFD simulation

The simulation of cyclone separator used the tetrahedral meshing for complex geometry. The total number of elements and skewness ratio was shown in Table 4. The simulation was conducted based on Reynolds Averaged Navier Stokes (RANS) as the turbulent approach. The type of RANS used the Reynolds stresses Model (RSM). The standard wall function was used to solve turbulent flow problems in the wall regions. The detail of CFD setting was described in Table 5. The fluid phase of Syngas and particulates was simulated as dispersion model. *Discrete Phase Model* (DPM) with one-way coupling was used for the description of the dispersed phase.

Table 4. The total number of elements and skewness ratio

	Geometry A	Geometry B	Geometry C
Number Of Element	495,000 cell	470,000 cell	470,000 cell
Quality Mesh Average	0.28	0.29	0.29

Table 5. CFD setting

Details of Setting :	
Type	*Pressure based*
Turbulence model: RANS	*RSM, The standard walls function*
Trajectory (LPT) Lagrangian particle track	*Discrete phase model One-way coupling* *Max. number of steps 1e-06* *Step length factor 5*
Solution method	*Pressure-Velocity Coupling SIMPLE*
Terms of convergence:	10^{-3}
Spatial discretization:	*Pressure Momentum: second order upwind* *Turbulent kinetic energy, Turbulent dissipation rate, Reynolds stresses: first order upwind (low order scheme)*

The equation of particle motion is based on the following assumptions: 1) The particles are perfectly spherical in shape, 2) The volume fraction of the dispersed phase in the continuous region is negligible, and thus no influence was due to the presence of the particles, 3) With the dilute particle flow in continuous flow, there are zero inter-particle interactions and 4) Collisions between particles and the wall are assumed to be perfectly elastic [8]. Under these assumptions, the particle trajectories are obtained by integrating the force balance on the particle [5,7,8] and [9]. The fractional efficiency was calculated based on equation (1).

$$Efficiency = \frac{trapped}{number\ of\ tracked - incomplete} \tag{1}$$

3. Results and discussion

Based on the experiment results and characteristic of gasification of palm starch waste, the particle size 0.1 μm to 20 μm was simulated by using the three type of cyclone sparator geometry. Figure 4 shows the simulation results of the fractional efficiency of cyclone separator without and with the counter-cone. The additional of counter-cone in the cyclone separator has affected the number of particles trapped and the distribution efficiency of particle diameter. This results are in line with the cyclone separator in coal-fired boilers application [10] and in cyclone separators of cement clinker burning [5] . The geometry type C (cyclone separator with counter-cone 120^0) showed the higher efficiency comparing the geometry B. This is means that the apex angle of counter-cone has affected the efficiency of particulates trapping in the cyclone separator. The apex angle of counter-cone also affected the efficiency of particulates diameter distribution that could be trapped by the cyclone separator. Where is the geometry type C could trap the gas particulate of palm starch waste gasification 0.1 μm with efficiency 0.16. On the other hand, the cyclone separator without the counter-cone could not trap the particle in Syngas less than 1 μm. This is due to the decreasing of turbulence at the end of the vortex (upper of counter-cone position) as the effect of the addition of counter-cone in the cyclone separator. Therefore, the particle that had trapped in the hopper could not get back into the vortex. The additional of counter-cone in the cyclone separator was good way to decrease the turbulence at the end of the vortex [10]. This argumentation was strengthened by the profile of velocity in the body of the cyclone separator as shown in Figure 5.

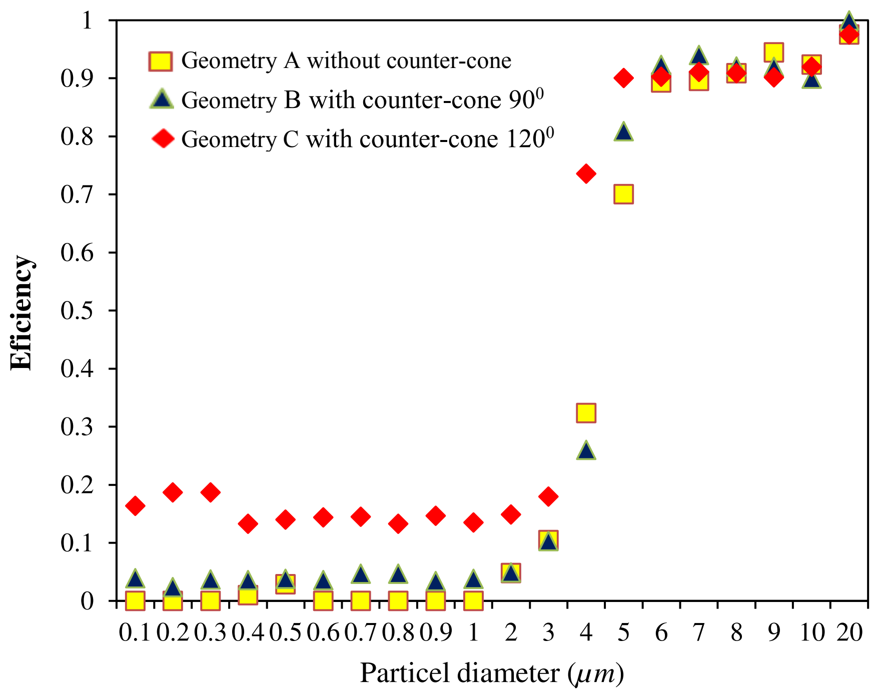


Figure 4. Fractional efficiency of cyclone separator without and with the counter-cone

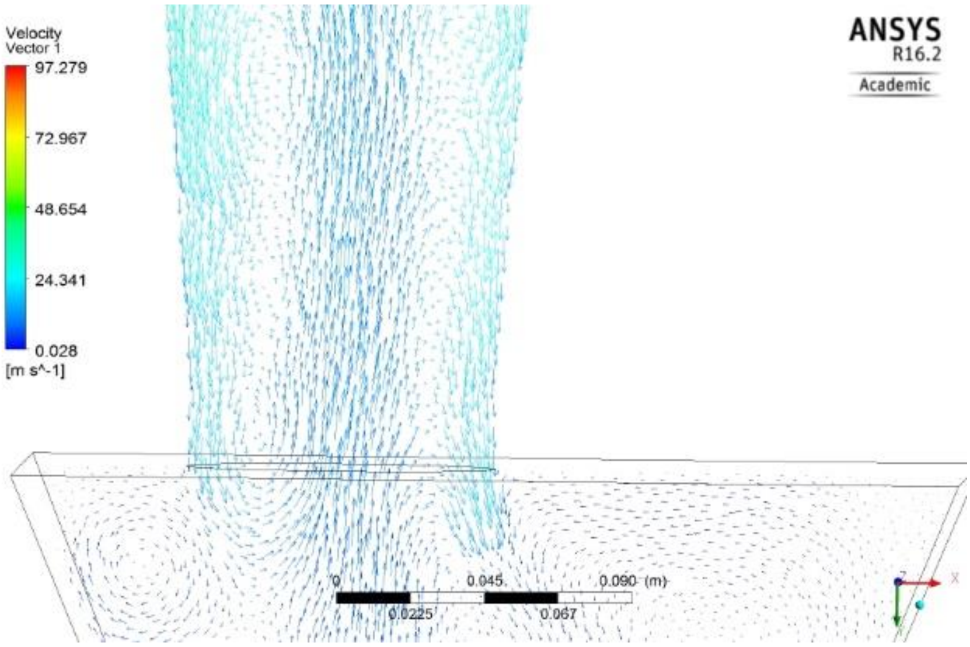


Figure 5a. Profile vector velocity close vortex finder (Cyclone separator without counter-cone (Geometry A))

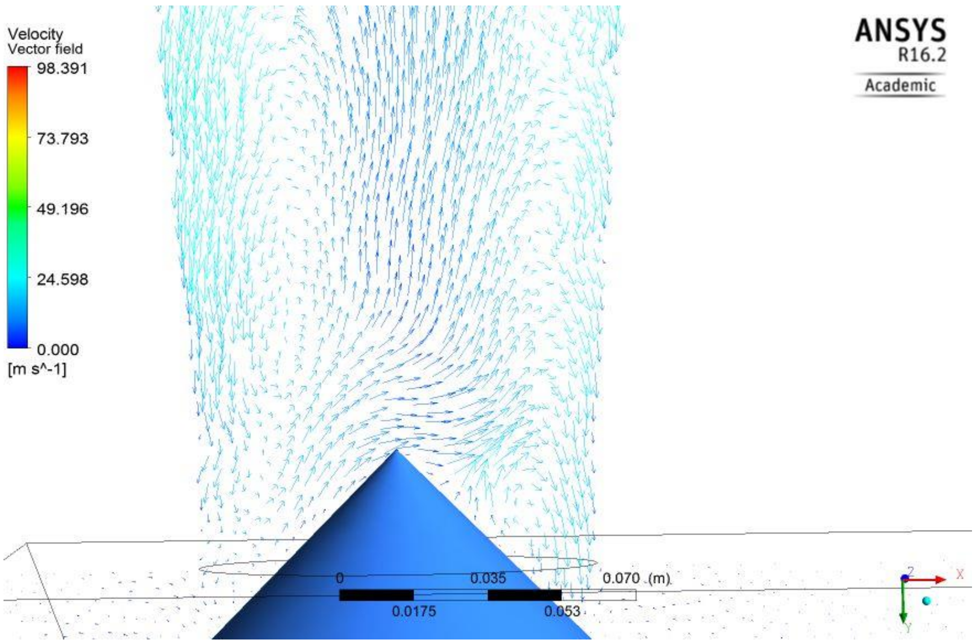


Figure 5b. Profile vector velocity close vortex finder (Cyclone separator with counter-cone 90^0 (Geometry B))

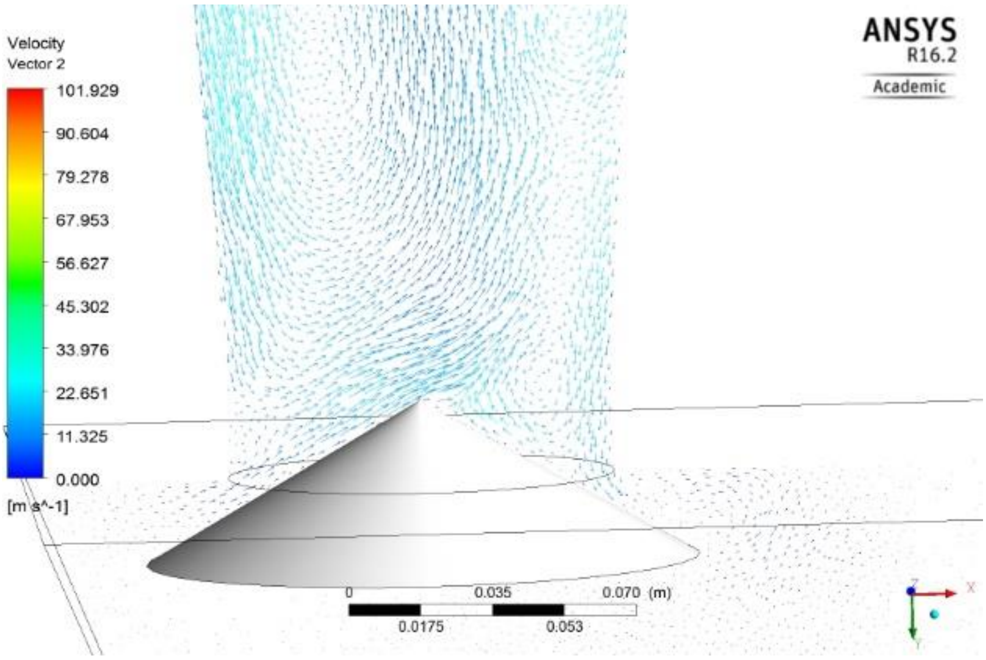


Figure 5c. Profile vector velocity close vortex finder (Cyclone separator with counter-cone 120^0 (Geometry C))

Figure 6 shows the velocity vectors near the counter-cone, the velocity was dominated by the axial velocity than the radial or tangential velocity. Therefore, the Syngas direction in the inner vortex of the cyclone separator rotates to the upwards the vortex finder and the small (lighter) particle was sucked into the vortex finder. In order to investigate the pressure drop in the cyclone separator without and with counter-cone, the pressure analysis was conducted in several point of cyclone separator as shown in Fig. 6.

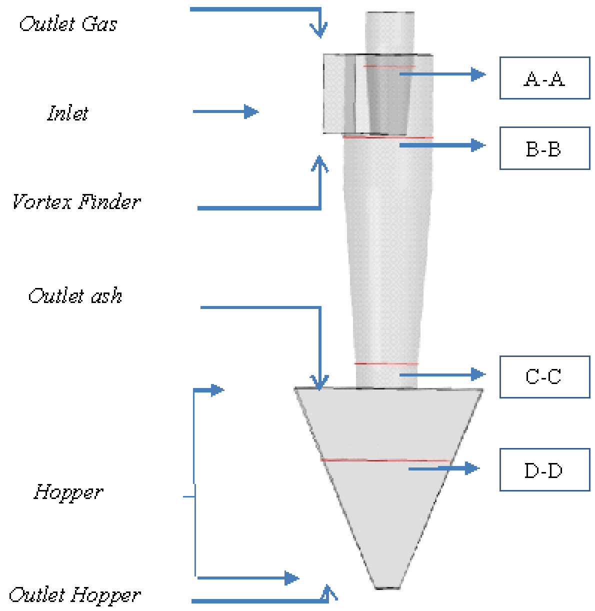
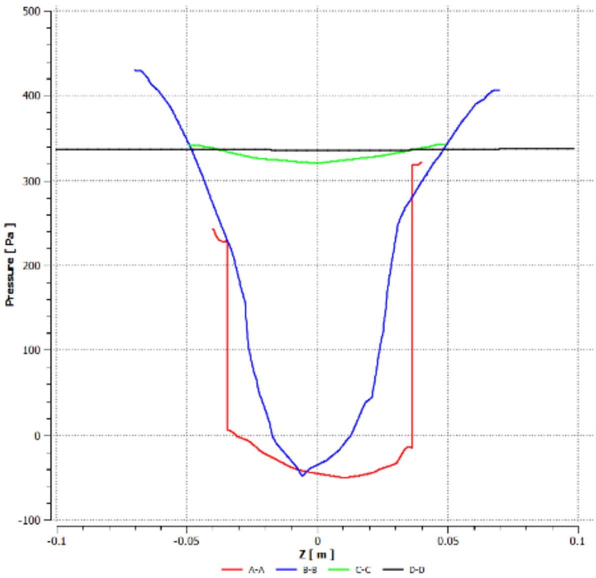
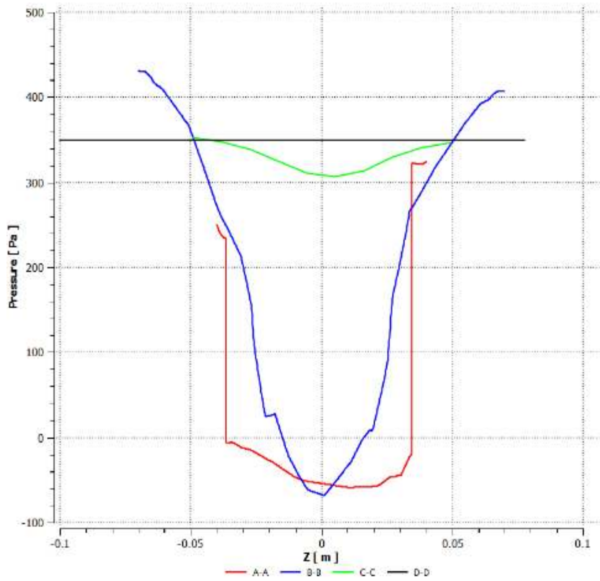


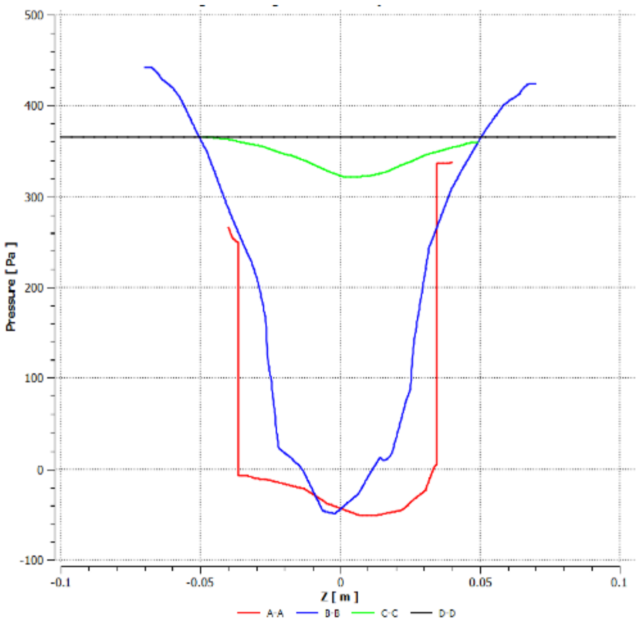
Figure 6. The detail position of pressure investigation



(a) Cyclone separator Geometry A



(b) Cyclone separator Geometry B



(c) Cyclone separator Geometry C

Figure 7. Pressure Graphs

Figure 7 performed the pressure analysis in different position of cyclone (A-A, B-B, C-C and D-D). When the syngas entrances the cyclone separator, the cyclone wall pressure is higher than the center of the axis (Z). Pressure losses significantly affect the efficiency of collection [7]. Pressure losses derived from the difference between the inlet and the outlet of cyclone and can be used as an indicator of improved efficiency. Table 6 was shown the comparison of pressure loss cyclone separator geometry type A, B, and C. When the value of pressure loss is higher, the cyclone efficiency increase. Pressure loss can be extracted from the area weighted average based on the inlet and outlet cyclone. Furthermore, the pressure losses could be used as an indicator of efficiency. The cyclone separator geometry type C shown the higher value of pressure loss comparing to the other. This result is strengthened the particulates efficiency Fig. 4 that the geometry type C has the higher efficiency.

Table 6. Pressure Losses

Model	Pressure losses
Geometry type A	195.30 Pa
Geometry type B	196.01 Pa
Geometry type C	202.65 Pa

4. Conclusion

In order to improve the quality of Syngas from the particulates impurity in gasification process of palm starch waste, counter-cone could be applied to the cyclone separator. The results of this simulation show that by adding the counter-cone in the cyclone separator increasing the number of particulates trapped and the distribution efficiency of particle diameter. The additional of counter-cone in the cyclone separator was good way to decrease the turbulence at the end of the vortex the geometry of the cyclone separator type C show the best efficiency compared with geometry A and geometry B. Therefore, the geometry type C (Cyclone separator with counter-cone 120^0) is suitable to the characteristic of gasification process of palm starch waste.

Acknowledgements

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