

PAPER • OPEN ACCESS

Numerical Validation and Study of Particulate Flow in Cyclone Separator using Commercial Computational Fluid Dynamics Code

Recent citations

- [Conceptual Design of Sandglass-like Separator for Immobilized Anionic Radionuclides Using Particle Tracking Based on Computational Fluid Dynamics](#)
Tae-Jin Park *et al*

To cite this article: Mayuresh Mutha *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **312** 012027

View the [article online](#) for updates and enhancements.



ECS **240th ECS Meeting**
Oct 10-14, 2021, Orlando, Florida

Register early and save up to 20% on registration costs

Early registration deadline Sep 13

REGISTER NOW

Numerical Validation and Study of Particulate Flow in Cyclone Separator using Commercial Computational Fluid Dynamics Code

Mayuresh Mutha¹, Vineet Katkamwar¹, Bageerathan Thirunavukkarasu¹, Thundil Karuppa Raj R^{1*} and Sivamurugan P²

¹ School of Mechanical Engineering, VIT University, Vellore, Tamil Nadu, INDIA – 632014

² Vel Tech Rangarajan Dr.Sagunthala R & D Institute of Science and Technology, Chennai, Tamilnadu, India.

*Corresponding author email id – thundilr@gmail.com

ABSTRACT: The cyclone separator is widely used for particle separation in industries because of ease in manufacturing and maintenance free working capability. It has also been an automobile component used in air intake system. It's necessary to understand the flow of air and particles inside the cyclone separator for the design of cyclone separator. Its performance depends upon operational and geometrical parameters. This study is focused on geometric parameter in which a numerical simulation has been carried out to understand the effect of air and particle flow on varying the cone height of cyclone separator using ANSYS 15.0. The analysis involves determining pressure drop at different inlet velocity with corresponding change in cone height of the cyclone separator. The results were obtained for different velocity condition with maximum of 8% of error. Moreover, collection efficiency for cyclone separator was also determined by varying particle size from 0.01 to 10 micron. Decreasing cyclone height led to increase in tangential velocity thus increasing the cyclone efficiency.

Keywords: CFD, Cyclone separator, Particle separation, collection efficiency, pressure drop

1. Introduction

Cyclone separators are widely used for particulate emission control in industries because of their simple design and low maintenance working capability. Cyclone separator is a stationary device which is used to separate the dust or liquid particles from the air or gas. Being an Inertial type of separator, it works on the principle of centrifugal and gravity action. In cyclone separator, the flow enters in the separator tangentially due to which the centrifugal



action is generated and because of which the particles or liquid gets trapped at the cyclone surface. Due to the spiral action or moment, the particles moves down and scatter in the hopper located underneath and this outlet is called as particle outlet. The gas with lower density pressurized in cyclone collector is escaped from the outlet which is situated at the top position of the cyclone collector and is called pressurized outlet. Cyclone collector are mostly used in ship unloading installation, power station, spray drier, detergent production units etc.

There are various techniques available for particle separation but cyclone separator is the only one with minimum operating cost and with least maintenance requirement hence preferred the most wherever possible. Selection of the right technique being the most critical part, depends on the size of particles needed to be separated. Figure 2 below shows different types of techniques available and the size range they cater to. Cyclone collectors are used for particle size 3 microns and above. They are considered a better option to filters that require particle separation above 3 micron especially in case of high collection requirement.

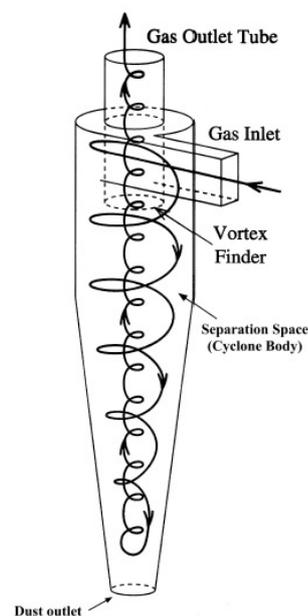


Figure 1. Typical reverse flow in cyclone separator.

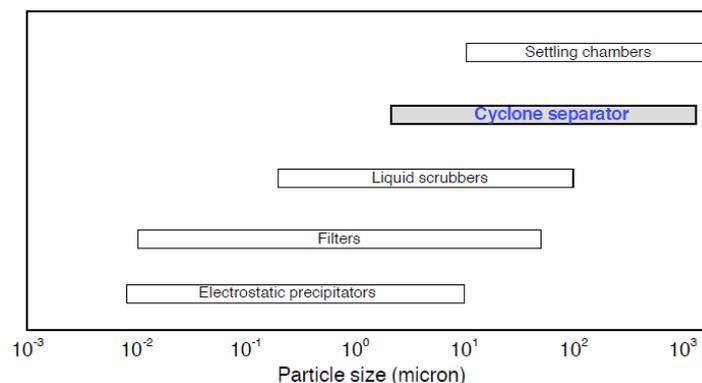


Figure 2. Various particle separation techniques for different particle size

The inlet for cyclone collector is rectangular in cross section with dimension $a \times b$ as shown in Figure 6. The gas swirl inside the cyclone collector because of the conical characteristic of cyclone. It receives the axial movement and escapes from the top of cyclone. Once manufactured, it is very difficult to change construction of such structures and hence the effect of geometrical parameters needs to be studied.

2. Cyclone Performance

Parameters affecting cyclone performance include cyclone dimensions, gas properties, particle properties and shape of vortex finder. Cyclone dimensions being major part of study found in literature includes effect of cyclone diameter, inlet height, inlet width, vortex finder diameter, vortex finder length, cylinder height, cyclone total height and cone tip diameter. Gas properties like velocity, density, viscosity, temperature and pressure along with particle properties like density, shape, mass loading, diameter and distribution also affect the cyclone performance. Xiang et al. [1] has conducted the investigation on the performance of the cyclone separator with varying geometry profiles. They studied the effect of varying bottom diameter and cone size on collection efficiency of the cyclone separator. The authors have validated with the Barth's, Leith's and Licht's theory. They found that none of the theories have better prediction over effect of the cone size. Chuah T.G et al. [2] has conducted CFD studies on the cyclone separator with varying cone dimensions. The modelling of high swirl cyclone separator is critical. The authors have an algebraic turbulent model to overcome the problem.

The authors have validated the results with the experimental data available in literature with acceptable error deviations. This model has the benefit of enlarging or reducing of the cone profile of cyclone separator. The author have shown that CFD can be used to predict the flow regime of the cyclone separator. Hideto yoshida et al. [3] studied the effect of the height of the cone on the collection performance of the cyclone separator. The authors have conducted experimental and numerical simulations and validated. The author have studied the effect of velocity, resistance of incoming particles by varying the apex cone angle of the cyclone separator. They found the change in the velocity in the upper part of the separator with the optimum cone height configuration. Ting Zhang et al. [4] conducted CFD studies on the cyclone separators with square, hexagonal and circular cross section cyclone separators. The authors have designed optimised cyclone separators with three parameters. They found that the hexagonal outer body has better efficiency and lower wear rate. Yaxin Su et al. [5] has numerically simulated the gas-solid turbulent flow in cyclone separator with CFD method. The author has modelled the fluid with Reynolds Stress Model (RSM) and traced the particle with Lagrangian model. Exhaust gases have been used as the gas-solid medium with a circular and two square cross section model. The performance characteristics of the cyclone separator were compared and pressure drop of the three models were evaluated. They found that square cross section has better efficiency than circular cross section.

Yaxin Su et al. [6] used the three dimensional particle dynamic analyser to trace the particle in the square cyclone separator with downward gas exit. The authors have conducted cases with varying inlet velocities and different particle concentrations. They used glass beads as the particle with diameter from 30 microns to 40 microns. The author has evaluated parameters like flow vector, turbulent intensity, mean velocity and kinetic energy of both the gas and solid particles. The author has found that the elevation of temperature of the cyclone separator has better uniform flow when compared to the case at room temperature. The laminar motion of the particles has increased the turbulent kinetic energy of the particle-particle collisions and particle wall collisions. The authors have found that the corners of the cyclone separator has contributed towards the increase in the kinetic energy of the particle. Yuki Wakizono et al [7] has conducted CFD simulations on cyclone separators with the ring configuration to the upper outlet region. The pressure drop is less due to the ring configuration used. The author has parameterized the cut off ratio, wall thickness, pressure drop and collection efficiency. The author has found that the ring has contributed

over the collection efficiency at the bottom of the cyclone separator. The numerical simulations were validated along with experimentation with allowable error percentage. Yifang Zhu et al [8] has conducted experimental studies on high flow rate conditions in small cyclone models. The authors have conducted studies on seven different cyclone models with varying flow rate conditions and particle sizes. The authors have varied the height of cylinder and length to the diameter of the exit tube to study the cyclone collection efficiency. The authors have found that the increase in cylinder height is efficient to some extent. The author concludes that cylinder height and exit tube length affects the collector efficiency of the cyclone separator. Eflita Yohana et al. [9] has numerically modelled three dimensional new cyclone separator model and studied the particle separation with varying inlet velocity configurations. The author has used the Reynolds averaged Navier Stokes equation with Reynolds Stress Model to solve finite volume method based on the SIMPLE algorithm model. The author concludes that the newly modelled cyclone separator has better efficiency than the conventional cyclone separators. Ali Sakin et al. [10] has investigated cyclone separator in air intake system of automobile and studied the influence on the engine performance. The author has preferred the cyclone separator in place of air filter, as the filter acts as porous medium and pressure drop arises. The author has conducted performance studies on the engine with both filter and cyclone separator intake systems. Numerical simulation were validated with experimentation and found to be satisfactory.

3. CFD Simulation:

In this paper, CFD simulation is done to validate the results of experimental setup by Xiang et. al. and the analysis done by Chuah et. al. [2]. O grid blocking done in ICEM CFD as shown in figure 3 below and Hexa meshing is done as in the figure 4. FLUENT was selected for analysis.

Boundary conditions include inlet air being at 8 m/s or 30 lpm, 10.66 m/s or 40 lpm, 13.33 m/s or 50 lpm and 16 m/s or 60 lpm. Pressure drop being the key parameter, is validated and found to be within 8 percent, error being maximum at 16 m/s velocity or 60 lpm discharge. Reynolds Stress Model (RSM) with discrete phase modelling was used for particle simulation. Figure 7 represents the pressure contour of the case of cyclone separator with height of 36 mm and alpha angle 5 degree. Figure 8 shows the tangential velocity of the case with height 36 mm and 5 degree alpha angle.

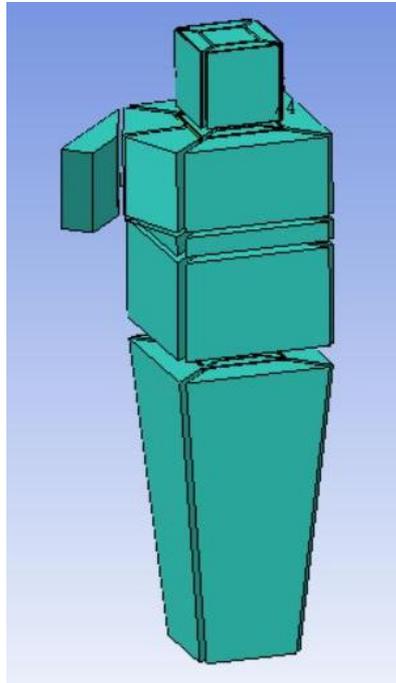


Figure 3. Blocking of cyclone separator with O- Grid

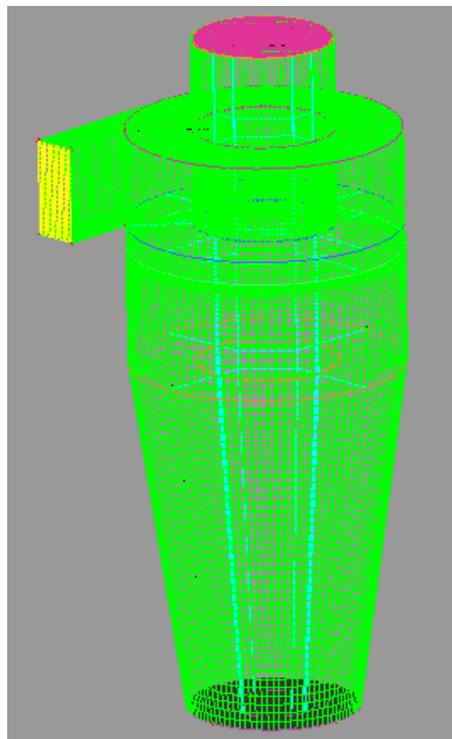


Figure 4. Hexa meshing in ICEM CFD

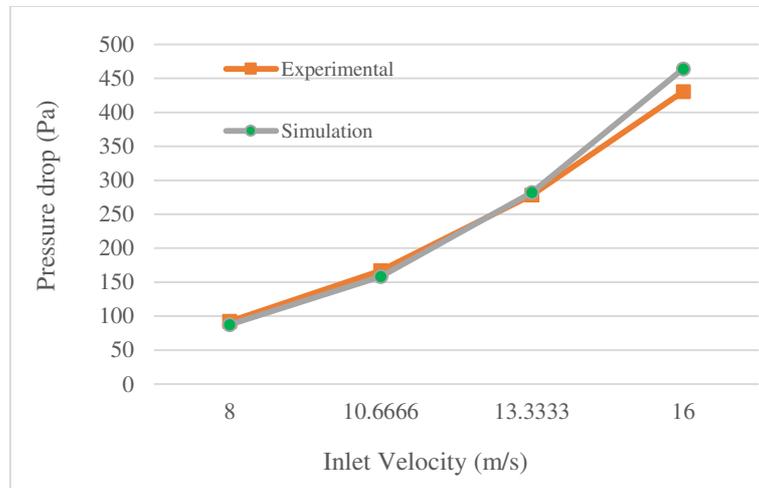


Figure 5. Pressure versus velocity for experimental and simulation values

Table 1. Pressure drop validation of Experimental Cyclone by Xiang et.al.

Inlet Velocity (m/s)	Pressure		Percentage error (%)
	Experimental (Pa)	Simulation (Pa)	
8	92.18	87.5	5.08
10.66	166.71	158.20	5.17
13.33	278.51	281.80	1.18
16	430.51	464	7.78

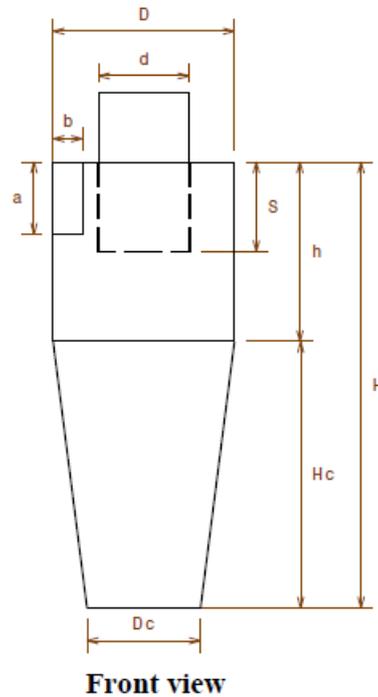


Figure 6. Geometrical layout of Cyclone

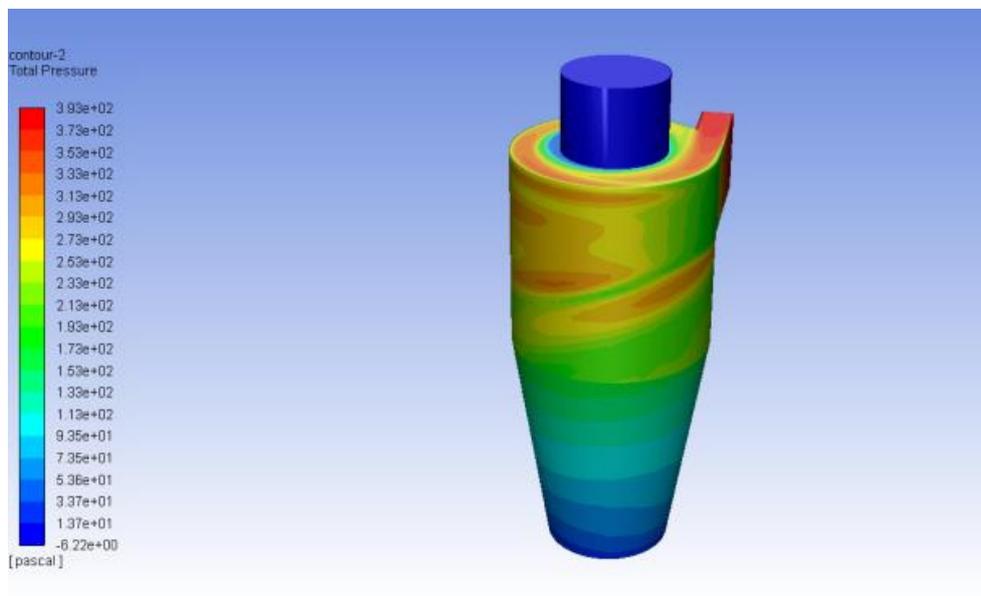


Figure 7. Pressure contour of case with $H = 36$ and $\alpha = 5$

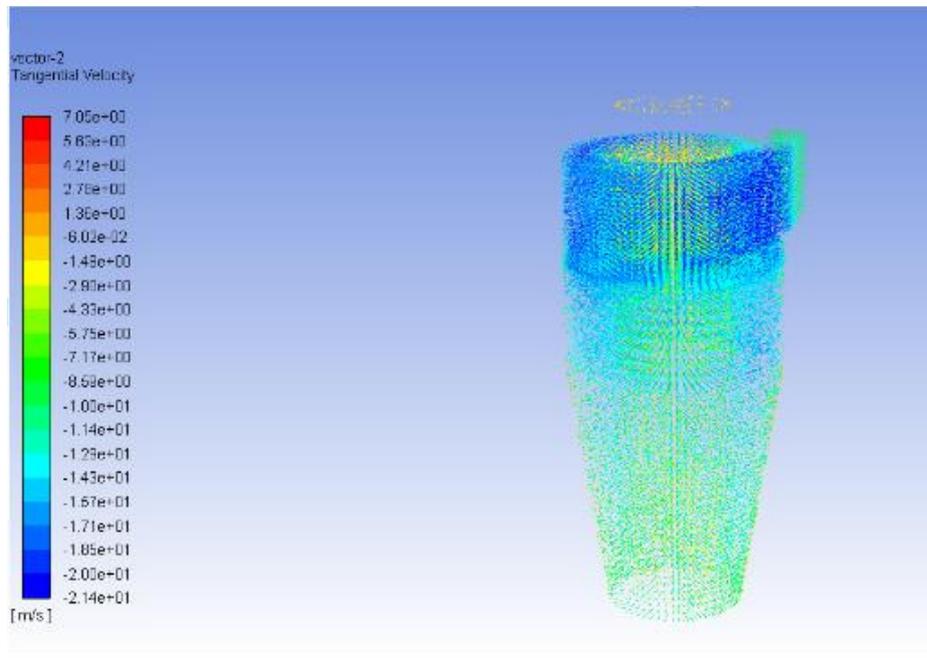


Figure 8. Tangential velocity vector with $H = 36$ and $\alpha = 5$

Table 2. Geometrical dimensions of cyclone studied

Dimension	Value (mm)	
Body Diameter (D)	31	
Gas Outlet Diameter (d)	15.5	
Inlet Height (a)	12.5	
Inlet Width (b)	5	
Gas Outlet Duct Length (S)	15.5	
Cylinder Height (h)	31	
Cyclone Height (H)	77	
Cone Height (Hc)	Cyclone 1	46
	Cyclone 2	36
Cone Outlet Diameter (Dc)	19.4	

The cone height of cyclone was also varied and the effect was studied. It was found that with decrease in cone height, the tangential velocity of air increases and the efficiency increases.

4. Results and Discussion:

4.1 Effect of inlet velocity, alpha angle and height of the cyclone separator on collection efficiency

Numerical simulations were conducted on the cyclone separator with varying inlet velocity and particles with 0.01 microns to 10 microns. The particles allowed at inlet and the particles collected at outlet is traced. The collection efficiency is calculated by the number of particle traced. When the inlet velocity of the particles is increased, the collection efficiency is also increased. When the velocity at the inlet is increased, the total pressure drops down which makes the gas to escape out easily through the upper outlet. The velocity of the particle at inlet is significant in determining the collector efficiency. The trend of velocity is shown in figure 10.

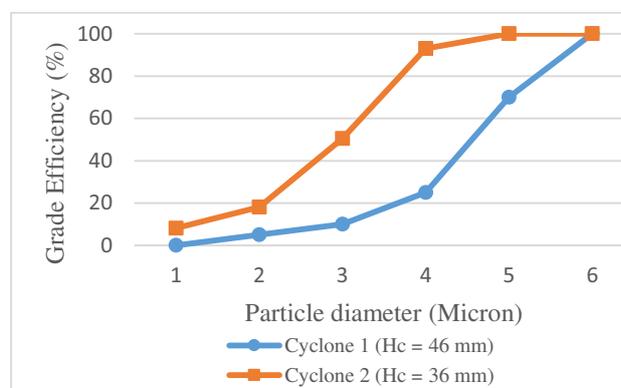


Figure 9. Effect of Cone height variation on Grade or Collection efficiency for different particle size

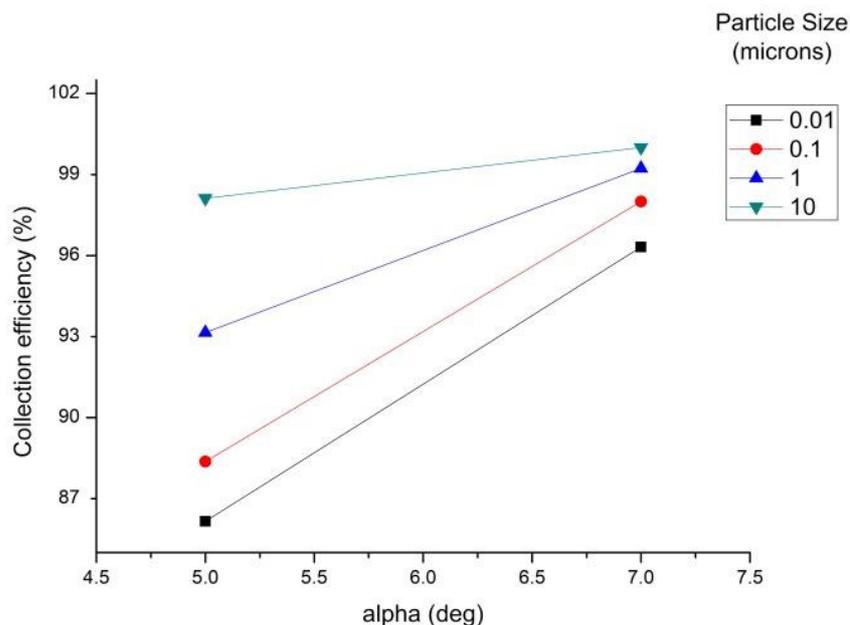


Figure 10. Alpha angle vs collection efficiency

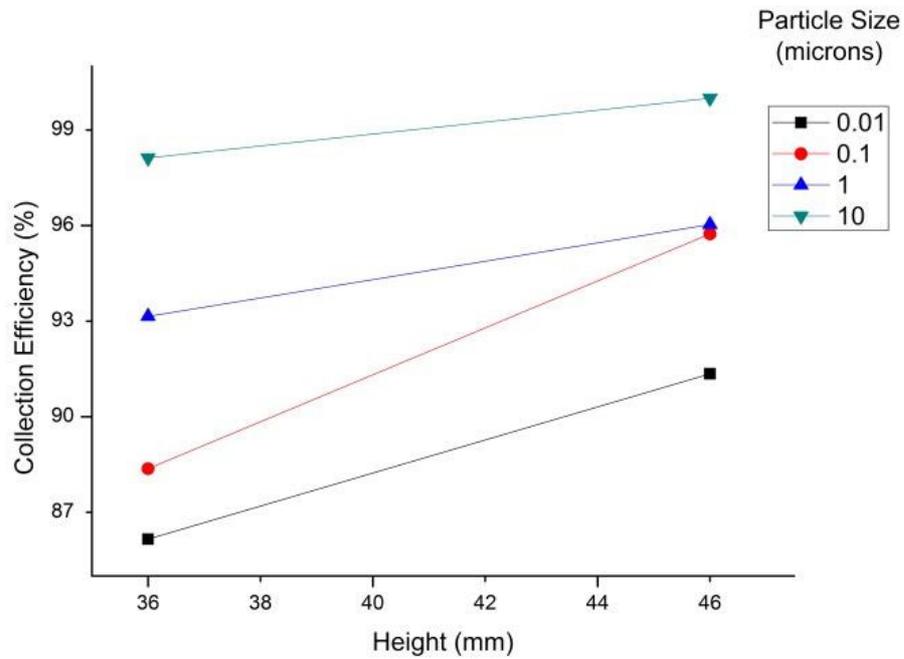


Figure 11. Height vs collection efficiency

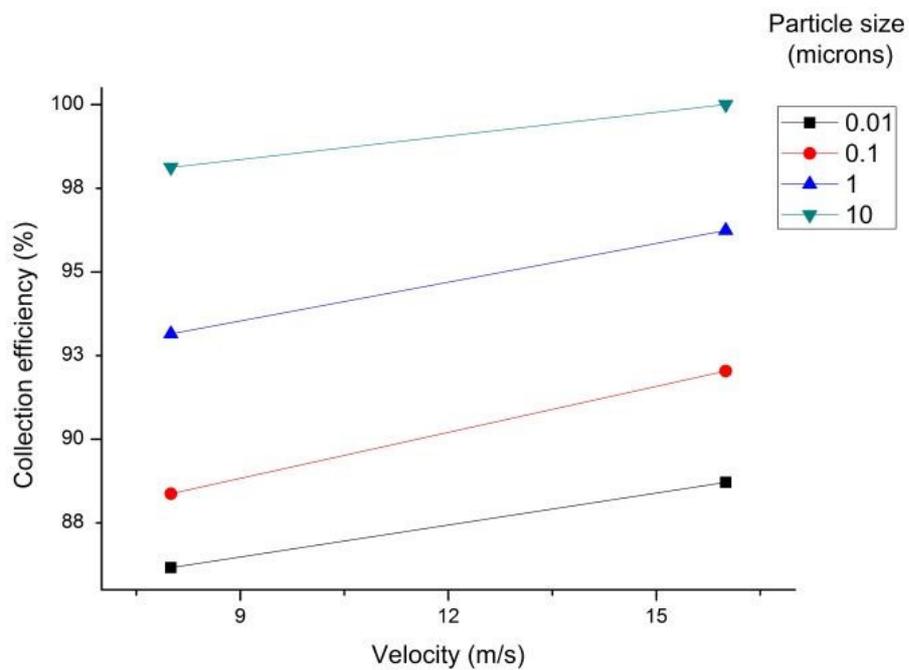


Figure 12. Velocity vs collection efficiency

Simulations were conducted with varying alpha angle values of 5 degree and 9 degree angles with height of 36 mm and 46 mm. When the alpha angles have been increased, there is significant increase in the collector efficiency along with increase in height. The height of the cyclone separator needs effective alpha angle where the collector efficiency is maximum. The trend is shown in figures 8 and figure 9. The particle-particle interaction and particle-wall interaction in cases with less alpha angle along less height is efficient because the proportional alpha angle and height allows the particle-gas mixture to move in a streamlined flow where the particle gets collected in the bottom outlet and gas escapes through top outlet.

5. Conclusion:

Cyclone separator is observed to separate particles above 1 micrometre but it is found to be more effective in separation of particles above 5 micrometre. Cone dimensions have great impact on cyclone performance. It was found that the efficiency increases with decrease in cone bottom diameter. Higher the inlet velocities, better is the grade efficiency and thus the cyclone can separate particles with lower particle size too. Decreasing the cyclone height increases tangential velocity and leads to increase in the efficiency. Thus cyclone separator design is very critical and the cone dimensions need to be decided based on particle size to be separated and inlet velocity of the air.

6. Nomenclature:

\dot{m}	-	Mass flow rate, g/sec
P	-	Pressure, Pa
T	-	Temperature, K
U	-	Superficial velocity, m/s
ρ	-	Density of air, kg/m ³
ΔP	-	Pressure drop, Pa
L	-	Substrate length, mm

7. References:

- [1] Xiang, R., Park, S.H. and Lee, K.W., 2001. Effects of cone dimension on cyclone performance. *Journal of Aerosol Science*, 32(4), pp.549-561.
- [2] Chuah, T.G., Gimbin, J. and Choong, T.S., 2006. A CFD study of the effect of cone dimensions on sampling aerocyclones performance and hydrodynamics. *Powder technology*, 162(2), pp.126-132.
- [3] Yoshida, H., Kwan-Sik, Y., Fukui, K., Akiyama, S. and Taniguchi, S., 2003. Effect of apex cone height on particle classification performance of a cyclone separator. *Advanced Powder Technology*, 14(3), pp.263-278.
- [4] Zhang, T., Liu, C., Guo, K., Liu, H. and Wang, Z., 2015. Analysis of flow field in optimal cyclone separators with hexagonal structure using mathematical models and computational fluid dynamics simulation. *Industrial & Engineering Chemistry Research*, 55(1), pp.351-365.
- [5] Su, Y., Zhao, B. and Zheng, A., 2011. Simulation of turbulent flow in square cyclone separator with different gas exhaust. *Industrial & Engineering Chemistry Research*, 50(21), pp.12162-12169.
- [6] Su, Y. and Mao, Y., 2006. Experimental study on the gas–solid suspension flow in a square cyclone separator. *Chemical Engineering Journal*, 121(1), pp.51-58.
- [7] Wakizono, Y., Maeda, T., Fukui, K. and Yoshida, H., 2015. Effect of ring shape attached on upper outlet pipe on fine particle classification of gas-cyclone. *Separation and Purification*

- Technology, 141, pp.84-93.
- [8] Zhu, Y. and Lee, K.W., 1999. Experimental study on small cyclones operating at high flowrates. *Journal of Aerosol Science*, 30(10), pp.1303-1315.
- [9] Yohana, E., Diana, A.E., Maulana, A.F., Tauviqirrahman, M. and Choi, K.H., 2019, April. Inlet velocity influence on particle separation in three-dimensional new cyclone separator using CFD modelling. In *AIP Conference Proceedings* (Vol. 2097, No. 1, p. 030067). AIP Publishing.
- [10] Sakin, A., Karagoz, I., Ergul, M., Demirtas, U. and Savas, F.H., 2018. An investigation into the use of a cyclone separator in the intake air system and its influence on the engine performance. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 232(5), pp.667-678.