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Design and Analysis of Cyclone Separator

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Abstract:

The gas-solids cyclone separator is industrial equipment that has been widely used. Due to its industrial relevance, a large number of computational studies have been reported in the literature aimed at understanding and predicting the performance of cyclones in terms of pressure and velocity variation. One of the approaches is to simulate the gas-particle flow field in a cyclone by computational fluid dynamics (CFD). Cyclones have often been regarded as low-efficiency collectors. However, efficiency varies greatly with particle size and cyclone design. Advanced design work has greatly improved cyclone performance. This paper have discussed the design parameters required to construct a high performing cyclone through the application of the classical cyclone design, However, the pressure drop in this design does not consider any vertical dimensions as contributing to pressure drop, This is a misleading in that a tall cyclone would have the same pressure drop as a short one as long as cyclone inlets and outlets dimensions and inlet velocities are the same.

I. INTRODUCTION

Dust Collectors

There are four principal types of industrial dust collectors namely, inertial separators, fabric collectors, wet scrubbers and electrostatic precipitators. The inertial separators separate dust from gas streams using a combination of forces, such as centrifugal, gravitational, and inertial. These forces move the dust to an area where the forces exerted by the gas stream are minimal. The separated dust is moved by gravity into a hopper, where it is temporarily stored. The three primary types of inertial separators are settling chambers, baffle chambers, and centrifugal collectors (e.g. cyclone separator). Cyclone separator is a method of removing particulate from an air, gas or liquid stream without the use of filters, through vortex separation. Rotational effects and gravity are used to separate mixtures of solids ands fluids. The method can also be used to separate fine droplets of liquid from a gaseous stream. A high speed rotating (air) flow is established within cylindrical or conical containers called a cyclone. Air flows in a helical pattern, beginning at the top (wide end) of the cyclone and ending at the bottom (narrow) end before exiting the cyclone in a straight stream through the centre of this cyclone and out the top.

Larger (denser) particles in rotating stream have too much inertia to follow the tight curve of fall to the bottom of the cyclone where they can fall to the bottom of the stream, and strike the outside wall, then fall to the bottom of the cyclone where they can be removed. In a conical system, as the cyclone, the rotational radius of the stream is reduced, thus separating smaller particles. The cyclone geometry, together with flow rate, defined the cut point of the cyclone. This is the size of particle that will be removed from the stream with 50% efficiency. Particles larger than the cut point will be removed with a greater efficiency and smaller particles with a lower efficiency.

Principles of Cyclone Separation

In centrifugal devices, the dust-laden gas is initially brought into a swirling motion. The dust particles are slung outward to the wall, and transported downward to the dust outlet by the downwardly directed gas flow near the wall.

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II. CYCLONE DESIGN

Cyclone Design Procedure

The cyclone design procedure outlined in Cooper and Alley (1994), hereafter referred to as the classical cyclone design (CCD) process, was developed by Lapple in the early 1950s. The CCD process (the Lapple model) is perceived as a standard method and has been considered by some engineers to be acceptable. However, there are several problems associated with this design procedure. First of all, the CCD process does not consider the cyclone inlet velocity in developing cyclone dimensions. It was reported (Parnell, 1996) that there is an "ideal" inlet velocity for the different cyclone designs for optimum cyclone performance. Secondly, the CCD does not predict the correct number of turns for different type cyclones. The overall efficiency predicted by the CCD process is incorrect because of the inaccurate fractional efficiency curve generated by the CCD process (Kaspar et al. 1993).

In order to use the CCD process, it is assumed that the design engineer will have knowledge of (1) flow conditions, (2) particulate matter (PM) concentrations and particle size distribution (PSD) and (3) the type of cyclone to be designed (high efficiency, conventional, or high throughput). The PSD must be in the form of mass fraction versus aerodynamic equivalent diameter of the PM. The cyclone type will provide all principle dimensions as a function of the cyclone barrel diameter (D).

Classification of Study Approaches

There is a widespread literature on the effect of cyclone geometry on performance, using one or more of the four main approaches of study, which are:

1. Analytical methods (mathematical models), which can be classified into:

(a) Theoretical and semi-empirical models (b) statistical models

2. Experimental measurements

3. Computational fluid dynamics (CFD) simulations

III. MODELLING

THE STAIRMAND OPTIMIZED DESIGN

Stairmand conducted so many experiments on the cyclone separator and finally developed the optimized geometrical ratios. By considering this geometric ratio's the modeling of the cyclone done in solid works.

TABLE 1: Cyclone geometry used in this simulation (stairmand optimized design)

Geometry	a/D	b /D	D x/D	S /D	h /D	H /D	B /D
Stairmand High Efficiency	0.5	0.2	0.5	0.5	1.5	4	0.375

Modelling In Solid Works

To design the cyclone the diameter (D) is considered as 20 mm.

Step 1: Draw the sketch according to the stairmand ratios.

Step 2: specify the dimensions.

Step 3: Revolve the sketch 360 degrees and give thickness as 0.1mm.

Step 4: to get the inlet, draw a rectangle on the part which is developed by revolving.

Step 5: extrude the rectangle along the Z-axis (L=D).

Step 6: draw a rectangle on the extruded plan to get the hallow inlet. Select the rectangle and give extrude cut throughout the extruded rectangle.

Step 7: save the geometry.

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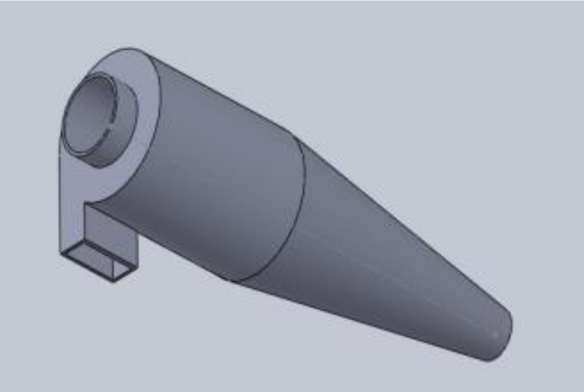

Fig 1: design of cyclone separator

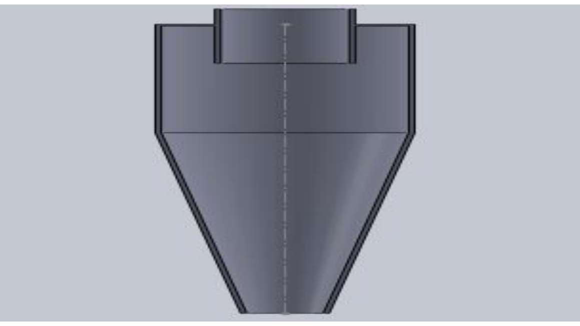

Fig 2: half sectional view of cyclone

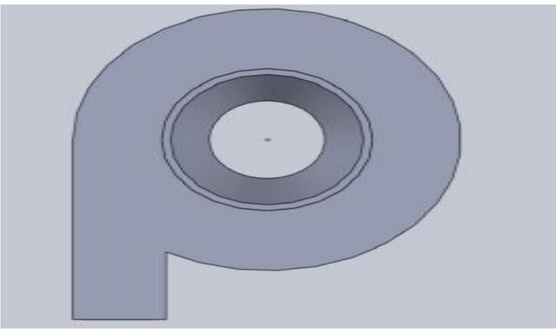

Fig 3: Top view of cyclone

IV. CFD ANALYSIS

Stairmand's Optimized Design Analysis

Cyclone Geometry

Import the cyclone design from the solid works. open the design modeler. Click on generate the imported geometry appears. Select the part body in the tree outline .select the body click on the screen. Change the solid body into the fluid body. Close the design modeler and save the project.

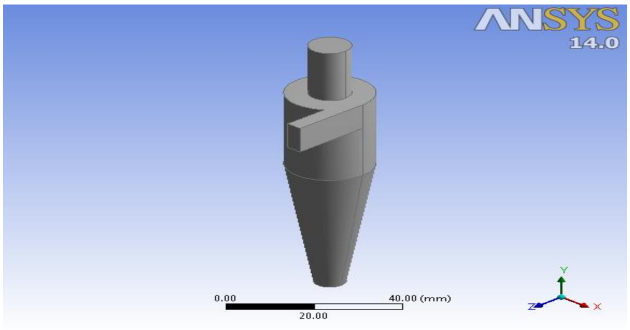

Fig 4: solid cyclone geometry for the simulation.

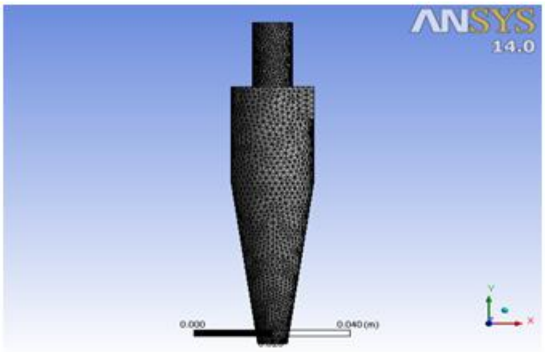

Fig 5: mesh front view

Residuals

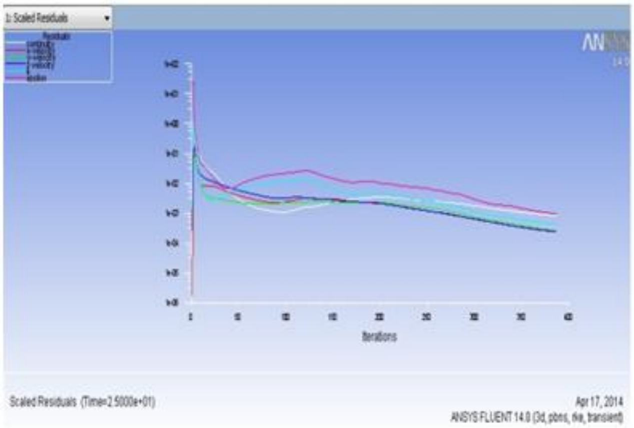

Fig 6: residual graphs

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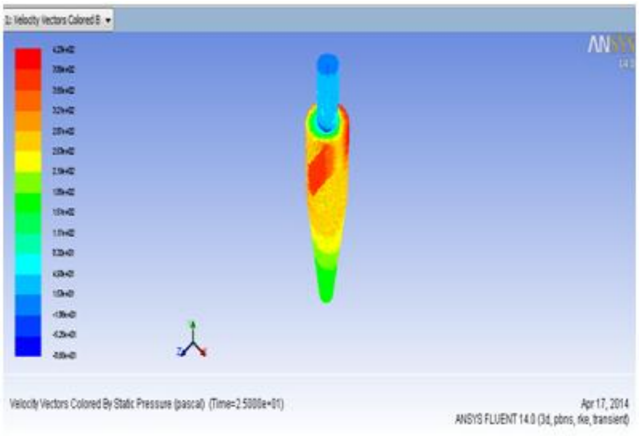

Fig 7: vectors of velocity

Pressure- velocity contours

The pressure in the cyclone separator increases from the center to wall. The maximum and minimum static pressures are 4.122e+002 (pa) and -6.44e+001 (pa) respectively. The velocity first increases then decreases from center to towards wall. The maximum and minimum velocity magnitudes are 23.62 m/s and 0 m/s respectively.

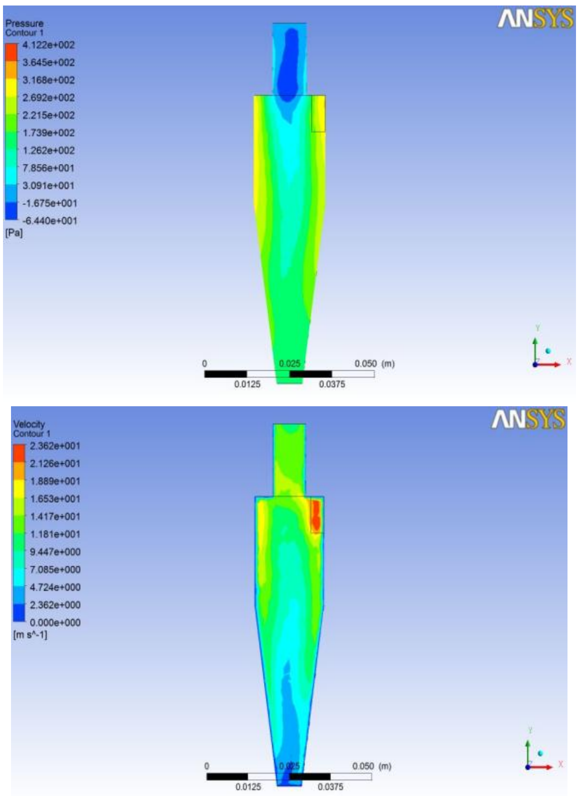

Fig 8: the pressure and velocity contours at the section Z=0.

Pressure-velocity charts

The following charts shows the pressure and velocity variation along the y-axis at different sections. The graphs are plotted with y-axis as pressure/velocity and x-axis as radial distance along the x-axis.

Table 2: The sections

SERIES 1	AT Y=0
SERIES 2	AT Y=0.01
SERIES 3	AT Y=0.02
SERIES 4	AT Y= -0.01
SERIES 5	AT Y= -0.02

Graphs

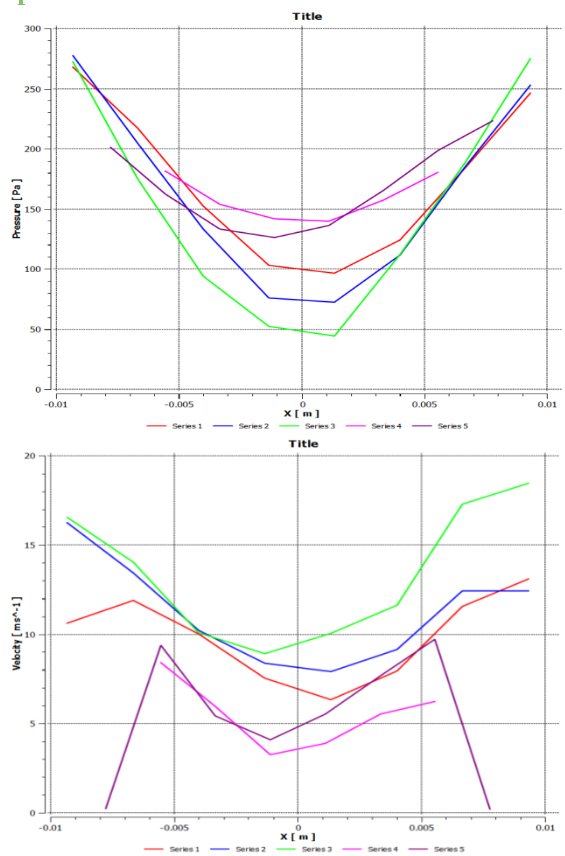

Fig 8: the pressure and velocity graphs at different section along the y-axis.

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The stairman's optimized design results are shown in above graphs. To study the variations in pressure and velocity 5 different sections are created along the y-axis as shown in the table 2.

Temperature Analysis

This analysis involves various flow studies at various temperatures. The stairmand's design is used for the simulation in fluent. The same set up is used for the temperature analysis as the stairmand's design analysis. Additional to that energy equation is activated to start the temperature analysis. In the velocity inlet boundary conditions the temperature of the inlet flow is added. This study involves in the simulation of the cyclone at 4 different temperatures. The variations in the pressure and velocity are noted and compared. The effect of the temperature is justified. The analysis is done at the temperatures 290,300,310 & 320 (k).

Table 3: pressure and velocity readings at different temperatures

Temp (k)	290	300	310	320
Max pressure (pa)	533.5	535.35	522.15	522.6
Mini pressure (pa)	-185.1	-192.7	-194.7	-194.7
Max velocity (m/s)	25.25	25.22	25.12	25.12
Mini velocity (m/s)	0	0	0	0

GRAPHS

The graphs are drawn by taking y-axis as pressure/velocity and the x-axis as radial distance along X.

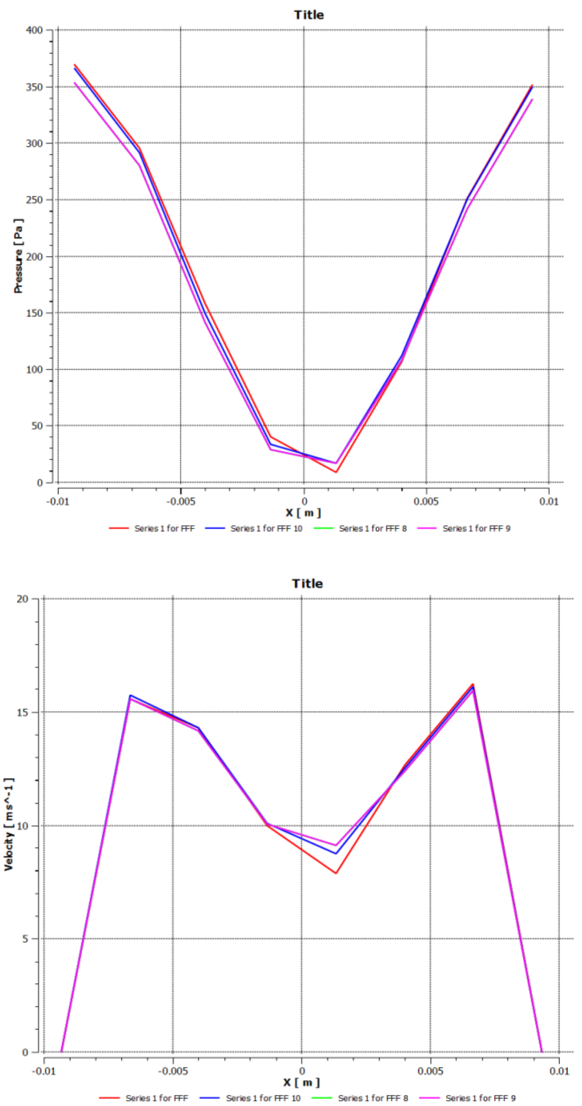
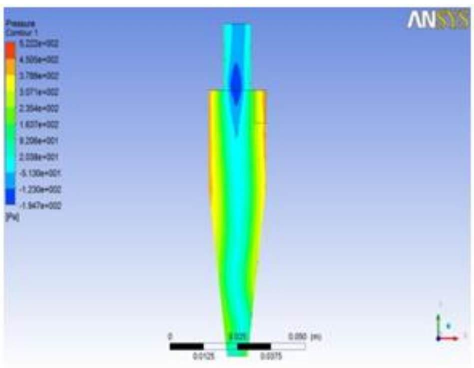


Fig 9: The variation of pressure velocity in cyclone and at section Z=0.

Pressure contours



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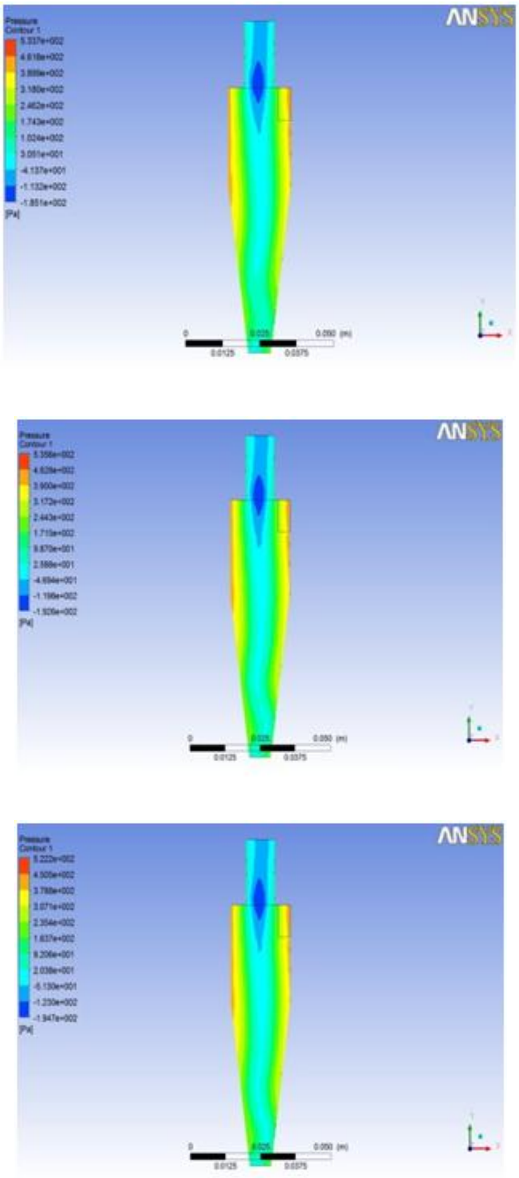


Fig 10: variation of pressure along the radial distance (x-axis) at z=0

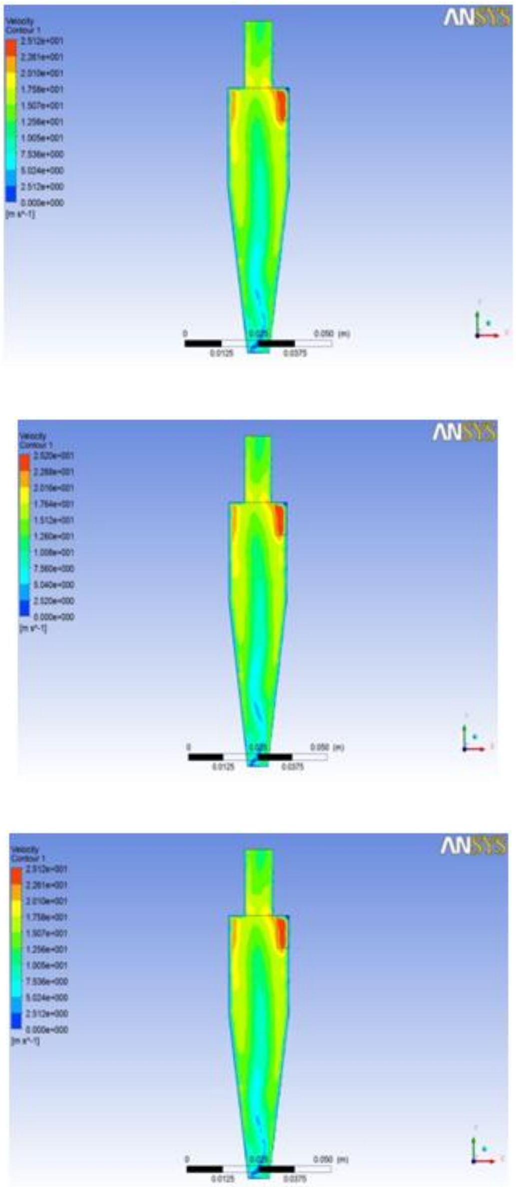
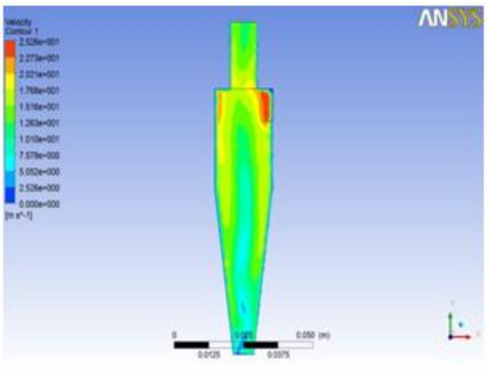


Fig 11: variation of velocity along the radial distance (x-axis) at z=0.

Velocity contours



The results are concluded that the cone height has significant effect on the performance of the cyclone. The pressure in the cyclone varies along the X-axis as shown in the contours. The pressure first decreases and then increases. The minimum pressure occurs at the mid section (x=0). The graph shows the variation in the pressure along the radial direction. The curve is in U shape explains the decrease and increase of pressure. The velocity in the cyclone first increase from the centre and then decreases at the wall.

The curve will be in M shape or reversed W shape. The velocity is high at the middle portion of the center and the wall.The variation in the flow temperature slightly varies the pressure for every 20k. The velocity of the flow doesn't vary with the temperature. So we can say that the temperature cannot affect the performance of the cyclone because of the slight variations we can neglect the effect of temperature.

The Analysis of Stairmand's Design with Collector

The collector is the attachment to the cyclone where the particles are collected. Collector is of any shape (ex: cube, cylindrical). It locates at the end of the cone tip and it prevents the re-entertainment of particles. In this analysis a cube shaped collector is provided at the bottom (with dimensions 15mm*15mm*15mm). The same set up is used to simulate the cyclone with collector.

Cyclone Geometry with Collector

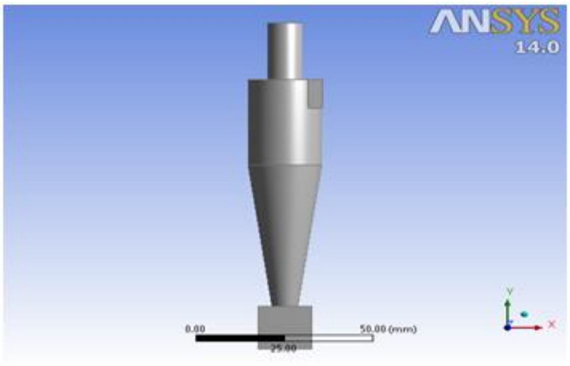


Fig 12: geometry of cyclone with collector

Meshing Of the Cyclone with Collector

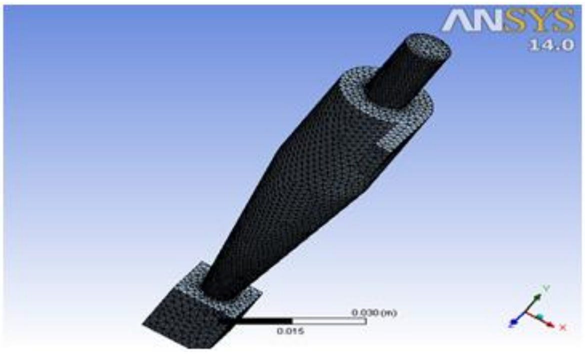


Fig 13: mesh of the cyclone with collector

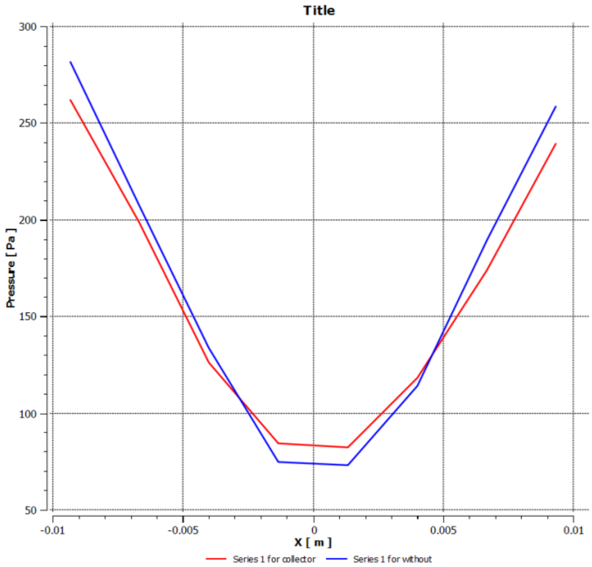
The solution of the simulation of the cyclone with collector is compared with the cyclone without collector. The variations in pressure and velocity are noted and compared & the cyclone performance is justified.

Table 4: the pressure and velocity readings

	Without collector	With collector
Max pressure (pa)	418.5	403.4
Mini pressure (pa)	-66.28	-55.11
Max velocity (m/s)	23.65	23.5
Mini velocity (m/s)	0	0

Graphs

The graphs are drawn by taking the y-axis as pressure/velocity and x-axis as radial distance along X



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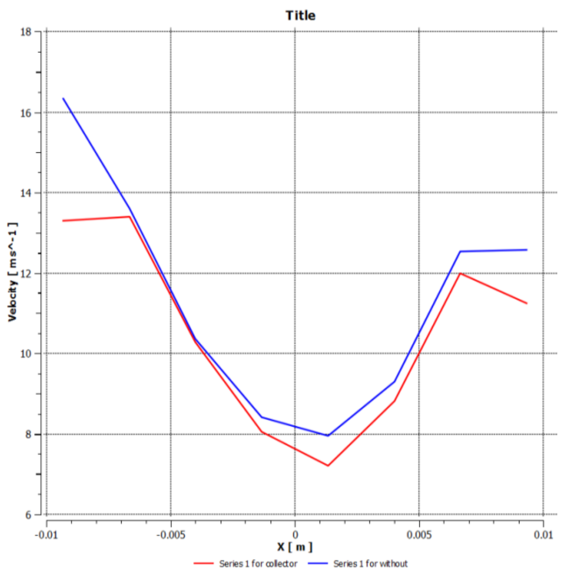

Fig 14: variation of pressure and velocity

The results are concluded that the cone height has significant effect on the performance of the cyclone. The pressure in the cyclone varies along the X-axis as shown in the contours. The pressure first decreases and then increases. The minimum pressure occurs at the mid-section (x=0). The graph shows the variation in the pressure along the radial direction. The curve is in U shape explains the decrease and increase of pressure. The velocity in the cyclone first increase from the centre and then decreases at the wall. The curve will be in M shape or reversed W shape.

The velocity is high at the middle portion of the center and the wall.The study shows that the collector doesn't have much effect on the cyclone performance. There are slight variations in the pressure and velocity which can be neglected.As a last remark, from both the experimental and simulation points of view, the grade efficiency is the final result of a combination of geometry, flow conditions and particle dynamics. It thus conveys all the errors possibly incurred in each measurement/calculation. Taking into account the complexity of the very intrinsic phenomena present in the gas–solid flow in cyclones, the results for the grade efficiency are need to be studied further.

V. CONCLUSION

After studying the existing literature and performing analysis on certain cyclone parameters, the following conclusion can be drawn:

- The separation mechanism inside cyclone separators is not well understood yet, and needs more investigations.
- Nearly all published articles have no systematic and complete study for the effect of geometrical parameters on the flow field and performance
- In all operating conditions and cyclone types the FLUENT CFD wasfound to be much closer to the experimental measurement.
- This project is done taking into consideration single parameter at a time, the results may vary if multiple parameters are taken at a time.
- Some parameters have less interest compared with others like the effect of vortex finder shape and number of inlet sections.

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