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CFD Simulation of the Fluid Flow, Pressure Drop and Turbulence Parameters in a Standard Cyclone Separators

Kalaiarasan R[1], Vivekanandan M[2], Gokul Prasath B[3], Muthupandy P[4], Karthikeyan N[5]
[1,2,3] PG Student, MAM College of Engineering and Technology, Trichy, Tamil Nadu, India
[4,5] UG Student, Anna University Chennai, BIT Campus, Trichy, Tamil Nadu, India

Abstract— The CFD simulation of the fluid flow pressure drop and Turbulence is presented by CFD techniques to characterize the performance of the three types of standard cyclones the three types of cyclones named 1D3D, 2D2D and 1D2D. The length of cylindrical part of the body is equal to 1, 2 and 1 times of the body diameter, respectively; and the length of the conical part is 3, 2 and 2 times of the body diameter. Transient numerical simulation is applied for varying inlet velocities from 5, 10, 15 and 20 m/s. This article quantifies the inlet velocities at which maximum collection efficiencies are obtained for 1D3D, 2D2D and 1D3D cyclones and the marginal pressure drop associated with reaching these collection efficiencies. Turbulence parameters are also studied for these cyclones. From inference of the three numerical simulation models of standard cyclone, it was observed that cyclone of geometry 1D3D is optimal for fluid flow, pressure drop and turbulence parameters..

Index Terms— CFD, Cyclone, Pressure Drop , 1D2D,2D2D,1D3D

1 Introduction

Cyclones are widely used in the air pollution control and gas– solid separation for aerosol sampling and industrial applications. With the advantages of relative simplicity to fabricate, low cost to operate, and well adaptability to extremely harsh conditions, the cyclone separators have become one of the most important particle removal devices which are preferably utilized in scientific and engineering fields

Since cyclones have been used extensively in various industries, a considerable number of experimental, numerical and theoretical investigations have been performed on the cyclone separators to the present. Among those, Stairmand [1] presented one of the most popular design guidelines which suggested that the cylinder height and the exit tube length should be, respectively, 1.5 and 0.5 times of the cyclone body diameter for the design of a high efficiency cyclone. In the agricultural processing industry, 2D2D cyclone (Shep- herd and Lapple [2,3]) and 1D3D cyclone (Parnell and Davis [4]) designs are the most commonly used abatement devices for particulate matter control. The D in the 2D2D designation refers to the barrel diameter of the cyclone. The numbers preceding each D relate to the length of the barrel and cone sections, respectively. A 2D2D cyclone has a barrel and cone lengths two times the barrel diameter, whereas a 1D3D cyclone has a barrel length equal to the barrel diameter and a cone length of three times the barrel diameter. Parnell and Davis [4] first developed a 1D3D cyclone for cotton gins in an attempt to provide a more efficient fine dust collector. This cyclone design is referred to as the traditional

1D3D cyclone. Holt and Baker [5] and Funk et al. [6] conducted fur- ther experimental research on this cyclone design and reported a significant improvement in efficiency by modifying the traditional

1D3D design to employ a 2D2D inlet. This modified 1D3D cyclone design is referred to as 1D3D in this article (Fig. 1a and Table 1). Wang [7] indicated that, compared to other cyclone designs,

1D3D and 2D2D are the most efficient cyclone collectors for fine dust (particle diameters less than 100 lm). Mihalski et al. [8] re- ported ‘‘cycling lint’’ near the trash exit for the 1D3D and 2D2D cy- clone designs where the Particulate Matter (PM) in the inlet air stream contained lint fiber. Mihalski reported a significant increase in the exit PM concentration for these high efficiency cyclone de- signs and attributed this to small balls of lint fiber ‘‘cycling’’ near the trash exit causing the fine PM that would normally be collected to be diverted to the clean air exit stream. Simpson and Parnell [9] introduced a new low-pressure cyclone called the 1D2D cyclones for the cotton ginning industry to solve the cycling-lint problem. Wang.et.al.[7,10] studied the three afore mentioned cyclones simultaneously and they proposed a mathematical model for calculating pressure drop, number of active turns for the cyclones.

For a given gas flow rate and inner and outer radii, how long must the body of the cyclone be to ensure that a desired collection efficiency for particles of a given size be attained? Since the length of the body of a cyclone is related through the gas flow rate to the number of turns executed by the gas stream, the design problem is often posed in terms of computing the number of turns needed to achieve a specified collection efficiency.

2 Flow Simulation

2.1 Dimensions

Figure 1 shows the dimension parameters of the standard cyclone and figure 2 expalins the dimesions of 1D3D, 2D2D , 1D 3D Cyclones

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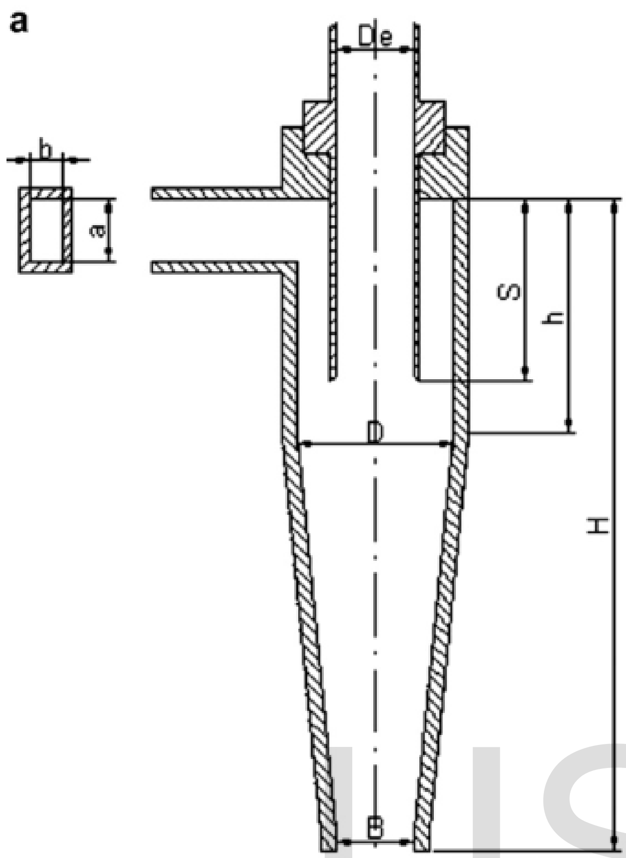
Fig 1 : Dimensional parameters of standard cyclone



Dimensions	*1D3D* cyclone	*2D2D* cyclone	*1D2D* cyclone
Cyclone diameter, *D*/*D*	1	1	1
Vortex finder diameter, D_e/D	0.5	0.5	0.625
Inlet height, *a*/*D*	0.5	0.5	0.5
Inlet width, *b*/*D*	0.25	0.25	0.25
Outlet height, *S*/*D*	0.625	0.625	1.125
Cyclone height, *H*/*D*	4	4	3
Cylindrical body height, *h*/*D*	1	2	1
Dust outlet diameter, *B*/*D*	0.25	0.25	0.5

Fig 2 : Dimesions of standard cyclone

2.1 Mesh and Grid Details

All the 3 cyclones are meshed with cosmos xpress software and grid details are sjown in figure 3, figure 4 shows the meshed view of 1D2D cyclone

2.2 STANDARD K - Є MODEL

The turbulence models are the two-equation models. The simplest one is the standard k - ϵ model, which is proposed by Launder and Spalding. It is widely used in turbulence simulations because of its general applicability, robustness and economy. The two transport equations for the kinetic energy and dissipation rate are solved to form a characteristic scale for both turbulent velocity and length. These scales represent the turbulent viscosity. The modeled transport equations for K and Є in the realizable K - Є model are

In these equations, Gk represents the generation of turbulence kinetic energy due to the mean velocity gradients. Gb is the generation of turbulence kinetic energy due to buoyancy. Ym represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate. C2 and C1Є are constants. σ are the turbulent Prandtl numbers for K and Є respectively

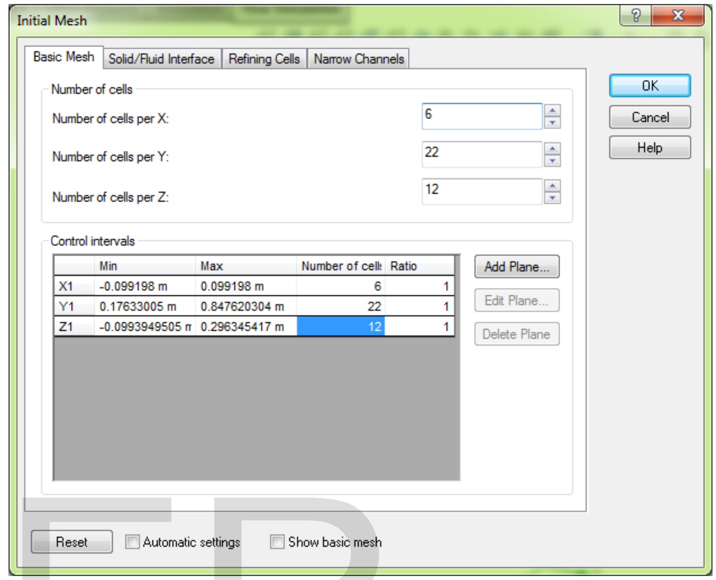


Fig 3 : Grid of details of standard cyclones

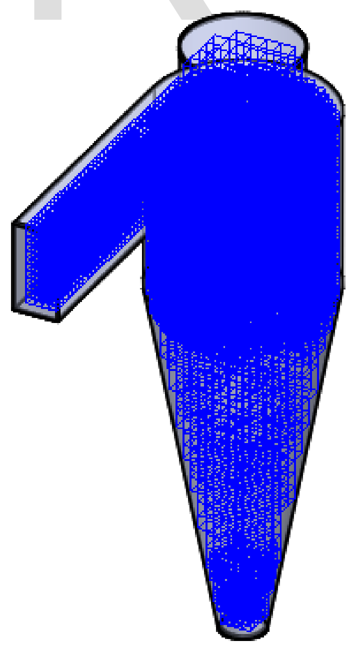


Fig 4 : Meshed View of 1D2D cyclone

3 Results and Discussion

Three types of standard cyclones with the names of 1D3D, 2D2D and 1D2D which were tested by the previous researchers have been numerically investigated. Geometries of the cyclones are shown in Fig. 1 and Fig 2.

3.1 Axial Velocity

The velocity field in a cyclone has three components: tangential, axial and radial. Since the flow is strongly swirling, the tangential velocity component is more important than the axial and radial components. In this study, the axial velocity is investigated in the different sections
of cyclones by CFD. Velocity profiles are numerically obtained along the radial orientation at three axial stations in the cyclones.

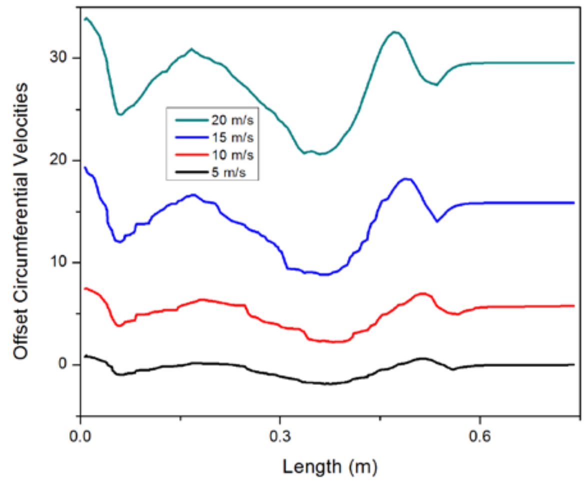


Fig 7 : Axial Velocity plot of 1D2D Cyclone for different flow rate

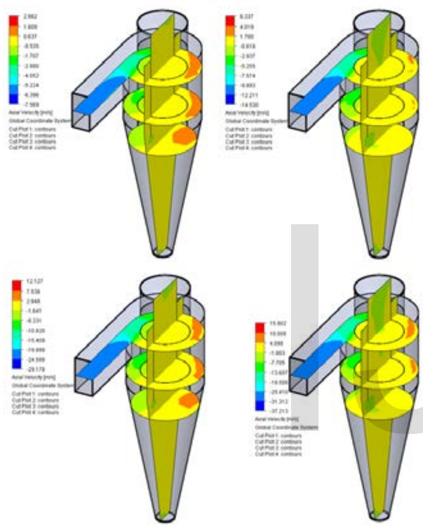


Fig 5 : Axial Velocities for 1D2D Cyclone

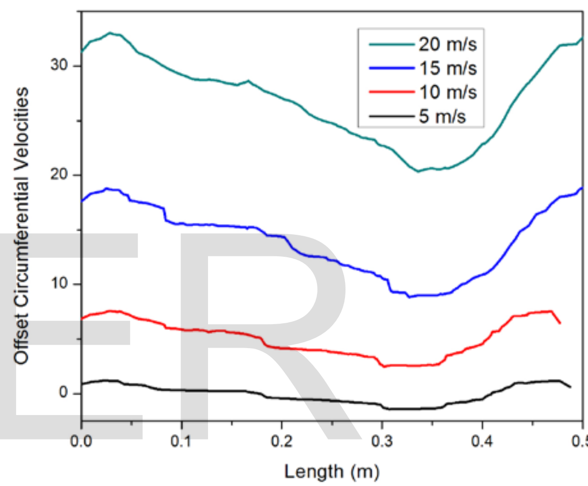


Fig 8 : Axial Velocity plot of 2D2D Cyclone for different flow rate

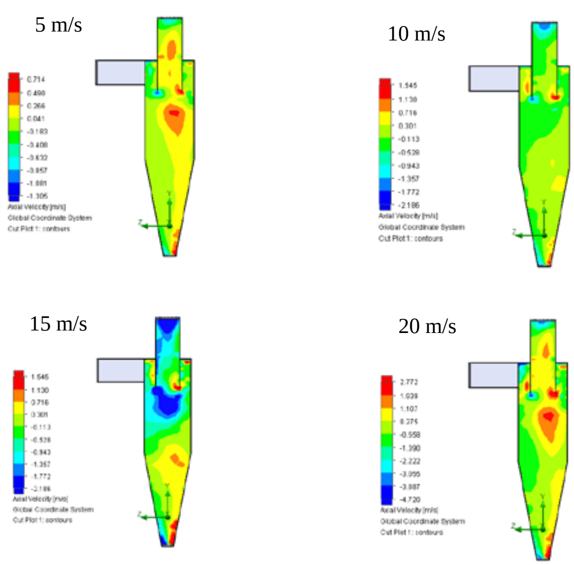


Fig 6 : Axial Velocities for 2D2D Cyclone

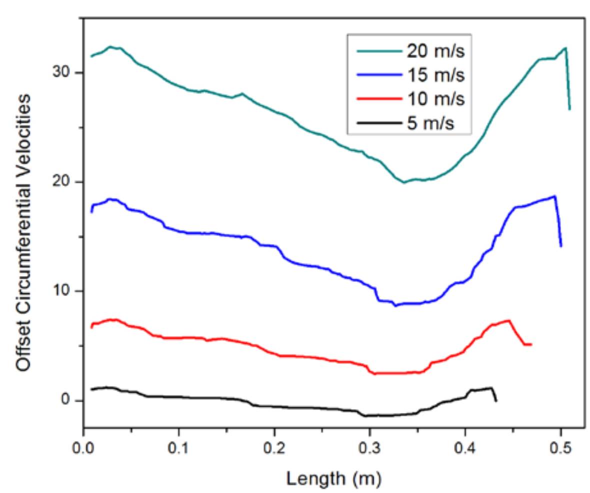


Fig 9 : Axial Velocity plot of 1D3D Cyclone for different flow rate

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3.2 TURBULANCE INTENSITY

The contours of turbulence intensity for three different cyclone Fig. 10. As shown, 2D2D and 1D3D has a maximum value of turbulence intensity at the entrance of vortex finder but in 1D2D which has bigger vortex finder diameter, the maximum value of turbulence intensity occurs at the entrance of cyclone

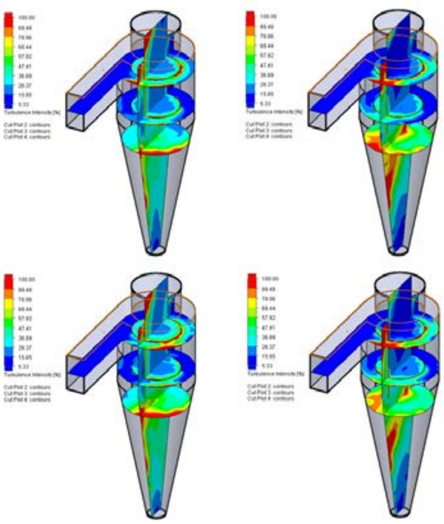

Fig 10 : Turbulence intensity of 1D2D Cyclone for different flow rate

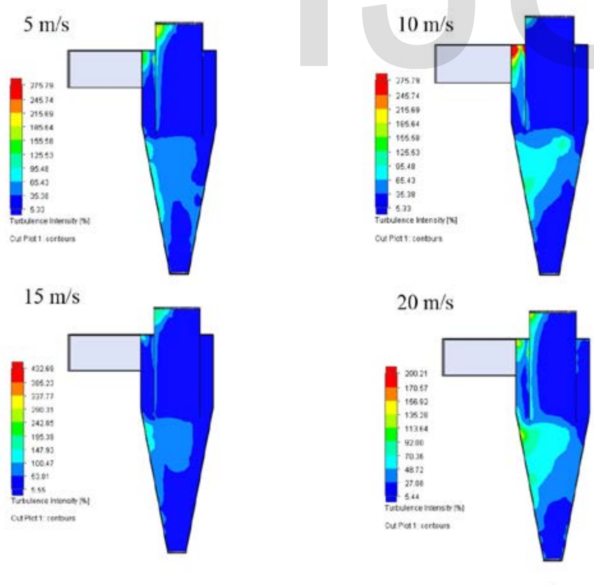

Fig 11 : Turbulence intensity plot of 1D3D Cyclone for different flow rate

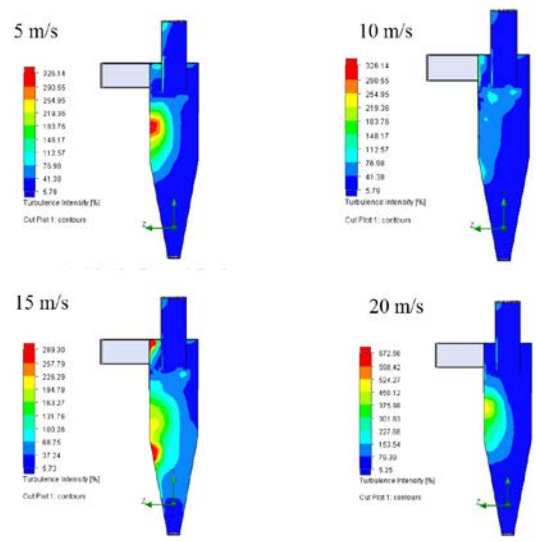

Fig 12: Turbulence intensity of 1D3D Cyclone for different flow rate

3.3 PRESSURE DROP

The total pressure drop in a different cyclone, by taking it as a sum of pressure drops due to friction on the cyclone wall, and the hydrodynamic loss in the inner vortex
Pt=Pf + Pi
This goal of this section is find the optimized cyclone from three different cyclone

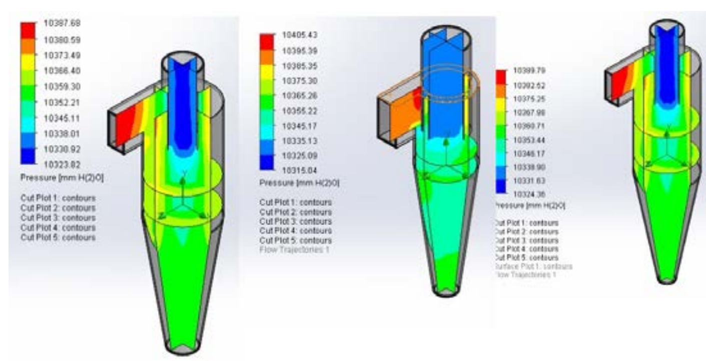

Fig 13: Pressure plots for differernt cyclones

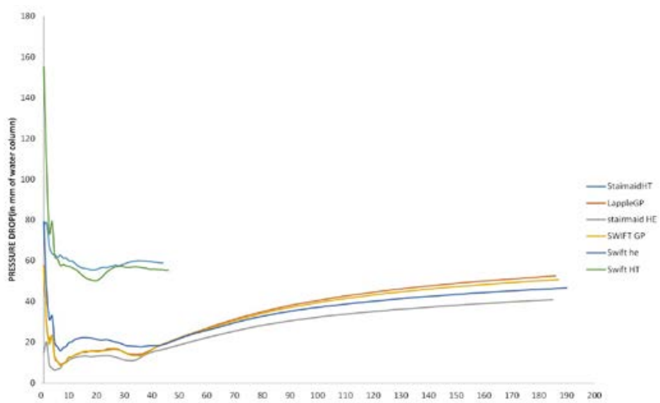

Fig 14: Pressure drop plots for differernt cyclones

4 Conclusions

A numerical approach is employed to study the flow in three standard types of cyclone 1D3D, 2D2D and 1D2D. The flow field parameters at the different flow rates are numerically investigated. The pressure drop velocity and the turbulence intensity for three cyclones at different flow rates are computed and compared. Based on the presented results the following conclusions may be drawn

i. Obtained results show that CFD is a powerful tool for the study of the flow in cyclones and can be used for optimization purposes
ii. The numerical and experimental analyses showed that the pressure drop, velocity and turbulence are almost independent of cyclone body diameter and 1D2D type has the least dependency on body diameter.
iii. In an equal inlet velocity, the least and the highest turbulence intensity for these three cyclones are almost equal.
iv. As shown the magnitude of axial velocity in 1D2D is less than the two other cyclones, and this fact leads us to the conclusion that 1D2D cyclone is not an efficient one

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