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Impact of Baffle and Cone Roughness on the Performance of a Solid-gas Separator Cyclone

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***Abstract*:** *In this paper, the influences of the helical baffle inside the cylindrical part of a cyclone with an initial pitch length of L = and cone roughness with a height of 0.2 mm on the operation of the basic parameters of a reverse flow cyclone are evaluated numerically using ANSYS Fluent software. The simulations are performed using the RSM turbulence model and Eulerian-Lagrangian approach. The simulation results show that for the cases of 0.5 and 1.5 turns of the helical baffle, the maximum and minimum values of tangential velocity is observed, respectively. It is found that by increasing the baffle pitch length and applying roughness, the pressure in the center of the cyclone becomes more negative. In all cases, the placement of the baffles and application of roughness leads to the pressure drop decreases. Also, the roughness and more turns of the baffle weaken the central vortex of the cyclone. It is also concluded that the separation efficiency is more than 50% when baffle is mounted in the cyclone.*

Keywords: *RSM turbulence model, Eulerian-Lagrangian, Helical baffle, Cone roughness, Separation efficiency, Pressure drop*

1. Introduction

Gas flow processes in the industry include solid suspended particles of different sizes that require rapid separation. Among the various particle separation devices, cyclones are often recommended due to their simple structure, low maintenance costs, low cost, and high separation performance. The two main parameters of cyclones are pressure drop and separation efficiency. Many researchers have studied the geometric conditions of cyclones and reported the great impact of these parameters on the performance of cyclones, and considered that achieving an optimal cyclone requires a careful study of geometric conditions [1-3]. Yoshida et al. [4] examined the different angles of the cone of the cyclone and found that decreasing the cone angle enhances the separation efficiency. El-Sayed and Lacor [5] evaluated the effects of inlet dimensions and cyclone cone diameter on the flow pattern and cyclone performance. They found that the input dimension and the cyclone diameter have major effects on the cyclone flow pattern and performance. Zhang et al. [6] performed numerical simulations of flow in a cyclone separator to improve particle separation efficiency and reduce pressure drop compared to conventional cyclones. Brar et al. [7] investigated the effect of vortex diameter in the fluid flow field and cyclone particle separation efficiency. In this research, five different diameters of vortices were determined by using ANSYS Fluent software. Hoekstra et al. [8] performed an experimental study of a cyclone by laser beam method. In this study, tangential and axial velocity patterns were measured at different sections of fluid flow.

In this study, a helical baffle is utilized to accelerate and increase the centrifugal force of the fluid-particle flow in the cylindrical part of the cyclone. Simultaneously, 0.2-mm roughness is applied on its conical part and important cyclone performance parameters are estimated. The Reynolds stress method (RSM) is considered for turbulence fluid flow and the Eulerian-Lagrangian model is utilized for solid particles. Pressure drop, tangential velocity, and particle separation efficiency are determined.

2. Problem description

In the present study, the performance of a cyclone is evaluated by placing a helical baffle with different pitch lengths in its cylindrical area. A 0.2-mm roughness is also applied on the conical part. The baffle is considered in 3 modes of 0.5-turn, 1-turn, and 1.5-turn with variable pitch length. The first step is L and the second step is 0.8L. The first pitch is L = 160 mm and the second one is 128 mm. The length of the vortex finder that is placed inside the chamber is equal to the baffle length. The baffle guides the solid-gas flow in a stronger rotation, resulting in a powerful outer vortex in the cyclone. The baffle causes a strong particle accelerator, resulting in a stronger impact and greater tangential acceleration of the particles to the walls to lose the inertial force. At the same time, the presence of roughness can help the process of separating larger particles as well as reducing the pressure drop. Numerical simulations are done using ANSYS Fluent software and particle tracking is analyzed by employing the Eulerian-Lagrange method. The results are compared with the Hoekstra cyclone. Fig. 1 shows a schematic of the cyclone, and Table (1) presents its dimensions.

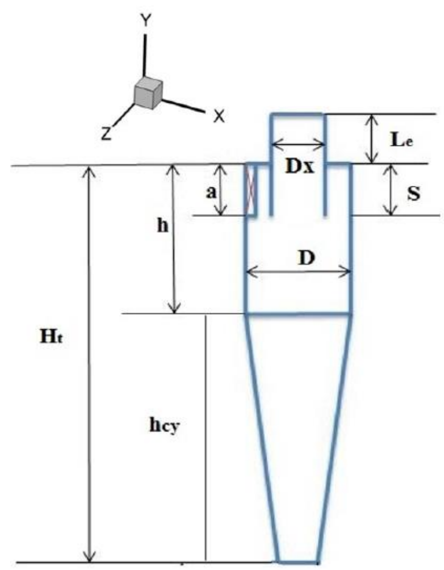

Fig. 1: Schematic of the problem studied in the present work.

TABLE I: Dimensionless ratio of cyclone dimensions

Dimensions	(m)
Body diameter(D)	290
Inlet height, a	145
Inlet width, b	58
Gas outlet diameter, Dx	145
Gas outlet duct length, S	290
Height of cyclone, Ht	1160
Inner cone height, h	435
Height of cone, Hc	725

3. Governing equations

The flow in the cyclone is three-dimensional. The fluid is considered an isotherm and incompressible. For such a flow, Reynolds averaged Navier-Stokes equations and mass conservation equations are as follows [9]:

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial u_i \partial u_j} - \frac{\partial}{\partial x_i}\left(\overline{\acute{u}_i \acute{u}_j}\right) \tag{2}$$

where u_i is the average velocity, P is pressure, x_i is the length characteristic, ν is kinematic viscosity, and ρ is the gas density. Due to the low particle concentration (volume fraction less than 15%), it can be assumed that the particle collision and its effect on fluid flow is negligible. These conditions are introduced as one-way coupling [1] for particle tracking. For suspended particles, the equilibrium equation of force is as follows:

$$\frac{du_{pi}}{dt} = F_D\left(u_i - u_{pi}\right) + \frac{\left(\rho_p - \rho\right)}{\rho_p} g + F_i \tag{3}$$

In the above relation u_{pi} is particle velocity, F_D is the particle drag force, ρ_p is particle density, g is gravity acceleration and F_i is external force such as Brownian force and Soffman lift force.

4. Grid study

Creating a proper grid to solve the governing equations of the model is one of the most important parts of modeling. In the present work, polyhedral elements are used. The advantage of using this grid is the high speed and accuracy of convergence (Fig. 2).

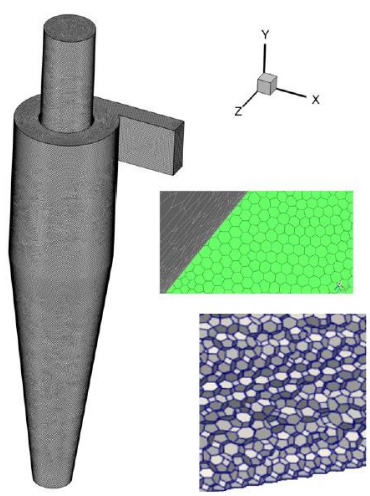

Fig. 2: The grid used in the present work.

For grid independence test in the present work, five grids with 336237, 539701, 622482, 876489, and 1184071 elements are examined. As can be seen in Table 2, by increasing the elements from 622482 to 876489 and 1184071, the pressure drop changes in the cyclone are negligible. Thus, in the present study, the number of cells of 622482 is considered as a solution.

TABLE II: Pressure drop for different grid resolutions.

No. of elements	Pressure drop
336237	956
539701	720
622482	761
876489	753
1184071	757

5. Results

The gas enters the cyclone tangentially at a velocity of 30 m/s. After passing the path of the outer vortex and reaching the end of the cyclone, an inner vortex is formed in the opposite direction of the outer one due to the creation of the reverse pressure gradient. Due to the centrifugal force and the impact of particles on the wall, the separation of particles from the gas flow occurs. The SIMPLEC algorithm is used for the coupling of velocity and pressure. Table 3 shows other numerical solution methods used in this research.

TABLE III: Numerical solution method used in this research.

Numerical setting	Scheme
Pressure discretization	PRESTO
Momentum discretization	QUICK
Turbulent kinetic energy	Second order upwind
Turbulent dissipation rate	Second order upwind
Reynolds stress	First order upwind

The dimensionless tangential velocity contours on the X = 0 plane is shown in Fig. 3. Tangential velocity contours are similar in all cases. The tangential velocity from the wall to the axis of the cyclone first increases and then decreases. Symmetry in the contours indicates the formation of two outer and inner vortices in the cyclone chamber and in opposite directions. The presence of the zero velocity zone (minimum tangential velocity) in the central core (central axis) of the cyclone is observed in all cases. By increasing the number of turns of the baffle and also the presence of roughness on the conical section, the tangential velocity is reduced due to losses and friction. The inner vortex area is defined as the zero velocity zone. It is observed that in high tangential velocity modes, more rotational flows occur in this plane. The maximum tangential velocity, negative and positive, is formed around the baffle. Fine roughness in the conical part where the pressure changes direction causes the boundary layer to shift and the gradients to move toward the center of the cyclone. The roughness of the cylindrical section reduces the rotational flows in the center of the cyclone. The roughness also reduces the turbulence of the flow on the cyclone central plane.

Fig. 4 shows the comparison of pressure drop in 4 cyclone modes with different baffle turns and the roughness of different conical sections. No pressure drop. As can be seen, in all cases, the lowest pressure in the vortex section is forced outwards of the cyclone and the pressure gradient increases from the cyclone axis to the walls. It can be seen that the main effect of the baffle is on the static pressure in the outer vortex area. But, the baffle can also affect the diameter of the inner vortex area. For the case of 0.5-turn of the baffle, a distortion is observed in the inner vortex area, which can be due to the forced rotation of the flow around the baffle at the entrance to the cyclone chamber. The roughness of the conical section weakens the inner vortex of the cyclone. It can be seen that positive pressures decrease from 7300 to 5000 Pa but negative pressures increase from 300 to 1400 Pa. The pressure drop in a cyclone is due to the energy loss of vortices and rotational flows, which is caused by friction between the gas and particles. Reducing pressure drop has negative effects on cyclone separation efficiency.

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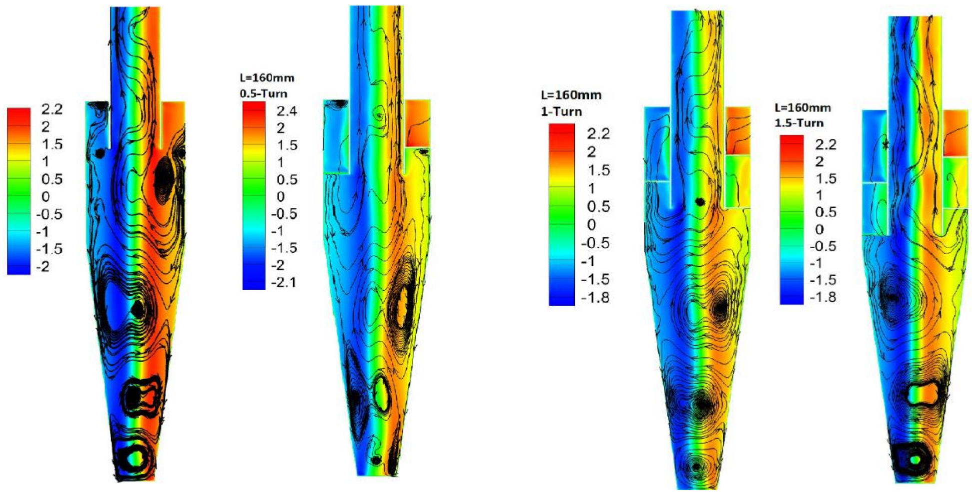

Fig. 3: Tangential velocity contours for the cyclone with different baffle turns.

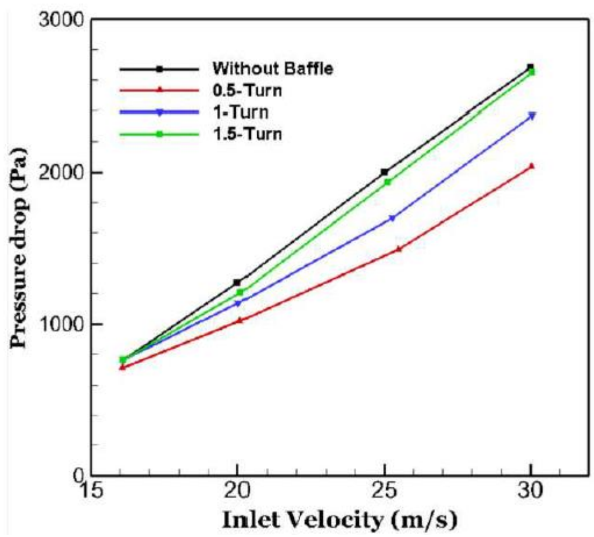

Fig. 4: Comparison of pressure drop for four inlet velocities.

Fig. 5 shows the particle separation efficiency for different inlet velocities and various baffle turns. As can be seen, in all three baffle cases, particles with a diameter of less than 1.5 μm have higher efficiency, which is due to the acceleration and orientation of the particles, as well as the presence of roughness on the conical part. By increasing the particle diameter due to the short separation time, the efficiency in the conical section decreases. It is noteworthy that the particle separation process in the cyclone Hoekstra starts from the cylindrical part to the bottom of the chamber. It is observed that the particle separation of 50% of particles in the proposed cyclone is 1.24, 1.02, 1.2, 1.32 μm, respectively, compared to the Hoekstra cyclone However, there is not enough time to separate these larger particles for the separation of larger particles and an efficiency of 10% due to the movement of the baffle near the cone section. As a result, the separation curve moves towards larger diameter particles. At all diameters of less than 1.6 μm, better separation is observed by the proposed cyclones.

6. Conclusions

In this study, effective parameters of a cyclone separator, including tangential velocity, pressure drop, and particle separation efficiency are investigated by applying the baffle with different turns and applying a roughness height of 0.2 mm on the conical wall. The results are as follows: 1- For the cyclone with a 0.5-turn baffle, most of the tangential velocity inside the cyclone is enhanced. 2. As the inlet velocity increases, the pressure drop between the inlet and outlet of the cyclone increases due to the loss of viscosity due to the rotation and reverse motion of the fluid flow. 3- The minimum and maximum pressure drop corresponds to 0.5 and 1.5 turns. 4- By increasing the particle diameter due to the short separation time, the efficiency in the conical section decreases.

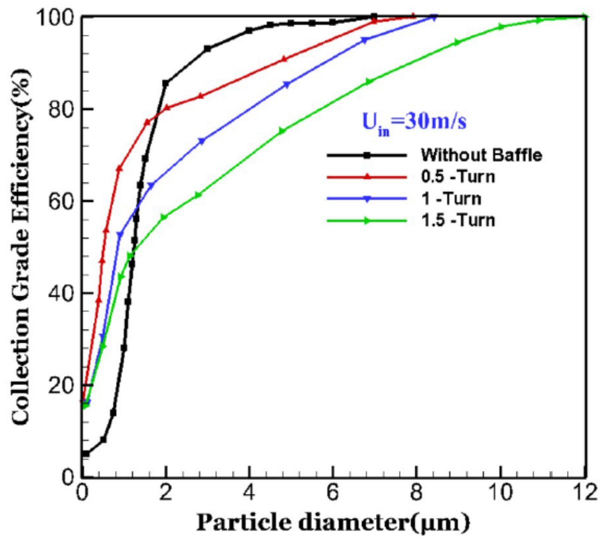

Fig. 5: Particle separation efficiency for a cyclone with different baffle turns.

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