The Effect of the Outlet Geometry on the Velocity Profiles of Hydro cyclones

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Abstract—: The present study aims at investigating the effects of different shapes of the overflow tube on the pressure drop in the hydrocyclone. The pressure drop is a measure of the energy required to operate a hydrocyclone unit, and due to its continuous operation, the lowest possible value is preferred. Three different models are analyzed viz. the tapered overflow tubes and a standard model. The former consists of two variants: the first with inclination of 2° inwards (referred to as HC1) and the second with inclination of 2° outwards (referred to as HC3), whereas the latter variant is a straight tube with no inclination (referred to as HC2). Block structured mesh has been generated using ICEM CFD with cell faces aligned along curved streamlines to reduce numerical diffusion.

Large-eddy simulation (LES) is used to directly resolve large eddies, whereas the smaller eddies are modeled with standard Smagorinsky model. The simulation has been carried on in Hsieh and Rajamani hydrocyclone model using LES which has no deviation in the vortex finder. Flow is developed in steady state and dust particles were injected after the air-core formation in transient state. Same working conditions were applied on the altered hydrocyclone models. The codes of ANSYS Fluent has been used for numerical study.

Conclusive results indicate that the pressure drop is highly sensitive to the shape of the overflow pipe in hydrocyclones. This study points out the main factors of improving performance of hydrocyclones which simplifies the decision making of engineers.

Keywords: **Axial velocity, Collection efficiency, Large-Eddy Simulation (LES), Overflow, Renormalized group (*RNG* k-ε), Reynolds Stress Model (RSM), Underflow, Vortex**

I. Introduction

A hydrocyclone is a static structure with no moving parts which takes advantage of centrifugal force to separate solid impurities from fluid. Hydrocyclone is a unique design with on tangential inlet and two outlets along its axis; one at the top known as overflow and the other referred to as underflow. Fluid along with solid particles are injected through the inlet at high velocity. The tangential inflow of fluid results in circular motion inside creating a vortex developing centrifugal force which pushes the solid relatively heavier particles to move towards the outer region resulting in lower kinetic energy and gets exhausted through the underflow. While the relatively lighter particles remain at the inner vortex region and gets released through the overflow. The basic model of a hydrocyclone is described in figure 1.

The anisotropic flow of fluid inside a hydrocyclone makes the study of fluid motion complex. This complexity can be reduced by the help of Computational Fluid Dynamics (CFD) [1]. Engineers have been using Computational Fluid Dynamics since 20th century to detect the flow inside and find ways of optimizing the use of hydrocyclones. With the help of advanced computers complex flow pattern can be studied at a faster speed [2]. Modifications in the hydrocyclone design changes the flow pattern greatly which can be solved using CFD. The velocity field has to be computed by resolving the Navier-Stokes equation [3]. There are various methods to resolve these equations out of which the simplest yet most computationally intense approach is the Direct Numerical Simulation (DNS) method. Even for highly sophisticated supercomputers the high number of mesh becomes very costly [4]. The number of mesh and its size greatly impacts the simulation time and results obtained. For better results of complex fluid flow, high number of mesh is required [5]. Other than DNS method, the Large Eddy Simulation (LES), Renormalized-group (RNG k-ε) and Reynolds Stress Model (RSM) are also used for calculating fluid flow. Three models have been used to model the turbulence of the hydrocyclones. The study concluded that the vortex core and velocity profiles can be resolved by all the three approaches. Out of which LES shows the most promising result.

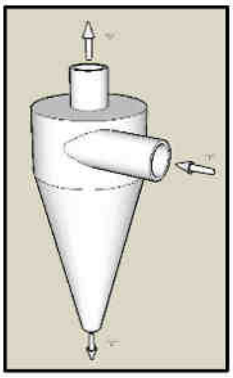

Fig. 1. Design of a Hydrocyclone where "1" represents inlet, "2"&"3" refers to underflow and overflow respectively

II. Procedure and Validation

Before proceeding with the numerical study graphical representation is used to validate the simulated result with the experimental data. Hsieh and Rajamani's (1988) velocity profile mapping of 75 mm hydrocyclone have been utilized for verification [6]. The simulated results of velocity profiles were compared at different axial locations, air core diameter formed and grade efficiency as obtained

Manuscript received March 30, 2020

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by the simulation RSM model, RNG K-ε model and LES model were compared with the experimental values. The predicted results of velocity profiles at axial stations 60mm, 120mm and 170mm from the top were validated. The same base model used in the work of Delgadillo [7] was validated using the same parameters and working conditions. After verification of the base model, certain changes in the outlet geometry was taken into consideration keeping other dimensions unaltered and their performance, velocity profiles, air-core formation are compared with the base model.

A. *Velocity profile comparison at different axial stations:*

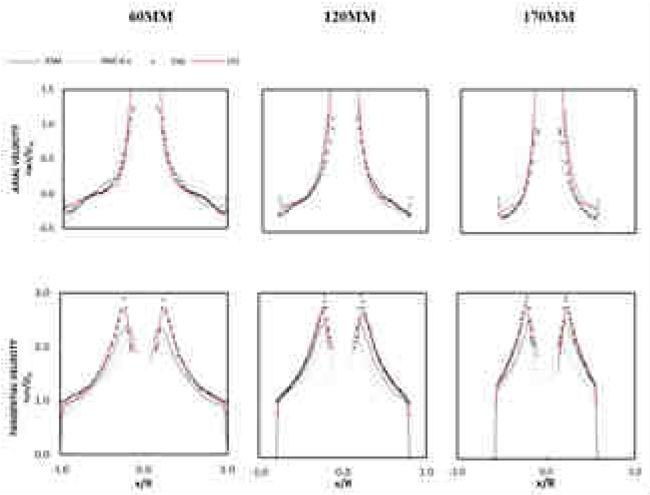

Fig. 2. Comparison of experimental data with RSM, RNG k-ε & LES model for axial and tangential velocity

The above graphs represent the comparison between experimented results with simulated RSM, RNG K-ε and LES models. The columns from left to right determine the three axial station viz. 60mm, 120mm and 170mm from the top. The top row represents the axial velocity comparison while the lower row of graphs represents the tangential velocity comparison. The diagrams have been standardized for accommodation, with the radial distance along the X-axis is divided by the radius of the hydrocyclone and the velocity values along the Y-axis is divided by the inlet velocity.

All the three models show relatively promising results for axial velocity at the three axial stations. On the other hand, for tangential velocity both RSM and RNG K-ε model under predicts the experimental values at the inner core region at all the three axial stations; while LES shows the most precise values along the inner core on all three axial stations.

B. *Grade Efficiency of hydrocyclone using three models:*

The grade efficiency is the ratio of number of particles collected through the underflow to the number of particles injected through the inlet [8]. In our research we have considered the inflow of 12220 particles entering at 2.28 m/sec. It is determined according to how well particles are distinguished and separated according to size and density. It was first stated well by Svarovsky. [9]. The variation in efficiency of the classification process is known as the grade efficiency curve. The heavy particles or the particles with relatively larger diameter exit through the underflow where they are collected [10]. Henceforth, the efficiency of heavy particles reaches to an almost 90% whereas the light particles or the particles with small diameter flow upward along the inner vortex and exits through the overflow. Since our grade efficiency calculation is based on the number of particles exiting the underflow, the efficiency of relatively smaller particles shows lower efficiency. The comparative graph study between the experimental separation efficiency to particle size with simulated grade efficiency of RSM, RNG k-ε and LES model is shown below. The collection efficiency of a hydrocyclone is calculated by the formulae as shown below [11]:

$$\Delta\eta = \frac{m_c f_c \Delta D_p}{m_c f_c \Delta D_p + m_f f_f \Delta D_p}$$

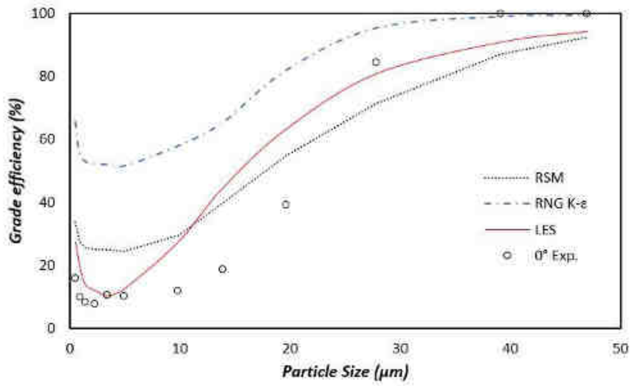

Fig. 3. Grade efficiency comparison of RSM, RNG K-ε and LES model with experimental data

The RSM model slightly underpredicts grade efficiency for particles having diameter greater than 25 microns and slightly overpredicts for particles below that range. The RNG K-ε model shows unrealistic results which overpredicts the grade efficiency for all particle sizes. Whereas the LES model shows the most promising result. The values as obtained from LES model simulation are very realistic and accurate as compared to the other two models. From the above discussions it is very evident that LES model shows the most accurate result for validation purposes, hence for the altered geometry of hydrocyclone, LES model simulation is considered for further numerical studies.

III. RESULTS AND DISCUSSION

The LES model has proven to be the most reliable model for numerical studies as observed during validating the results of the base model hydrocyclone chosen than RSM and RNG K-ε model. For this reason, the hydrocyclones with altered geometry; 2° inward tapered and 2° outward tapered overflow tube are calculated using LES method. All the parameters and working conditions have been kept same as during validation process. The pre-processing part such as mesh size, mesh number, inlet velocity and pressure have been kept same.

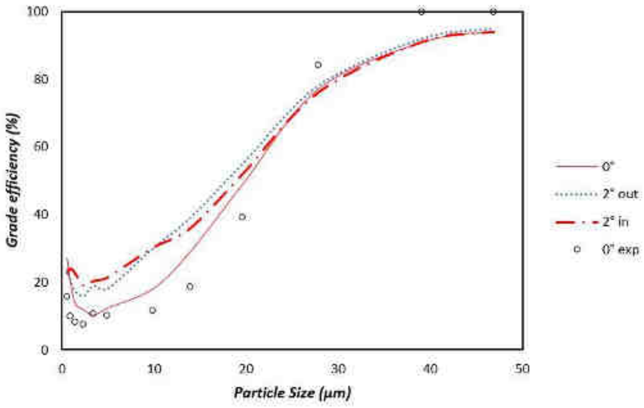

Fig. 4. Grade efficiency comparison of altered hydrocyclone models

From the above graph it is evident that grade efficiency for particles having higher diameter have equal discharge rate irrespective of variation in over flow geometry. However, for smaller particles the discharge rate through the underflow is relatively lower in inward tapered (HC1) than in outward tapered overflow. The smaller particles of HC3 have relatively lower grade efficiency than HC1. The particle size has been denoted in the X axis and Grade efficiency have been graded in the Y axis. The discharge rate of particles through the underflow have been graded and since heavier particles have higher masses, so the centrifugal acting on them is higher resulting in the collision of them with the inner wall of the hydrocyclone body resulting in drastic decrease in kinetic energy, hence gets discharged through the underflow. It is for this reason it is observed form this graph that heavier particles have higher efficiency of getting discharged though underflow than lighter particles.

IV. CONCLUSION

For numerical studies, the LES model approach is the most reliable approach to calculate fluid flow motion and particle tracking inside of a hydrocyclone. RSM and RNG K-ε also shows promising result for axial velocity profiles but slightly underestimates the tangential velocity. The grade efficiency is rightly predicted by the LES approach and hence this method is used for further numerical study of hydrocyclones with altered geometry. For smaller particles the discharge rate through the underflow is relatively lower in inward tapered (HC1) than in outward tapered overflow. The smaller particles of HC3 have relatively lower grade efficiency than HC1. This study will help engineers to design their hydrocyclones as per their requirement.

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