

## CFD SIMULATIONS OF A HYDROCYCLONE IN ABSENCE OF AN AIR CORE

J.A. Delgadillo<sup>\*</sup>, M. Al Kayed<sup>\*\*</sup>, D. Vo<sup>\*\*\*</sup>, and A.S. Ramamurthy<sup>\*\*\*</sup>

<sup>\*</sup>Facultad de Ingeniería- Instituto de Metalurgia,  
Universidad Autónoma de San Luis Potosí, México

<sup>\*\*</sup>Department Of Civil Engineering, Al-Zaytoonah University, Amman, Jordan.

<sup>\*\*\*</sup>Department of Building, Civil and Environmental Engineering,  
Concordia University, Montreal, Canada

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### *Abstract*

*Computational Fluid Dynamics (CFD) is a versatile means to predict the characteristics of flow in fluid mechanics problems under a wide range of design and operating conditions. Applying the CFD in many engineering fields alleviates the problem of the usual engineering design. Recent advance in computational methods and computer technology make CFD an efficient means to study the dynamics of many physical systems. CFD simulations use three dimensional grid and the Reynolds Stress Model (RSM) to investigate the flow without air core in a 6" hydrocyclone have been conducted using FLUENT. The numerical results are compared with the experimental data related to the Laser Doppler Anemometry (LDA) measurements of velocity. In the experimental study, a new procedure is developed to reorient the laser beams that permit one to measure two velocity components at a single point using LDA. The conclusion developed from these experiments enables one to use the LDA directly in the hydrocyclone wall without recourse to auxiliary attachments such as an enclosing box that usually used to minimize the refraction effects of laser beams which are caused by the curved solid wall of the hydrocyclone and the refractive index of the test medium.*

*Keywords: LDA; CFD; Hydrocyclone; Reynolds Stress Model (RSM)*

### **1. Introduction**

Simulation is applied in many areas of metallurgy [1-3], and the applications of

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<sup>#</sup> Corresponding author: jose.delgadillo@uaslp.mx

CFD to simulate the specific flows in hydrocyclones have been examined by several researchers [4-9] Hsieh and Rajamani [10-13]), Cullivan et al. [14], Schuetz et al. [15], Narasimha et al. [7], Nowakowski et al. [16], Delgadillo and Rajamani [17], Wang and Yu [18, 19] , Sripriya et al. [20], Wang et al. [21]

The objective of this study simulation is to investigate no air core flow patterns in a 6" hydrocyclone Figure 1 by CFD software package FLUENT (version 6.3.26) and to compare the numerical results with the experimental data conducted using LDA measurements of velocity.

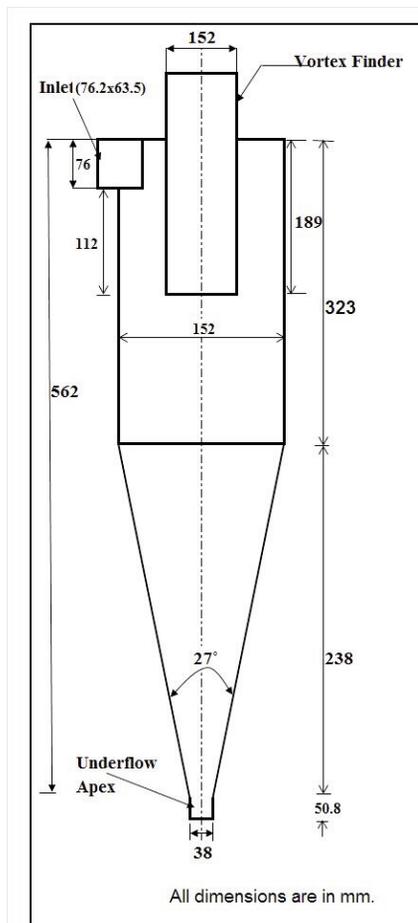


Figure 1. Hydrocyclone dimensions

GAMBIT, which is the main preprocessor of FLUENT, was used to create geometry, specifying boundary types and meshing of Hydrocyclone. Fig.2 depicts the created geometry and Figure 3 illustrates the meshing geometry.

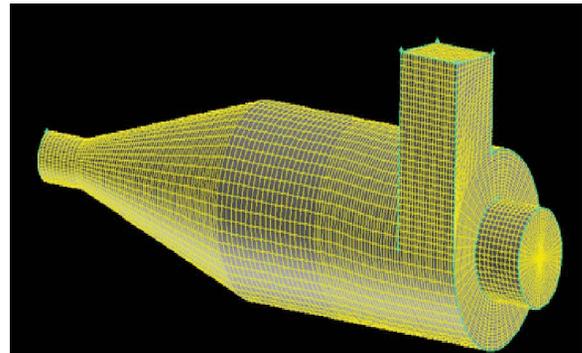


Figure 2. Hydrocyclone Geometry created by GAMBIT

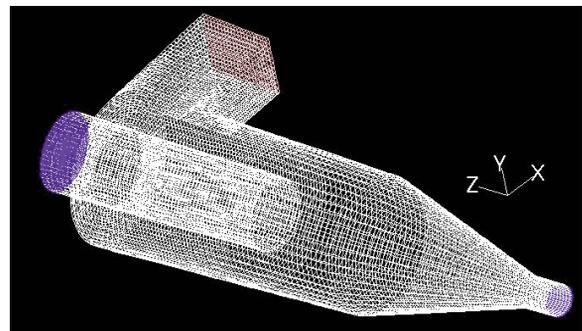


Figure 3. Meshing Geometry

The numerical grids were developed three-dimensionally in an unstructured manner with meshing size equal 256,800 elements. For meshing, hexahedral mesh were used for cylindrical part, conical part, inlet, overflow and underflow sections of hydrocyclone as shown Figure 2.

Boundary types are considered as mass flow for inlet, overflow and underflow as outflow. The flow rate of feeding inlet,

overflow and underflow were known from the experimental data. The body of the hydrocyclone is considered as wall boundary type. FLUENT can read the created meshing geometry by GAMBIT and proceed with the simulation of the model.

## 2. Computational Modeling

According to Nowakowski et al. [16] and Cullivan et al. [14] the full three-dimensional modeling is essential in order to accurately model the hydrocyclone flow field; therefore, 3D modeling was used in this study. The flow pattern in hydrocyclone was modeled by Reynolds Stress Model (RSM). RSM can describe the swirl flow field in a hydrocyclone accurately [15, 21], especially in absence of an air core.

The applied solution parameters were PRESTO scheme, First Order Upwind and SIMPLEC discretization type for momentum and stress equations.

Wang et al. [18, 21] illustrate the RSM governing equations which will be solved by FLUENT 6.3.26. The presence of air-core interface in hydrocyclone makes the flow unsteady and by removing the air-core, as in this study, makes the solution steady state. It took 30,000 iterations to converge for the single phase flow (water only) simulation.

## 3. Experimental Procedure

The overall objective of the experimental study was to investigate the flow field characteristic within the hydrocyclone, which will lead to improve the understanding of flow patterns and permit one to know the relation between the hydrocyclone

parameters. LDA was the major experimental tool used to achieve this task. The LDA was deployed to measure the mean velocities directly without using any box or jacket to encase the hydrocyclone that was generally used to avoid the refraction of laser beams which is caused by the curved solid wall of hydrocyclone. The data collection was conducted at two different positions. Firstly, the planes in which laser beams are present form a  $90^\circ$  angle; one of these planes contains the axis of the hydrocyclone (Fig. 4).

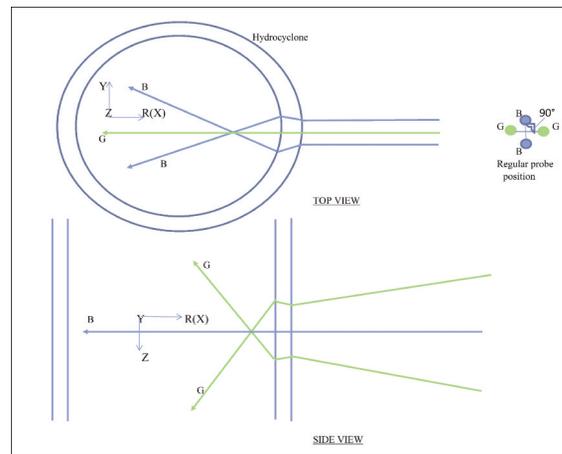


Figure 4. Regular LDA position,  $90^\circ$  angle between the laser beams (Case A)

This is the regular position traditionally used by LDA to measure the mean tangential and axial velocity components; this position is called the regular position. However, the two pairs of the beams do not meet at the same point. To force the two beam pairs to meet at the same point, the probe was tilted by  $45^\circ$  (Figs. 5) to measure the two mean velocities (tangential and axial); this position is called the transform position. This is a new method, which uses the probe positioning differently to measure the mean velocity

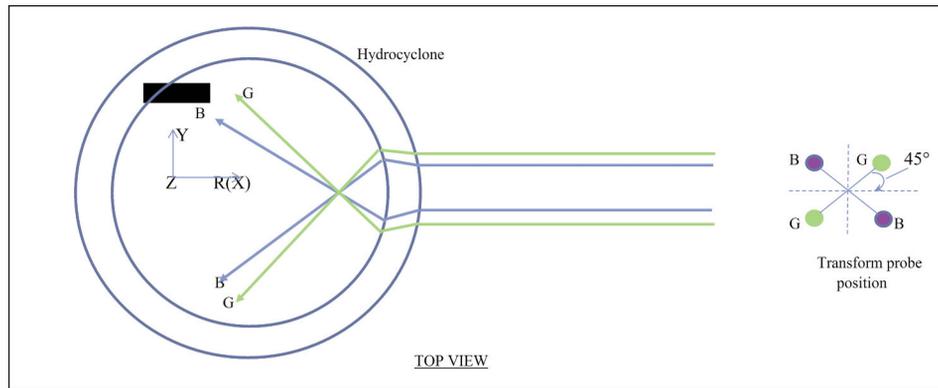


Figure 5. Transform position,  $45^\circ$  angle between the laser beams (Case B)

components in a hydrocyclone in the absence of a flat surface box or jacket to surround the hydrocyclone, as done by earlier hydrocyclones researchers who used the LDA. However, the measured axial velocity profiles in the transform position were all corrected for index of refraction effects, which are called the corrected measurements. The data of both positions were collected, analyzed and verified for precision of measurement.

#### 4. Simulation results and discussions

In FLUENT, the contour and vector plots were used to analyze the simulation results. Some measured data in the experimental study as well as the operating conditions were used in the FLUENT simulation. Feed flow rate was  $2.32 \times 10^{-3} \text{ m}^3/\text{s}$ . 50% of flow passed out as the overflow and 50% passed out as the underflow. The system operated without an air core using water only (single phase). The size of the hydrocyclone in this research, as well as the dimensions of the inlet, underflow and overflow was retained during the study. The flow was kept steady by adjusting the valves at the inlet, underflow and overflow. Therefore, no air

core exists during the data collection using LDA. During the course of experiments, the flow conditions were monitored continuously, no significant changes occurred during any of the experiments, except the positions of the optical probe as stated earlier.

The LDA probe was positioned on a specific axial station and aligned to be perpendicular to the wall of the hydrocyclone, because the curvature of the solid wall of hydrocyclone will cause an optical refraction of the laser beams. This was made many authors and researchers used a separation or protection flat box or jacket filled with water (or another liquid) surrounding the hydrocyclone to minimize the effect of beams refraction at the curved solid wall of the hydrocyclone [22-26].

In the experiments, the LDA measurements were taken with a four-beam LDA, the laser produced lights of two different colors (two green (G) and two blue (B)) which have wavelengths 514.5 nm and 488 nm respectively. For each measurement point, a sample of 5000 Doppler bursts was taken, and the measurement interval was 50 sec. The probe focal length was 399.3mm, and the used software was PDA flow and

particle software 1.40 from Dantec, USA.

The laser was an Ar-Ion A 35mW Model No. 5500 A-00. The experiments conducted on 168 points (87 points in cylindrical part and 81 points in conical part), on which the mean velocity profiles were measured.

#### 4.1 Comparison with the Experimental Data

The experiments conducted in case B proved that it is possible to measure both the axial and the tangential velocities at the same point since the intersecting point (the crossing point of the two green and blue colors) is the same. Therefore, two velocity components measured by the LDA in this case, the tangential and the axial velocities.

A noticeable feature of both experimental cases (A and B) is that, the both axial velocity profiles are quite similar at different depths. However, the axial velocity components in case B must be corrected for index of refraction effects. Fig.6 illustrates

the comparison of axial velocity profiles between regular and transform (the probe tilted 45°) positions of the optical probe, the corrected profiles and that predicted using CFD. As can be seen in Figure 6, there is a reasonably good agreement between experimental and predicted results. There are some small differences in the magnitudes due to the assumptions made in the CFD simulation. It is noticed that the axial velocity values in regular case are always greater than that in the transform case (case B). Near the central axis of the hydrocyclone, the values of axial velocity components seem approximately same because they have small magnitudes. Both experiments show the same trends, for axial velocity, and significant degrees of asymmetry, but the axial velocity values in case “B” have less values than in case A between 8 % to 11 % which abiding with the calculations of the optical and particle velocity conducted by Al Kayed [27].

The fact that the shape of the axial

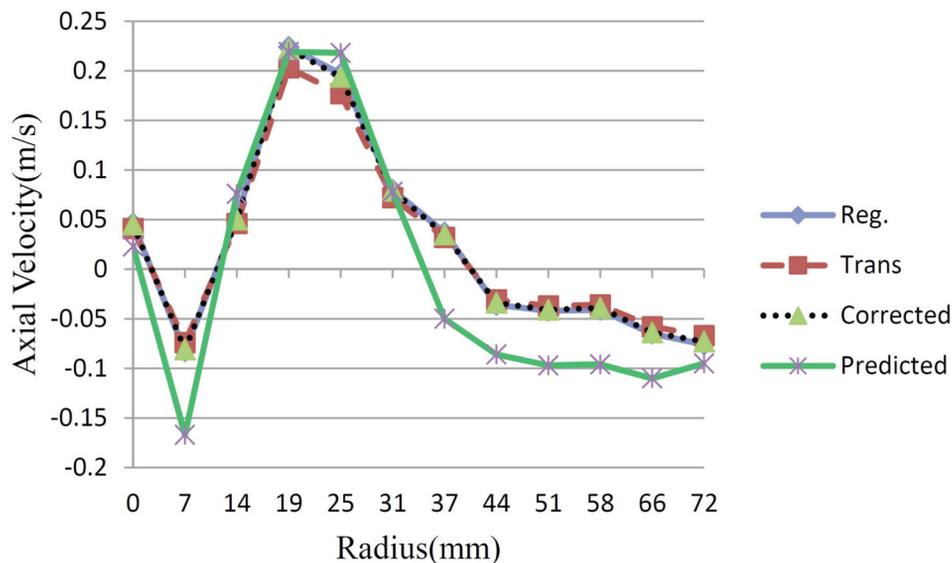


Figure 6. Comparison of the axial velocities at axial plane Z=200mm

velocity profiles are nearly identical throughout the cylindrical and conical parts, further confirms this point of view.

It is obviously clear that the corrections of the axial velocity profiles (Figure 6) due to refraction phenomena produced symmetrical values closed to the measured axial velocities in case A (regular position of the optical probe) which indicate that the applied corrections are correct. The tangential velocity in case B are not corrected because there are no data obtained in case A for this velocity as discussed earlier, so to correct the tangential velocity in case B it should be compared with axial velocity data that collected in a regular position of the optical probe, which only be done by immersed the hydrocyclone in a flat box or jacket filled with water or other suitable material, which is the traditional method when using the LDA in a hydrocyclone.

As elaborated earlier, and contrary to regular case A, the tangential velocity was

measured by LDA in case B only. Here, the position of the tilted probe enables one to have the crossing point of the two laser beams at the same point. Therefore, the axial and the tangential velocities could be measured at the same location.

Figure 7 shows the tangential and axial velocity profiles at axial plane 200mm measured from hydrocyclone roof and covering the full axial plane from wall to wall so as to examine the sort of symmetry within hydrocyclone as conducted by CFD. It is obvious that there is a good symmetry in the flow within hydrocyclone especially in the tangential velocity profiles, so only one half of the hydrocyclone is needed to record velocity profiles. However, the axial velocity profiles show some variations and asymmetry in the region below the vortex finder between the axial level 200 mm and below which denotes to the recirculation zone [27].

Fig.7 depicts the comparison of the

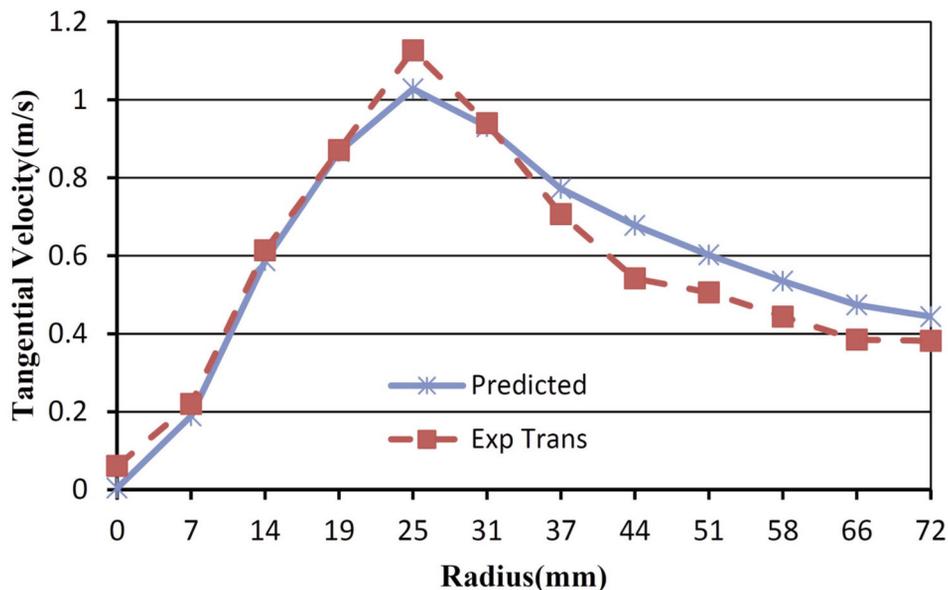


Figure 7. Comparison of the tangential velocities at axial plane  $Z=200\text{mm}$

tangential velocity ( $V_\theta$ ) profiles between the experimental data obtained in the transform position (dashed line) of LDA optical probe (Al Kayed, 2008) and CFD simulation. The model predictions for  $V_\theta$  showed good quantitative agreement with the LDA measurements, the maximum levels of tangential velocity were predicted very well by the simulations. It is obvious that both LDA and CFD show the same trends and significant degrees of symmetry, this revealed that  $V_\theta$  are predicted accurately.

### 4.2 Flow Patterns

Figs. 8 and 9 illustrate the model predicted contours and vectors of velocity magnitudes of flow field patterns within hydrocyclone. The comparison with the experimental test data are provided subsequently [27]. The velocity vector displays some of the minor flow patterns in the hydrocyclone flow field. As observed in Figure 8, the velocity magnitude is more at the underflow section. Below the vortex finder of the hydrocyclone, the velocity magnitude is medium at some middle section and has minimum magnitude at the centre axis and at the upper portion of vortex finder. As described in the flow visualization study the predicted flow by CFD matching with that observed in the study and for clarifying purposes, it will be discussed according to the types of flow pattern presented in.

Figure 10 depicts the short circuit phenomenon. The fluid is seen flowing downward along the outer wall of vortex finder and merges with the upward flow at the tip of vortex finder, which was observed in the flow visualization experiment and this

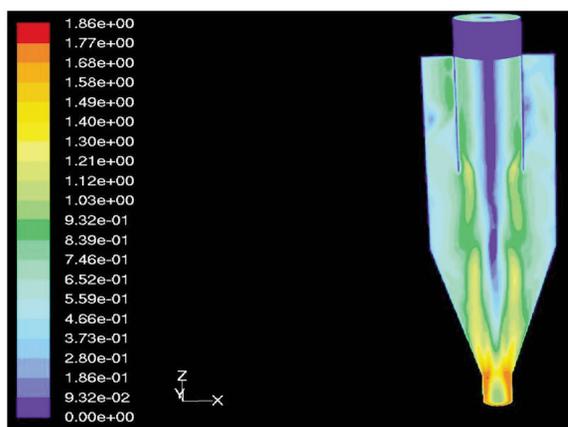


Figure 8. Contours Plot of Velocity magnitudes

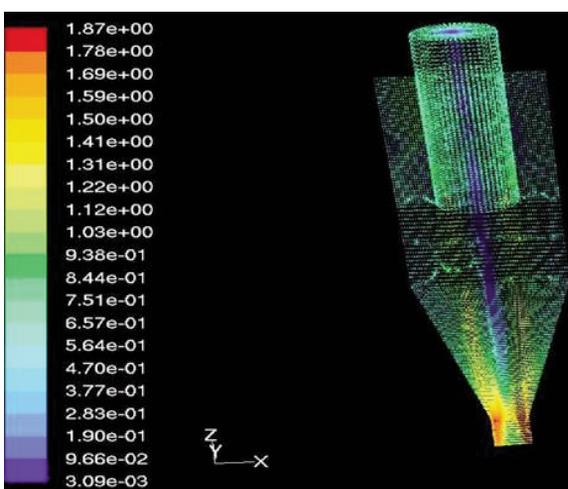


Figure 9. Velocity Magnitude Vectors

complied with the experimental data. Figure 10 shows the recirculation (eddy) flows or eddies. A recirculation zone is seen clearly in the velocity vector plot at regions below the vortex finder which is in good agreement with the experimental results presented in Al Kayed research [27].

Figure 11 depicts the contours and vectors of tangential velocity within hydrocyclone. It shows the maximum tangential velocity as on the regions below the vortex finder while the minimum occurs in blue at the central

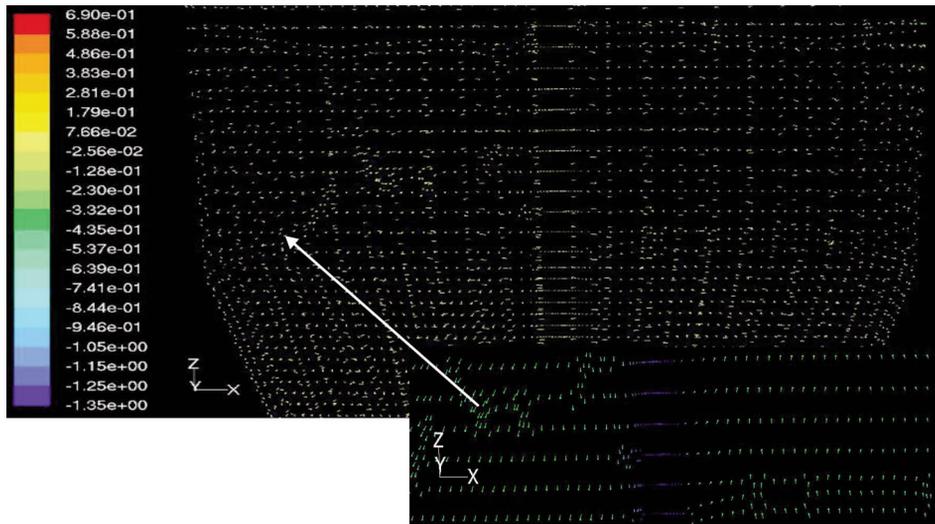


Figure 10. Recirculation (Eddy) Flow

axis, within the tube of vortex finder and at the outside walls of hydrocyclone.

Figs. 11 and 12 show the contours and vectors of axial velocity within hydrocyclone. It is obvious from Figure 12 that the minimum axial velocity occurs at the underflow discharge and varies between medium and high at the rest of hydrocyclone body. The maximum axial velocity occurs at entrance of the vortex finder. In the next section the computed axial velocity data characteristics using FLUENT will be briefly described.

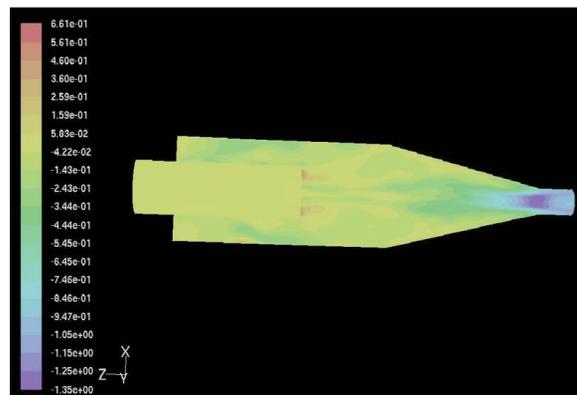


Figure 12. Contours of Axial Velocity

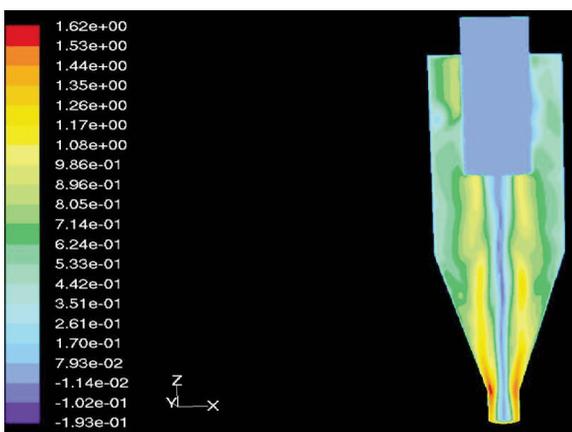


Figure 11. Contours of Tangential Velocity

### 5. Conclusions

The experimental study revealed that the LDA system is able to directly yield velocity component data at a single point, although the hydrocyclone has curved solid walls. To this end one has to orient the LDA optical probe in the transform position, which is suggested by Al Kayed [27], so as to obtain two components of the mean velocities at the same point. The axial velocity profiles obtained in the transform position were corrected for index of refraction effects and

the result was very close to the axial velocity profiles obtained in the traditional position of the optical probe. Using the transform position for the probe one can obtain the mean velocity components in the hydrocyclone flow field.

In the CFD simulations, the 3-D Reynolds Stress Model (RSM) predicts the velocity field in the hydrocyclone very well. There is good agreement between the measured and observed flow patterns. The simulation captures the flow characteristics inside the hydrocyclone which agrees well with the experimental results using LDA. Results of this simulation clearly proved that the CFD technique has great potential in understanding the fluid flow behaviour in the hydrocyclone. A good CFD model permits one to determine the flow characteristics of hydrocyclones for various conditions encountered in the field without recourse to costly test procedures.

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