Application of GIS & CFD for design of Pump Intake

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Abstract— Hydraulic structures used to withdraw water from a river or reservoir. As the high levels of circulation in the flow upstream of the pump sump region leads to asymmetry in the approach flow, this influences considerably the quality of intake design. The vortices originating at the lateral walls, floor or at the free surface can form in the vicinity of the pump intake area can be classified as either free-surface vortices or sub-surfaces vortices according where they originate. [1] All the vortices formed like this induce high levels of unsteady swirl inside the pump column, which results to uneven loading on impeller, and reduce the efficiency of the pumps. One of the major problems in water intake flows is a swirling-flow problem in the pump sump. If this problem is not solved, the effectiveness of the intake is reduced which directly influences the efficiency of the pump. Significant cost savings could be realized if the designs for pump intakes and other structures could be developed using computational fluid dynamics (CFD) models. CFD code can successfully predict vortices, and these models can be used extensively in design of basins with pump intakes.

Keywords— Pump Intake, CFD, Raster GIS, Vortices, Submergence, Sink, Superimposition, k-e model

Introduction

The function of proper intake structure of pumps is to supply uniformly distributed flow of water to the suction bell of pump. Uneven distribution, higher discharges favor formation of vortices, and cause low submergence. The intake of air into suction pipe reduce the capacity accompanied by noise and vibration. All possible streamlining efforts should be incorporated in the design to reduce formation of wakes. The amount of submergence mainly depends upon approach design and pump capacity. Good intake design also eliminates hydraulic phenomena and other conditions, such as sedimentation and accumulation of floating debris that can have a negative impact on pump performance. In addition, the sump should be kept compact and straightforward to reduce the installation footprint and minimize construction costs. The complete analysis is highly mathematical and complicated Navier Stokes equations can be seldom solved to provide viable engineering solutions. The other alternatives available are simulation using CFD software, model analysis and similitude. Raster GIS can simulate various velocity potential functions like uniform flow, vortex flow and has capability of superimposing the above functions in order to estimate possible velocities and depth of submergence.

Circular intakes offer more compact layout on account of smaller circumference and hence minimizes the sump volume and constructional costs. This cost enhancement is significant if the river bed is rock formation. However, circular geometries are recommended for lesser velocities and discharges. In the present study the adoptability of circular geometry is studied for a lift irrigation pump well having wet well diameter 7.0m with two pumps. The diameter of each suction pipe is 1.0 m and discharge of each pump is 1.31m3 /s

Literature Review

Tanweer S. Desmukh & V.K Gahlotuses studied the commercial CFD package ANSYS CFX-10 to predict the three dimensional flow and vortices in a pump sump model. The CFD model predicts the flow pattern in detail and the location, and nature of the vortices. However, considerable post-processing of the basic data is needed to fully comprehend the details of the flow. Thus CFD model can be used to study the effect of various parameters and hence can become an important tool for optimization of pump sump geometry. Kadam Pratap M. and D. S. Chavan studied the flow characteristic in a pump sump of physical model by using Computational Fluid Dynamics (CFD) code FLUENT.

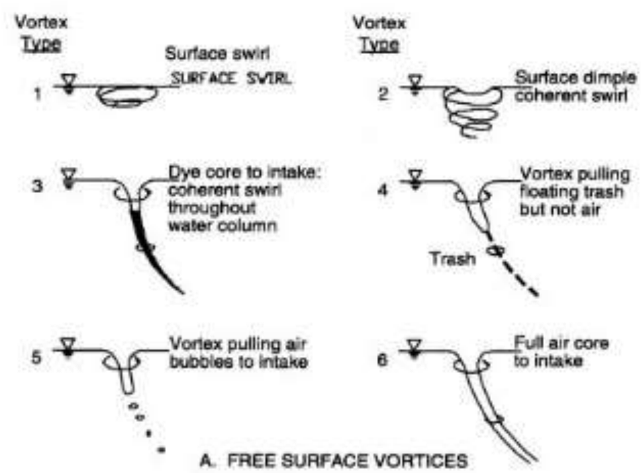
The experimental procedures include the data collection using a flow meter and swirl meter (Rotometer /Vortimeter). Two types of measurements were conducted which are flow, and swirl angle. A visual test that involves the dye tracing technique was also carried out to characterize the flow. The CFD analysis is done at critical cases, Grid generation is done in ICEM-CFD and numerical analysis are carried out in FLUENT , and flow is analyzed with the help of velocity stream lines and vector plot and velocity contour at the entrance of pump chamber, in CFD-POST software and concluded on experimental and cfd results.

A C Bayeul-Lainé, G Bois and A Issare produced the flow pattern and confirm the geometrical parameter influences of the flow behavior in such a pump. The numerical model used solves the Reynolds averaged Navier-Stokes (RANS) equations and VOF multiphase model for two cases. In the validation of this numerical model, emphasis was placed on the prediction of the number, location, size and strength of the various types of vortices. Previous studies, without simulation of air entrainment, have shown the influence on a single type of mesh with different cell numbers, different intake pipe depths and different water levels, for two turbulence models closure.

Cecilia Lucino, Sergio Liscia Y Gonzalo Duró verified the ability of a commercial computational fluid dynamic (CFD) code to predict the formation of vortices in a pump sump. It was intended to identify vortices of diverse origin and intensity in a geometrically simple pump sump of which experimental results under the same operating conditions are known.

Intake Structures and Pumps:

The basic function of the intake structure is to help in safely withdrawing water from the source over predetermined pool levels and then to discharge this water into the withdrawal conduit. Intake wells are widely used to draw water and pump to various applications. They can be classified as dry, wet well intakes. Wet well intakes provide sufficient storage to allow fluctuations in water levels. These intakes are used in stormwater, waste water pumping, lift irrigation schemes, water supply schemes, cooling applications in power plants. Efficiency of pumps depends pump bays, dimple vortex, air entraining vortex, submergence vortex, Swirling flow and placing of the pumps where as economy depends on proper sizing of intake structure.



The static pressure (head) of the delivered water significantly changes while passing through the pump from the inlet to the outlet. The minimum overpressure is around the entrance of the impeller. Steam bubbles arise here, if the pressure of the delivered water decreases below the pressure value of saturated steam with the same temperature. In the course of energy conversion in the pump, the pressure increases again along the stream when the water is passing through the pump and when it exceeds the pressure of the steam the bubbles are crushed (cavitation) thus starting to destruct the impeller mechanically. To prevent cavitation at the inlet of the pump the minimum inflow pressure should be maintained.

Each pump has a minimum suction head value, at which it can still work. This value is always smaller than the atmospheric pressure value expressed in pressure head of the liquid to be delivered. This value is known in the Anglo-American literature as the necessary "net positive suction head" - that is the NPSH of a pump.

This value can be considered as a loss factor and must be always subtracted from the theoretical suction head. Manufacturing companies always indicate these values for different deliveries and revolutions, since along with the increase of delivery these values increase as well. To apply properly these values, the $NPSH_a$ value of the pump under the actual conditions should be calculated.

Simulation of Pump Intake Flow

In the present investigation to study the influence of submergence depth required above suction pipe to avoid influence of vortices, the ‘Basala Doddi Pump’ Located in Kurnool district is considered. The following are the technical specifications of the pump considered in the present simulation: ‘Basala Doddi’ pump intake has wet diameter 7.0m with two pumps. The diameter of each suction pipe is 1.0m m and discharge is 1.31m3 /s. The MWL in the well is 318.5m and the floor level of the well is 308.436m The LWL is312.0m.The level of suction bell-bottom is 309.5m

The level of water above the floor is 3.564m for low water level. The clearance between floor level and suction pipe bottom is G=C=1.064m. The submergence depth above of suction bell-bottom is 3.564-1.064=2.5m,for low water level of 312.5m.The minimum submergence depth required is 1.8m as per code.

As per FSI ,

$$S=D(1+2.3F_D) \quad (1)$$

F_D is Froude number = $V/\sqrt{(gD)}$ (2)

Where V=velocity of suction inlet .
D=bell diameter.

$V = Q/A = [(1.31x4)/(\pi*1.0892)] = 1.406$ m/s.
$FD = 1.406/\sqrt{(9.81*1.089)} = 0.43.$
$S = 1.089(1+2.3*0.43) = 2.17$m. (FSI sump design guidance)

The minimum submergence required to prevent strong air core vortices is 2.17m for Basala Doddi pump intake. The actual submergence of 2.5m is greater than minimum required and possibility of air core vortices is almost negligible.

The 2d flow is simulated from the concept of potential flow theory. Each suction pipe is assumed as a sink. The equation for potential lines is given by [2]

$$\Phi = m*\ln(r) \quad (3)$$

Where Φ = velocity potential function
m = strength of sink.
r = radial distance from sink.

$$m=Q/(2\pi b) \quad (4)$$

Where Q = 1.31 m3/s.
b = height of bell invert above floor level.
b =1.064m as per the design drawings.
$m = 1.31/(2\pi*1.064)$.
m = 0.196m2/s

On account of two suction pipes placed symmetrically along the center line of horizontal axis, two sinks are placed with constant strength m 0.196m2/s. In potential flow theory two valid stream functions or velocity potential functions can be superimposed to obtain a valid combination of velocity potential functions. The velocity potential valid for a sink is simulated using SAGA GIS and the functions and their combinations are given in the following figures. Figure 1 shows the Velocity potential function from SAGA GIS showing potential values for single sink. Similarly Figure 2 and Figure 3 represents the velocity potential function from SAGA GIS showing potential function from SAGA GIS showing potential values for second sink and the potential function from the combination of two sinks respectively.

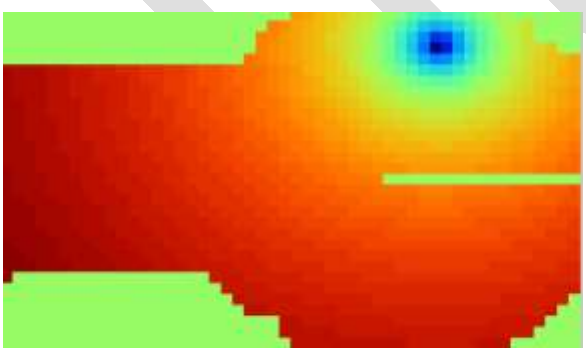


Figure 1: Velocity potential function from SAGA GIS showing potential values for single sink.

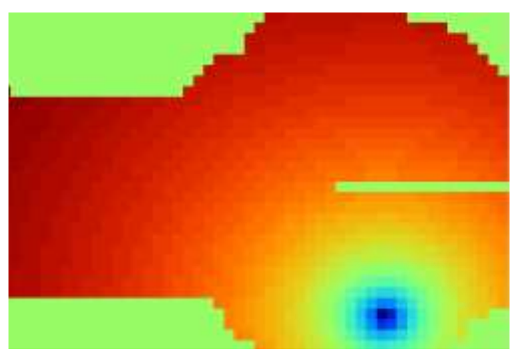


Figure 2: Velocity potential function from SAGA GIS showing potential values for second sink

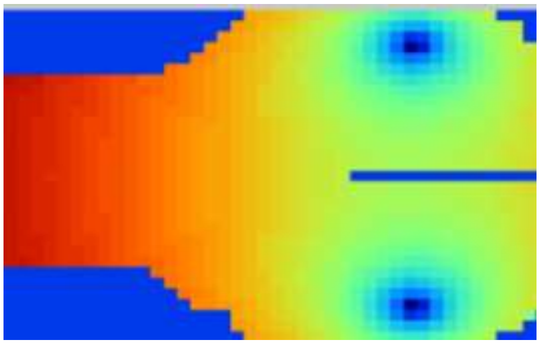


Figure 3: The potential function from the combination of two sinks

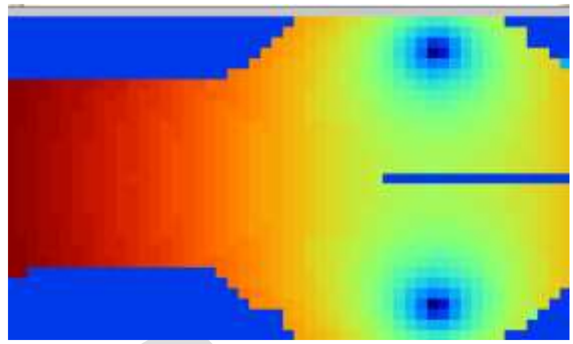


Figure 4; The constant head is superimposed for the given boundary conditions

Velocity potential for a The water surface profile on account of the superimposed Sinks is also presented and the minimum head above pump suction bowl is 5.5m which is much higher than minimum submergence depth, avoiding the possibility of vortex formation.

The resulting potential heads on account of two sinks and minimum water level of 2.5 m above the suction pipe inlet.

From the above analysis it is verified the possibility of strong vertex core and cavitation is almost negligible.

3D Analysis

The pump intake flow of Basala Doddi irrigation scheme is also simulated by using Fluent software (Which uses finite volume approach to solve continuity and Navier stokes equation.).The geometry of approach duct and pump intake well is generated using Gambit software. The pressure distribution along the bottom wall, inlet and outlets are provided in the following results.

Water is used as fluid material with a constant density of 998.2kg/m^3 with hydrostatic pressure variation. Standard k – e model is used for turbulent flow. This model is used as Reynolds number is much higher to simulate turbulent kinetic energy dissipation. One thousand iterations are used for the convergence criteria and appropriate boundary conditions are imposed. The converged solution results are provided in the following figures.

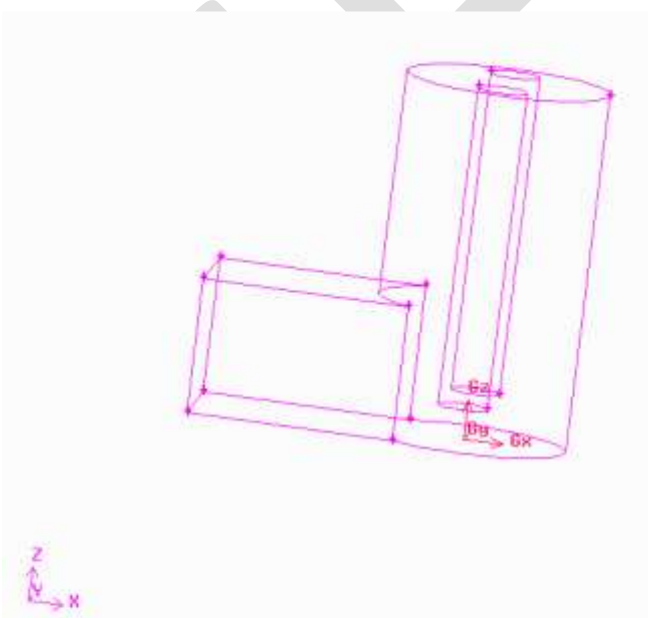


Figure 5: 3D pipe intake model generated with Gambit software

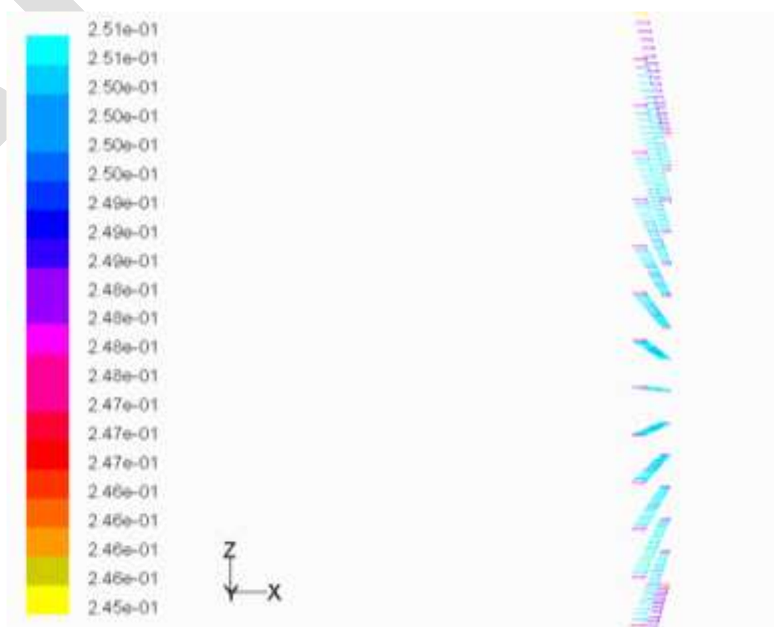


Figure 6: Velocity profile at duct inlet of area 10.5m^2 with almost constant magnitude of

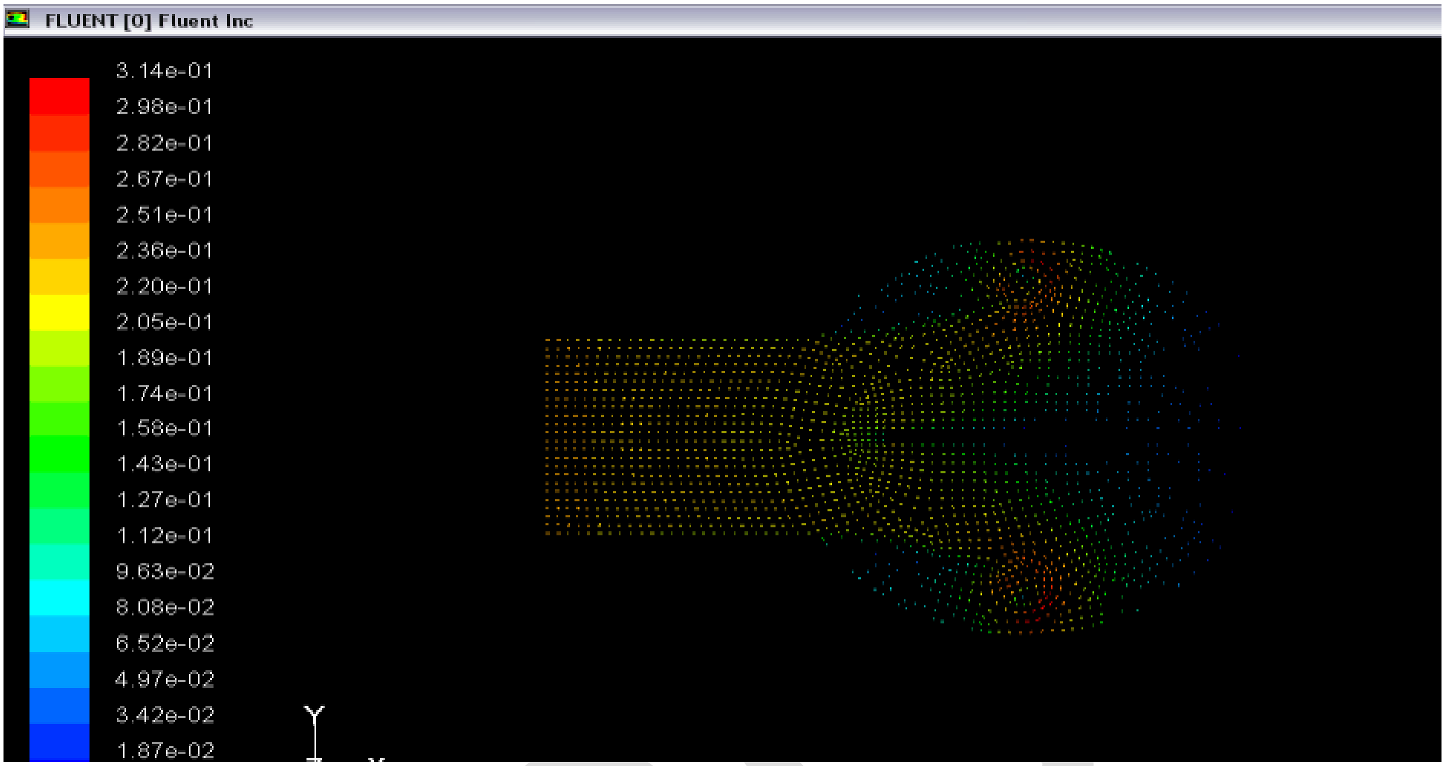


Figure 7: Velocity profile and stream flow pattern along the bottom wall of the well with maximum velocity of 0.32m/s

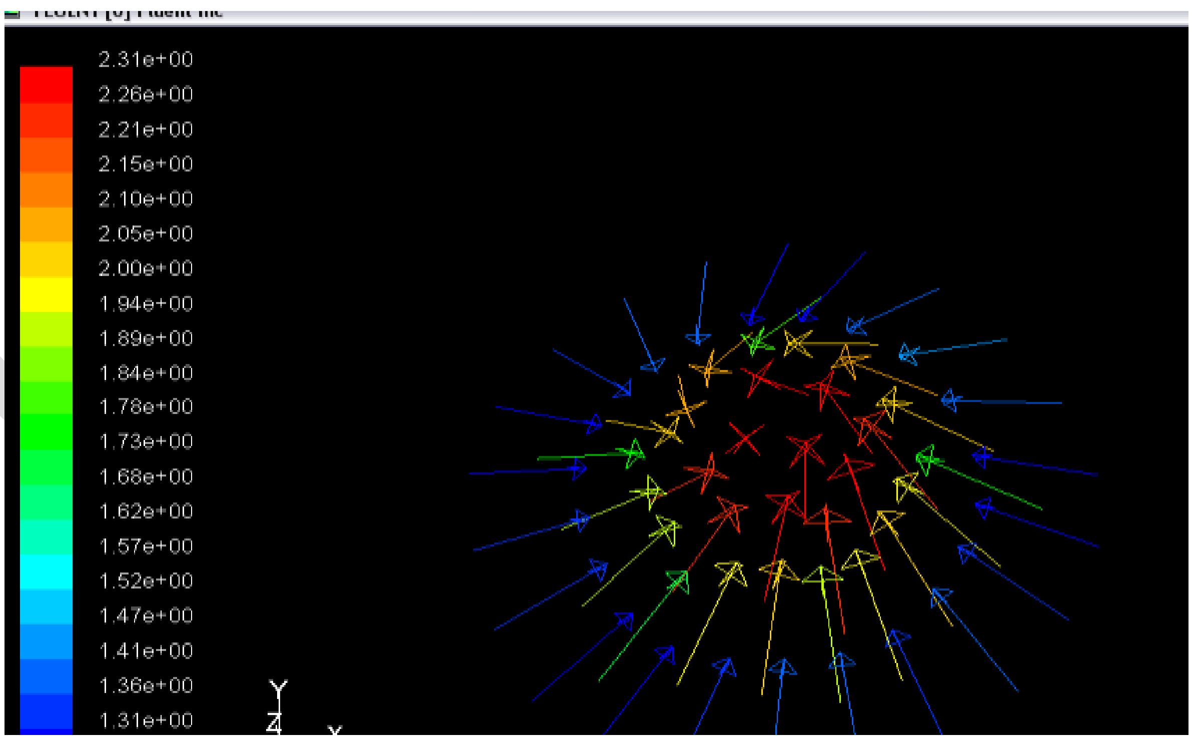


Figure 8: The velocity vector profile through one of the pipe suction pipe (The max & mini velocities are 2.28m/s and 1.25m/s

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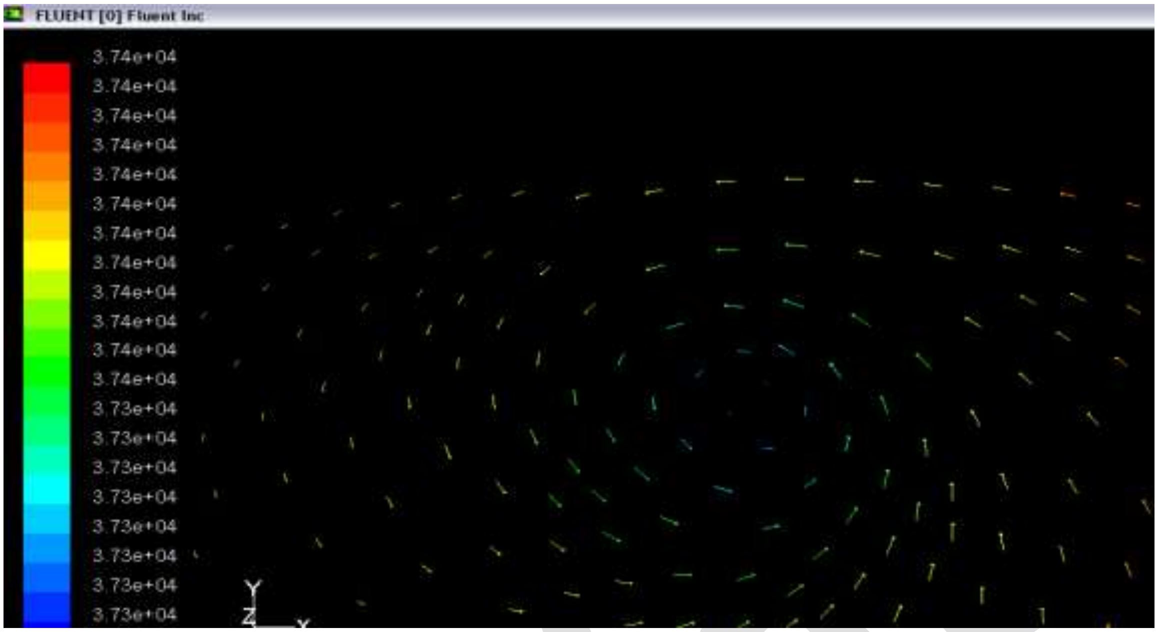

Fig 9: The pressure profile on the bottom wall of the well with the minm and maxm values of 37.3KPa to 37.4Kpa.

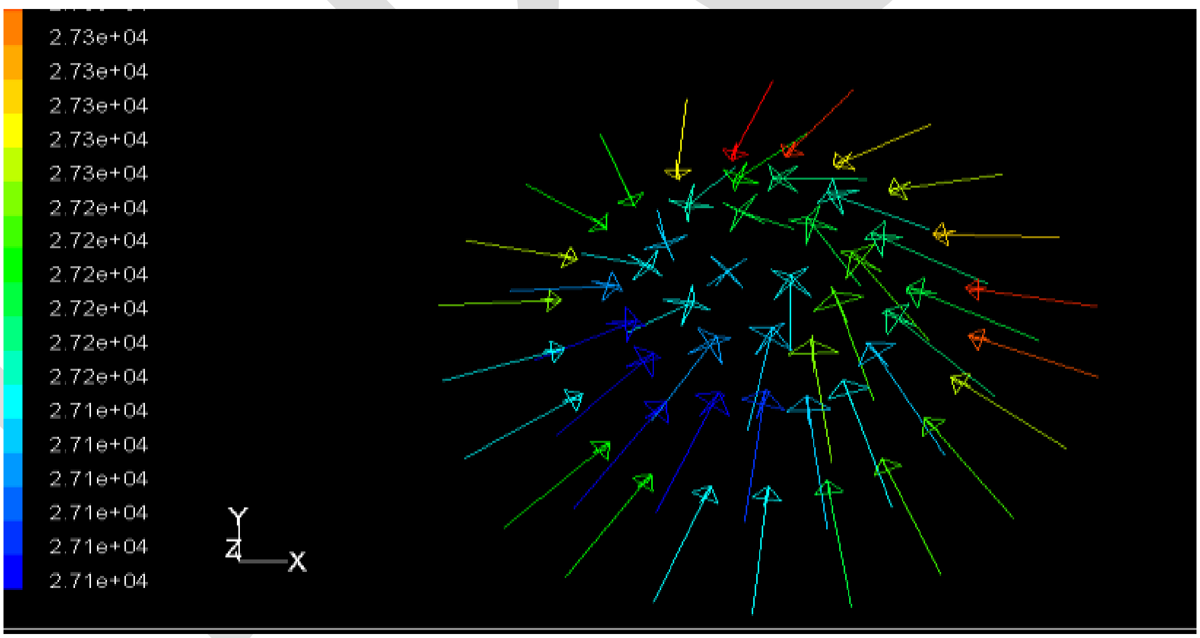

Fig 10: Pressure profile through one of the pump intakes suction intakes. (min and max pressures are 27.1 and 27.4 Kpa guage)

The above mentioned gauge pressures are much higher in order to avoid vortex formation.

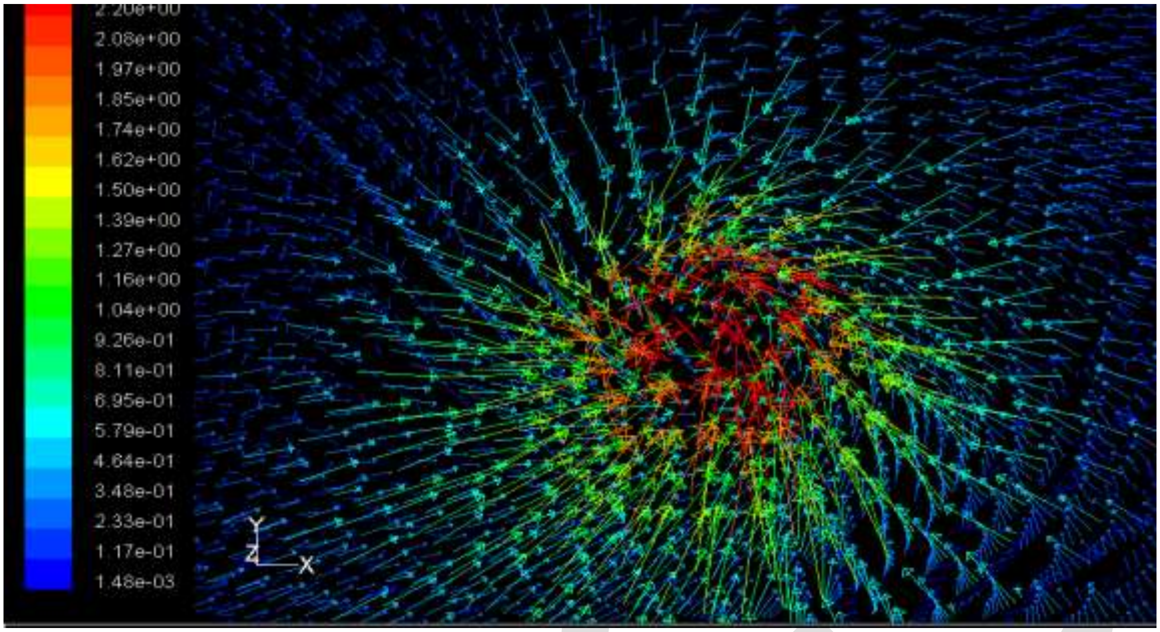

Fig 10: **Flow pattern inside the intake**

Conclusion

1. The minimum submergence depth required above suction pipe bowl is 2.17m, to avoid strong air core vortices. The depth of submergence is 2.5 m from Two D analysis and 2.76m from Three D analysis.
2. The maximum velocities are .39m/s and 1.1m/s respectively, inside pipe intake well , which are less than permissible values.
3. Splitters are provided in order to avoid swirl velocities. The required criteria for all clauses are met during normal operating conditions.
4. Raster GIS can be used for in fluid flow simulations

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6. Rane et al., International Journal of Advanced Engineering Research and Studies E Int. J. Adv. Engg. Res. Studies/III/II/Jan.-March.,2014/ ASSESSMENT FOR ALTERNATIVES OF GEOMETRY FOR THE INTAKE SIDE OF THE SUMP TO ENHANCE PERFORMANCE 1 Jagruti Dilip Rane, 1M E- Mechanical Design, appearing, 2Department of Mechanical Engineering, 3Director-Ethika Engineering Solutions India Pvt. Ltd., Pune