On a few Aspects of Vortex Motion

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Abstract - **Intricacies of vortex motion have been drawing the attention of scientists for many years. A number of works both experimental and numerical have been conducted to understand the various features of vortex motion and its effects on drag, etc. In the present experimental work we have made an attempt to visualize the patterns of both Forced and Free vortex motion. Here colored die has been used to understand the profiles and an arrow shaped strip marks the difference between irrotational and rotational flow. In the Forced vortex motion it has been observed that the parabolic profile remains invariant with the flow rate (speed of paddle), height of the lowest point of the profile decreases with the increase in flow rate (paddle speed). In the Free Vortex motion observations, the hyperbolic profile doesn't change with the change in flow rate. In this case, suction is created towards the centre where as in the case of Force vortex no such suction arises. With the reduction in the size of the orifice diameter, the profile becomes less steep for Free vortex. In this case the velocity profile in the core region is straight, as the radius increases the profile becomes rectangular hyperbola where as in the case of Forced vortex the velocity profile maintains its linear nature for the entire range of radii.**

I. INTRODUCTION

Swirling flows are observed in natural flows, such as tornadoes and typhoons, and have been widely used, for many years, in technical applications, such as aeronautics, heat exchange, spray drying, separation, combustion, etc. Their importance and complexity have preoccupied research investigations for decades. This swirling action is referred to as vortex motion. When a fluid moves over a curved path or fluid particles rotate then vortex motion is created. Vortex motion can be classified into Free vortex motion and Forced vortex motion. In Forced vortex the rotational motion is created by an external driving force e.g. by a rotating paddle, where as in Free vortex the motion is due to natural phenomena. Examples tornado, smoke ring (free vortex motion), paddle motion (forced vortex motion).In combustion systems, such as in gas turbine engines, diesel engines, industrial burners, and boilers, swirling flows were originally used to improve and control the mixing rate between fuel and oxidant streams in order to achieve flame geometries and heat release rates appropriate to the particular process application [1]. Various analyses have been done on the vortex motion. Helmholtz' theorem implied that link and knot types of vortex lines remain unchanged throughout the flow evolution. A century passed before Helmholtz discovered the key to the heart of vortex motion that the vortex lines are frozen into the fluid [2]. Vortices in superconductors have been intensively studied since Abrikosov's prediction of the vortex lattice [3]. An extension of the investigation of vortical flows in Newtonian fluids to non-Newtonian fluids has been carried out by many authors. Rao [4] and Erdog˘an [5] studied this type flow for a Reiner–Rivlin fluid. It was found that the cross-viscosity had a pronounced effect on the flow. The vorticity in such a fluid flow damps more rapidly than in the case of a Newtonian fluid. Erdog˘an [5] investigated this type of flow for a Rivlin–Ericksen fluid. He found that the viscoelastic properties of the fluid had a pronounced effect on the flow and that the core radius was smaller than that for a Newtonian fluid. The core radius can be defined as the value of the radius for which the tangential velocity meets the potential field. This type of flow for a Maxwell fluid was investigated independently Bretteville and Mauss [6] and, Lagnado and Ascoli [7]. In the early 1960s, detailed experimental studies of the performance of screw conveyors were undertaken by Roberts and Willis (1962), and by Rehkugler and Boyd (1962). These researchers used dimensional analysis and dynamic similarity to predict the performance of geometrically similar screw conveyors handling grain.

In the present study an attempt has been made to observe and conceive the patterns of Free vortex and Forced vortex motion. Experiments were conducted on a Hydraulic bench using a cylindrical set up. Water was used as the working fluid. Red and blue coloured dye has been used. Paddle and shaft was used to produce Forced vortex motion. Two orifices 16 mm and 18 mm were used to study the free vortex motion. Needles and bridge piece were used to understand the pattern. Valve of the hydraulic bench was used to regulate the flow rate into the setup.

II. EXPERIMENTAL METHOD AND ANALYSIS

Hydraulic bench and a cylindrical apparatus have been used to conduct the experiments. F1-10 Hydraulic Bench was used to perform the experiments, whose specifications are given below. The unit is designed as a portable and self-contained service module for the range of accessories described later in this data sheet. The bench is constructed from lightweight corrosion resistant plastic and is mounted on wheels for mobility. The bench top incorporates an open channel with side channels to support the accessory on test. Volumetric measurement is integral and has been chosen in preference to other methods of flow measurement for its ease of use and accuracy and safety in use. The volumetric measuring tank is stepped to accommodate low or high flow rates. A stilling baffle reduces turbulence and a remote sight tube with scale gives an instantaneous indication of water level. A measuring cylinder is induced in the supply for measurement of very small flow rates. A dump valve in the base of the volumetric tank is opened by a remote actuator. Opening the dump valve returns the measured volume of water to the sump in the base of bench of recycling. An overflow in volumetric tank avoids flooding. Water is drawn from the sump tank by a centrifugal pump and a panel mounted control valve regulates the flow. An easy to use quick release pipe connector situated in the bench top allows for the rapid exchange of accessories without the need for hand tools. Each accessory is supplied as a complete piece of equipment needing no additional service items other than the Hydraulics Bench. When coupled to the bench they are immediately ready for use. Figure 1 shows the pictorial view of the original set-up where vortex studies have been carried out.

III. RESULTS AND DISCUSSION

In the present work experiments have been conducted to study the Free vortex and Forced vortex motion patterns and results have been discussed in the following.

A. FORCED VORTEX

The experiment has been conducted with the help of the hydraulic bench. The hose and the Y-divider pipes and two quick releases were connected to the unit. The outlet valve was kept fully open. The central shaft was placed in the orifice located at the base of the cylinder; the paddle was located on the top of the shaft. The bridge piece was placed on the top of the cylinder with the measuring needles inserted in the holes of the bridge. Pump was switched on to fill the cylindrical vessel with the coloured water. The latter end of the outlet hose was lifted until the set up got filled with water. This continued until the steady state was achieved. The measuring needles were adjusted until the needles touched the surface of the vortex. The rotational speed of the paddle was measured by counting the number of rotations in a specific time.

This process was repeated three times and the observed data has been made in tabular form. Table 1-3 shows the revolution of the paddle and the height of the water surface from the datum for different revolutions of the paddle fitted at the bottom of the experimental tank. Figure 2-4 shows the nature of the water surface profile drawn on the basis of the observed data. Figure 5 represents the variation of the height of water surface with different angular speed. It has been observed from the figures that the parabolic profile remains invariant with the flow rate (speed of paddle) and the height of the lowest point of the profile decreases with the increase in flow rate (paddle speed).

Fig 1: Photograph of the experimental set up

Table 1: Tabulation of the observed data for 0.93 r.p.s:

Number of rev.	Time(sec)	Revolution/sec(N)	Radius (m)	Measured length of needles (m)	Height from datum (m)
28	30	0.93	0.110	0.085	0.190
28	30	0.93	0.090	0.096	0.179
28	30	0.93	0.070	0.104	0.171
28	30	0.93	0.050	0.108	0.167
28	30	0.93	0.030	0.110	0.165
28	30	0.93	0.000	0.112	0.163

Table 2: Tabulation of observed data for 1.033 r.p.s:

Number of rev.	Time(sec)	Revolution/sec(N)	Radius (m)	Measured length of needles (m)	Height from datum (m)
31	30	1.033	0.110	0.088	0.187
31	30	1.033	0.090	0.096	0.179
31	30	1.033	0.070	0.104	0.171
31	30	1.033	0.050	0.109	0.166
31	30	1.033	0.030	0.113	0.162
31	30	1.033	0.000	0.117	0.158

Table 3: Tabulation of the observed data for 1.266 r.p.s:

Number of rev.	Time(sec)	Revolution/sec(N)	Radius (m)	Measured length of needles (m)	Height from datum (m)
38	30	1.266	0.110	0.093	0.182
38	30	1.266	0.090	0.114	0.161
38	30	1.266	0.070	0.123	0.152
38	30	1.266	0.050	0.135	0.140
38	30	1.266	0.030	0.138	0.137
38	30	1.266	0.000	0.144	0.131

B. *FREE VORTEX*

With the same experimental set up observations have been carried out for free vortex motion and those are made in the tabular form. Due to absence of the paddle on the shaft, the water in the tank does not have any motion except the overflow. When the water in the tank reached a steady state condition, the shaft was plugged out of the base and at once the free vortex gets started. Table 4 shows the measured height of the needle and height of the datum for 16 mm orifice and Table 5 represents the same for 18 mm orifice. Figure 5 and 6 represent the variations of the height of the water surfaces for 16 mm and 18 mm orifices, respectively. Figure 7 represents how the variation of water surface takes place with the change in diameter of the orifices. Table 6 compares the velocities for forced vortex and free vortex motion for the same discharge. Figure 9 and 10 represent the velocity profiles for forced vortex motion and free vortex motion, respectively.

Table 4: Tabulation of the observed data for 16mm orifice :

Radius(m)	Measured length of the needle(m)	Height from the datum(m)
0.11	0.089	0.186
0.09	0.101	0.174
0.07	0.120	0.155
0.05	0.130	0.145
0.03	0.155	0.120
0.015	0.160	0.115

Table 5: Tabulation of the observed data for 18mm orifice:

Radius(m)	Measured length of the needle(m)	Height from the datum(m)
0.11	0.092	0.183
0.09	0.104	0.171
0.07	0.121	0.154
0.05	0.136	0.139
0.03	0.176	0.099

IV. STREAMFUNCTION CALCULATION OF FORCED AND FREE VORTEX

The streamfunction for forced vortex clockwise motion is $\Psi=(r^2\ \omega)/2$. the streamfunction for free vortex clockwise motion is $\Psi=(\Gamma \log r)/2\pi$.

Table 6- Tabulation of streamfunction values for forced vortex at different rps

Radius	Ψ for 0.93 rps	Ψ for 1.033 rps	Ψ for 1.266 rps
0	0	0	0
0.03	0.0026	0.0029	0.0036
0.05	0.0073	0.0081	0.0099
0.07	0.0143	0.0159	0.0195
0.09	0.0237	0.0263	0.0322
0.11	0.0354	0.0393	0.0481

Table 7- Tabulation of Theoretical calculations of velocities for ideal free vortex motion by inserting diffrenet orifice i.e one is 16mm and one is 18mm

Radius(m)	Velocity with 16 mm orifice (m/sec)	Velocity with 18mm orifice (m/sec)
0.11	0.6905	0.6905
0.09	0.84392	0.84392
0.07	1.08504	1.08504
0.05	1.519056	1.519056

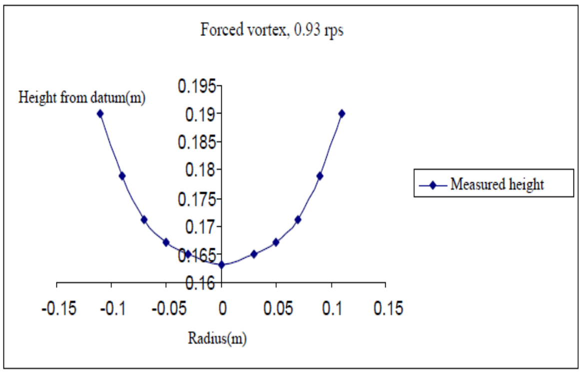

Fig 2: Variation of height from datum with radius for 0.93 r.p.s

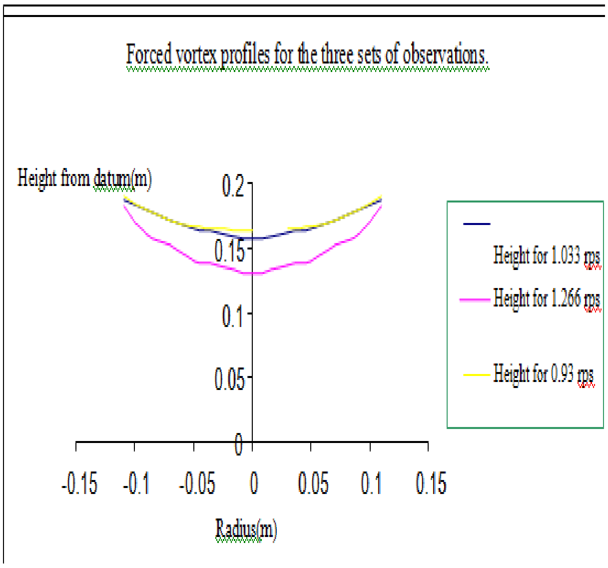

Fig 3: Variation of height with the change in angular speed

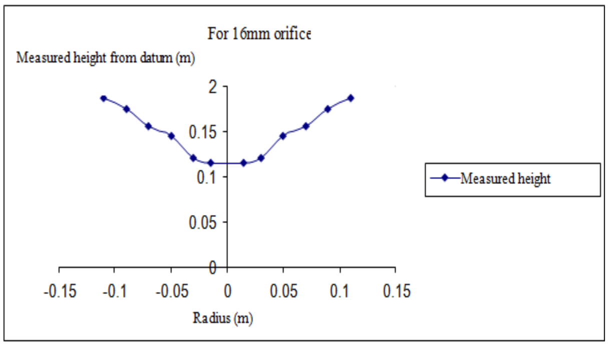

Fig 4: Variation of height with radius for 16mm orifice

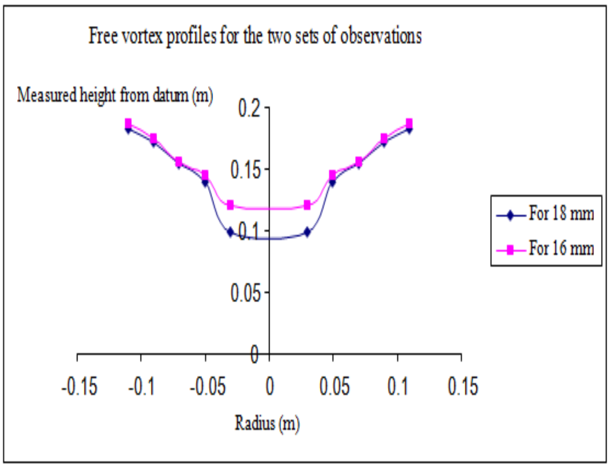

Fig 5: Variation of height with the change in diameter of orifice.

V. COMPARISON OF VELOCITY PROFILE OF FREE VORTEX AND FORCED VORTEX

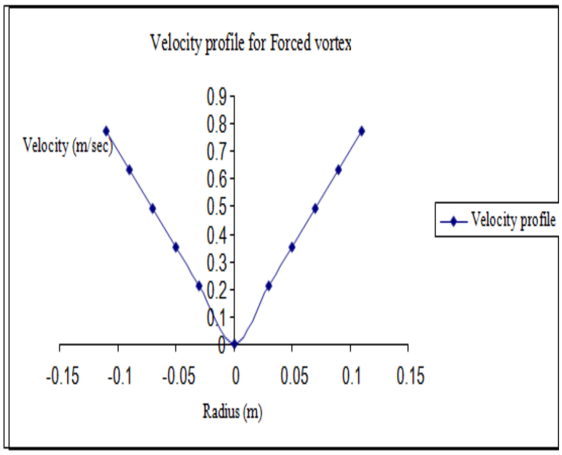

Fig 6: Velocity profile for forced vortex motion

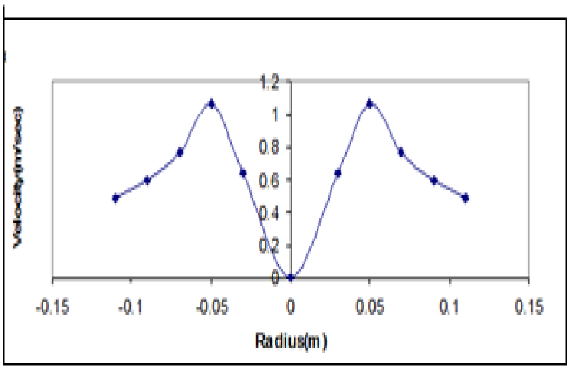

Fig 7: Velocity profile for rankine free vortex motion

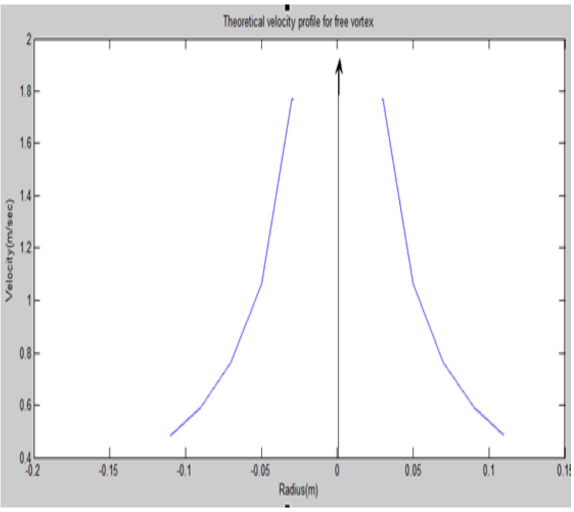

Fig 8. Thoretical velocity profile of free vortex

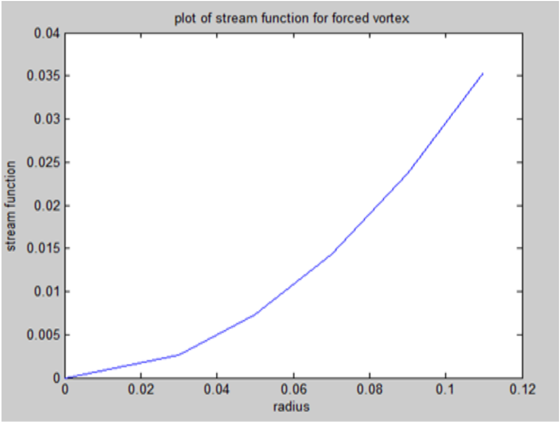

Fig-9- plot of stream function for forced vortex for .93rps

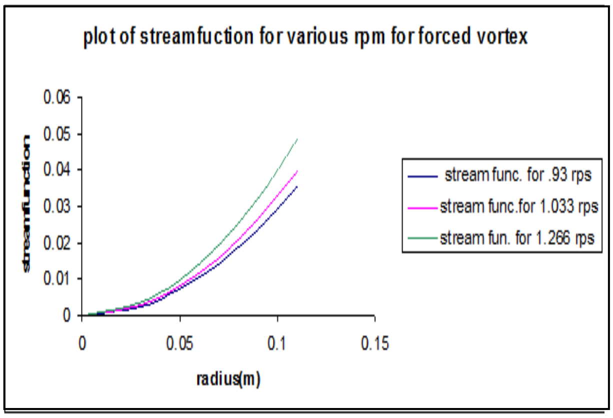

Fig 10-plot of streamfunction for various rpm for forced vortex

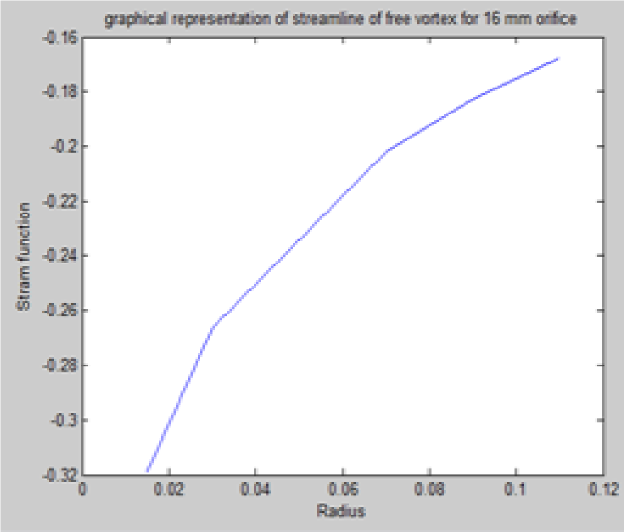

Fig-11-graphical representation of free vortex for 16 mm

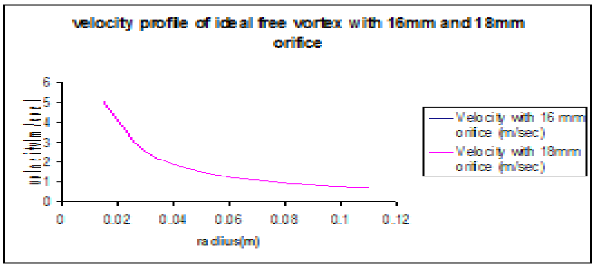

Fig-12- velocity profile of ideal free vortex with 16mm and 18mm orifice

VI. CONCLUSION

The present limited study makes the following conclusions

i) The velocity is inversely proportional to radial distance and its variation with radius is of hyperbolic in nature for Free vortex motion. In case of real fluids as radius tends to zero the viscous action becomes increasingly dominant and tends to rotate as a solid body with velocity directly proportional to radius. Therefore the hyperbolic nature does not appear in the core region where the flow has rotational characteristics.

ii) The vorticity within the core is non-zero and has an infinite value at the vortex axis. The core region represents the vortex tube for free vortex motion.

iii) In the case of Forced vortex motion, the vorticity of the flow everywhere within the fluid is non-zero and finite causing flow to be rotational.

iv) The object used for testing rotational nature of Forced vortex shows that it may change its orientation from place to place indicating the existence of rotation of the object about its mass centre. This shows that vorticity may not exist at every point characterizing rotational aspect of the flow.

v) The flow is irrotational in case of free vortex motion whereas simultaneous existence of both rotation and revolution of the fluid particles occur in Forced vortex motion.

vii) The stream function formed in forced vortex is parabolic in nature . With the increase in angular velocity, the slope of the curve increases.

vii) The stream function formed in free vortex is hyperbolic in nature and remains invariant with orifice diameter.

VII. REFERENCES

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