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An Experimental Model of Flow Surface Patterns at Vertical Downward Intake With Numerical Validation

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Abstract: As intakes used frequently for industrial supply, feeding different turbomachinary or drawing water from reservoir, etc recognition of important and effective phenomena such as vortices is very important for their design. In this research by using experimental works "particle tracing methods " form of surface flow pattern is defined and the region which was influenced by vortices , is determined.

Key-Words: Vertical water intakes, Vortices, Critical submergence, Swirling flow, Suction entrance, Particle tracing method

1 Introduction

Hydraulic intakes with draw water from sources like basins, rivers and lakes in order to supply water for domestic, irrigation and industrial demands. Swirling flow occurrences are inherent in such intakes and reduce their efficiencies. [1], [2]
Generally turbomachinaries related to intake such as different pumps and turbines are impressed of intake shape. Therefore it is necessary that reservoir design creates the least disturbance in intake complex and is transferred to downward turbomachinary.
So it is very important to realize the effective factors in design of an intake . Because of importance of above mentioned points in recent years, Theoretical and numerical modeling of intakes has been taken a lot of notice. Whereas manufacturing of physical model of intakes and hydraulic structures is time consuming and expensive, therefore all efforts are for presentation of a numerical method based on practical experiences, because of many reasons such as: a lot of non dimensional parameters, importance of model ration to sample, total modeling of complex and etc, has not been accomplished functionally.
One of the most important disturbances in entrance flow to turbomachinary is forming surface vortices with air core and or without it which can cause reduction in efficiency of supplying with hydraulically cavitation, vibration in pipe lines as well as turbomachinaries. Whereas recognition and estimation of surface vortices theoretically is relatively difficult and problem suffers from uncertainty in event and stability of surface vortices

Therefore physical model for recognition and vortex elimination is used. During formation of surface vortices, surface velocity of fluid particles increases, suspended and floating trashes on water surface are drawn out into feeding pipe turbomachinary which can have destructive effects, therefore formation and spread of surface vortices must be prevented by any possible ways.[6],[7]

2 Problem and Physical Model Description

2.1 Physical model presentation:

As it was described in section 1 because of various parameters such as viscosity, effects of surface waves, wind, Reynolds number, etc presentation and access of a mathematical or analytical model to recognize surface vortices is too difficult. In addition, it is impossible to design a similar model to authentic sample dynamically and geometrically. So recognition of magnitude of error in model is very important. Also magnification ratio of real sample to physical model is important and can affect on results very much. Because of above reasons optimizing of Theoretical and experimental methods is operated simultaneously and if it is possible to minimize errors of Theoretical methods by utilization of physical model results and achievements, time and cost reduction in fulfillment of a project will be remarkable.[7]

2.2 Introduction of particle tracing method

This method is used to recognize the behavior of surface flows. In this method temporal tracing of particles become possible by utilization of cine-camera, recognizable floating particles, chronometer, a regular mesh on the surface of water. By the aid of this technique measuring the radius and location of curvature of stream lines and surface velocity is possible.

Methods of research operation

In this research, at first by utilization of a physical model of an intake, in laboratory and particle tracing method, profiles of surface flows are recognized and related graphs and radius of swirling flow are specified, then velocity contours and stream lines are measured by numerical Fluent code and using the boundary conditions.

2.4 Introduction of physical model and description of accomplished experiments

In hydraulic industry in order to investigate of hydraulic structure behavior trustfully, a physical model is usually used and a related model for every sample is design and made. In making a physical model following conditions should be considered:

1-Geometrical similarity should exist between model and main sample.
2-Model should be similar to main sample dynamically.
3-Proportion of main sample magnification to model should be considered correctly. If mentioned proportion is not proper, results will be impressed by it.
4-As far as real condition are considered to have more reliable results.
5-Economical regulations should be considered.

general researches in laboratorial scale.[5]

With attention to above points designing and manufacturing a physical model was taken action. It is important to mention that this model is not related to a specific sample and is only made to achieve general researches in laboratorial scale.

Experiment device is consisting of following parts:

1-Water feeding tank for experiment that is located upward the intake tank and required water is conducted to intake by this tank at experiment time. Tank is made of steel and its capacity is about 3.5 (m3).Whereas water is evacuated freely, its saddle height to bottom of tank is considered 2(m). Experimental activities will be valid if conditions are stable, therefore we should prevent of any changes in conditions. So tank volume has been calculated to minimize the altitude changes of water in feeding tank which has been obtained by unconformity of input and output Mass flow. These changes are because of incorrect setting of the pump outlet valve and caused by using the gate valves instead of special valve for Mass flow controlling. Economical remarks are the mere reason to use gate valve.

2-A linking pipe between feeding tank and intake tank with 0.10(m) in entrance diameter equipped by an on and off valve to control the Mass flow. Gate valve has been set up to intake tank before pipe entrance in distance of 6×D and we can control it by changing its situation. So immergence altitude in intake tank in different mass flow is reusable.

3-The test were performed in a tank of 2.4 m length, 1.8 m width and 1.2 m depth. (see figure 1 and 2) that intake downward channel 0.09m in entrance diameter has been set up into it. This tank is made of transparent plastic glass (plexi-glass) and fluid behavior is observable simply through all sides. Steel net used around and under the intake tank to reinforce tank body to stand the water weight and so it is prevented from bending that caused leaking and breaking.

4-Laminator of inlet flow that is made of two porous steel plates and distance of two plates has been filled by straw. So a laminar flow is made in input tank of intake. The laminator part has 0.10 m thickness that is set up 0.15 m in distance of entrance of tank and length of remain part has been considered 2.15 m to accomplish the experiment.

5-Intake entrance is made of P.V.C, 0.09 m in diameter which is placed in different distances of front head of channel, so distance of suction duct to intake forehead will be changeable.

A pump under the intake tank has been used to provide obligatory suction. So it is possible to change Mass flow from zero to 32 m^3/h.

6-A pump under the intake tank has been used to provide obligatory suction. So it is possible to change Mass flow from zero to 32 m^3/h.

7-Mediator pipes between pump and intake reservoir with an on and off valve to isolate the pump. mentioned valve is used for probable repairs and services so there is no need to evacuate the intake tank.

8-Pressure side pipe of pump with an on and off valve is arranged to intake tank to control the amount of passing water.

9-Weir tank has been made of a steel reservoir with capacity of 215 m^3 and has two laminators and a triangle-shaped weir. A graded transparent plastic cylinder is used to read water height from edge of weir which is set up in a suitable

distance to weir crown. It is possible to read water height at the head of weir easily.
10-A downward tank below the weir is used to evacuate water of weir.
11-A pump under weir evacuation tank to transfer water to feeding tank is used above intake reservoir.
12- Mediator pipes between above-mentioned pump and two water feeding tanks and two evacuating weir tanks with two on and off valves are used to isolate pump and arrange passing mass flow of turbomachinary.
13-Using a regular grid on the surface of water in intake tank. This grid is made of an Aluminum frame and silk strings. Color of strings is white so they are observable in video images. This grid is simply movable vertically, therefore it is possible to minimize its distance to water level during experiment and prevent from optical error because of much distance of camera and floating particles. If distance between grids and water level is a lot, particles displacement is not real in video images and observed displacement from video images get into trouble.
14-Using a recorder-camera and a projector to accomplish the experiment Important properties of above system are:
1-Ability of regulation and changing of mass flow from zero to 32 m^3/h.
2-Ability to set up different suction duct horizontally, vertically towards down and vertically towards up.
3- Ability to change vertical and horizontal distance of suction duct to lateral and frontal walls of intake.
4-Ability to set the water altitude above suction entrance from zero to 75cm.
5-Ability to change the suction duct location from symmetrical condition to unsymmetrical condition.

Total plan of system has been displayed in figures (1) and (2).

Properties of weir:
It is a kind of triangle one with 90’ angle and it is designed according B.S Standard in number of 3680.[3]
A Plexi-glass sink has been arrange at the head of weir about 4 times of maximum water increase and is connected to fluid of weir tank by a plastic pipe and it is possible to read water altitude of tank (H) and then we can measure mass flow by following formula:[4],[6]

$$Q = 1.2239\sqrt{(H + 0.00092)^5}$$

(Ref. to Notation)
That Q is water mass flow in m3/sec
H is altitude of water from weir apex.

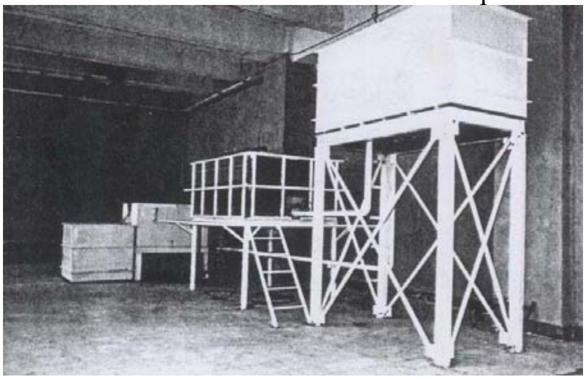

Figure 1 : View of the physical model

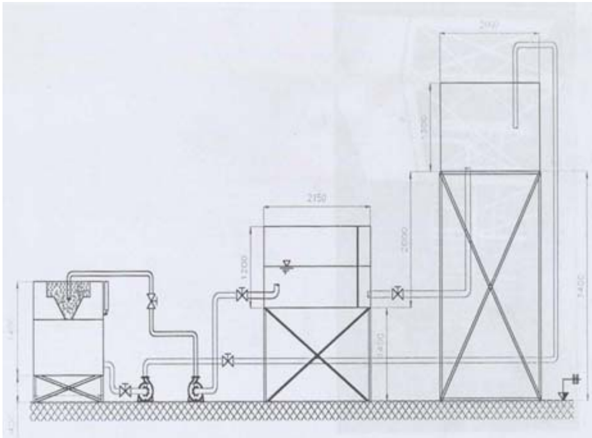

Figure 2: Map of the physical model

3 Results and discussion

3.1 Introduction of experiment method

The purpose of this experiment is to specify surface flow field and radius of swirling flow area for different water supplying regimes that has been done by particle tracing method.

In particle tracing method following instrument are used:
1-A regular grid: It is possible to investigate particles displacement trace after cinematography by the aid of a mesh grid with 10 cm×10 cm dimensions then size and direction of particles displacement can be distinguished.
2-Cine-camera: It is possible to distinguish trace of particles from Lagrangian view and then specify floating particles displacement by a video and a monitor. By this way flow field and swirling flow area can be determined.

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3-Floating particles: These particles stay Suspended on water surface and because of less weight and small dimensions, they move by the surface velocity of fluid and then their cinematography is investigated.
4-Chronometer: It is possible to get the path and velocity of fluid particles in different points by use of a chronometer and a video image. By attention to dimensions of grids and time of particle displacement from one point to another point through grid, path and velocity of fluid particles is measurable.

3.2- Accomplished measurements:

At this research effects of each below parameter change on surface flow field and radius of swirling flow area are investigated.
1-Effects of progression length change.
2-Effects of submergence depth change.
3-Effects of Froud number change.(Effects of intake entrance change)
Experiments has been accomplished in symmetrical condition and in four progression lengths 84.5, 67.5, 50, 15 cm and by this way wall effects have been investigated.
In each progression length, Froud number effect of entrance of intake in a constant submergence depth on surface flow has been investigated. Then in maximum obligatory evacuation, depth of submergence decreases and instability has been studied then the results have been presented in results section.

3.3 Results of physical model:

3.3.1 First experiment :

In this experiment the outlet valve is completely open and submergence suction is 11.5 cm. this vortex has air core that is started from the water level and it is extended until the suction entrance. The amplitude of air core is approximately 2 cm. coefficient of discharge is .86 cm and the vertical height of the concave part of surface is 2.7 cm.
2-from the Odgard formula the suction of submergence is calculated :

$$H = 1.7\frac{V_m{}^2}{g} \quad \rightarrow S = 0.76\Gamma\left(\frac{V_m}{g}\right)^{0.5}$$

S=2.7cm → Γ=0.0944 cm/sec → ω=0.0742 rad/sec
4-the direction of vortex swirling is right hand and at the downward of the right hand of the intake some disturbances have been seen.
5-the distribution of velocity around the channel is no uniform and the main amount of flow enters from the left side of entrance of intake.
6-the inlet velocity in channel is high and then it is decreased and in extremer point it is became to its minimum amount .
7-the distance of the starting of swirling flow from the center of intake is 17cm.

flow rate (m^3/sec)	=	0.00887
h (cm)	=	11.5
pipe velocity (m/sec)	=	1.394
h/d	=	1.2778
x/d	=	10
l/d	=	9.389
radial reynoldse no.	=	0.76825e5
pipe froud no.	=	1.4836
submergence froud no.	=	1.3124
type of vortices	=	strong with air core
circulation number	=	0. 0

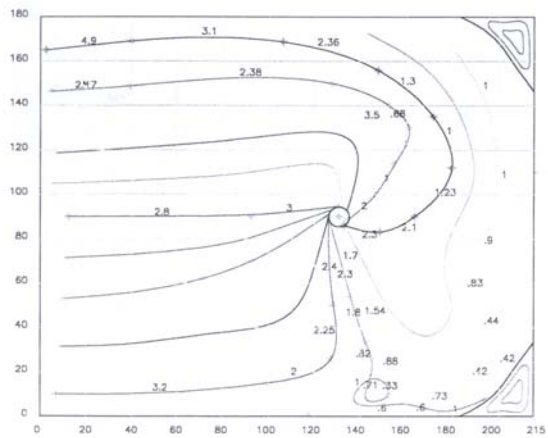

Figure 3: velocity contour plot

3.3.2 Second experiment :

The illustration of figure 4
1-In this experiment the outlet valve is adjusted in middle situation . the deepness of the submergence is 11.5 cm. coefficient of discharge is .86 cm and the vertical height of the concave part of surface is 1.5 cm.
2-from the Odgard formula the depth of submergence is calculated :[3]

$$H = 1.7\frac{V_m{}^2}{g} \quad \rightarrow S = 0.76\Gamma\left(\frac{V_m}{g}\right)^{0.5}$$

S=1.5cm → Γ=0.0836 cm/sec → ω=0.0657 rad/sec
3-the changes of velocity on each stream line is first able rising and in extremer point is digressed then again it continues rises until port of intake.
4-the main amount of flow is arrived from the left side in to the entrance of intake. In this situation the distribution of flow is non uniform.
5-in this experiment t swirling velocity of vortex is dextrose right hand and the disturbances

have been seen in the underneath of the right side of entrance of the intake.

6- the distance of the starting of swirling is 45 cm.

velocity contour plot

flow rate (m^3/sec)	=	0.00349
h (cm)	=	11.5
pipe velocity (m/sec)	=	0.5486
h/d	=	1.2778
x/d	=	10
l/d	=	9.389
radial reynoldse no.	=	0.29962e5
pipe froud no.	=	0.5837
submergence froud no.	=	0.5164
type of vortices	=	strong with air core
circulation number	=	0.0

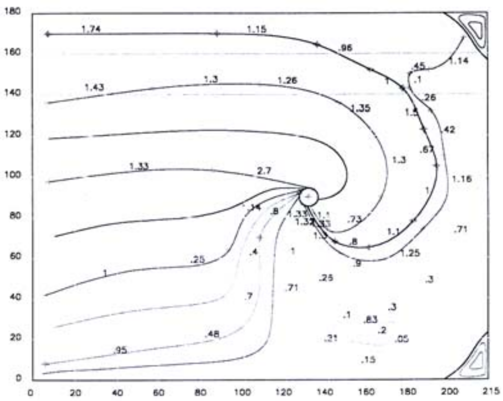

Figure 4: velocity contour plot

3.3.3Third experiment:

In this experiment the outlet valve is completely open and the deepness of submergence is 4.9 cm .the coefficient of discharge C_D .611 and vertical height of the concave part of surface is 4.9. In this situation vortex is established in alternative form and the period of roll is 6.7 sec.

2-the vortex has deepness at the point that is product and in the half of the period it is reached to the critical point then it is decayed and this manner is continuative.

3-during the establishment of vortex that mentioned before, the froud number of submergence is overcome than froud number of trap door.

4-the velocity of flow regarded to the last situation is clearly, that indicates the more power of eddy flow.

5-S=4.9cm → Γ=0.192 cm/sec → ω=0.15 rad/sec

6-in this experiment in spite of more circulation than the previous experiment, fluid is interred radial in channel of intake because of enormous increase surface velocity.

7-at the distance of 25 cm from the center of the entrance of intake on left side fluid is deflected.

8-field of flow regarded to symmetry axes of channel of intake is symmetric.

flow rate (m^3/sec)	=	0.00702
h (cm)	=	4.9
pipe velocity (m/sec)	=	1.1034
h/d	=	0.544
x/d	=	10
l/d	=	9.389
radial reynoldse no.	=	1.4148e5
pipe froud no.	=	1.174
submergence froud no.	=	1.5912
type of vortices	=	strong with air core
circulation number	=	
period of instability(sec)	=	6.7

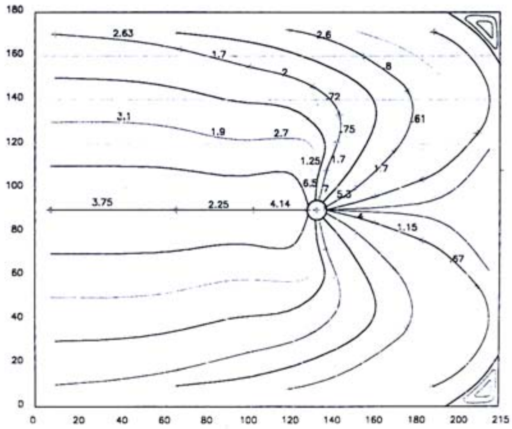

Figure 5: velocity contour plot

3.3.4 Fourth experiment:

In this experiment the outlet valve is completely open and the deepness of submergence is 11.2 cm .the coefficient of discharge C_D .86 and vertical height of the concave part of surface is 2.6 cm.

2-the establishment of vortex is formed with suction of air core to the channel of intake.

3-S=2.6cm → Γ=0.091 cm/sec → ω=0.071 rad/sec

4- At the distance of 29 cm from the center of the entrance of intake and regarded to same position in figure 3 we have increase.

5-the rest comments is like the illustration of figure 3.

flow rate (m^3/sec)	=	0.00886
h (cm)	=	11.2
pipe velocity (m/sec)	=	1.392
h/d	=	1.244
x/d	=	10
l/d	=	7.5
radial reynoldse no.	=	0.7879e5
pipe froud no.	=	1.4812
submergence froud no.	=	1.32779
type of vortices	=	strong with air core
circulation number	=	0. 0

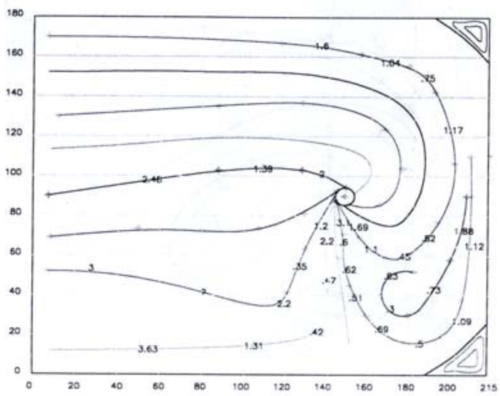

Figure 6: velocity contour plot

3.3.5 Fifth experimetn:

1-This experiment is like the experiment of figure 4 ,but the difference is the decrease of the length of progression of entrance of intake in comparison with last situation.

2-The depth of submergence is 11.2 cm .the coefficient of discharge C_D .915 and vertical height of the concave part of surface is 1.5 cm.
3-S=1.5cm → Γ=0.0836 cm/sec → ω=0.0657 rad/sec.
4-the considerable point is that the decrease of L/D in constant Froud number causes the increase of distance of begining of flow to 110 cm.
5- the shape of vortices is systematic and like helicoids . we don't have disturbances at the right side of intake.
6- the rest comments is like the illustration of figure 4.

flow rate (m^3/sec)	=	0.003489
h (cm)	=	11.2
pipe velocity (m/sec0	=	0.5484
h/d	=	1.244
x/d	=	10
l/d	=	7.5
radial reynoldse no.	=	0.3103e5
pipe froud no.	=	0.58354
submergence froud no.	=	0.5231
type of vortices	=	strong with air core
circulation number	=	0.0

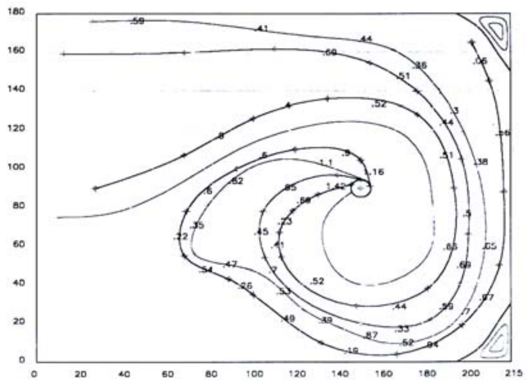

Figure 7: velocity contour plot

3.3.5 Sixth experiment:

1-In this experiment the outlet valve is completely open and the deepness of submergence is 5.3 cm .the coefficient of discharge C_D .695 and vertical height of the concave part of surface is 4cm cm.
2-In this experiment vortex is formed alternatively and the period of alternate is 7.3 sec.
3-The little increase coefficient of discharge C_D is because of decrease the length of progression and increase of deepness of submergence to 4 mm.
4-S=5cm → Γ=0.194 cm/sec → ω=0.152 rad/sec.
5-the field of flow is non symmetrical because of non uniform distribution of the vertical vectors i=at the entrance of intake .this problem is due to laminator surfaces.
7- the rest comments is like the illustration of figure 5.

flow rate (m^3/sec)	=	0.007163
h (cm)	=	5.3
pipe velocity (m/sec)	=	1.126
h/d	=	.58
x/d	=	10
l/d	=	7.5
radial reynoldse no.	=	0.1346e5
pipe froud no.	=	1.198
submergence froud no.	=	1.5613
type of vortices	=	strong with air core
circulation number	=	
period of instability(sec)	=	7.3

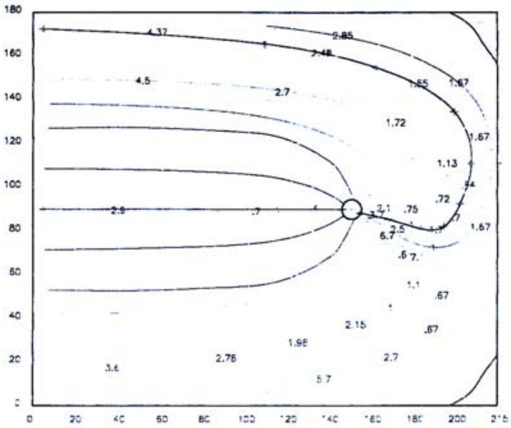

Figure 8: velocity contour plot

3.3.6 Seventh experiment:

1-In this experiment the outlet valve is completely open and the deepness of submergence is 11.6 cm .the coefficient of discharge C_D .86 and vertical height of the concave part of surface is 2.5 cm.the amplitude of vortex is 1.8 cm.
2-S=2.5cm → Γ=0.0875 cm/sec → ω=0.0688 rad/sec.
3- the distance of the starting of swirling flow from the center of intake is 49 cm. regarded to same position in figure 6 we have increase.
4 – the length of helicoids line is decreased and the rotataion to.
5- the rest comments is like the illustration of figure 5.

flow rate (m^3/sec)	= 0.00884
h (cm)	= 11.6
pipe velocity (m/sec)	= 1.391
h/d	= 1.2889
x/d	= 10
l/d	= 5.55
radial reynoldse no.	= 0.7161e5
pipe froud no.	= 1.395
submergence froud no.	= 1.2287
type of vortices	= strong with air core
circulation number	= 0. 0

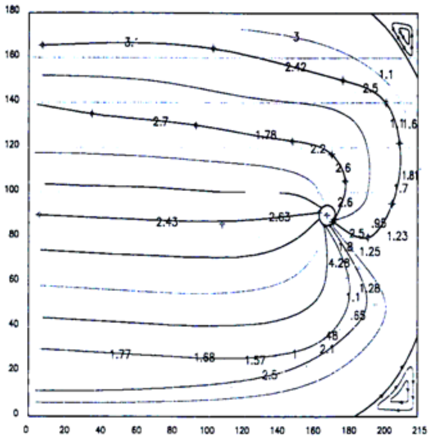

Figure 9: velocity contour plot

3.3.7-Experimental observation:

With attention to physical model and accomplished experiments in this research, the results of this section are very noticeable. Validation of these results is verified by experimental measurement.

1-In vertical down towards intakes, when depth of immergence is decreased to approximately 0.6D (D: Diameter of suction entrance), a strong vortex is made alternately. The view of concave of these vortices on the parallel plate with the free surface of fluid, has greater area with area of suction. That means the vortex is so intense, During the establishment of mentioned vortex, the concave part of the surface Is extended to inside of suction entrance and in this case separation of boundary layer occurs on suction entrance. This problem is justified as following :

2-It is mentioned that intensity of vortex is related to fluid velocity, since this type of vortex is very intense, velocity of fluids on the surface is increased and velocity vector makes an angle with the normal of area section of entrance of intake, So this phenomena causes separation of boundary layer.

3--Mentioned vortex has been formed alternately and frequency of that is exactly constant. In this state, in time of t = T/2 the vortex is initiated with concave of surface And concluded to suction of air core by intake entrance. Then in t = T/2 suction of air core is stopped and intensity of vortex will be reduced. So surface velocity of fluid is decreased and this event will be continued with beginning of next cycle.

4-During the establishment of mentioned vortex, surface velocity of fluid is increased and surface trashes is drawn into the suction entrance simply. By the way created vibrations are very destructive and total structure of instrument is vibrated alternately and this phenomena exerts a fatigue load to hydraulic structure.

5- During establishment of mentioned vortex, mass flow in intake enterance is decreased in amount of 20-25 percent.

6-In the condition that an alternate vortex exists, if internal mass flow to canal of the intake is not more than maximum mass flow of the pump, altitude of water in canal will remain unchanged. It means slight changes internal mass flow has been neutralized and water altitude will not be increased in channel of intake.

7-If during the formation of alternate vortex, depth of submergence is increased over than 0.6D, mass flow of intake will be increased.

8-If submergence depth is increased less than 0.4-0.6D, process of regular formation of vortex will be stopped and a series of vortexes with different frequency will be formed. For example if depth of submergence is decreased in 0.27D, passing mass flow of intake is decreased in amount of 82 percentage and in this condition the regular period does not exist and generally it will be increased.

9-With reduction of L/D, formation period of alternate vortex is increased and this procedure will continued till L/D~2, after that alternation period will decreased. This problem is probably because of increase of walls effects is nonlinear.[8]

10-When the vortex being formed the coefficient of discharge is decreased because:

A-Reduction of effective area section of internal flow to intake since that part of area section is occupied by air and in other hand air taking of pump is increased and air bubbles are completely visible in outlet of pump.

4 Conclusion

An experimental method using particle tracing and changes of ratio of intake pipe length to the intake entrance diameter was developed to study the influence of vortex formation in intakes. Therefore reduction of this ratio lead to decrease of vortex intensity. this result has a good agreement with other researchers founds. Also increasing of entrance section area reduces the strength of the vortex. Based on the obtained results in this work by installing the moveable barrier near the intake entrance can be recommended for reducing vortex formation at vertical intake .

Notation:

The following symbols are used in this paper:

C_D = Coefficient of Discharge

Q = Mass Flow

F_{rD} = Froud Number

g =Gravity Acceleration

V_m =Maximum tangent velocity

S = Submergence

T = Time

r =Distance of particles of fluid to vortex center

D =Suction pipe diameter

L = Intake pipe length

L/D =Wall clearance

H =The depth immergence

Greek symbols:

Γ =Circulation

ω =Angular velocity

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