UGC Approved Journal

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 4, Issue 8, August 2017

Investigating the Setting of the Entrance of Multiple Vertical Suction Pipes in Storm Water Pump Station

Asst. Prof. Dr. Hasan Mahdi M. Al-Khateeb [1], Asst. Prof. Dr. Hayder Abdulameer K. AL-Thamiry [2], Ali Hussein Athab [3]

University of Kufa, Faculty of Engineering/ Civil Eng. Dep. Najaf- Iraq [1]

University of Baghdad, College of Engineering/Water Resource Dep. Baghdad- Iraq [2]

Faculty of Engineering, Department of Civil Engineering, University of Kufa, Iraq [3]

Abstract: Storm water pump stations are usually utilized to facilitate drainage of run-off water from segments of cities and neighborhoods. The velocity of inlet suction pipe (v) and the water depth from suction pipe onset to the water surface (submergence) represent important factors to avoid free and subsurface vortices at pump suction pipes. The present study set out to determine effect of submergence (s) and velocity of inlet suction pipe (v) on the hydraulic conditions of storm water pump station. Through this study, a physical model has been constructed to simulate a typical wet well side for multiple vertical suction pipes with the same diameter (d) and bell mouth out diameter (D). Many runs have been conducted through which effects of the pipe flow velocity, suction pipes spacing (b) and submergence were observed through the four glasses sided well model by means of naked eye, and detected by pressure gauge situated at suction side. Measurements were made for diameter and height of vortices formed. This study aims to determine the best arrangement of pumps intake suction pipes with respect to operational submergence to prevent the occurrence of any type of vortices using minimal wet well dimensions for a given flow rates. The results showed that, surface vortices do not formed when the submergence ($s \geq 1.75D$) and spacing ($b > 2D$) for Fr (u) ≤ 1.

Keywords: Vortices, Pump Intake, Submergence.

I. INTRODUCTION

Storm water pump stations are necessary to facilitate drainage of run-off water from sections of cities that cannot to be drained by gravity. However, due to high costs and possible problems associated with storm pump stations, their use is advisable only where other drainage systems are not practicable [1].

There are several important considerations in the design of a suction side in storm water pumping station. It is imperative that prevention of vortices occurring at a pump-intake structure, free and sub surface vortices is an important problem encountered in hydraulic design of wet well side [2], [3]. These vortices may reduce the performances of pump station as a whole, also have negative effects on the operating conditions and lead to increase pump station operating costs [4]. The flow near an intake is very complex, so it is not readily evaluated using theoretical solution, especially, when shape of the intake medium is not idealized [5], [6]. Therefore, to design intakes free of distasteful air-entraining vortices, it is advisable that the design is based on physical-model studies. Several experiments using physical models have been conducted in order to select best operational submergence and flow velocity in pumping station corresponding to appropriate suction pipes spacing [7], [8], and [9] and [10].

II. METHODOLOGY

This study involved simulation of a wet well with multiple suction pipes by means of a physical hydraulic model. The main objectives of this study are to investigate the effect of three parameters, namely as submergence (s), inflow velocities (v) and suction pipes spacing (b). Each effect of these parameters is studied, particularly, on formation of air-entraining vortices that may endanger the pumps. The indicator to reach best hydraulic conditions is to prevent the occurrence of any type of vortices. As much as the operational conditions yield maximum pumps' flow without formation of vortices, such conditions may be considered to reach optimum hydraulic performance of the pump station. Accordingly, such conditions help to enhance pumps efficiency and elongate their service life. The simulation was for storm water pump stations, in this study, to eliminate the probable effect of water organic content on its viscosity and density. The results of this study are applicable for drinking water pump stations, too.

DOI10.17148/IARJSET.2017.4810

III.EXPERIMENTAL WORK DESCRIPTION

The physical model consisted of four principal components. They are; wet well (platform water tank), suction pipes, pumps, discharge pipe, Fig. (1). the tank was supplied with stilling basin. Each suction pipe was equipped with valves to control water flow, and pressure gauge to observe suction pressure. The discharge pipe included flow meter to check flow rates. Model components are described below:-

Fig.1. Physical model used in the study

A. Experimental Platform Tank

Runs of laboratory work were conducted in three tanks with the same length and depth as (0.97m), (0.75m) respectively, but with three different values of width depending on distance between pipes (b). The first tank was (0.45m) wide, whereas the second was (0.68m) and the third was (0.92m). The tanks were made of steel frame. Their wall faces were glass sheets of (10mm) thick to allow clear view inside the tank. Bottom face was steel sheet with (2mm) thickness. At the reflex side, most of flow energy was dissipated by means of the perforated pipes, the trench, and the screens in such a way that make the flow much uniform and free of circulation. Perforated PVC pipes (10cm diameter each) put inside the trench to reduce water flow turbulence before reaching the trench as an initial stage, Fig. (2). The trench (as a box with no cover) was constructed from fiberglass panels attached to each other with waterproofed silicone paste forming three sides attached to tank wall.

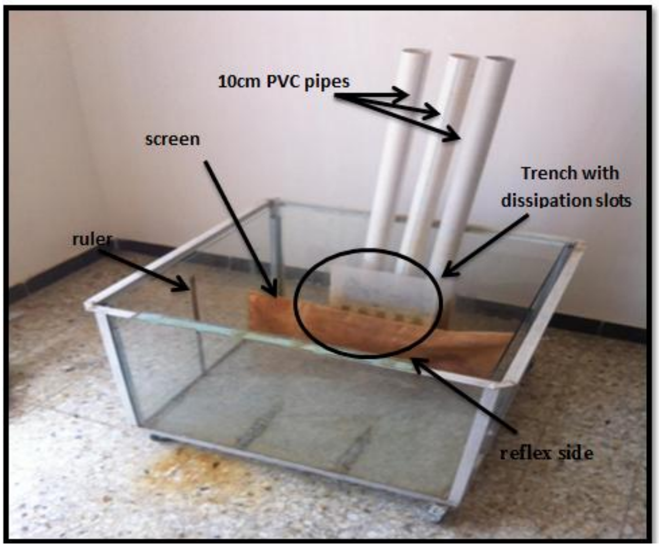
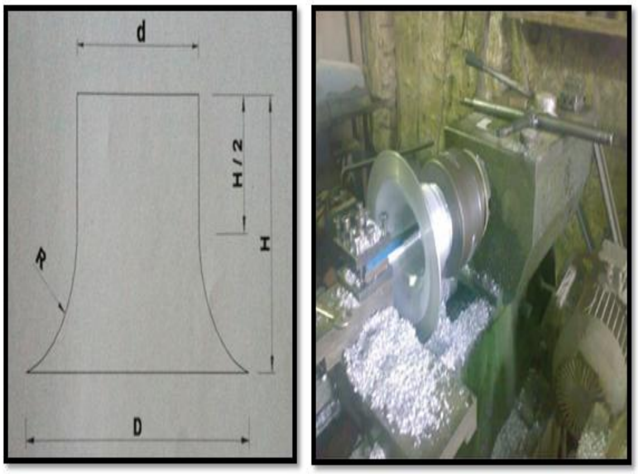


Fig.2. Lab. platform wet well (Intake tank) used.

UGC Approved Journal
IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 4, Issue 8, August 2017

It has outer dimensions of (34cm) long, (17cm) width and (40cm) depth. Several openings with (32*2cm) dimensions have been made on the three sides of the trench to allow water goes toward suction pipes after passing through two successive rows of screens made of coarse textile cloth. Water depth in the tank was adjusted for each run according a ruler reading which installed on one side of the sump.

B. Bell Mouth
Bell mouth entry situated at the inlet of pump suction pipe helps to minimize entrance local head loss through suppressing flow separation. It enhances uniform flow throughout the intake pipe cross-section. Fig. (3-a) illustrates the dimensions of bell mouth adopted in this study. Selection of this bell mouth agree with Prosser (1977) [11], where mostly recommended bell mouth diameter (D) lies in between (1.5 – 1.8) times the diameter of discharge pipe (d).



a) b)

Fig.3. (a) Bell mouth configuration adopted in this study, (b) bell-mouth fabrication through the study

C. Pressure Gauge
The physical model was provided with a mechanical (analog) pressure gauge (EN 837-1) installed on each suction pipe having measure range of (0 to -1 bar), Fig (4).

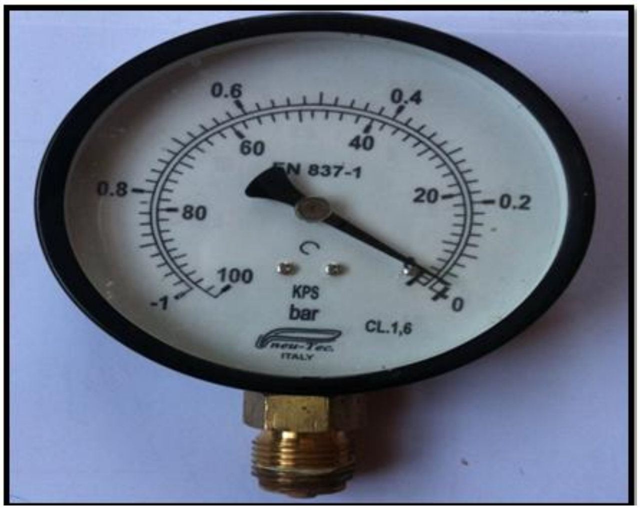


Fig.4. Mechanical Pressure gauge used.

D. Flow meter
The flow meter used in this study is Variable Area Flow meter or so called Rota meter with vertical installation, Fig. (5). It employs a glass tube with varying diameter (larger end at the top) containing metering float. Because range of flow rates adopted in this study (91.2 – 365 L/min) is rather wide, two variable Area Flow meters have been used. First measures the flow rates (91.2 – 182.4 L/min) corresponding to flow velocities of (0.75-1.5m/s) in the suction pipes, while the second measures the remaining flow rates (243 and 365 L/min) of the two velocities (2 and 3m/s).

UGC Approved Journal

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified

Vol. 4, Issue 8, August 2017

Fig.5. Variable Area Flow meters used

E. Pump

The function of using pumps in this study is to create suction flow in the suction pipe of the physical model. Type of pumps used is centrifugal type (Shimge**,** 2SGPm **(2" x 2")**) which consists of three parts; single-phase motor of asynchronous type, water pump of centrifugal impeller and single seal, Fig. (6). this pump has properties suitable for the experimental work that is reliable and cost effective. It has built-in assembly with direct link (coupling) type, and satisfying operating conditions (temperature range from 0 up to 80°C, max head 50m of water column, suction water head up to 8m, max discharge 600 L/min).

Fig.6. Centrifugal pump used

F. Digital Thermometer

Digital thermometer shown in Fig. **(7)** Was used to monitor water temperature throughout lab work. It enable measuring a wide range of water temperature as (-50C to +300C) with good resolution of 0.1 C/F with accuracy of ±1 C/F, while power supply needed is only DC 1.5 V (LR44).

Fig.7. Digital thermometer used

DOI10.17148/IARJSET.2017.4810

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 4, Issue 8, August 2017

G. Valves and Fittings

Three types of valves were used in constructing the physical model, they were:-

Ball Valves, These valves usually are quarter-turn and have a round closure element (round plug) which rotates 90° from fully opened to fully close.

Gate Valves, A one gate valve has been used at the end of each suction pipes near to the pumps to adjust flow rate passing through each suction pipe. It has a vertical thin disc sliding in a cap at a right angle to the flow direction.

Foot Valve, It is one of the simplest types of check valves often installed in a vertical position near the inlet of vertical suction pipes. The objective of using these valves in the model, Fig. (8), is to prevent back flow from the pump while shut-off. In addition, the foot valve has been used to keep suction pipe filled with water that allow the pump to maintain prim.

Fig.8. Foot valve used

Other fittings have been used, such as long radius elbows 90, reducer, tee junction, flanges, coupling, welded union, cross junction and others of minor pipe system accessories to connect the individual pipes of the physical model, Fig.(1).

IV. MEASUREMENT TECHNIQUES AND OBSERVATIONS

A. Investigated Parameters and Scenarios

Water temperature was nearly constant (20 ± 2^0C) throughout the experiments. The clearance between pipes centrelines and tank side wall (a) and the clearance between bell mouth and tank bottom (z) were constant as (a=z=D). The Length of tank measured from bell mouth centre to the stilling basin (L) was constant as 10D. The total width of the tank is 3D. Table (1) illustrates parameters studied and their proposed values.

In each run, visual observation for the formation of vortices (if any) was carried out by the naked eye through the four sided-glass walls of the tank. The observation lasts for 15 minutes (while the flow in tank is completely steady). If any vortex appeared, measurement were made visually for; vortex depth, diameter and location. At the meantime, pressure gauge reading when air-entraining vortex initiates is recorded, too.

B. Observing Surface Vortices

In this investigation, four cases were observed for free surface vortices. They have been denoted by proposed symbols as (type I-1, type I-2, type I-3 and type I-4) to be distinguished. They are described as follows:-

Type I-1: This type formed as very simple swirl ring on water surface without a considerable depth (as a dimple) as appear in Fig. (9). It was observed only by reflection of light from the water surface. This vortex type does not affect the performance of the pumps absolutely because it does not cause the air to enter pump suction pipe.

TABLE: 1. PARAMETERS STUDIED AND THEIR PROPOSED VALUES

Dimension symbol	Dimension description	Proposed dimensions
D	Inlet bell diameter	76.2 mm
s	Submergence depth to bell mouth inlet face.	(D, 1.25D, 1.5D, 1.75D, 2D)
v	Suction pipe flow velocity	(0.75, 1, 1.5, 2 & 3)m/s
b	Distance between inlet suction pipes c/c	2D,3D,4D
L	Length of tank measured from bell center to the stilling basin.	10D
W	Width of tank	3b

UGC Approved Journal
IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 4, Issue 8, August 2017

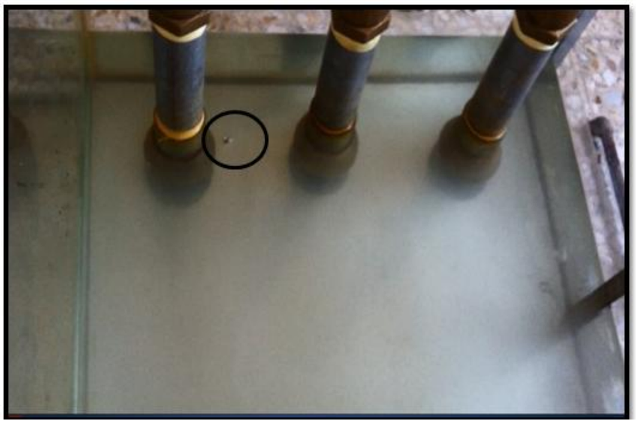


Fig.9. Appearing of vortex type (I-1)

Type I-2: According to this type, vortex motion on the surface of the water be more severe than the first type (**I-1**) and has a short tail extends from water surface to a few centimetres away in depth and disappears without producing separated bubbles, Fig. (10). Vortex tail can be seen more readily by naked eye due to obvious depression. This type does not affect the performance of the pumps because the air does not reach intake pipe onset, However, it is not favourable to have this kind of vortices in the pumping stations because it may developed to other types of vertices endangering the pumps.

Fig.10. Forming vortex of type (I-2)

Type I-3: In this type, the vortex tail becomes deeper and wider. Separated air bubbles from the bottom of the tail can be distinguished as they pulled into the bell mouth inlet, Fig. (12). Air bubbles may reach to the pump. Thus, creation of this genre vortex type has to be avoided in the intake pump sump.

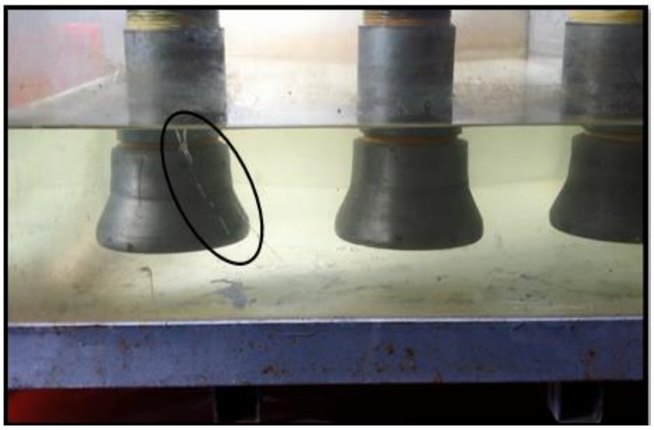


Fig.12. appearing the vortex type (I-3).

Type I-4: In this type, vortex formed as air cavity like a cord connecting water surface and pipe bell mouth, fig. (13). this cavity cord sucks air into the pump continuously. Through experiments, this type had observed very clear during some runs. The cavitations occurred in this type can harm the pumping system through decreasing pumps' efficiency. It may reduce pump operating life through impacting pump casing and impeller. It may, also, destabilize pump supports due vibration caused by cavitations. It may produce effective noise, too.

UGC Approved Journal
IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 4, Issue 8, August 2017

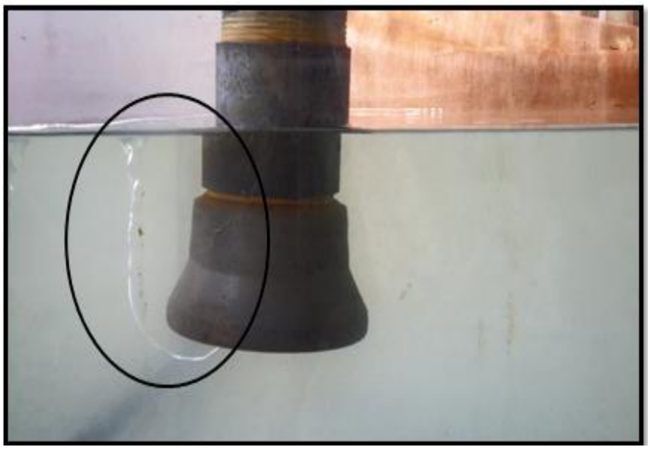


Fig.13. Forming vortex of type (I-4)

C. Observing Subsurface Vortices

Subsurface vortices are that form beneath water surface and usually attached to the wall or floor of a pump intake structure. Vorticity generated in a separation zones close to pump suction entrance or below the suction bell mouth, usually, produces vortices submerged under water surface (sub vortices). The sub-surface vortices have been denoted by proposed symbols as (type II and type III) to be distinguished.

They are described as follows:-

Type II: This type formed as connecting between the bell mouth inlet and either nearest wall or floor as appears in Figures (13) and (14).

Type III: This type formed as connecting between two adjacent bell mouths inlets of two suction pipes as appears in Fig. (15).

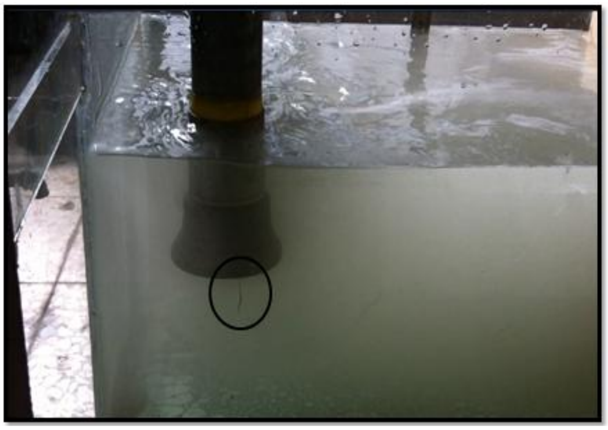


Fig.14. Sub-surface vortex type II (wall attach)

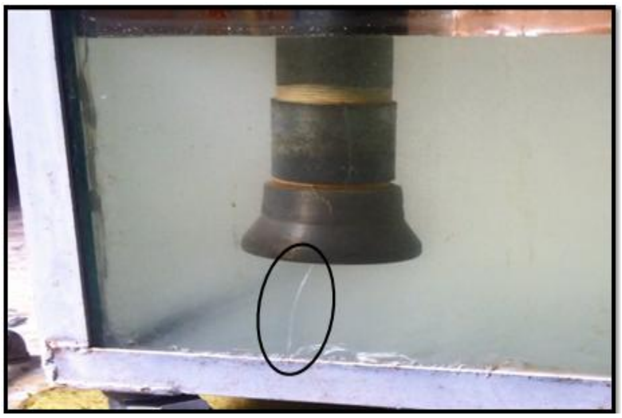


Fig.15. Sub-surface vortex type II (floor attach)

DOI10.17148/IARJSET.2017.4810

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 4, Issue 8, August 2017

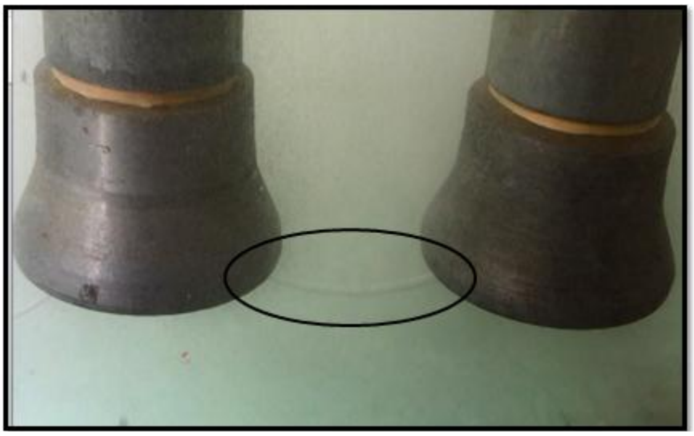


Fig.16. Formation of Sub-surface vortex type III (superposition)

V. RESULTS AND DISCUSSION

A. Effect of Flow Velocity in Pump Suction Pipes (v) with pipe spacing

1. Free surface vortices
The velocity of inlet suction pipe (v) is expected to be a dominant factor in the incidence of vortices with free surface type. A strong effect of (v/u) on appearance of all vortices types can be seen obviously, where (v) is flow velocity in suction pipe and (u) flow velocity in the tank near the inlet of the pipes. When (v) velocity is small, the vortex is so low and forms on the surface with a little depth, and referred to as (I-2). If the velocity rose up, the vortex becomes even more severe and sucks air intermittently to the pump suction pipe (type I-3). If the velocity increases, a little more vortex formed often withdraws air to the pump continuously (type I-4).

The general trends of results explain that, effect of velocity ratio (v/u) on the surface vortices occurrence decreases whenever the value of pipes spacing (b) increases. At the biggest value of intake width, highest (v/u) is required to allow surface vortices to occur. At low suction velocity (v=0.75 m/s) any vortex type did not happen at all, except some simple surface swirls. At (v=1m/s), vortex (I-3) was the most likely occurred. Increasing velocity over this limit may lead to forming vortex type (I-4) with high prospect, especially when it exceeds (1.5m/s). Occurrence of cavitations or vibration in association to vortex type (I-4) happened at high velocities (2 to 3m/s).

2. Sub surface vortices
As expected, the possibility of vortices occurrence increases with increasing flow velocity in suction pipes (v). Tests carried out in this study showed that flow velocity in pipes (v) is important parameter in the occurrence and strength of sub surface vortices of types (II) and (III). At (v=0.75 -1m/s), a weak vortex -mostly type (II) - occurred only with (b=2-3D). At higher velocities, the sub-vortices occurred even with high values of (b).
The influence of flow velocity distinctly decrease with pipes spacing increase, where they started to form at (v=1 m/s) with (b=2D), whereas they formed at (v=1.5m/s) at (b=4D). However, at higher spacing, vortices formed with lower submergence (s/d).

B. Effect of Submergence depth above Inlet Bell (s) with pipe spacing

1. Free surface vortices
One of the most important parameters control the occurrence of surface vortices is the submergence depth (s). To explain influence of this parameter, relative submergence (s/d) is plotted against inlet suction pipe Fraud number (FRS) which is equal to (FRS= $v/\sqrt{gd}$). The increase in submergence depth (s) reduces the chance of vortices formation. When (s) increased, high inlet pipe Fraud number (Frs) was required to permit vortices to occur, hence reducing the probability of free surface vortices formation regardless of others parameters, Fig.(17) .

Rarely, vortices are formed when the submergence depth is equal or greater than (s=1.75D) even with high values of (a) and small (b).

Mostly, the surface vortices occurred with all experimental circumstances when the submergence was equal or less than (s=D). Submergence when reduced to a depth equal or below (D), eddies did not occur provided that (a=D and b>2D).

DOI10.17148/IARJSET.2017.4810

UGC Approved Journal

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified

Vol. 4, Issue 8, August 2017

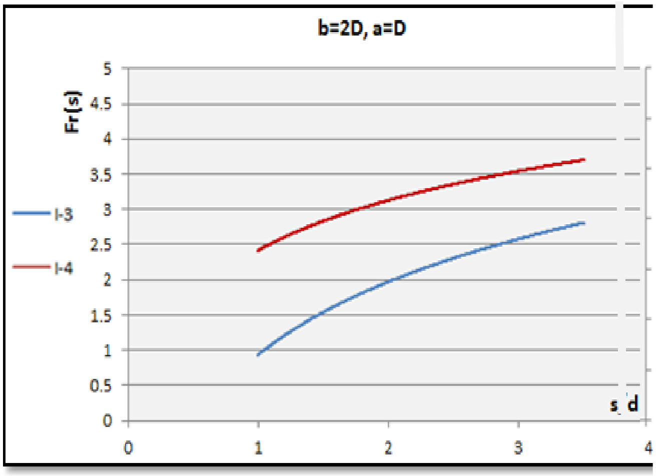


Fig.17. Relation of (s/d) with Fr (u) to initiate forming the vortices (I-3 and I-4)

2. Sub surface vortices

A graphical representation for the effect of submergence depth (s) is shown in Fig. (18). In general, for all spacing values (b) and a part of the remaining parameters, rising water depth above inlet bell (s) reduces the sub vortices formation in the intake zone. By means of fig. (18), it can be seen that the influence of (s) is affected largely by the spacing (b), since the decrease in pipes' spacing (b) usually associated by vortices formation with a low values of inlet pipes Fraud number (FRS). It, also, can be noticed that at the first value of (b) as (2D), there is a high possibility for sub-vortices to occur with a wide range of depths with lower Fraud number values along with increasing submergence depth. Neither in (b=3D) nor (b=4D) any vortex type occurred with depth (s/d=3). At (b=3D), it occurred in a weak strength with depth (s/d=2.62) but needed relatively high (FRS), while it did not occur with (b=4D) except at few depth range (s/d=1.5 – 2.25) and high flow velocities (high FRS).

Increasing water depth above pipe onset will cause a rising in water weight, which reduces destabilization of water pressure near the pump suction, and thus prevent the air gaps to form inside the pump sump. This mechanism reduces the appearance of vortices.

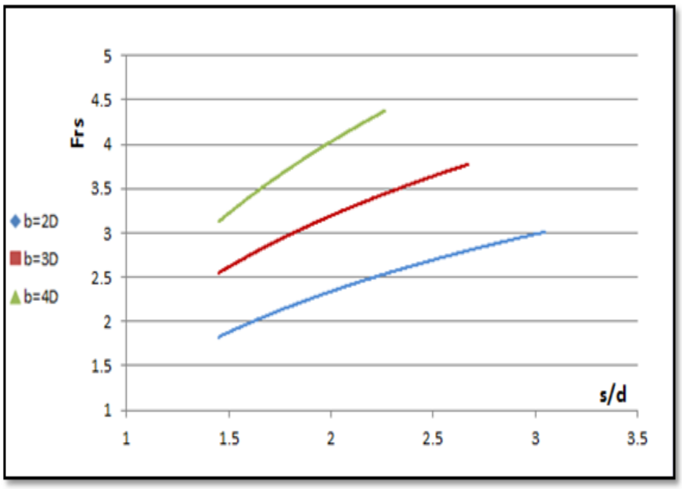


Fig.18. Plot of submergence depths against (FRS) at the beginning of sub- surface vortices appearance.

VI. CONCLUSION

- Surface vortices do not formed when the submergence ($s \geq 1.75D$) and ($b > 2D$) for Fr (u) ≤ 1.
- Flow velocity has a very significant effect on both free and sub surface vortices. Effect of velocity ratio of flow in suction pipes/ approaching flow velocity to the suction pipes (v/u) on the surface vortices occurrence decreases with increasing pipes spacing (b). However, for the conditions tested, possibility of vortices occurrence significantly increased at high flow velocities (v = 2.5 - 3m/s), while no vortices happened when ($v \leq 1$m/s).

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified

Vol. 4, Issue 8, August 2017

- To avoid subsurface vortices with flow velocity ($v \leq 1$m/s), for each average unit increase in pipe spacing to pipe diameter (b/d), a unit decrease in (s/d) is required, while an average 0.6 decrease in (s/d) corresponds to unit increase of (b/d).
- Most surface vortices of type (I-4) are accompanied by occurrence of cavitations (sometimes turns off the pump); noise and vibration, while no such phenomena appear with sub surface vortices. This may indicate that, free surface vortices are more harmful than sub surface vortices.

REFERENCES

[1] City of Reno, 2007, “Wastewater Lift Station Design Standards”, Reno, Nevada, USA.
[2] Ansar, M., and Nakato, T. (2001), “Experimental Study of 3D Pump-Intake Flows with and without Cross Flow”, Journal of Hydraulic Engineering, Vol. 127, (10), p: 825-834.
[3] British Standard, BS 8005-2, 1987, "Sewerage. Guide to Pumping Stations and Pumping Mains".
[4] Denny, D. F., and Young, G. H. J. (1957). “The Prevention of Vortices and Swirl at Intakes.” Proc. of 7th IAHR Congress, C1, Lisbon.
[5] Durgin W.W and Hecker G.E. (1978), “The Modeling of Vortices at Intake Structures”, Proc. of IAHR, June 1978, Vols. I and III.
[6] Daggett L. L., and Keulegan G. H., (1974), “Similitude in Free-Surface Vortex Formations”, Journal of the Hydraulics Division, Vol. 100, p: 1565-1581.
[7] Amiri S.M., Zarrati A.R., Roshan R. and Sarkardeh H., (2011), “Surface vortex prevention at power intakes by horizontal plates”, J. Water Management, (ICE), 164(4), 193-200".
[8] Anwar H.O., (1967), “Vortices at Low Head Intakes”, J. Water Power, 19 (11), 455-457.
[9] Anwar H.O., Weller, J.A. and Amphlett, M.B., (1978), “Similarity of Free Vortex at Horizontal Intake”, Journal of Hydraulic Research, (2), 95-105.
[10] Anwar, H.O. and Amphlett, M.B., (1980), “Vortices at Vertically Inverted Intake”, Journal of Hydraulic Research, 18 (2), 123-134.
[11] Prosser, M. J., (1977), “The Hydraulic Design of Pump Sumps and Intakes”, British Hydromechanics Research Association (BHRA) Fluids Engineering, Canfield, Bedford, England.