VORTEX FORMATION AT VERTICAL PIPE INTAKES EQUIPPED WITH A VORTEX-BREAKER

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ABSTRACT

The aim of the present work is to investigate the flow characteristics in the gap between the buffer plate of a vortex breaker and the bottom of a floating roof tank, and in the vertical pipe intake. The study is an attempt to solve the problem of vortex formation at intakes, and to avoid impingement of the lower deck of the floating roof when filling or emptying the tank, at the required flow rate. This is a typical problem encountered in crude oil double deck floating roof tanks, and reported by the Arab Petroleume Pipeline Company (SUMED). The investigation was carried out in a geometrically similar transparant tank, to simulate the tank under consideration. Results showed that, swirl flow may be caused by abnormal operating conditions or large scale rotation in the bulk of the fluid in the tank . The rotation is then amplified as the flow converges into the tank, which is accompanied by a rapidly rotating inner core , even if there is no surface vortex visible.

INTRODUCTION

Vortex formation at intakes is a significant engineering problem in many situations. Many serious and undesirable effects are experienced when the vortices entrain air . Such vortices cause appreciable loss in the efficiency of hydraulic machinery and produce vibration and noise. Denny [1] has reported that a vortex entraining 1% (by volume) of air can cause as much as a 15% reduction in the efficiency of a centrifugal pump. He has further stated that, in extreme cases, over 10% of the flow entering the intake could consist of air, and swirling angles of up to 40^{o} could be realized, thereby resulting in disastrouse effects. Furthermore, there is increased susceptibility to cavitation damage and the swirling flow in the pipeline causes increased energy loss. Jain et al., [2] carried out an experimental study concerning vortex formation at vertical pipe intakes due to circulation in the approach flow. The aim of the study was to understand clearly the role of the different dimensionless parameters on vortex formation. An example of their experimental program is one in which the approach flow is radial, and thus the approach flow is free from circulation. The flow obtained under such conditions aroused the interest of Raju et al. [3], and prompted them to study this aspect in detail. They have concluded that in radial approach flow towards vertical pipe intakes, the condition for onset of air entrainement has been found to be independent of viscous and surface tension effects.

Most vertical intakes will therefore require some antivortex device, if weak vortices are to be avoided [4]. Sweeney, et al. [5] state that at pump intakes, no organized or subsurface vortices equal to or greater than that visually represented by a coherent swirl into the intake (dye core vortices) can be allowed. It was also reported that use of horizontal plates over vertical intakes reduce vortex development. However, a typical problem due to the installation of such a vortex breaker was observed in the Arab Petroleum Pipeline Company (SUMED) tank farm and was subsequently reported; in which crude oil double deck floating roof tanks, having the capacity of 100,000 cu.meter, are equiped with an off bottom inlet/outlet nozzle. The diameter of the tank is 86 mt., and the drawoff nozzle diameter is 2.68 mt. The tank has to be emptied to the minimum possible level. Accordingly, the roof position was modified to rest at 0.8 m. from bottom and therefore the incoming flow can cause impingement of the lower deck of the roof during filling. To overcome this problem a buffer plate was installed at a distance of 0.5 mt. on top of the nozzle. This gave rise to vortex action in abnormal operating conditions leading to the sucking of the buffer plate.

This paper presents the results of pressure measurements that may be used to qualitatively define the

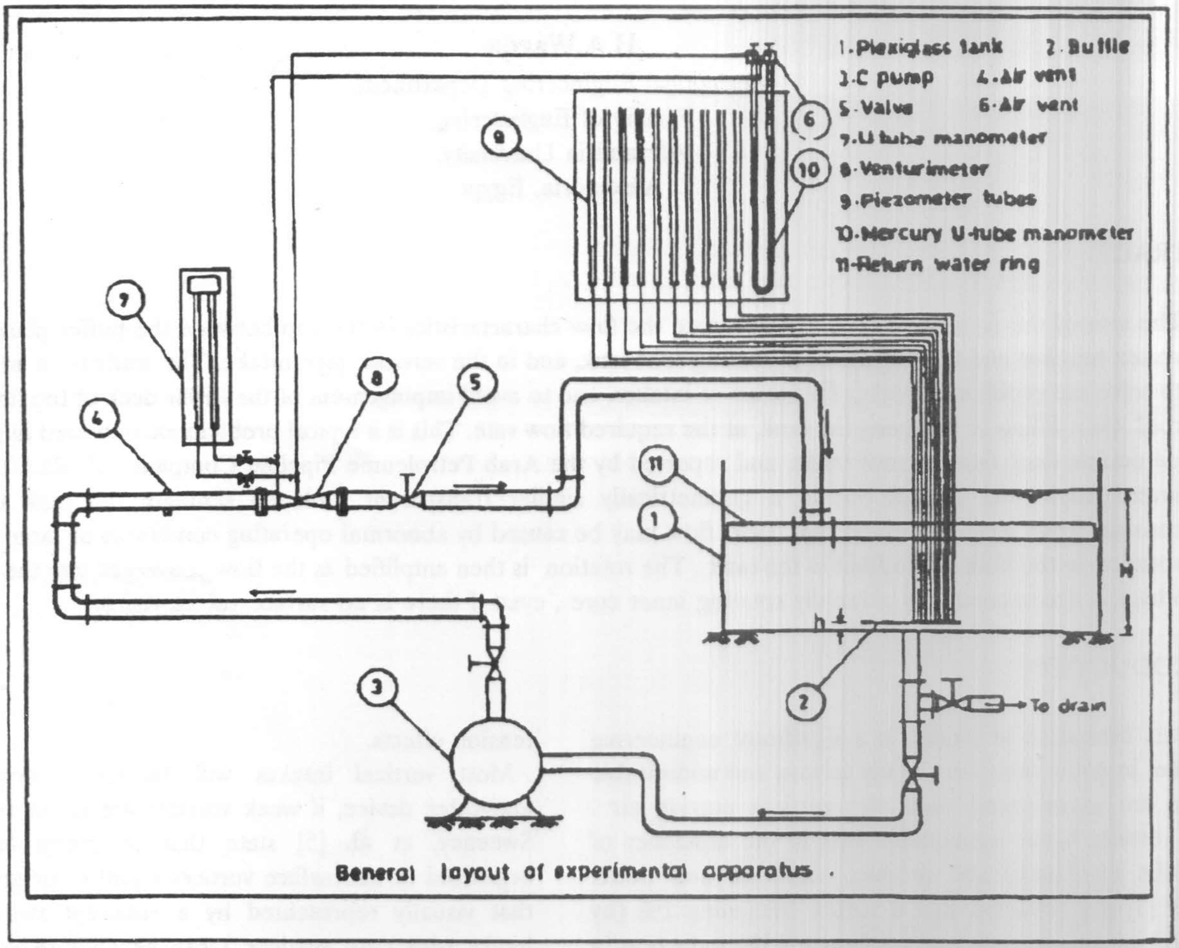

Figure 1. General layout of the experimental apparatus.

conditions upon which vortices would form at the pipe intake, underneath the vortex breaker. The results of pressure measurements were also confirmed visually by injecting a dye into the gap, and observing the formation of a persistent dye core vortex.

EXPERIMENTAL PROGRAM

Prototype intake installation have such irregular and complex approach boundaries that mathematical description is inadequate. Consequently scaling criteria, and thus scale effects, for vortex phenomena are uncertain, despite considerable research efforts to elucidate them [6]. As such, recourse has invariably to be taken to hydraulic model studies. In order to construct such a model and translate the results to the prototype, it is essential that similarity laws governing the phenomenon be thoroughly known. Unfortunately ,the similarity conditions for vortex formation at pipe intakes are not well established. However, many hydraulic engineers agree that equality of Froude number in model and prototype is essential to ensure dynamic similarity. Contrary to this, based on a study of the behavior of vortices in model sumps, Denny[1] found that for vortex similarity , the velocity in the model must be equal to the velocity in the prototype and thus suggested the equal velocity concept.

In the present study the geometrical similarity between the model and prototype was preserved. However, the model was operated at a range of intake velocities that covered the actual intake velocity in the prototype , i.e adopting the equal velocity concept.

EXPERIMENTAL PROCEDURE AND EQUIPMENT

The experimental Set-up

The equipment used for the tests was especially designed for the modelling of the oil tanks in SUMED . Figure (1) is a diagramatic sketch of the apparatus showing the general layout and defining the various features to which referance is made. The apparatus is illustrated in Figure(2). The model comprised a transparent tank of internal diameter .87 mt. and height .5 mt., installed with a vertical pipe intake ,of diameter 25.4 mm., centrally located in the tank bottom. The tank could be filled with water within few cms. of its rim. The inflow was uniformly distributed around the tank periphery. Pumped outflow, which was circulated back into the tank was used to obtain the desired range of discharge, independent of the submergence. The discharge was measured by means of a calibrated venturimeter located in the delivery side.

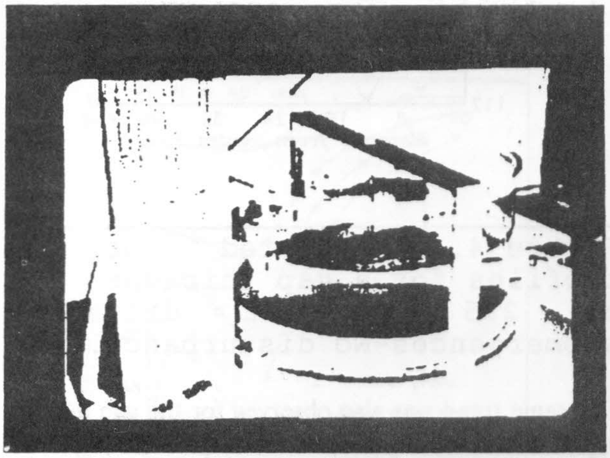

Figure 2. General view of the apparatus.

Preliminary tests showed that some changes occured in the shape of the pressure profiles when the method of circulating the flow was changed without , however, significantly altering the flow rate or height of the fluid above the level of the outlet. Hence, to exclude any effect of circulation upon the flow, the liquid was returned through a ring of plastic pipe of 25.4 mm. diameter through 2 mm. holes distributed along the inner pipe wall. The pipe was layed in a rectangular channel, which is circular in plain and laid along the inner circumference of the tank. The channel was maintained in a horizontal position, and the space between the ring and the edge of the channel was packed with gravel so as to destroy the kinetic energy of the incoming flow. This arrangement of inflow distribution resulted in a quite free surface at inlet, and radial flow was also ensured.

Procedure For Taking Observations

The pressure measurements were taken for the range of discharge of 0.53 - 1.586 Lit/second, and gap thicknesses 'h' of 5 mm. and 2.5 mm. between the vortex breaker and the bottom of the tank. After having filled the tank and the associated recirculating system with water, the centrifugal pump was started and the discharge regulating valve adjusted to have the desired discharge passing through the intake. The submergence 'H' was reduced in steps of 5 cm., and for each subsequent step steady state conditions were allowed to prevail before pressure measurements were taken. The pressure was measured in the gap between the vortex breaker and the tank bottom, and in the pipe intake. Measurements were taken at intervals of 3 mm. in the intake, and 6 mm. in the gap , as shown in Figure (1).

Measurements were also designated to confirm visually the formation of a persistent dye core vortex, by injecting dye through a syring into the water, in the gap. The definition of a persistent dye core vortex is somewhat arbitrary and is usually developed for the convenience of the experiments. Hecker [7] has suggested using the percent of time a vortex is persistent as a criteria for hydrodynamic model studies, when turbine and pump intakes should have dye core vortices present less than 50% of the time.

EXPERIMENTAL RESULTS AND DISCUSSION

The pressure distribution in the gap ,between the vortex breaker and the bottom of tank , was measured. The whole range of discharges obtainable (up to 1.58 Lit/sec.) was investigated for a given setting of the submergence 'H'. The same procedure was followed for two gap thicknesses of 2.5mm. and 5mm.

The measurements are plotted ,as the head depression below the static head at the tank bottom against the radial distance from centerline. The first set of runs were conducted after excluding any effect of circulatin upon the flow. This condition was insured by filling the space , in the channel, above the return flow pipe by gravel, so that a quite free surface was maintained.

Samples of the pressure profiles for 'H' = 45, 40 and 30 cms. are presented in Figures (3a-3c). It is apparant that the pressure decreases rapidly towards the intake due to the increasing radial velocity. As the flow reaches the edge of the intake pipe the pressure starts to rise again.

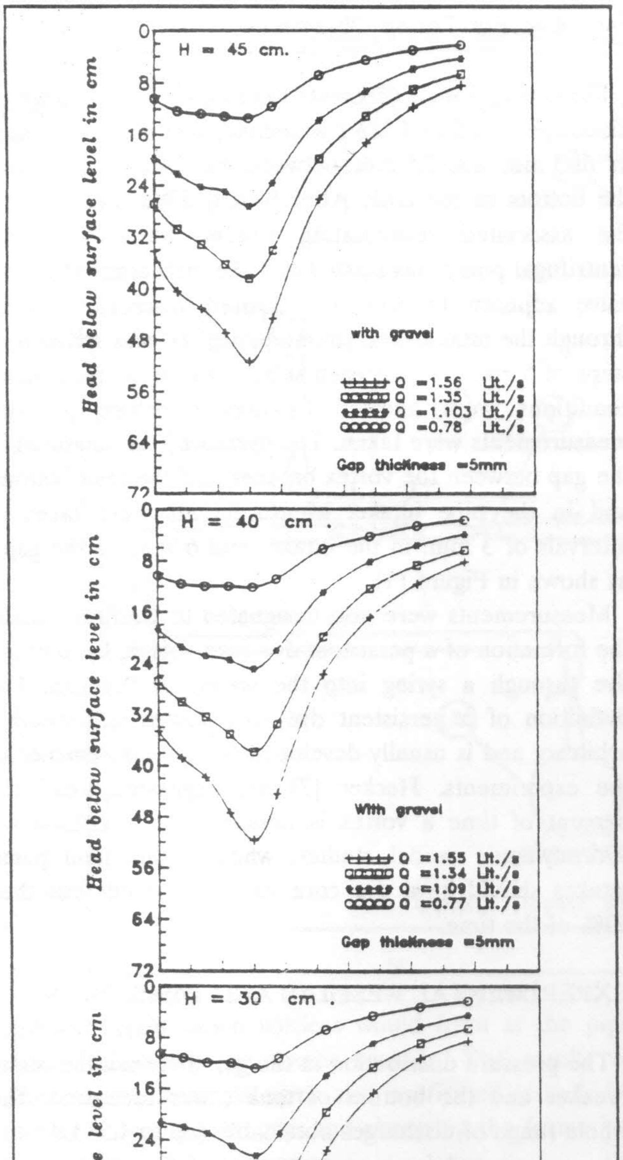

Figure 3. Measured pressure profiles for a gap thickness "h" of 5 mm, at different submergences-No disturbance .

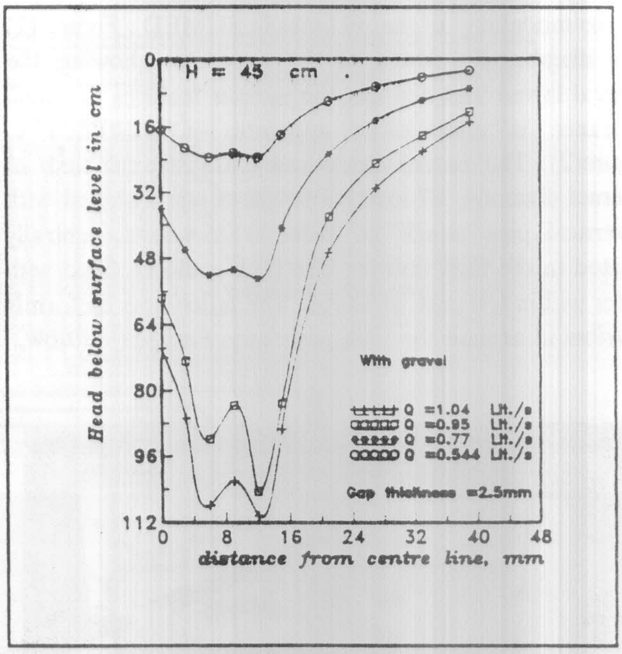

Figure 4. Measured presure profiles for a gap thickness "h" of 2.5 mm, at different submergences-No disturbance.

The same trend was also observed for the gap thickness h = 2.5 mm.. However, the extent of pressure depression increases due to the increased radial velocity for the same rates of flow , as shown in Figures (4a-4c).

Since vortex formation is extremely sensitive to small disturbances, it was thought desirable to repeat the same set of runs conducted before, after removing the gravel from the channel, as this would provoke disturbances representing abnormal operating conditions. Figures (5) show the pressure distribution for a gap thickness of 5 mm. In this case a significant pressure depression in the vicinity of the core was observed, indicating a vortex action in the core. The occurance of such a vortex core was further supported by the visual observations of a persistent dye core, when the dye was injected in the gap, bellow the vortex breaker. This is attributed to the circulation generated by the uneven distribution of the incomming flow. The circulation was also related by Daggett [8] to the locations and alignement of various parts of the rigid boundaries. On the other hand, no circulation was depicted for a gap thickness of 2.5 mm.

In order to confirm that this behavior may be attributed to the effect of uneven disturbances, resulting in flow circulation, a forced circulation was imposed on the bulk of the fluid in the tank. This was achieved by introducing

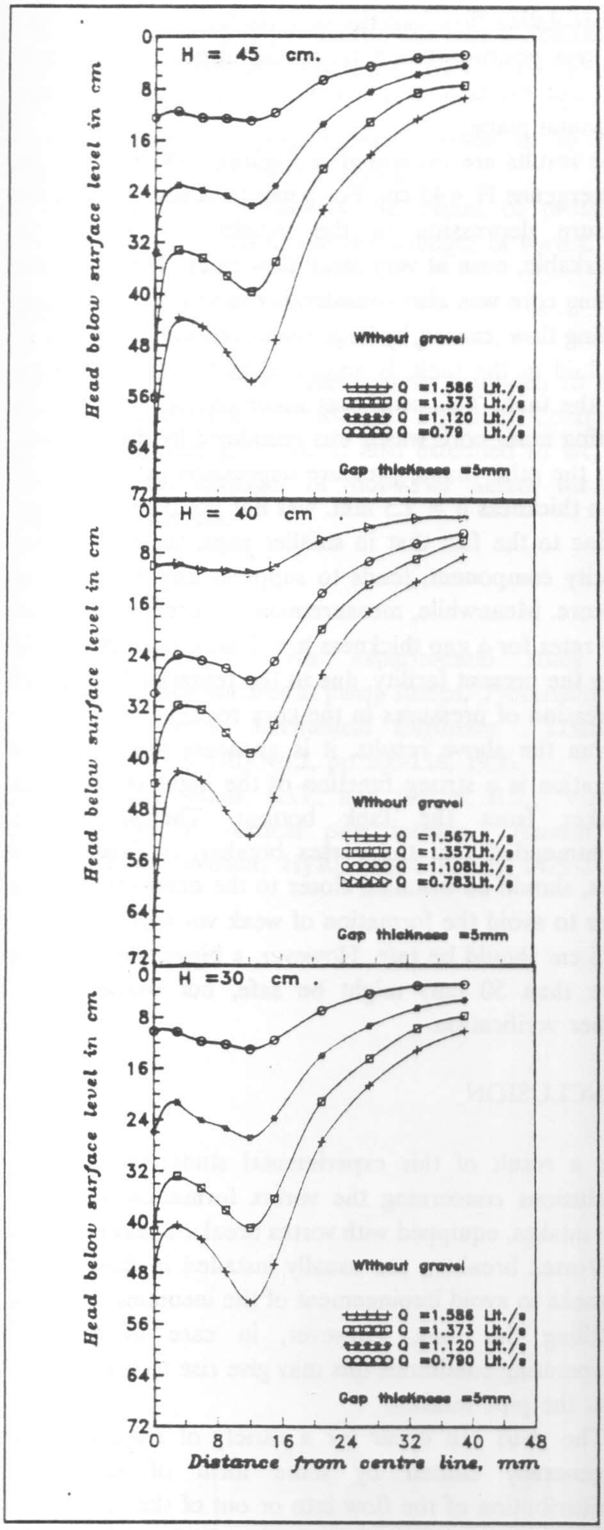

Figure 5. Measured pressure profiles for a gap thickness "h" of 5 mm, at different submergences - small disturbance.

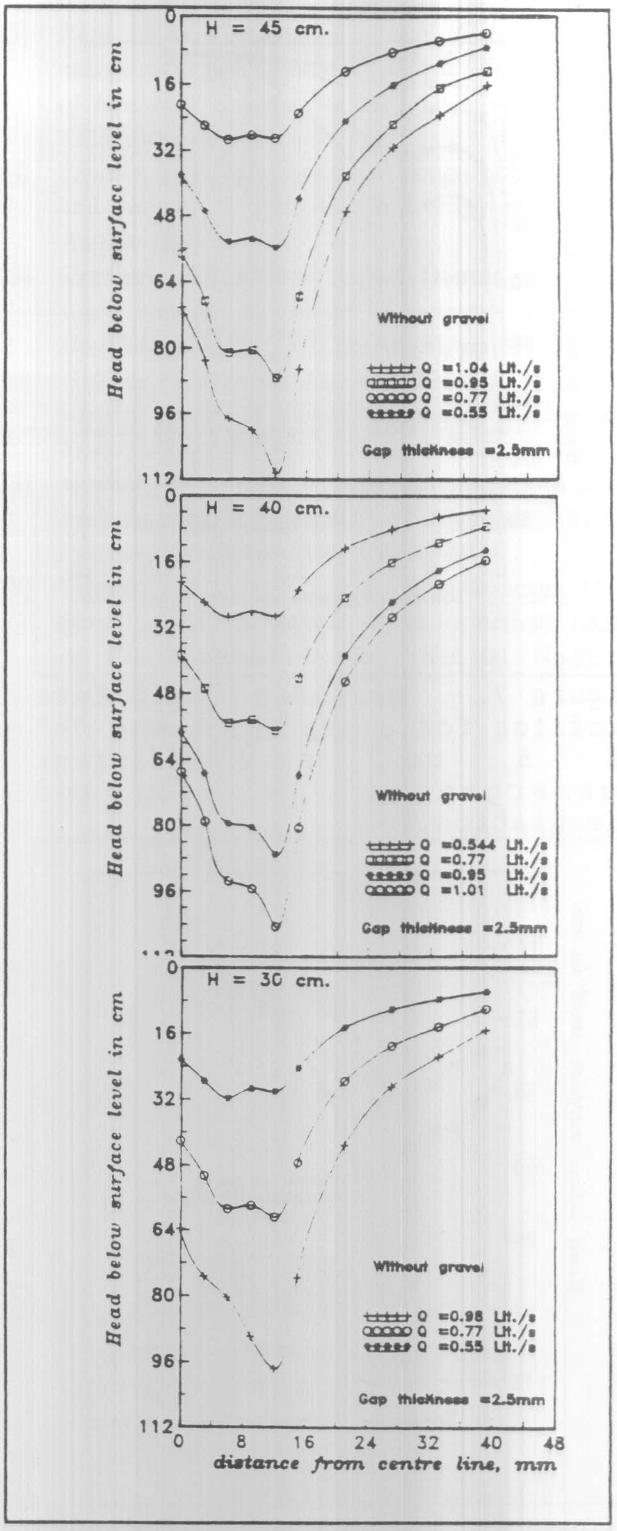

Figure 6. Measured pressure profiles for a gap thickness "h" of 2.5 mm, at different submergences-Small disturbance.

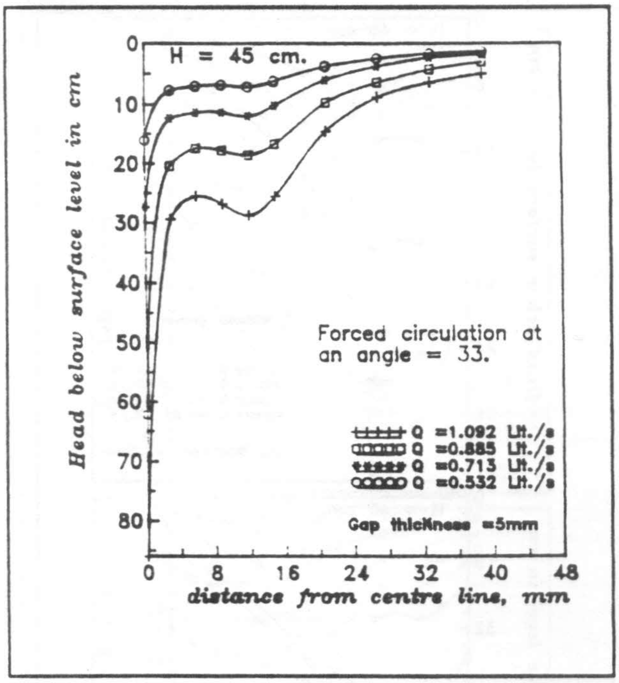

Figure 7. Measured pressure profiles for a gap thickness "h" of 5 mm, at different submergences - Imposed circulation.

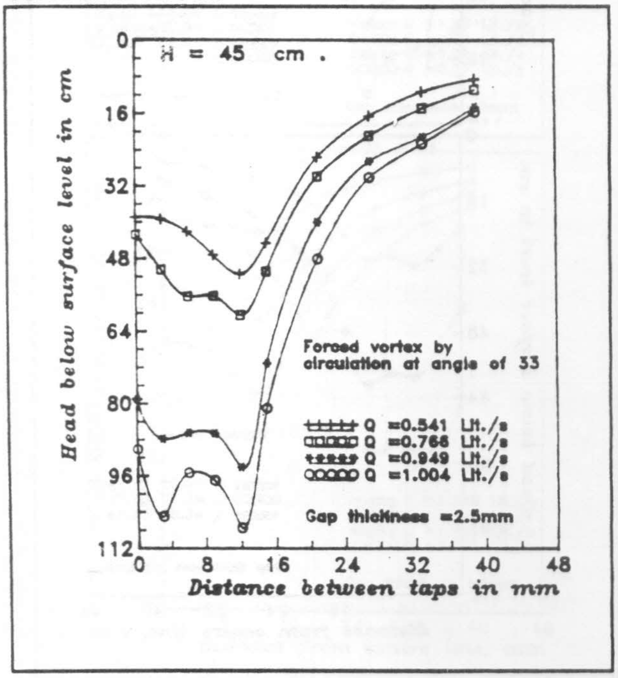

Figure 8. Measured pressure profiles for a gap thickness "h" of 2.5 mm, at different submergences - Imposed circulation.

the circulating flow into the tank via the return pipe. The pipe was positioned in a tangential direction to the tank wall, and directed at an angle of 33 degrees with the horizontal plane.

The results are presented in Figures (7-8), only for the submergence H =45 cm. For a gap thickness of 5 mm the pressure depression in the vicinity of the core is remarkable, even at very small flow rates. The size of the swirling core was also considerably increased. In this case swirling flow ,caused by large scale rotation in the bulk of the fluid in the tank, is amplified as the flow converges into the tank. This swirl was accompanied by a rapidly rotating inner core which was visualized by dye injection.

On the other hand, pressure depression in the core for a gap thickness h = 2.5 mm. was not predicted. This may be due to the fact that in smaller gaps, the larger radial velocity component, tends to suppress any circulation in the core. Meanwhile, measurements of pressure at higher flow rates for a gap thickness h = 5 mm. was not possible using the present facility, due to the remarkably very high depression of pressures in the core region.

From the above results, it is apparant that the vortex formation is a strong function of the hight of the vortex breaker from the tank bottom. Therefore, it is recommended that the vortex breaker, in floating roof tanks, should be installed closer to the draw off nozzle in order to avoid the formation of weak vortices. A distance of 25 cm should be safe. However, a bigger distance (not more than 50 cm) might be safe, but would require further verification.

CONCLUSION

As a result of this experimental study, the following conclusions concerning the vortex formation at vertical pipe intakes, equipped with vortex breakers may be drawn;

1. Vortex breakers are usually installed in floating roof tanks to avoid impingement of the incoming jet during filling the tank. However, in case of abnormal operating conditions this may give rise to vortex action at the pipe intakes.
2. The swirl can occur for a variety of reasons, but is generally caused by some form of nonuniform distribution of the flow into or out of the tank.
3. This uneven distribution may be steady in time, but it can be a prime reason for swirl and vortex formation at the intake.
4. The hight of the vortex breaker from the bottom of

tank, is a controlling parameter, that has a significant effect on the swirl and vortex formation at the intake. Consequently, the hight of the buffer plate should be reduced than the present value which is 50 cm, equivalent to 5 mm in the model.

5. The flow rate also affects the extent of pressure depression in the core, and the strength of vortex.

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REFERENCES

[1] Denny, D.F., " An experimental study of air-entraining vortices at pump sumps," *Proceeding of the Institute of Mechanical Engineers* , London, England, Vol.170, No.2, pp 106-116, 1956.

[2] Jain, A.A., Raju, K.G., and Garde, R.J., "Vortex formation at vertical pipe intakes.", *Journal of Hydraulic Division*, Hy10, October, pp 1429-1445, 1978.

[3] Raju, K.G., Jain,A.K., and Garde,R.J., "Air entrainment in radial flow twoards intakes", *Journal of Hydraulic Division, ASCE*, Hy9, September, pp 1323-1329, 1978.

[4] Prosser, M.J., "The hydraulic design of pump sumps and intakes", *BHRA Fluid Engineering*, U.K., August 1985.

[5] Sweeney, C.E.,Elder,R.A.,and Duncan, H., "Pump sump design experience :Summary", *Journal of Hydraulic Division, ASCE*, 108(3), pp 361-378, 1987.

[6] Gulliver, J.S., Asce, M., and Rindels, A.J., "Weak vortices at vertical intakes", *Journal of The Hydraulic Engineering*, Vol.113, No.9, pp 1101-1116, 1987.

[7] Hecker, G.E., "Model-Prototype comparison of free surface vortices.", *Journal of Hydraulic Division, ASCE*, 107(10), pp 1243-1259, 1979.

[8] Daggett, L.L., ASCE, A.M., and Keulegan, G.H.," Similitude in free-surface vortex formation", *Journal of The Hydraulic Division*, Vol.100, No.11, pp 1565-1579, 1974.