Effect of pump intake geometry on vortex suppression

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Experimental results are presented to indicate the effect of centrifugal pump intake geometries on vortex suppression and pump operational performance. These geometries include flanged intake geometry, two tandem disks geometry and covered intake geometry. The experimental study presents the effect of these different geometries on the pump head, discharge, absorbed power, operational efficiency and sound pressure level in addition to the critical submergence. The study indicates that, the presence of the flanged geometry at the tip of the pump intake pipe affected negatively the pump performance and increased the critical submergence. While the location of tandem disks geometry improves the pump performance by suppressing the air entraining vortices and lowering the critical submergence. This improvement is remarkable at larger disk diameters and higher gaps.

يعرض هذا البحث نتائج الدراسة المعملية التي أجريت لمعرفة تأثير شكل مدخل ماسورة السحب لمضخة طاردة مركزية على إخماد الدوامات وأثر ذلك على أداء المضخة نفسها. في هذه الدراسة تم استخدام ماسورة ذات مدخل رأسي المحور وقد تم تعديل شكل المدخل بإضافة فلنجات مختلفة الأقطار أو قرصين متوازيين بأقطار وبأبعاد مختلفة بين القرصين. ثم تم استخدام قرص واحد فوق مدخل أنبوب السحب على ارتفاعات مختلفة. وقد تم دراسة تأثير الأبعاد المختلفة لهذه الأشكال على إمكانية قضائها على الدوامات المتولدة عند مدخل السحب بالإضافة إلى تأثير ذلك على أداء المضخة من خلال قياس رفع المضخة، تصرفها، قدرتها وكفاءتها وكذلك مستوى الضوضاء المتولدة بالإضافة إلى قيمة العمق الحرج لمدخل السحب. وقد أظهرت هذه الدراسة إن تركيب فلانجة على مدخل أنبوب السحب ذو تأثير ضار على أداء المضخة وكذلك العمق الحرج. أما استخدام قرصين متوازيين عند مدخل أنبوب السحب فانه يؤدي إلى إخماد الدوامات الساحية للهواء وكذلك خفض قيمة العمق الحرج للمدخل كما يؤدي إلى تحسين أداء المضخة وقد لوحظ أن هذا التحسن يزداد بزيادة كلا من قطر القرص والبعد بين القرصين.

Keywords: Centrifugal pump, Pump intake, Vortex

1. Introduction

The vortices formed near or at the centrifugal pump intake continue to be one of the major engineering problems in design and construction of sumps. Serious and undesirable effects are experienced when the water level in the suction side of a pumping station is low and results in air core vortex formation, thus causing air entraining in the pump. The air-entraining vortices under severe conditions have a harmful effect on the pump performance through decreasing pump pressure head, discharge and efficiency. These vortices may also result in serious mechanical problems during pump operation such as vibration, cavitation and reduction in pump life. There have been numerous cases reported with regard to the operation of the pump and maintenance problems due to air entraining vortices and sump swirl. However, instead of finding a definite solution to the cause of vortices and getting rid of it, the replacement of the damaged parts such as bearings, seals and impeller in many cases was the solution. This led to increase the maintenance cost of the pump station and sometimes led to shut down the power plant where the damaged pumps were used. The suppression of the vortices is surely the cheapest solution.

The appearance of air entraining vortices, their causes and the critical submergence have been studied extensively and are widely reported in the literature (Fraser [1], Deny [2], Anwar [3&4] Zajdlik [5]; Jain et al. [6] Dicmas [7], Sweeney [8], Padmanabhan and Hecker [9], Odgaard [12], Karassik et al. [11], Nakato [10]. Although the formation of air entraining vortices in the sump has been well established, the general criteria to prevent them need more investigation.

Recently, it has become a rather routine practice to conduct small-scale laboratory model tests to find experimentally the solutions to suppress vortices in a particular sump problem. Nakato [13] studied experimentally the possible solution to suppress both air entraining vortices and boundary-attached subsurface vortices in wet-pit pump intakes. In his prototype, vertical pumps were used with pump bells to withdraw water radially toward the impeller of withdraw water radially toward the impeller of the pumps. Nakato presented two solutions to suppress vortices. The first solution employed flow–tuning vanes, a horizontal grating, floor and backwall splitters, floor corner fillets, and the second, a combination of these and an inverted draft tube layout. He concluded that, all subsurface vortices were suppressed by means of floor and backwall splitters whereas free surface vortices were also suppressed by means of horizontal grating. Furthermore, he claimed that in both cases, the pump vibration problems were eliminated and the net positive suction heads were increased. Nakato et al [14] studied pumps vibration problems in the Union Electricity's Meramec plant. In this plant, the cooling circulating-water was withdrawn by means of several pumps from an extremely short pump-bay condition when the water level in the river was critically low. The pump vibration problems led to impeller damage due to local cavitation, excessive bearing wear..etc. They stated that the pump vibration problems were due to the formation of air entraining vortices, subsurface vortices attached to sump floors, sidewalls and backwalls. Furthermore, Nakato et al [14] designed and developed a 1:10 scale hydraulic model in order to determine the exact causes of the pump's vibration problem. They also designed devices to suppress formation of subsurface vortices attached to sump floors, sidewalls, backwalls and air entraining vortices including several types of perforated plates combined with deep flow turning vanes, and various types of vertical baffle blocks were used to suppress vortices. They concluded that these modifications of pump sump eliminated pump-vibration and cavitation problems, and made pump operation possible under extreme water levels which are much lower than those specified by the manufacturer.

Bauer et al. [15] studied the pump-flow distributions at a rectangular water intake with four vertical pumps. Detailed time-average two-dimensional, planar, velocity measurements were taken within the pump sump using electromagnetic flow meter. Swirl angle in each suction pipe was measured using a vortimeter and flow visualization surrounding individual pumps as well as the entire sump was achieved using food dye. These measurements were used as a basis to develop relatively simpler vortex-suppressing devices in a multiple–pump sump. For that reason, they conducted two laboratory investigations to suppress air-entraining vortices and pump swirling in sumps with multiple vertical pumps. The first laboratory model consists of seven vertical pumps located in line to eliminate sump swirling and near pump vortices through using a combination of two–straightening and vortex–suppression devices. The second model consists of four pumps located in line with triangular-shaped horizontal floor splitters which were placed beneath each pump bell along the axis of longitudinal symmetry, and between neighboring suction pipes. Furthermore, a vertical triangular-shaped backwall splitter was installed on the backwall behind each pump column. They concluded that, with these modifications, all the subsurface vortices were eliminated under all operating conditions.

From the previous literature review, it is clear that, up to date however, no definitive design criteria have been developed that have general applicability. The widely used design guideline for sumps and pump stations is that published by the British Hydromechanics Research Association, Prosser [16]. This guideline provides recommendations on the size and configuration of pump sumps, based on either the suction bell diameter or the anticipated flow rate, but no guaranties that this guideline will provide a solution for all sumps problems and in particular the vortex formation due to different pumps configurations and applications (for example for lifting water from lakes, rivers, channels, cooling towers, pools and reservoirs).

Despite the fact that a great deal of progress has been made in the numerical simulation of pump-approach flow distribution at water intakes made by Constantinescu et al. [17] and Rajendran et al. [18], the information presented in their work is suitable only for preliminary design, whereas the final configuration has to be determined by means of laboratory models.

In practice, each actual site-sump problem may require a site-specific solution to prevent the vortex formation. That might be due to the pipe intake shape (upward or downward), sump flow conditions (calm or large turbulence), water level (high or low), water quality (clean, silty, sandy or sewage), etc.. Since there are no reliable guidelines criteria for trouble free intakes, the flow conditions around pump intake have to be evaluated on a case by case basis. For this reason, it is recommended to construct a scaled model in a laboratory, observe the flow, and propose modifications to pump intake geometry in order to determine their impact on the pump performance characteristics.

Hammoud [19] presented a case study of one particular pump sump approach. He studied the pump problem when water is lifted downward from a sump. This intake shape is preferred because it prevents sand or sediment in muddy water pools and rivers to flow through the pump. However, when the water level in the river became low, air entraining vortices became visible and had audible noise. At low submergence, poor pump-approach flow distributions made the discharge and the pressure of the pump unstable. In order to determine the exact causes of this problem and eliminate it, a laboratory model pump configuration was built up and tested. He concluded that, the air-entrainig vortices under severe conditions have a harmful effect on the pump performance through decreasing pump pressure head, discharge and efficiency. Further investigations are required to eliminate the causes of the pressure and discharge fluctuations by making a more uniform flow distribution at pump approach, and to eliminate the air entraining vortices and their effect on the pump performance characteristics.

In the present investigation, the modification of pump intake is presented in order to prevent the vortex formation and suppress the air entraining vortices. This modification includes three different geometries, flanged intake geometry, two–tandem disks geometry and covered intake geometry. The effect of different intake geometries on the critical submergence depth and pump performance characteristics is also presented.

2. Experimental set up and procedure

Figure 1 shows the general features of the test rig used in the present investigation. Water, from the steel rectangular tank (2 m length, 1.2 m depth, 2m width), was re-circulated by means of a centrifugal pump driven by a 3 phase 6 kW motor operated by frequency inverter variable speed drive type Hitachi L100. Two fine mesh screens were used to damp the flow fluctuations inside the water tank. The suction pipe of 0.127 m inside diameter was made of Perspex to allow visual observation of the flow at the inlet and inside the pipe. A differential pressure transducer is used to measure the difference between the suction and delivery pressures, whereas the pump discharge is measured by a turbine flow meter and calibrated orifice meter at the end of the delivery pipe. The flow rate is controlled, either by the delivery throttle valve or pump speed that can be adjusted manually or automatically according to test requirements. Four different intakes geometry used in this investigation are sketched in Fig. 2. Case (a) shows flanged intake geometry in which the flange diameter was taken as 2,3 and 4 times the pipe diameter. Case (b) presents the covered intake geometry in which a disk of diameter 2, 3 and 4 times the pipe diameter is fitted over the pipe inlet at gaps equal to 0.4, 0.56 and 0.8 times the pipe diameter. Case (c) presents the perforated covered intake geometry. The disk with a diameter of 3 times pipe diameter was perforated by one hundred and fifty holes of 8-mm diameter equally distributed in both radial and tangential directions. The perforated area represents 20% of the disk surface area. Case (d) presents two tandem disks intake geometry in which two solid disks are located in tandem at the pipe entrance with particular gaps. The disk diameter was taken as 2, 3 and 4 times pipe diameter and the gap height was taken as 0.4 and 0.8 times pipe diameter.

The upper disk in cases (b, c and d) is carried on four steel bars of 3 mm diameters, 90 degrees apart with maximum blockage of 0.6% of the inlet area which has a negligible effect on flow distribution at pump intake.

Data acquisition type (HP 34970ADATA Acquisition/Switch Unit) was used for receiving data signals every 0.5 second from several sensors. These sensors are: differential pressure transducer, turbine flow meter, the pump rotational speed (RPM) and electrical current and the sound pressure level. The microphone type (Bruel & Kjaer) provides a direct reading of a range of 24 - 130 dB with a reference pressure of 0.00002 N/m^2. Acoustical calibration of the complete instrument is carried out using a Pistonphone Type 4220. The background level was also checked and found to be negligibly contributing to the recorded levels.The microphone signal connected to HP spectrum analyser type (8594E) is used to analyse the sound frequency. The estimated uncertainty in the measurements was ± 5% for the S.P.L., ± 3% for the pump pressure head and ± 6% for the discharge.

An HP-BASIC program was used for this study. The program is started manually when the vortex just tends to enter the intake pipe. The readings of all transducers are recorded during test period of 120 seconds at a scanning rate of 0.5 seconds. The program plots directly the data of the sound pressure level(S.P.L.) pump pressure, current and the rotational speed (R.P.M.) as a function of time, whereas the overall pump efficiency and the pump input power are calculated and then plotted on the screen. The program can operate under constant or variable pump speeds.

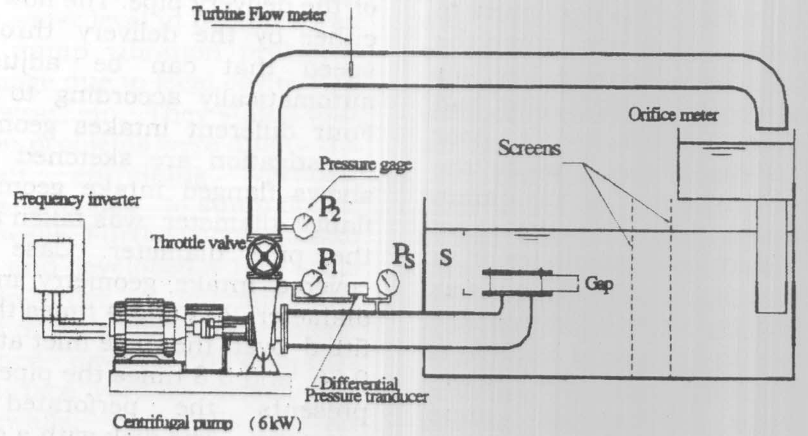
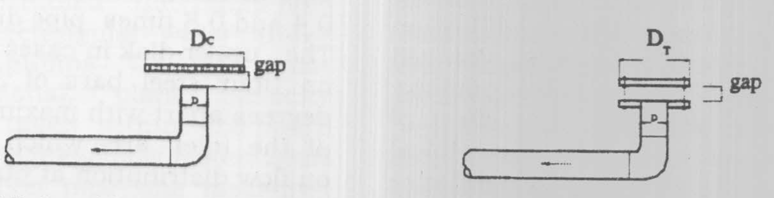


Fig. 1. Gerneral layout of the experimental apparatus.

a) Flanged -intake geometry

b) Covered -intake geometry



c) Perforated -intake geometry

d) Tandem disks-intake geometry

Fig. 2. Schematic of the different pump intakes.

All tests were carried out under the following experimental conditions:

The operating discharge of the centrifugal pump was around 10 - 45 L/s and the corresponding Reynolds number at pipe inlet was between 1×10^5 and 4.51×10^5.

The ambient temperature in the laboratory is approximately 20°C.

The atmospheric pressure is around 101 KPa.

Two different procedures were followed during this investigation: The first is to determine the critical submergence using the above mentioned pump intake geometry. The second is to determine which intake geometry is more effective in vortex suppression.

In order to determine the critical submergence, the procedure presented below was followed:

1. The pump was started and when steady state was attained, observations were made for a period of 30 to 60 minutes to determine whether a free–surface vortex is developed or not.
2. If no air-entraining vortex occurred during this period of time, the drain valve was opened and a small amount of water was drained from water tank.
3. When the water level in the tank reached the desired new level, the drain valve was closed to keep the water level constant.
4. The above sequence was repeated carefully until an air-entraining vortex was observed.
5. The pump discharge, in L/s, and the corresponding critical submergence were recorded and then the pump was stopped.
6. The above steps were repeated for different discharges.

This procedure was conducted using different flanges and all the tandem disks mentioned before.

However, in order to investigate the effect of air-entraining vortices on the pump performance, a sequence of experimental steps was followed:

i- Experimental conditions monitoring commenced at the beginning of vortex formation.

ii- At a given submergence and under certain discharge, the data signals of the discharge (L/s), the differential pressure (pump total head, m) and the electrical current (I) were recorded simultaneously at a scanning rate of 0.5 sec. over the test period of 120 sec.

3. Results and discussion

3.1. Critical submergence

3.1.1. Flanged intake geometry

The air entraining vortices occured when the water level dropped below the "critical submergence depth" For this reason, the variation of the critical submergence with the pump discharge for the flange diameters of 2D, 3D and 4D in comparison with the case of downward intake geometry i.e without flange(which is designed here as D_f = D) was investigated to determine the trend of the critical submergence of each individual case.

The measurements were based on visual observation of air-entraining vortices. Data were recorded when air entraining vortex was about to enter the pump.

All tests were carried out for the range of discharge of 10-45 L/s. On the other hand, the effect of air entraining vortices on the pump performance such as sound pressure level, pressure head, discharge, efficiency and electrical power was also investigated for all the available flanges and tandem disks.

Fig. 3. shows the variation of the critical submergence with the pump discharge for the flange diameters of 1, 2, 3 and 4 times the pipe diameter. This figure shows that for a certain discharge the larger the flange diameter, the higher the critical submergence. The results of fig. 3 indicate that as the flange diameter increases, air-entraining vortices were formed at a high water level, which should be avoided.

The probable reason for this is that the fluid around the intake and below the flange is acting as a damping region whereas the fluid above the flange is acting as a source. In flanged intake geometry, a large disk was interposed in the sump and acts as a separator between both regions. The separation of both regions by this flange led to the formation of large and stable vortices at the flanged intake of the pipe. Meanwhile, the larger the flange diameter, the stronger the effect on bubble generation, size and stabilization. Therefore, the vortices are sucked towards the center of the pipe causing a noticeable effect on the pump operation. The results presented in fig. 3 agree with Yildirim and Kocabas [20] study for free discharge through an open channel. In the present study, no air-entraining vortices were detected at a low flow rate. This is due to the fact that at a low discharge, the pump would not produce sufficient pressure depression to generate remarkable vortices.

3.1.2. Covered intake geometry

The variation of the critical submergence with the pump discharge for the covered intake geometry shown in Fig. 2-b with disk diameter D_C of 2 and 3 times pipe diameter are presented in Fig. 4 and 5 respectively. The gap height between the disk and the pipe intake tip was taken as 0.4 and 0.56 pipe diameter. The results demonstrate that, for a certain gap, the critical submergence increases as the flow rate increases. Furthermore, at a certain discharge, the greater the gap between the disks, the lower the critical submergence. Additionally, at low discharge less than 20 L/s, no evidence for air-entraining vortices were detected.

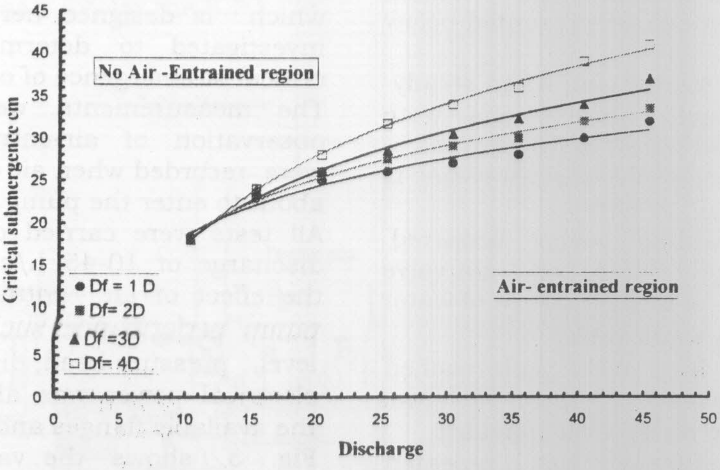


Fig.3. Variation of the critical submergence with the discharge for various flange diameters.

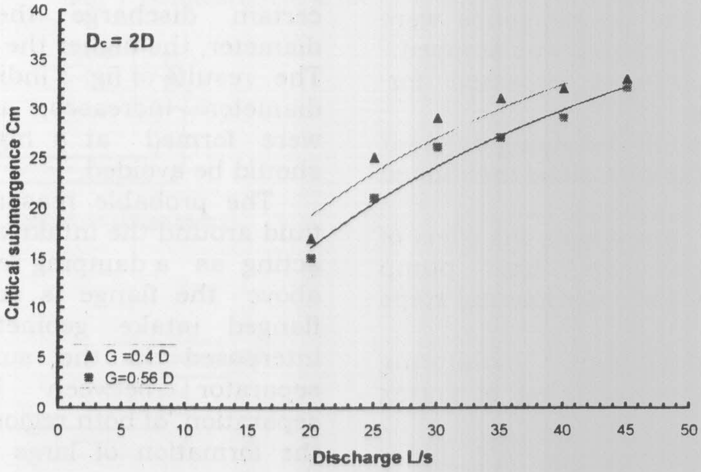


Fig. 4. Variation of the critical submergence with the discharge for covered intake with diameter D_c = 2D and gap G= 0.4,0.56D.

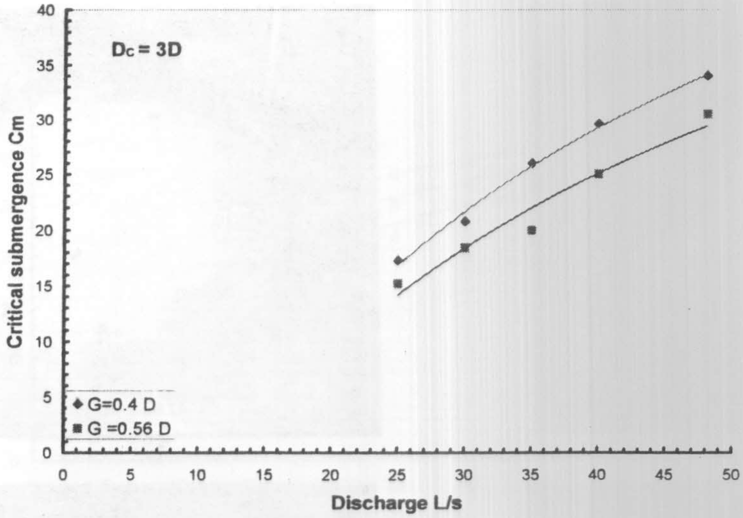


Fig. 5. Variation of the critical submergence with the discharge for Covered intake with diameter D_c = 3D and gap G= 0.4,0.56 D.

3.1.3. Perforated cover intake geometry

A similar behavior was observed when perforated cover of different diameters and gap heights were tested. No noticeable changes in the results were obtained in comparison with the previous test results of the covered intake geometry.

3.1.4. Tandem disks intake geometry

This investigation was conducted using two solid disks having diameter twice the pipe diameter with a gap varying as 0.4, 0.56 and 0.8 pipe diameter. The results of these tests are presented in fig. 6 and 7 respectively.

The figures indicate that the critical submergence increases as the discharge increases and decreases as the gap height increases. It is also shown that the critical submergence slightly decreases as the disk diameter increases.

The probable explanation for this finding is that when the gap height was reduced for a certain discharge, this may have led to higher inlet velocity and lower suction pressure and consequently higher critical submergence.

Some observations recorded by the video camera shown in photograph 1 (1-a, b, c, d, e and f) demonstrated that when weak vortex was developed, it moved around the periphery of the tandem disks (Photograph 1-a, b, c) tending to enter the pump intake (Photograph 1-d), but it was obstructed by the presence of the tandem disks. When the vortex increased in strength, its core extended downward creating a thin long tail vortex (Photograph 1-e). Meanwhile, its tail entered the pump intake and broke down quickly when it hit the top disk of the tandem configuration. After that, the vortex became weaker and moved away from the pump intake and then disappeared in the free surface (Photograph 1-f). At the same time, another weak vortex started to develop and the same phenomenon was observed. No evidence for a strong air-entraining vortices was noticed.

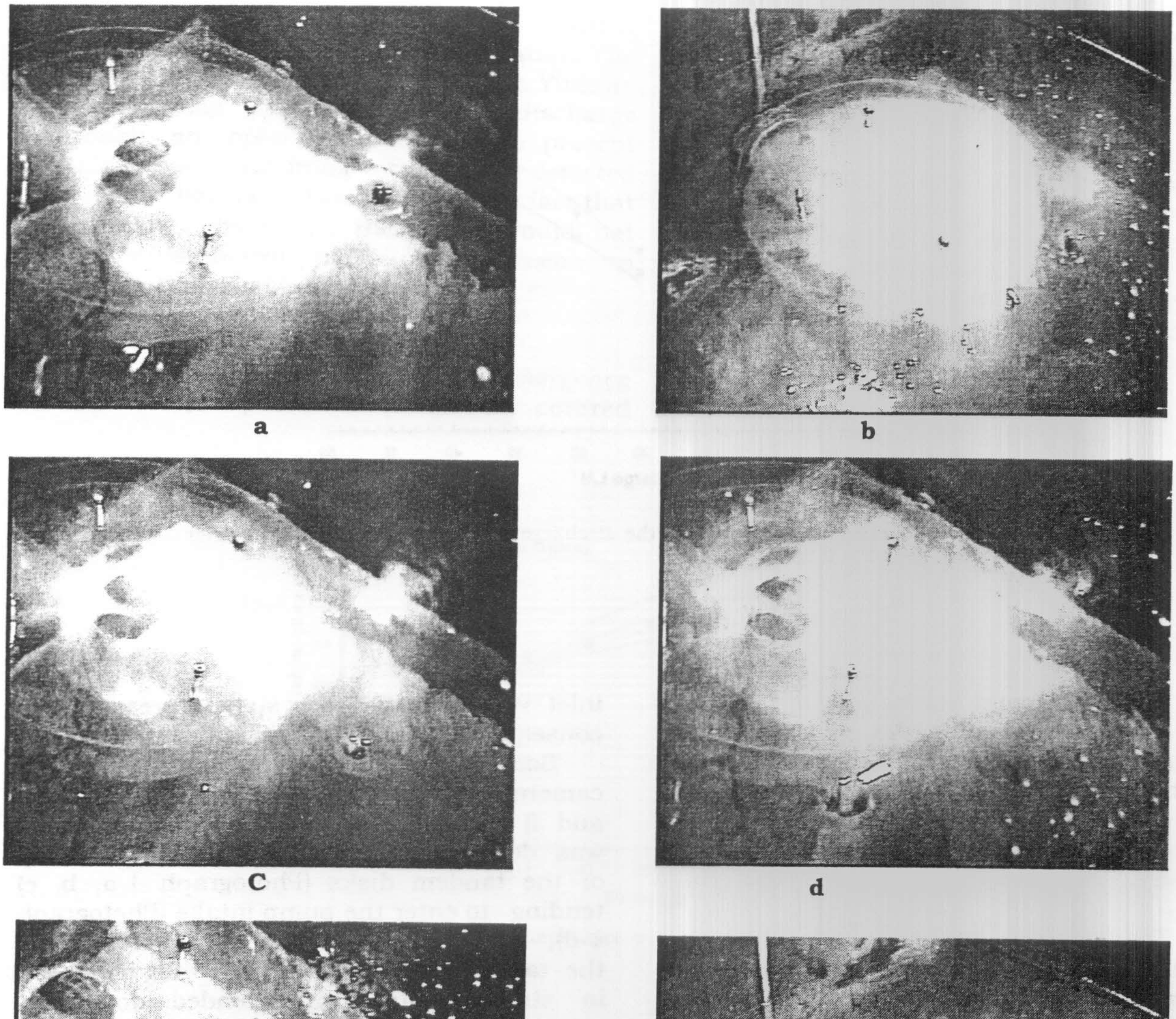


Photo 1 Movement of the vortex artex around the tandem disks configuration (DT=3D)

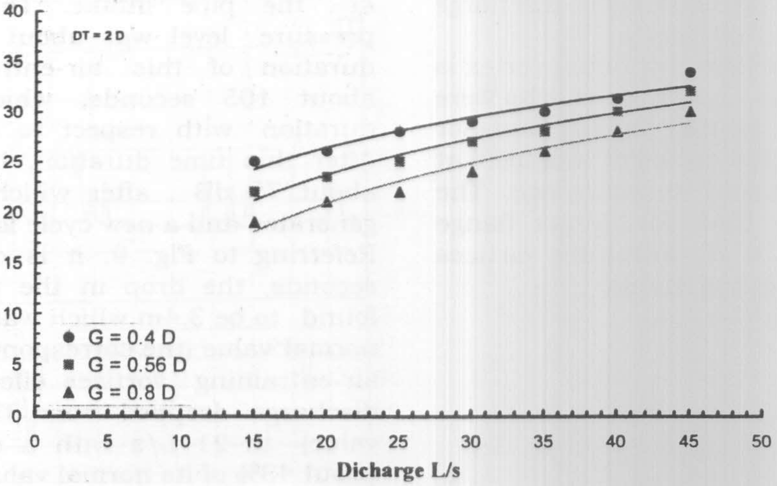


Fig. 6. Variation of the critical submergence with the discharge for tandem disks with diameter D_T = 2D and gap G= 0.4,0.56 and 0.8 D.

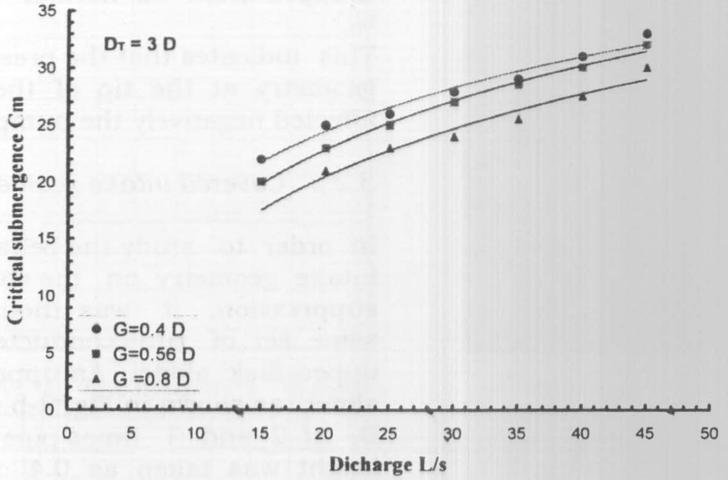


Fig. 7. Variation of the critical submergence with the discharge for tandem disks with diameter D_T =3D and gap G =0.4, 0.56 and 0.8D

3.2. The effect of intakes geometry on pump perfomance

3.2.1. Flanged intake geometry

Figure 8 shows for flange diameter having twice the pipe diameter, the microphone signal indicated that 10 vortex peaks in addition to the background level which is about 75 dB, were detected. These peaks present the sound pressure level generated by vortices. An example of the appearance of discrete noisy long tail vortex is shown in photograph (2). The average S.P.L. of these peaks was about 92 dB. The time duration of these vortices varies from 2 to 10 seconds. The evidence presented in these plots demonstrated that, part of the generated vortices affected the pump pressure head and efficiency. From the 10 peaks detected by the microphone signal (S.P.L.), only two of them were "hold" at the pump intake. These two peaks could badly affect the pump performance. The "hold" air-entraining vortices forced a large amount of air into the pump, resulting in significant fluctuations in the pressure head, discharge and drop in power and efficiency.

An example of "hold" air-entraining vortex is shown in photograph 2. Similar results were also detected when another flanged diameter having four times pipe diameter was used at the same discharge and submergence. The major difference is that for larger flange diameter D_f / D = 4, the air-entraining vortices became much stronger and stable.

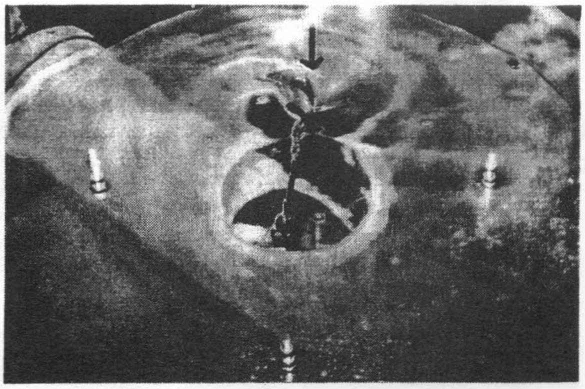


Photo. 2. Strong and stable vortex for flanged disk configuration (D_f = 4 D).

The evidence presented in Fig. 9. demonstrated that strong and stable air-entraining vortex was generated and continued entering the pump producing a significant fluctuation of the pressure head, discharge and power. Furthermore, the microphone signals indicated the sign of generation of a strong vortex which was "hold" at the pipe intake. The average sound pressure level was about 91 dB. The time duration of this air-entraining vortex was about 105 seconds, which is the longest duration with respect to the other flanges After this time duration, the S.P.L. drops to about 75 dB , after which a new vortex is generated and a new cycle is started.

Referring to Fig. 9, it is clear that at T = 50 seconds, the drop in the pressure head was found to be 3.4m which was about 50 % of its normal value (the corresponding value without air-entraining vortices effect). Instantly, the discharge dropped from 37 L/s (its normal value) to 21 L/s with a drop in discharge about 43% of its normal value.

The absorbed power dropped from its normal value as 3700 Watt to 3100 Watt .The drop in the absorbed power was about 16.2 % of its normal value, whereas the overall efficiency dropped from its normal value as 70% to 25 %.

This indicates that the presence of the flanged geometry at the tip of the pump intake pipe affected negatively the pump performance

3.2.2. Covered intake geometry

In order to study the behavior of the covered intake geometry on the vortex formation and suppression, it was thought to repeat the same set of runs conducted before using the upper disk alone. An upper disk was located alone as shown in Fig. 2-b with disk diameter D_C of 2 and 3 times pipe diameter. The gap height was taken as 0.4 pipe diameter. The tests were carried out at the same discharge and submergence presented before i.e. the discharge is 37 L/s and water level S= 24 cm. It is clear from the results shown in Figures (10a and b) that no evidence was obtained for the generation and presence of strong air-entraining vortices, while very weak long tail vortices were hardly detected.

3.2.3. Perforated covered intake geometry

Similar results were obtained when the upper perforated disk was located alone as shown in Fig. 2-c with disk diameter D_C of 3

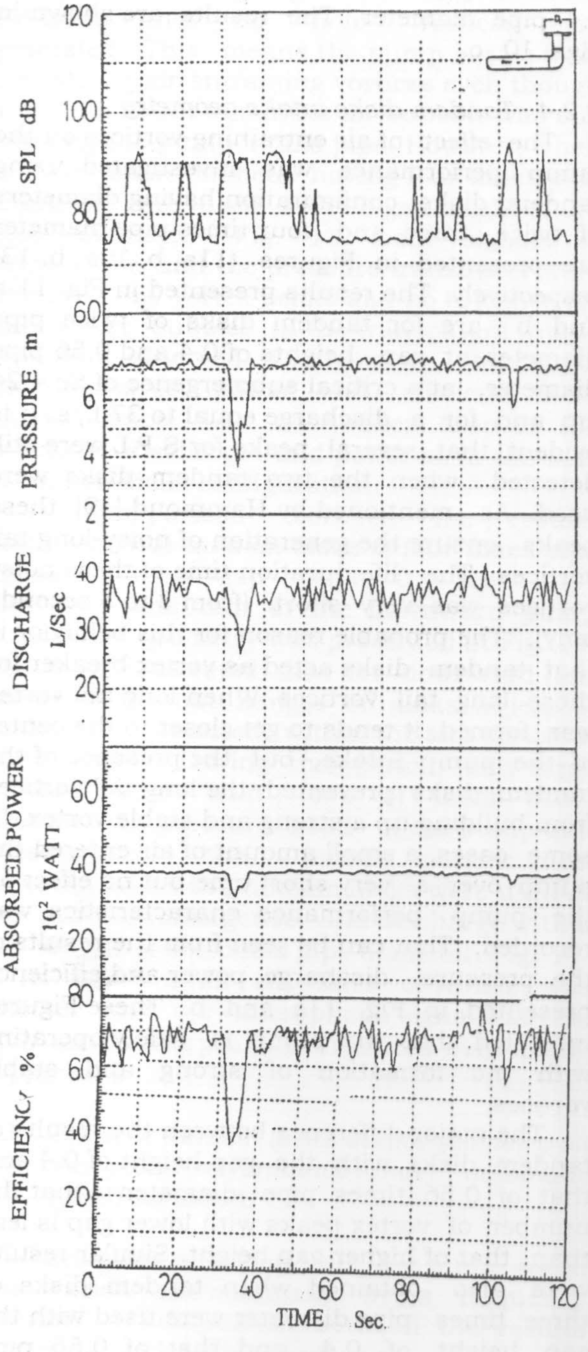


Fig. 8. Veriation of pump performance with time (Flanged disk D_f=2D, Q≈37L/s and Sc =24cm).

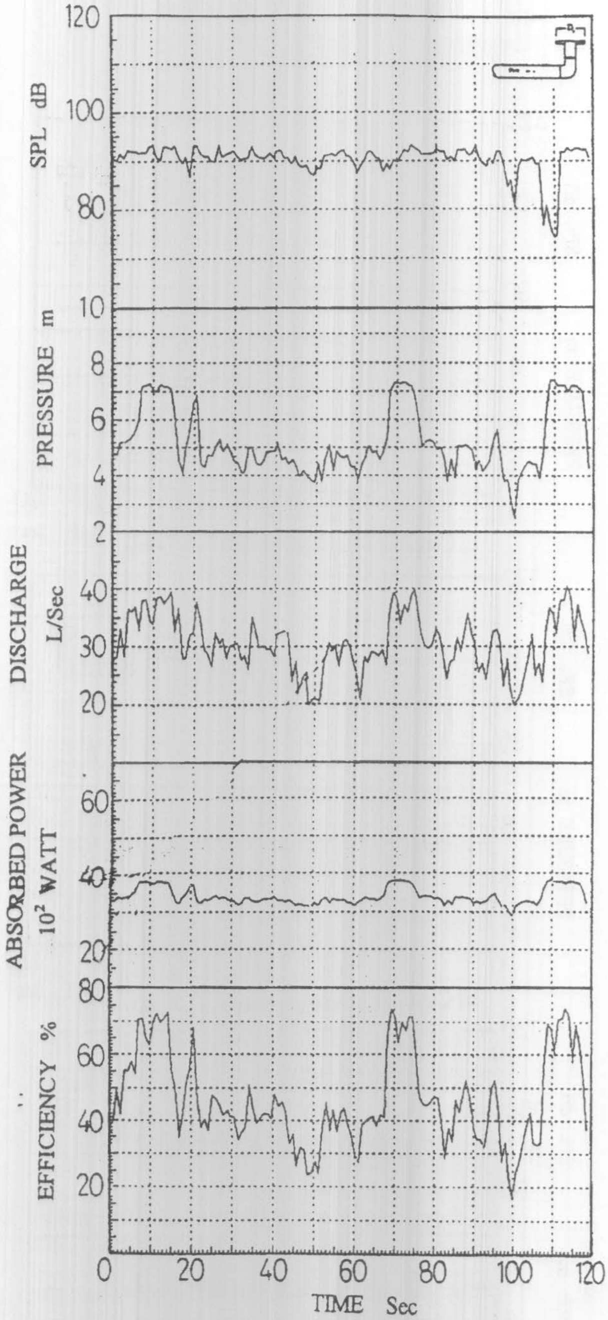
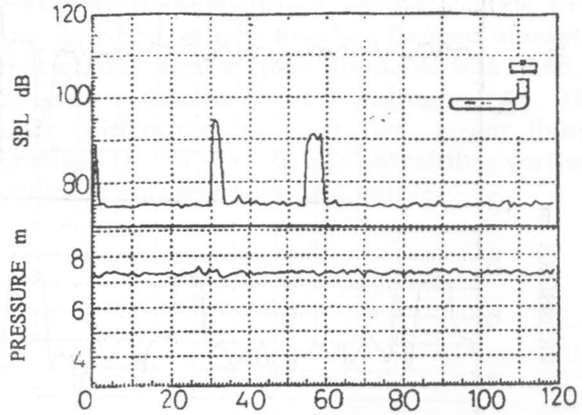
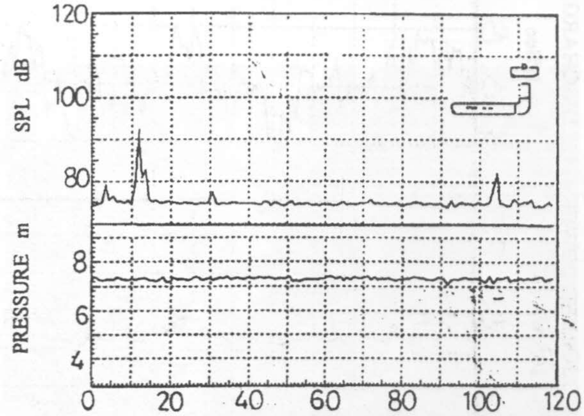


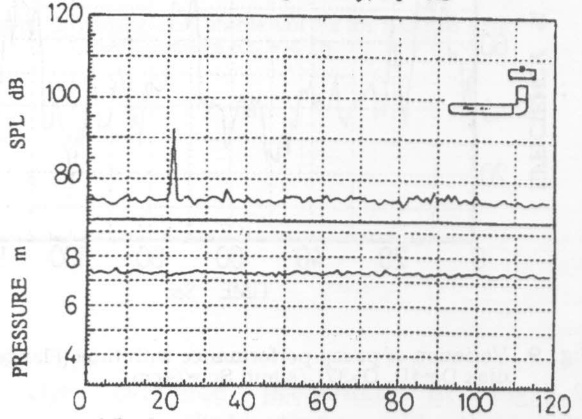
Fig. 9. Veriation of pump performance with time (Flanged disk D_f=4D, Q≈37L/s and Sc =24cm).



a) Covered intake geometry, $D_c = 2D$



b) Covered intake geometry, $D_c = 3D$



c) Perforated intake geometry, $D_c = 3D$

Fig. 10. Veriation of the S.P.L. and pump pressure head with time Q ≈37L/s, and Sc =24cm.

times pipe diameter at gap height equal 0.4 pipe diameter. The results are shown in Figs. 10 -c.

3.2.4. Tandem disks intake geometry

The effect of air entraining vortices on the pump performance was investigated using tandem disks configuration having diameters of twice, three and four times pipe diameter are presented in Figures (11a, b, 12a, b, 13) respectively. The results presented in Fig. 11-a and b are for tandem disks of twice pipe diameter at gap heights of 0.4 and 0.56 pipe diameter, at a critical submergence of Sc = 24 cm and for a discharge equal to 37 L/s. It is evident that several peaks for S.P.L were still detected when the two tandem disks were used. As mentioned by Hammoud [19], these peaks ensure the generation of noisy-long tail vortices. The life duration time of these noisy vortices was very short (from 3 to 5 seconds only). The probable reason for this behavior is that tandem disks acted as vortex breaker for these long tail vortices. When long tail vortex was formed, it tends to get closer to the center of the pump intake, but the presence of the tandem disks prevented the long tail vortices from building up a strong and stable vortex. In some cases, a small amount of air entered the pump over a very short time but no effect on the pump performance characteristics was recorded. That can be seen from the results of the pressure, discharge, power and efficiency presented in Fig. 11a and b. These Figures indicated that the pump is safely operating with no formation of strong and stable vortices.

The major difference between the results of tandem disks with the gap height of 0.4 and that of 0.56 times pipe diameter is that the number of vortex peaks with lower gap is less than that of higher gap height. Similar results were also obtained when tandem disks of three times pipe diameter were used with the gap height of 0.4 and that of 0.56 pipe diameter. However, since the microphone signal is very sensitive to sound pressure level (S.P.L.) generated by vortices, it was decided to present the data of the microphone signals accompanied with the data of the pressure transducer (pressure head) only. The results are presented in Fig. 12-a and b which are presented in Fig. 12-a and b which indicated that no "hold" vortices were generated. This means the pump is safe from the strong air-entraining vortices even though a small amount of minute air bubbles was still entering the pump intake pipe. However, when tandem disks diameter having four times pipe diameter were used with a gap height of 0.4 pipe diameter Fig. 13, both signals of microphone and the pressure transducer were free from any vortex peaks and no evidence for minute air bubbles in the transparent intake pipe was observed. Furthermore, the data of the discharge, power and efficiency were almost stable i.e. no sudden drop in the pressure, discharge and power as in the case of flanged disks configuration.

A comparison between the results obtained with tandem disks of four times pipe diameter at a gap height 0.4 times pipe diameter and that of the downward pump intake flow geometry was presented in Fig. 14. Fig. 14-a illustrated that for downward flow geometry without flanges or disks, at least 7 peaks were detected within the test period of 120 seconds. During this period, only three vortices were "hold", two of them badly affected the pressure head of the pump and consequently the pump performance. However, when two tandem disks were used at the same submergence and discharge with a gap height of 0.4 times pipe diameter, Fig. 14-b, no evidence for any kind of vortices was detected and the microphone signal was free from any vortex peaks i.e. vortices were totally suppressed.

3.3. *Effect of tandem disks intake geometry on the pump performance (under automatic speed variation)*

During the following tests, the pump speed was varied automatically by a frequency inverter. A comparison between the results obtained with downward pump intake and that of tandem disks of four times pipe diameter at a gap height of 0.4 pipe diameter are presented in Fig 15.

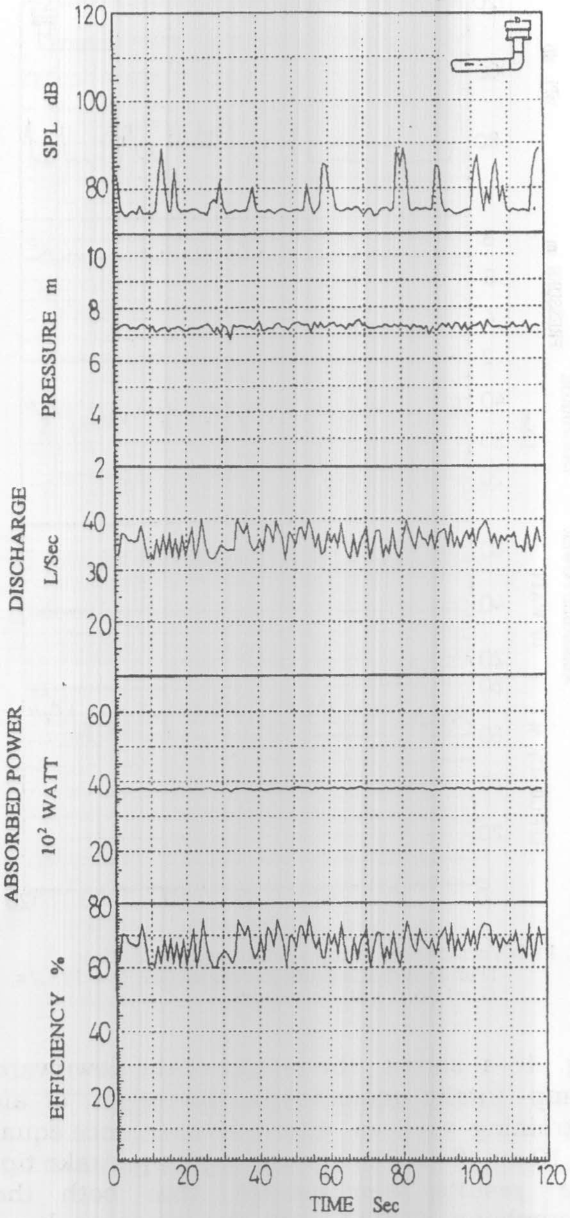


Fig. 11-a Veriation of pump performance with time (Tandem disks diameter equal 2D, Q ≈ 37 L/s, G =0.4 D and Sc =24cm).

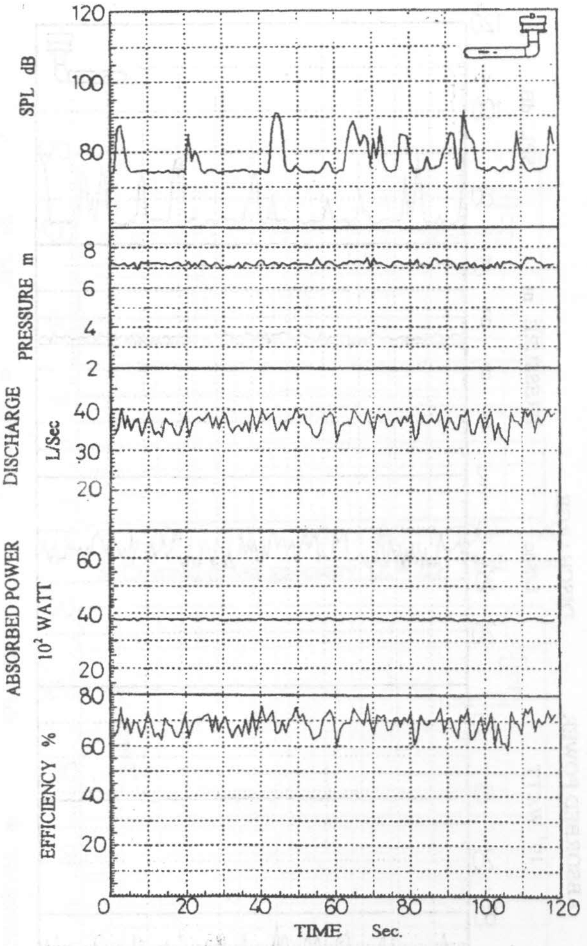
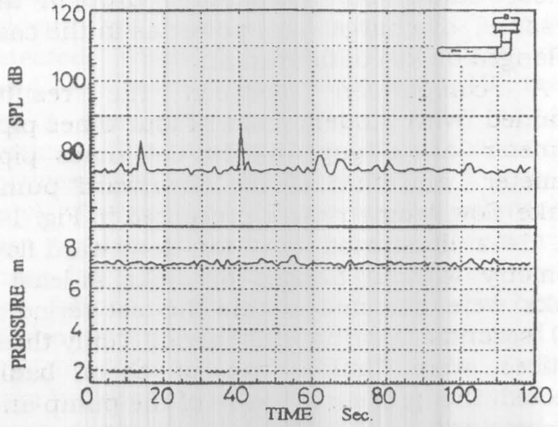
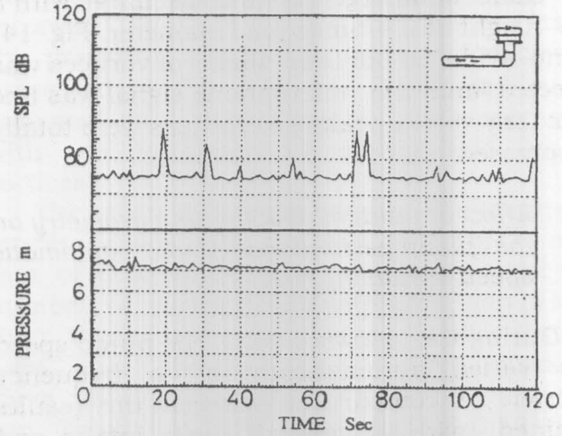


Fig. 11-b Veriation of pump performance with time (Tandem disks diameter equal 2D, Q ≈ 37 L/s, G =0.56 D and Sc =24cm).

Fig. 15-a shows the results of the downward pump intake geometry in the region of air entraining vortices at low submergence equal to 10 cm (S= 0.8D) above the pump intake tip. The results demonstrate that both the microphone (S.P.L) and the pressure head signals indicated the presence of strong air-entraining vortices. However when air-entraining vortex was "hold" at the pump intake, the pressure dropped and consequently the speed was increased automatically resulting in sudden jump in pressure and more pump disturbance. The sudden increase in pressure occurred at least7 times during the test period of 120 seconds. On the other hand, when the automatic variable speed was used with the modified shape of the pump intake i.e. tandem disks intake geometry (D_T = 4D), the pump became safer. The results presented in Fig. 15-b demonstrated that; even at very low submergence S = 10 cm above the tip of the tandem disk, no evidence for any kind of vortices was observed. This indicates that, the operation of automatically variable speed pump in the region where air-entraining vortices were expected to form became safer when tandem disks intake geometry was applied.



a) Tandem disks diameter equal 3D, Q ≈ 37 L/s, G =0.4D and Sc =24 cm



b) Tandem disks diameter equal 3D, Q ≈ 37 L/s, G =0.56D and Sc =24 cm

Fig. 12. Variation of the S.P.L. and pump pressure head with time.

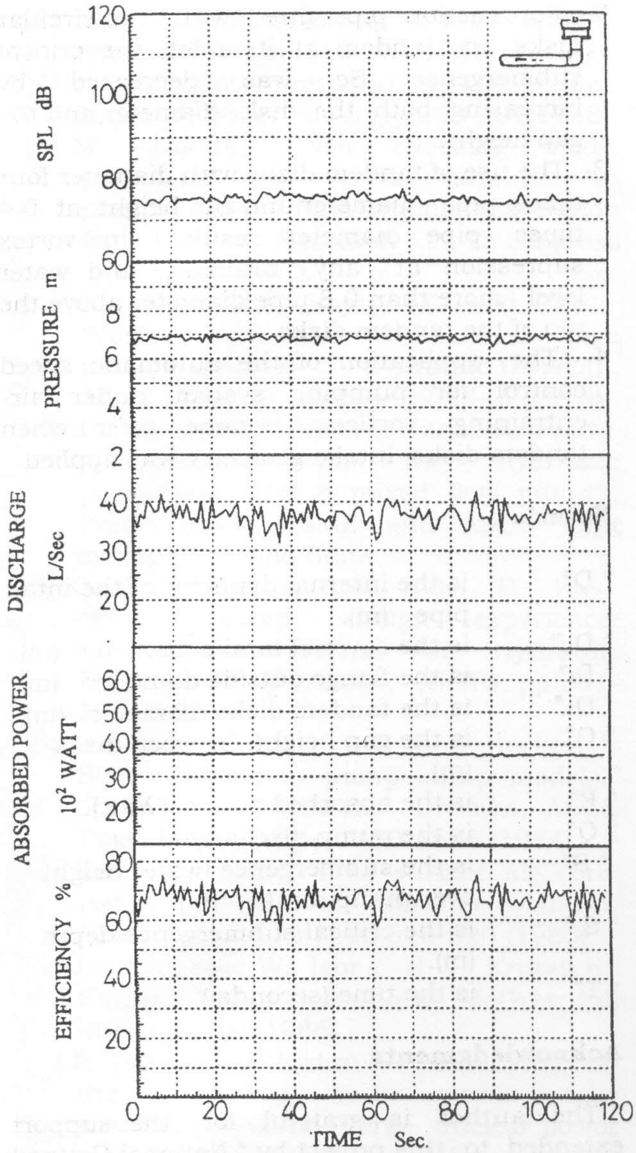
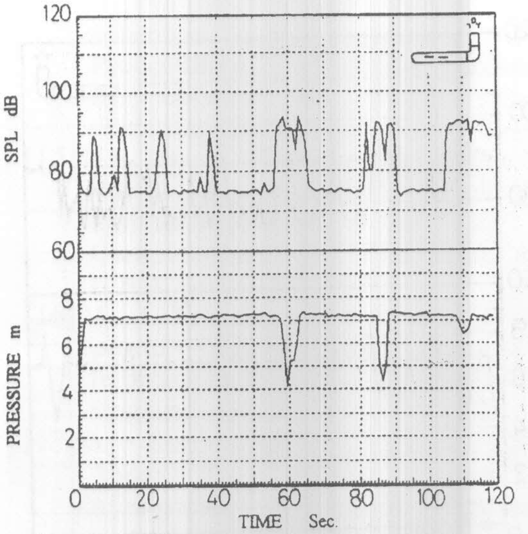
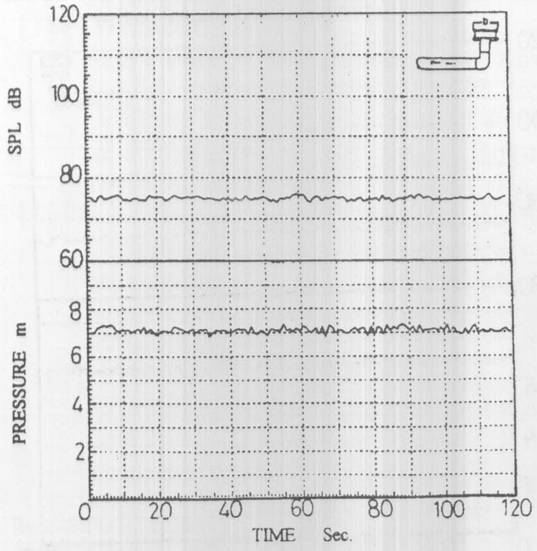


Fig. 13. Variation of pump performance with time. (Tandem disks diameter equal 4D, Q ≈37 L/s, G=0.4 and Sc=cm)

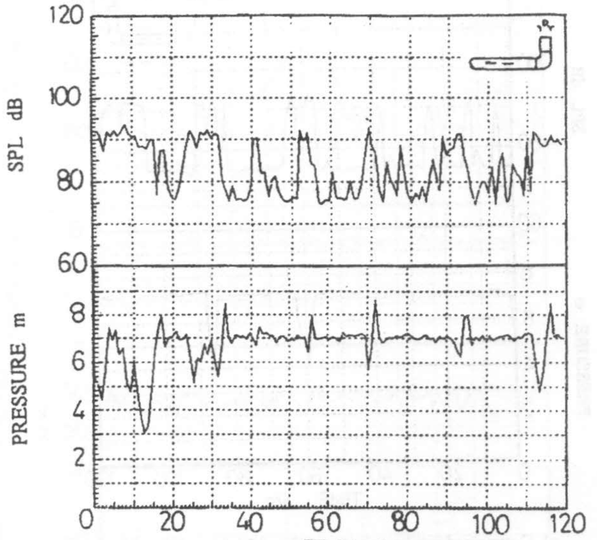


a) Downward intake geometry, Q ≈ 37 L/s and Sc =24 cm.

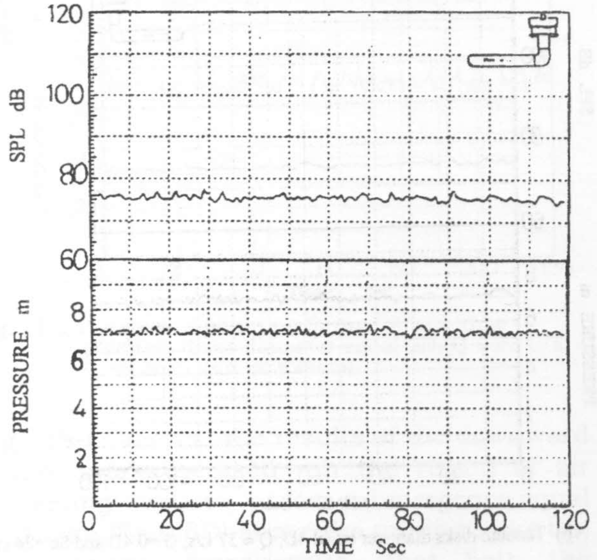


b) Tandem disks diameter equal 4D, Q ≈ 37 L/s, G =0.4D and Sc =24 cm.

Fig. 14. Variation of the S.P.L. and Pump pressure head with time.



a) Downward intake geometry, Q ≈ 37 L/s and S = 10 cm (Automatic speed control pump)



b) Tandem intake geometry $D_T = 4D$, Q $\approx$37 L/S, G = 0.4D, S = 10 cm
(Automatic speed control pump)

Fig. 15. Variation of the S.P.L. and Pump pressure head with time.

4. Conclusion

As a result of this experimental study, the following conclusions are deduced:

1- For suction pipe with flange only, the critical submergence Sc for pump intake is inversely proportional to the flange diameter.

2- For suction pipe fitted with two circular disks in tandem at its inlet, the critical submergence Sc was decreased by increasing both the disk diameter and the gap height.

3- The use of tandem disks with diameter four times pipe diameter and gap height at 0.4 times pipe diameter resulted in vortex supression at any discharge and water level more than 0.8 pipe diameter above the top of the tandem disks.

4- The application of the automatic speed control for pumping system under air-entraining vortices became safer when tandem disks intake geometry was applied.

Notation

“ D”	is the internal diameter of the intak pipe (m).
“ D_C”	is the covered intake diameter (m).
“ D_f”	is the flange outside diameter (m).
“ D_T”	is the tandem disks diameter (m).
“ G”	is the gap height between disks (m).
“ P”	is the absorbed power (Watt).
“ Q”	is the pump discharge (L/s).
“ S”	is the submergence (water height over pump intake) (m).
“ S_c”	is the critical submergence depth (m).
“ T”	is the time (seconds.)

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