International Journal of Civil Engineering (IJCE)
ISSN 2278-9987
Vol. 2, Issue 2, May 2013, 57-68

SUSPENDED SEDIMENT CONTROL AT WATER INTAKE USING AIR JET

BASIM K. NILE AL-SAEDY[1], AKTHAM M. S. AL-NASSIRI[2] & MAMDOUH NASIR MAMDOUH[3]

[1]Lecturer, Karbala University, Engineering Collage, Department of Civil Engineering, Karbala, Iraq

[2]Assistant Professor, Technology University, Department of Civil Engineering, Baghdad, Iraq

[3]Assistant Lecturer, Technology University, Department of Civil Engineering, Baghdad, Iraq

ABSTRACT

Air jet method is presented herein for the control of suspended sediment at water intake. The efficiency of the method has been investigated theoretically using dimensional analysis and experimentally in the laboratory. Three different sizes of sand (0.15mm, 0.30mm, and 0.60mm median diameter) were used. Empirical equations based on the experimental data have been developed, describing the efficiency of the proposed method. Tests were conducted to determine the effect of sediment size, water discharge and air discharge on efficiency of the proposed method in controlling the suspended sediment. The investigation has shown that as the air discharge increased and sediment median diameter decreased the corresponding efficiency increased. The efficiency was found to be reached up to a (60%) and which may be considered as a good controlling efficiency.

KEYWORDS: Sediment Control at Water Intakes, Watershed Management Research, Air Jet

INTRODUCTION

The construction of major hydraulic structures becomes necessary, as water is needed in modern times for water supply, thermal power stations, industrial projects, etc. Excessive sedimentation at water intakes on rivers causes interruption in water supply, reduces the system efficiency and serious abrasion of pumps with consequent high operating costs and system maintenance. One of the most important components connecting the construction and operation of the above-mentioned plants is the intake structure. The intake structure is a hydraulic device, constructed at the head of a power canal through which the flow is diverted from the river. The main purposes of the intake structure are to admit and regulate water from the river, and possibly to meter the flow rate; to minimize the silting of the canal, i.e. to control the sediment entry in to the canal at its intake; and to prevent the clogging of the entrance with floating debris. The design of the canal intake or head works is now sufficiently well known, but the sediment elimination practice is not yet well standardized. The problems of sediment control at the intake structure are undoubtedly difficult and complicated, but their solution is of considerable importance for the construction of safe and efficient structures. Attempts made towards developing safer, more economical and more effective approach. The function of water intake is to extract and deliver water to the users. Intake structures are required on river to provide water for different uses, for domestic water supply, electric power generation stations, water purification stations, nuclear reactors, irrigation, industrial and mining purposes, etc.

LITERATURE REVIEW

There are problems associated with intake structures. There is always the danger of sedimentation. Since the operation of water intakes is seriously handicapped by sediment, different measures are taken to prevent the entry of coarse material into the system. Sediment control techniques are often incorporated in the design of intakes so those problems of sedimentation are minimized in the canal systems, which they supply This study will be devoted to surveying the available literatures in the research of sediment as water flows to the intake**: Atkinson, E. 1996** was presented report which describes the processes involved in reservoir flushing and methods to predict the volume of sediment removed and the percentage of original storage capacity maintained by periodic flushing. He concluded methods to assess the feasibility of flushing sediment from reservoirs using simple criteria and readily available data are described.

Sadjedi, S.M., Habibi, M., and Rahmanian, M. 1997 conducted an experiment on the submerged vanes located in front of the intake. Three vanes orientation was used. The best result was obtained when the distance of inner vanes from the channel wall was three times the height of the vane. The results of their study showed that they using three vanes in each row, the sedimentation in the intake and delivery channel decreases %55. However with applying vanes in zigzag orientation the depth and shape of groove becomes more suitable and the sediment deposition decreases to 75%.

Yalin, W., Odgaard, and B., Bruce, W. M. 1997 studied the performance of two vane installations, are evaluated by comparing the bed topography before and after vanes were installed are shown to be appropriate.As a results of their study the riverbed aggrades in one portion of the channel and degrades in another.

Tatsuaki, N. 1998 presented five physical hydraulic model studies of riverside water intakes. Theses results provide design guidelines for bed-load sediment control at riverside water-intake structures on sand-bed rivers.

Brian, D., Robert, B. E., and Odgaard, A. 1999 conducted laboratory flume experiments to determine the limits to which submerged vanes can be used in preventing excessive bed-sediment ingestion into lateral diversions of flow from alluvial channels. The results of experiments show that a scheme of submerged vanes placed at the diversion entrance admits only a negligible rate of bed-sediment entry into the diversion when the ratio of unit discharge in the diversion to unit discharge in the canal is less than about 0.2.

Meilan, Q., Fujisak, K., and Tanaka, K. 2000 obtained a critical jet condition for the sediment re-suspension by turbulent jet in an intake pond. The results obtained for the scour to a limited sand bed by an impinging jet through cross flow is especially significant to the engineering design of intake ponds and culverts etc.

Thanos, N. P. 2000 presented two goals in his study which are: (I) finding an alternative methods for preventing sediment accumulation at the intake structure; (II) suggestion a remediation measures to control the sediment erosion process well upstream of intake This research utilizes 2D hydrodynamic modeling, to map the flow patterns in the river. The final product of his study will be the development of a river restoration technique that yields successful sediment for a variety of flow conditions.

Johnson, P. A. Hey, R. D., Tessier, M., and Rosgen, D. 2001 showed in their research that the effectiveness of vanes for preventing scour at single-span bridges with vertical wall abutments was evaluated based on laboratory experiments. Based on the experimental results, optimum design settings for the vane angle and height, most effective number of vanes, and distance upstream for placement of the first vane were determined. The results show that the vanes were highly effective in moving the scour away from the abutment into the center of the channel under all flow conditions tested.

Noh, M. Michiue, M. N and Hinokidani, O. 2001 were attempted to discover the sediment flushing performance through a sluice gate within the scope of 1D. Sediment flushing model for grit chamber under a steep slope condition. Their results show that the X_{max} line was found to be slightly higher for the case of flexible bed.

Christoph, O. 2002 showed the sedimentation within the reservoir, the effects of obstacles, screens, water jets and bubble curtains on the turbidity current were investigated with physical experiments and numerical simulations. The results of his study show that due to the blocking effect of the dam, the sediments in the area of the intake and bottom outlet structures can be prevented.

Finally **Mohammad, A Umesh, C.J. 2002** presented an experimental results on sediment removal efficiency of vortex chamber type sediment extractor. He was concluded a new relationship is developed for determination of sediment removal efficiency of the vortex chamber type sediment extractors.

DIMENSIONAL ANALYSIS

Theoretical Considerations

The variables determining the sedimentation at intake structure are numerous, the list of which is very long and some of them are, moreover, difficult to quantify. In any problem with a large number of independent variables, such as sediment control, a fully rational analysis becomes impossible. The approach of dimensional analysis was carried out using the Pi-theorem in an attempt to give a rational correlation. By considering a subcritical flow under steady uniform flow conditions, the outgoing suspended sediment per unit width of channel q_{out}, can be expected to be a function of the following variables:

- Variables characterizing the flow

  V= Mean velocity of the approaching flow $\left(m/s\right)$, Y = Depth of approach flow (m)

- Variables characterizing the sediments

  q_{in} =Concentration of sediment with air (kg/m^3) , q_{out}= Concentration of sediment without air (kg/m^3), D_s = Diameter of sediment (m), ρ_s = Density of sediment $\left(kg/m^3\right)$, ω = The fall velocity of the sediment particle $\left(m/s\right)$

- Properties of fluid

  ρ_w =Density of water $\left(kg/m^3\right)$, ν = Kinematic viscosity of water $\left(m^2/s\right)$, g= Gravitational acceleration $\left(m/s^2\right)$

- Variables characterizing the intake

  d = Diameter of intake inlet (m), Q_{int} = Discharge of intake $\left(m^3/s\right)$, 5- Discharge of air Q_{air} $\left(m^3/s\right)$

The above variables can be written as follows:

$$q_{out} = f_1\left(V, Y, \rho_w, D_s, \rho_s, \omega, \nu, g, d, Q_{\text{int}}, Q_{air}, q_{in}\right) \tag{1}$$

The general function is:

$$f_2 = \left(q_{out}, V, Y, \rho_w, D_s, \rho_s, \omega, \nu, g, d, Q_{\text{int}}, Q_{air}, q_{in}\right) = 0 \tag{2}$$

By using V, ρ_s , and Y as repeating variables and applying Pi-Theorem, equation (2) becomes:

$$f_3\left(\frac{D_s}{Y},\frac{\rho_s}{\rho_w},\frac{\omega}{V},R_e,F_r,\frac{d}{Y},\frac{Q_{\text{int}}}{VY^2},\frac{Q_{air}}{VY^2},\frac{q_{in}}{\rho_s},\frac{q_{out}}{\rho_s}\right) \tag{3}$$

Of the above variables, the following variables could be eliminated:

The terms of $\frac{D_s}{Y},\frac{d}{Y}$ and $\frac{q_{out}}{\rho_s}$ are very small therefore they will be neglected. NEIL[28] shows that the density ratio $\frac{\rho_w}{\rho_s}$ is not important since the particles used are of comparable density. HENG[13] has shown that the viscous effects become negligible when VY/ν >100, *i.e.* R_e can be eliminated. Thus equation (3-3) may be simplified and rewritten as:

$$f_4\left(\frac{\omega}{V},F_r,\frac{Q_{air}}{VY^2},\frac{Q_{\text{int}}}{Q_{air}},\frac{q_{in}}{q_{out}}\right)=0 \tag{4}$$

The data concerning the efficiency were analyzed on the basis of equation (4).

THE EXPERIMENTAL SETUP

The Flume

The experiments were performed in a rectangular flume, 10m long, 0.8m wide, and 0.9m in deep, having glass walls and a steel floor. On the top of the side walls, rails were installed along which the point gage carrier could be moved. A pump with maximum discharge of (0.0034 m^3/sec) was used. The thin plate rectangular weir installed at the downstream edge of the flume was used to control the flow depth. A schematic arrangement of the flume is shown in Figure (1).

The Intake

As shown in Figure (2), an intake made of a steel pipe, fixed on the top of flume, was used to draw the water from the flume by siphon action. The diameters of this pipe were (12.5mm and 25mm) and depth of it was at the mid depth of water in flume and lay in the center of the pipe supplying air.

The Air-Supplying Pipe

As shown in Figure (1), a fixed circular galvanized steel pipe was used to supply air from compressor. The diameter and radius of curvature of this pipe were (12mm), and (200mm). It injected air from bottom to the surface by compressor.

MEASURING DEVICES

The measurement facilities employed in the test programmer were required to measure:

Flow Characteristics

- Water Depth

A point Gage device was used to measure the depth of flow.

- Discharge

The water discharge was measured using V-notch weir, located at (1.0m) from the inlet. The weir calibration was made before carrying the experimental works. The discharge calibrated equation for the weir as:

$$Q = 2.0399\,H^{2.5945} \tag{5}$$

Air Discharge

A rotameter device was used to measure the air discharge.

THE SEDIMENT CHARACTERISTICS

- Sieves Shaker

A sieve shaker was used for mechanical analysis of the sediments.

- Vibrating Screen

The vibrating screen was used to obtain a single size bed material. Three different sediment samples with a 0.15mm, 0.30mm, and 0.60mm were obtained.

- Visual Accumulation Tube

The visual accumulation tube was used to obtain the fall-velocity of the sediments.

The physical characteristics of the sediments used in the present research are presented in Table (1).

THE EXPERIMENTAL PARAMETERS

In all the experiments carried out during the present research, experimental parameters were varied along the following lines:

- In order to investigate the effect of sediment size, three different sizes of sand were used (0.15mm, 0.30mm and 0.60mm).
- 2- In order to investigate the effect of air discharge, three different air discharges were used (1.80*10^{-4} $m^3/\sec$, 2.2*10^{-4} $m^3/\sec$ and 2.7*10^{-4} $m^3/\sec$).
- In order to investigate the effect of water discharge, four different water discharges were used (0.0034 $m^3/\sec$, 0.0024 $m^3/\sec$, 0.0016 $m^3/\sec$ and 0.0010 $m^3/\sec$).
- In order to investigate the effect of intake diameter, two different intake diameters were used (12.5mm, 25mm).Table (2) summarizes the experimental parameters.

EXPERIMENTAL PROCEDURE

A predetermined slope was given to the flume and the required discharge was allowed into it. Uniform flow in the channel was established with the help of the tailgate. The depth of flow at test section was measured by means of a point gage. Air was supplied to the perforated pipe by compressor and by rotometer, with air supplied by plastic pipe. After this state, the bubble rises to the surface from the air-supplying pipe in the bottom of flume. A known amount of chosen sediment was injected at a constant rate at a distance not less than (70 cm) upstream of the intake to get approximately the desired concentration. It was always insured that the rate of sediment injection was low enough to preclude the possibility of deposition in the channel for the given flow conditions. The discharge of intake was measured by volumetric method. The sediment deposited in the filtration was dried at 105^0C and weighed to determine the efficiency. The experimental results that the efficiency was found equal to 0.6 %

PRESENTATION OF RESULTS

In this research, the effects of variables on sediment control at water intake were evaluated. Different combinations of variables were tried including, the depth of water, the air supplying, and quantity of sediment, etc. Keeping in mind that the main objective in evaluating the hydraulic performance of intake protection system is drifting away the sediment particle. The creation of optimum operational conditions for four discharges of water in the flume were measured. The results of this research are presented in the form of dimensionless relationships. The flow associated with air bubble when water moves is complicated because of the additional variable of velocity of river. Therefore, dimensional analysis theorem is used in the analysis of air jet.

From the dimensional analysis presented in chapter three the dimensionless equation is:

$$q_{in}/q_{out} = f_5\left(\omega/V, F_r, Q_{air}/VY^2, Q_{int.}/Q_{air}\right) \tag{6}$$

The influences of the above terms are discussed in the following section.

The Intake Discharge (Q_{int})

Two different water discharges were used in this research, (0.0625*10^{-3} m^3/s, and 0.125*10^{-3} m^3/s). The intake discharge, in dimensional analysis, is included in the term $\left(Q_{int.}/Q_{air}\right)$.

The Air Discharge (Q_{air})

The air discharges in this research were (1.8*10^{-3} m^3/s, 2.22*10^{-3} m^3/s, and 2.7*10^{-3} m^3/s) released at the base of the channel, by controlling the air quantity from a compressor. Air discharge was found to be an important term in the protection system, since increasing (Q_{air}) increases the efficiency. In dimensional analysis, the air discharge is included in the terms $\left(Q_{air}/VY^2 \text{ and } Q_{int}/Q_{air}\right)$.

The Depth of Water (Y)

In this research the depth of water was kept constant at about (0.3m) for all flows. The dimensionless group containing (Y) is in term of $\left(Q_{air}/VY^2\right)$.

The Channel Velocity (V)

The velocity of flow is very important as it plays a role in the determination of the area protected by this system when river velocity is high. As a result, the main aim of protection may not be achieved. It is found that, the minimum value of water current velocity should be at least of river velocity. The channel velocity values are (0.014 *m/s*, 0.01 *m/s*, 6.6*10^{-3} *m/s* and 4.1 *10^{-3} *m/s*). This effect is included in the dimensional analysis in the term $\left(\omega/V \;\&\; Q_{air}/VY^2\right)$.

The Fall Velocity (ω)

The fall velocity value depending on the diameter of particle and its value are (0.020 *m/s*, 0.081 *m/s*, and 0.324 *m/s*). The dimensionless analysis containing (ω) is in term of $\left(\omega/V\right)$. It is well known that the fall velocity of the sediment is affected by the concentration of sediment. According to HETSRONI, G., (1982)

$$\omega = V\left(\frac{C\gamma_f}{\gamma_s}\right)^N \tag{7}$$

in which (γ_s and γ_f), are the specific weights of sediment and fluid respectively, (ω), is the fall velocity of the particle at concentration (C) and (N) is given by

$$N = 4.4\left(\frac{VD_s}{\nu}\right)^{-0.08} \qquad \text{For} \quad \frac{VD_s}{\nu} < 2500 \tag{8}$$

$$\text{And } N=2.35 \qquad \text{For} \quad \frac{VD_s}{\nu} > 2500 \tag{9}$$

GARDE, R.J., and SUJUDI, A.W.R., (1990) found that the fall velocity as computed by using the equations differed by less than 0.10% from the value for a single particle in clear water. Hence the fall velocity of a singly particle (assuming it to be spherical) in clear water was used in the analysis of data.

Froude Number $\left(F_r\right)$

The Froude numbers in this research were (8.16*10^{-3}, 5.83*10^{-3}, 3.85*10^{-3} and 2.39*10^{-3}) at the depth of 0.3m. In dimensional analysis Froude number was included in the terms of $\left(F_r\right)$.

Concentration of Sediment $\left(q_{in}, q_{out.}\right)$

The concentration of sediment with air $\left(q_{in}\right)$is less than the value of concentration of sediment without air $\left(q_{out}\right)$, because the air drifts the sediment particle from the region of controlling sediment.

The Dimensionless Relationships

Figure (3) shows the relation between ($\frac{q_{in}}{q_{out}}$ & ω/V) with value of Qair(1.8*10^{-4}) m^3/sec and value of D_s =(0.15 mm) and also we can get the same relations by using (Qair=,2.22*10^{-4} &2.7*10^{-4})m^3/sec and (Ds=0.3&0.6) mm. The R-square value (R^2) for this relations about (0.73 to 0.98). This figure indicate that the remaining of sediment particle ($\frac{q_{in}}{q_{out}}$), increases as the value of (ω/V) increases, in any value of (Q_{int}/Q_{air}).

Figure (4) show the relations between ($\frac{q_{in}}{q_{out}}$ & F_r).with values of Qair(1.8*10^{-4}) m^3/sec and value of D_s =(0.15 mm) and also we can get the same relations by using (Qair=,2.22*10^{-4} &2.7*10^{-4})m^3/sec and (Ds=0.3&0.6) mm. The R-square value (R^2) for this relations about (0.88 to 0.99). This figure indicate that the remaining of sediment particle ($\frac{q_{in}}{q_{out}}$), decreases as the value of (F_r) increases, in any value of (Q_{int}/Q_{air}).

Figure (5) show the relations between ($\frac{q_{in}}{q_{out}}$ & Q_{air}/VY^2)with values of Qair($1.8*10^{-4}$) m^3/sec and value of D_s =(0.15 mm) and also we can get the same relations by using (Qair= $2.22*10^{-4}$ & $2.7*10^{-4}$) m^3/sec and (Ds=0.3&0.6) mm..The R-square value (R^2) for this relations about (0.75 to 0.98). This figure indicate that the remaining of sediment particle ($\frac{q_{in}}{q_{out}}$), increases as the value of (Q_{air}/VY^2) increases, in any value of (Q_{int}/Q_{air}). That means increase in the efficiency of sediment control because the quantity of air increases.

Formulas

Empirical formulas are obtained for three different values of diameters (D_s). These formulas are:

- For diameter 0.15mm the formula is:

$$\frac{q_{in}}{q_{out}} = 3.7703 \text{x} (\omega/V)^{1.312} \text{x} (F_r)^{0.7314} \text{x} (Q_{air}/VY^2)^{-0.3807} \text{x} (Q_{in}/Q_{air})^{0.101} \quad (10)$$

see Table (3). The R-square value (R^2) for this Eq.= 0.97 . The difference between the quantity of ($\frac{q_{in}}{q_{out}}$) calculated from Eq. (10) and ($\frac{q_{in}}{q_{out}}$) observed is (0.006).

- For diameter 0.3mm the formula is:

$$\frac{q_{in}}{q_{out}} = 30.2746 \text{x} (\omega/V)^{2.5205} \text{x} (F_r)^{1.94026} \text{x} (Q_{air}/VY^2)^{-0.29156} \text{x} (Q_{in}/Q_{air})^{-0.1945} \quad (11)$$

see Table (3). The R-square value (R^2)for this Eq.= 0.88. The difference between the quantity of ($\frac{q_{in}}{q_{out}}$) calculated from Eq. (11) and ($\frac{q_{in}}{q_{out}}$) observed is (0.019).

- For diameter 0.6mm the used formula is:

$$\frac{q_{in}}{q_{out}} = 0.6 \text{x} (\omega/V)^{1.215} \text{x} (F_r)^{-0.35} \text{x} (Q_{air}/VY^2)^{-1.2} \text{x} (Q_{in}/Q_{air})^{0..0366} .. \quad (12)$$

see Table (3). The R-square value (R^2)for this Eq.= 0.81. The difference between the quantity . ($\frac{q_{in}}{q_{out}}$)calculated from Eq. (12) and ($\frac{q_{in}}{q_{out}}$) observed is (0.044).

A general formula may be obtained upon substituting different values of $\left(\omega/V, F_r, Q_{air}/VY^2, Q_{int.}/Q_{air}\right)$. This formula is:

$$\frac{q_{in}}{q_{out}}=0.0065\text{x}(\omega/V)^{0.068}\text{x}(F_r)^{-0.657}\text{x}(Q_{air}/VY^2)^{-0.489}\text{x}(Q_{\text{int}}/Q_{air})^{-0.19744} \quad (13)$$

see Table (3). The R-square value (R^2)for this Eq.= 0.77. The difference between the quantity of ($\frac{q_{in}}{q_{out}}$) calculated from the general Equation and ($\frac{q_{in}}{q_{out}}$) observed is (0.034), and the difference between the quantity of ($\frac{q_{in}}{q_{out}}$) calculated from the general Equation and the quantity of ($\frac{q_{in}}{q_{out}}$) calculated from the Equations (10), (11) and (12) equal to (0.022).

THE EFFICIENCY OF SEDIMENT CONTROL

According to the previous analysis of intake protection system the concentration of sediment in the zone of injected air is lower in value than at the outside of this zone. The efficiency (*Eff.*) for drifting away the sediment particle is represented:

$$Eff. = \frac{q_{out}-q_{in}}{q_{out}} \quad (14)$$

where:

q_{in} And q_{out} are the concentrations of sediment inside and outside respectively.

CONCLUSIONS

The following conclusions on the sediment control at intake structure using air jet are drawn from theoretical and experimental conditions and limitations relevant to the present work:

- Air jet can be used for controlling suspended sediment particles from entering the zone of water withdrawal at screens of intake pumps. With the limitation of the present research.
- A general relationship representing the efficiency of the air jet is developed. Represented equations of (10) through (13) and the boundary condition as found in Table (3).
- The parameters $\left(\omega/V, F_r, Q_{air}/VY^2, Q_{\text{int}}./Q_{air}\right)$ and concentration of sediment are found to govern the efficiency.
- The efficiency of air jet to control the suspended sediments is increased as the sediment diameter decreased, and the efficiency was found to be reached up to a (60%).

RECOMMENDATIONS

The following recommendations are suggested for future work:

- Further studies are required on a pilot scale and /or a prototype scale in order to evaluate and investigate in more detail the efficiency of the air jet method, compared with the other available methods.
- Extending the limitations of the present research by using different sizes of sediment, sediment concentration, air jet discharge and water discharge.

REFERENCES

1. HETSRONI, G., (1982) "Handbook of Multiphase Systems", Mc.Graw-Hill Book Co., New York, pp.9-118 to 9-121.
2. GARDE, R.J., and SUJUDI, A.W.R., (1990) "Design of Settling Basins", IAHR, Vol.28, No.1,pp.81-91.
3. ATKINSON, E., (1996), "The Feasibility of Flushing Sediment From Reservoirs", HR Wallingford, UK. Report no. OD 137. pp21.
4. SADJEDI S., M., HABIBI M., and RAHMANIAN M., (1997), "An Experimental Investigation On Sediment Control In Intakes Using Submerged Vanes", Soil Conservation And Watershed Management Research Center, Tehran, Iran.
5. YALIN W., A., JACOB O., and BRUCE W. M., (1997),"Sediment Control at Water Intakes", ASCE. Journal of Hydraulic Engineering. Vol.122, Issue 6, pp. 353-356.
6. TATSUAKI N., and FRED L. O., (1998), "Sediment Control at Water Intakes Along Sand Bed Rivers", ASCE. Journal of Hydraulic Engineering. Vol. 124, Issue 6, pp. 589-596.
7. BRIAN D., ROBERT,B. E. and JACOB, A. O., (1999),"Sediment Control at Lateral Diversions: Limits and Enhancement to Vane Use",
8. MEILAN Q., FUJISAK, K., TANNAKA, K., (2000), "Sediment Re-Suspension by Turbulent Jet in an Intake Pond", Journal of Hydraulic Research. Vol. 38, No. 5.
9. THANOS N. P., (2000), "The Role of Turbulence and Sediment Availability in Sediment Erosion Processes", State of Washington Water Research Center Report WRR-03 U.S. Geological Survey Grant No.1434.
10. JOHNSON, P. A., HEY, R. D., TESSIER, M. and ROSGEN, D. L., (2001), "Use of Vanes for Control of Scour at Vertical Wall Abutments", ASCE. Journal of Hydraulic Engineering, Vol. 127, Issue 9, pp. 772-778.
11. NOH, M., MICHIUE, M. N., and HINOKIDANI, O., (2001), "A Sediment Flushing Technique With a Grit Chamber", Department of Civil Engineering, Tottori University, Japan.
12. CHRISTOPH, O., (2002),"Effects of Obstacles and Jets on Reservoir Sedimentation Due To Turbidity Currents", Laboratories De Constructions Hydraulics.
13. MOHAMMAD A., UMESH C. K., and RAMCHANDRAL J. G., (2002), "Sediment Removal Efficiency of Vortex Chamber Type Sediment Extractor", ASCE. Journal of Hydraulic Engineering, Vol. 128, Issue 12, pp. 1051-1059.

APPENDICES

Table 1: Physical Characteristics of the Sediment

Mean Diameter of Particle $(D)_s$ mm	Bulk Density (ρ_b) Kg/m^3	Particle Density (ρ_s) Kg/m^3	Porosity (n)	Angle of Repose (ϕ_s) Deg.	Fall Velocity (ω) m/sec
0.15	1619	2650	0.39	12.70	0.020
0.30	1666	2650	0.37	14.03	0.081
0.60	1760	2650	0.33	16.70	0.324

Table 2: Number of the Experimental Tests

No. of Experimental Test	No. of Diameter of Intake Used	No. of Water Discharge Used	No. of Diameter of Intake Used	No. of Diameter of Particle Used
72	3	4	2	3

Table 3: The Boundary Condition

Discharge of Water Q (m^3/s)	Diameter of Particle D_s (*mm*)	ω / V (-)	F_r *10^{-3} (-)	Q_{int} / Q_{out} (-)
0.0010-0.0034	0.15-0.60	1.43-79.02	2.40-8.16	0.225-0.694

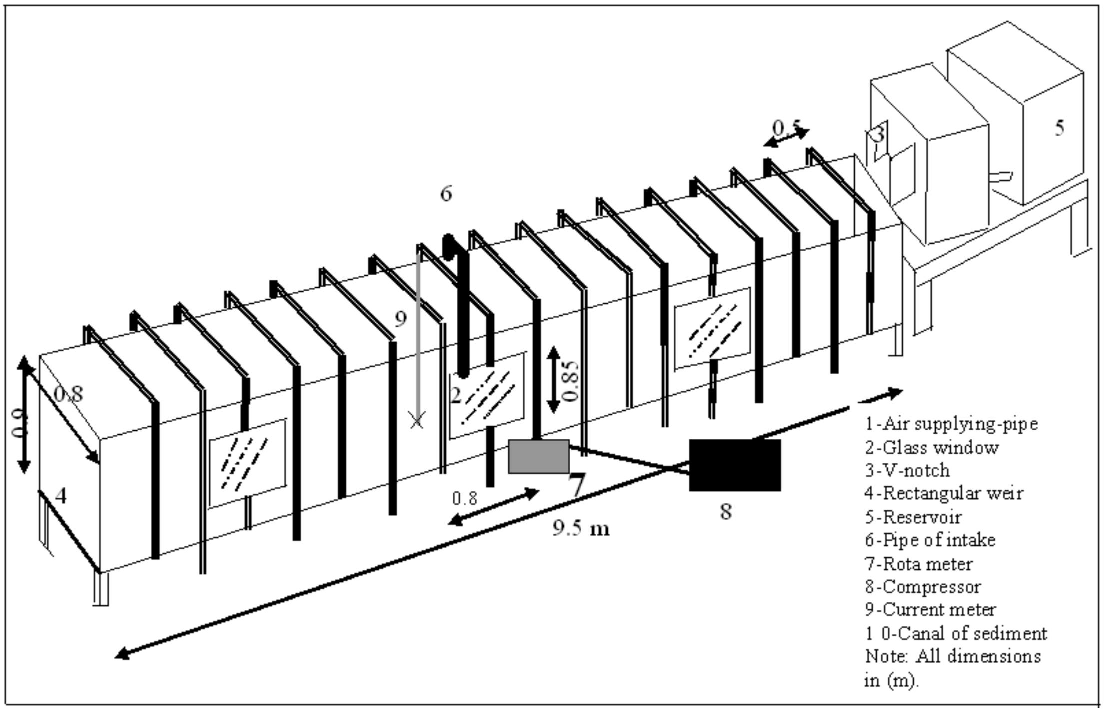

Figure 1: The Flume

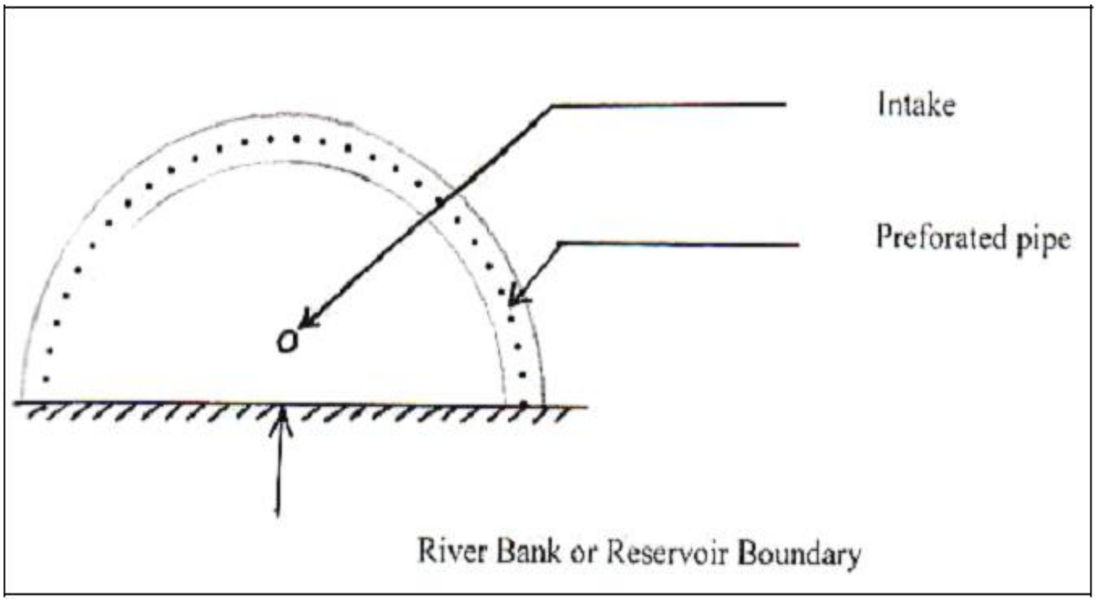

Figure 2: The Schematic Arrangement of the Intake

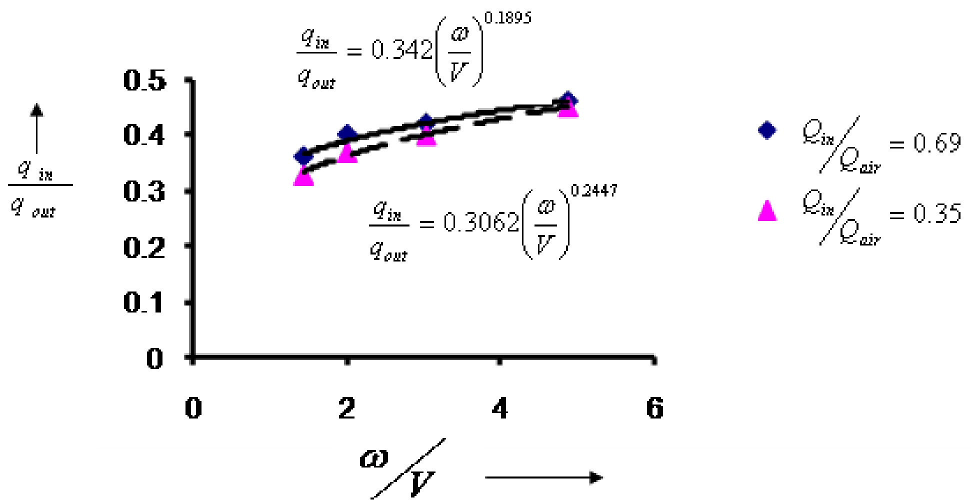

Figure 3: Relation between $\frac{q_{in}}{q_{out}}$ & ω/V (Q_{air} =1.8*10^{-4}m^3/sec & D $_s$ =0.15mm)

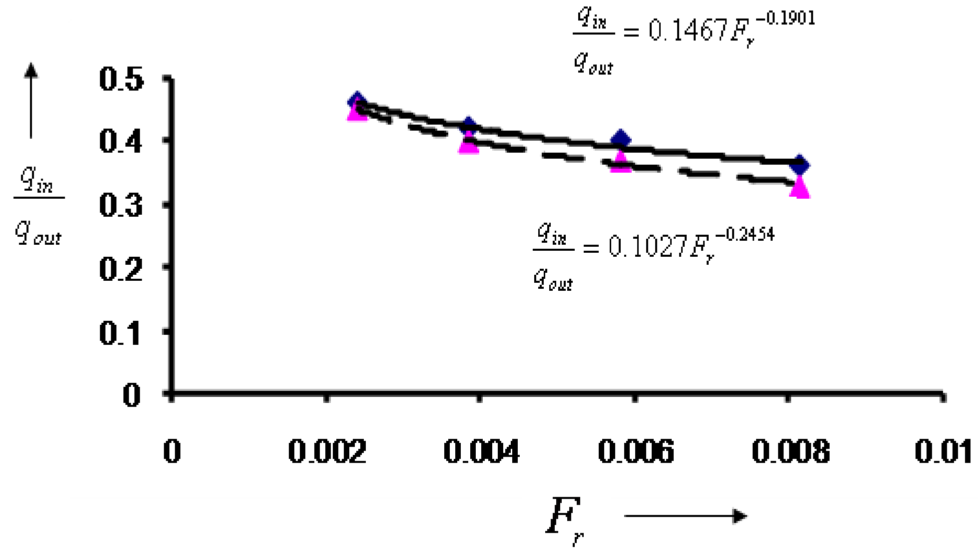

Figure 4: Relation between $\frac{q_{in}}{q_{out}}$ & F$_r$ (Q_{air} =1.8*10^{-4}m^3/sec & D $_s$ =0.15mm)

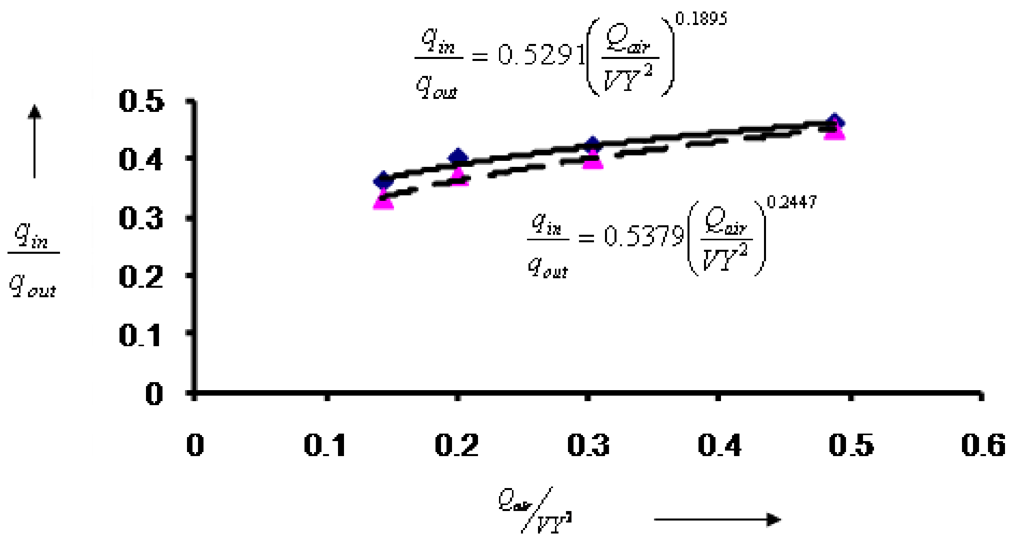

Figure 5: Relation between $\frac{q_{in}}{q_{out}}$ & Q_{air}/VY^2 (Q_{air} =1.8*10^{-4}m^3/sec & D $_s$ =0