An Experimental Study of the Influence of Open Channel Hydraulic Parameters and Soil Gradation on Jet Pump Sand Removal`s Efficiency

Mohammed Salah[1] and Mahmoud Zayed[1*]

[1]*National Water Research Center, Ministry of Water Recourses and Irrigation, Egypt.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Removing deposits is one of the most important maintenance activities that applied to irrigation canal. This research aims to study experimentally the effect of different flow conditions such as discharge and water depth on removing sand by using jet pump. To achieve this goal, an experimental program was set up and a small prototype of jet pump was tested under different conditions. The flow discharge, water depth and sand type were related to sand remove by the jet pump. Forty five runs were applied on the physical model built in the hydraulic lab of the Channel Maintenance Research Institute, National Water Research Center, Egypt. It was found that both of water depth and discharge of open channel had no direct effect on jet pump efficiency. The efficiency of jet pump was mainly affected by soil gradation. Finally, it is recommended to use jet pump in limited maintenance work where the soil is loose.

_____

Corresponding author: E-mail: mahmoudzayed13@yahoo.com;

1. INTRODUCTION

Sediment deposition in waterways is a serious issue facing the irrigation sector. Solid material or organic matter that transported and deposited by water or wind is defined as sediment [1]. Sediment deposition has a harmful effect on the capacity of the reservoir, the life of dams, hydropower operation efficiency, intake and outlet structure as it may be clogged [2]. Besides that it may cause flooding, navigation problems and environmental negative influence [3]. So without routine removing for sediment deposition, the water-based activates will confront several problems.

Jet pumps are hydraulic dredge devices used to remove sediment (sand/water mixture) from watercourses. Jet pumps bypassing system don't have moving parts and the jet of water can power it, so the primary component of jet pumps is differ from other pumps [4,5]. In the suction chamber of jet pump, mixing occurs between (sand/water mixture) and central water jet, the surrounding sediment is crumbled by small water jet near the intake end of the suction tube, thus enables the sediment to flow towards suction tube end [6].

The properties of the sediment play a major role on the jet pump performance. Designing the pumping system must include grain size distribution, in situ porosity, specific gravity of sediment solids, presence of cohesive material or cementing agents, presence of large objects such as debris [5].

Most studies focused on the jet pump geometry relations to improve the performance, but few studies explored experimentally the effect of flow characteristics and sediment type on the sediment removable by using jet pump, although it may play an important role in the performance and designing the jet pump. Bosman et al. [6] studied the removal of sediment from water intakes on rivers by using jet dredge pump to develop a reliable and simple jet pump design for the application in water intakes. El- Sawaf et al.[7] illustrated experimentally the influence of the pump geometries and operating conditions on the performance, the result showed that the jet pump head and the head ratio decrease with increasing suction capacity. Saker and Hassan [8], showed experimentally the effect of different

jet pump parameters on the performance. Mueller [9] explored experimentally the optimum dimensions for water jet pump at best performances. El-Sibaie and El-Haggar [10], reported experimentally the particle size and nozzle outlet location on the slurry jet pump performance.

2. AIMS OF THE RESEARCH

Most applied studies on the topic of water jet pump interested in studying the effect of jet pump geometry on its performance. However, the flow characteristics and sand type may play a role in the performance of jet pump. Therefore, the research aims to study experimentally the effect of flow discharge, water depth and different grain size distributions of sand on deposit removal efficiency by using jet pump.

3. EXPERIMENTAL WORK

The experiments were carried out in the hydraulic lab of the Channel Maintenance Research Institute, National Water Research Center, Egypt. The used flume is a reinforced concrete flume of re-circulating type as shown in Fig. 1. It has a total length of 22.10 m. An underground reservoir with the dimensions 24.10 m long, 1.75 m wide, and 1.50 m height was used to supply the flume with water. The main part of the flume is the trapezoidal concrete section that has the dimensions of 16.22 m length, 0.60 m width, 0.42 m maximum depth and 1:1 side slope. The inlet part of the flume has the dimensions of 4.52 m long, 1.63 m wide, and 1.16 m height, with two vertical reinforced concrete walls to dissipate any excessive energy. The two walls are in a basin with the dimensions 3.00 m length, 1.63 m width and 1.21 m height, the inlet bed has a ramp with slope 3:1 is located downstream the two vertical walls. The outlet part of flume consists of outlet basin of dimensions 0.96 m length, 1.63 m width and 1.21 m height. The water was drained through two pipes, 8-inch diameter to the underground reservoir.

A sand basin of 1.00 m length, 0.60 m width, and 0.10 m depth was constructed. Three-soil gradation was used to represent fine, medium, and coarse sand. The medium grain size of the experiment sand soil (D_{50}) was 0.41 mm, 0.47 mm, and 0.58 mm respectively.
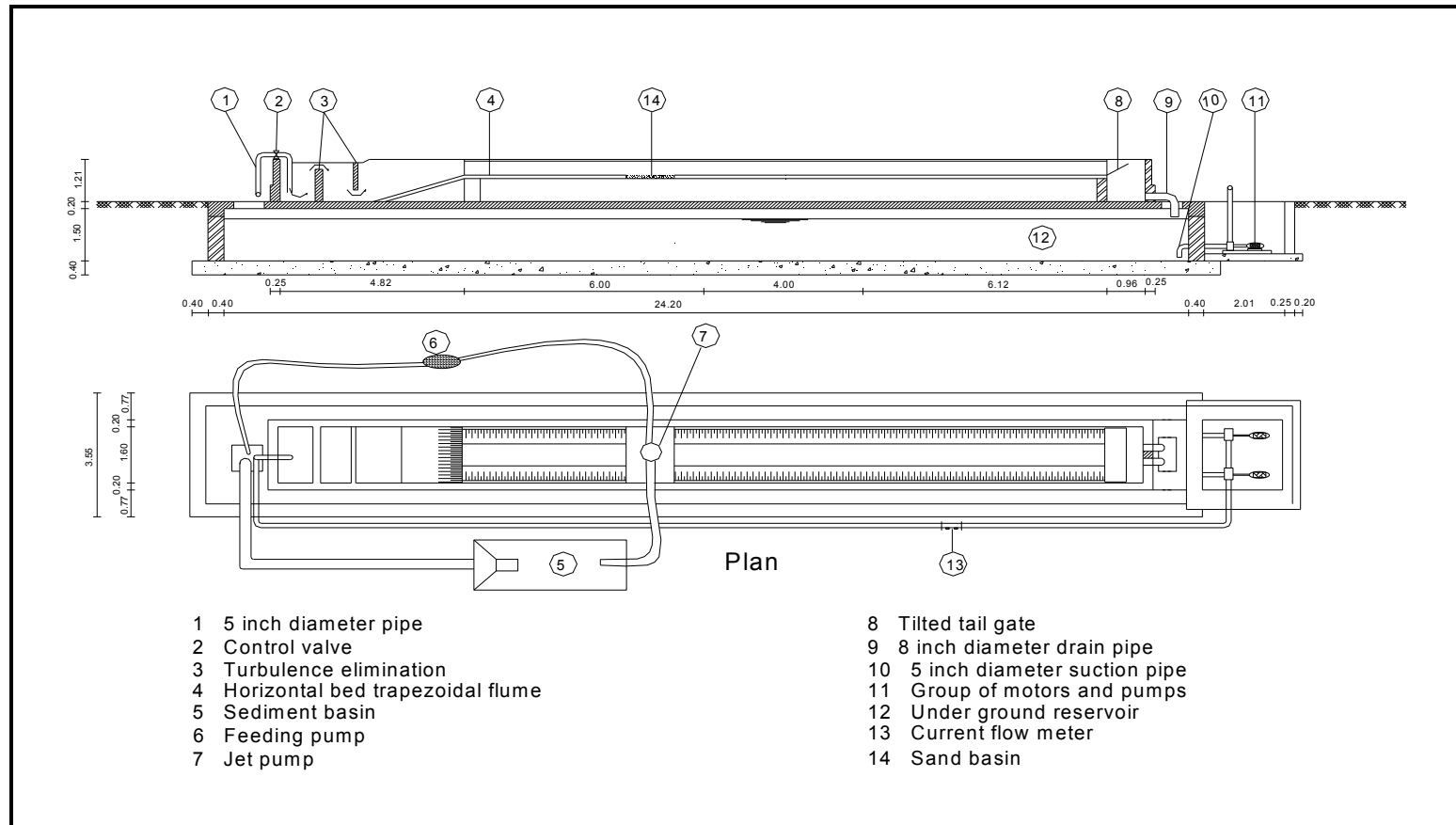
Fig. 1. Lay out of the experimental flume

1 5 inch diameter pipe
2 Control valve
3 Turbulence elimination
4 Horizontal bed trapezoidal flume
5 Sediment basin
6 Feeding pump
7 Jet pump

8 Tilted tail gate
9 8 inch diameter drain pipe
10 5 inch diameter suction pipe
11 Group of motors and pumps
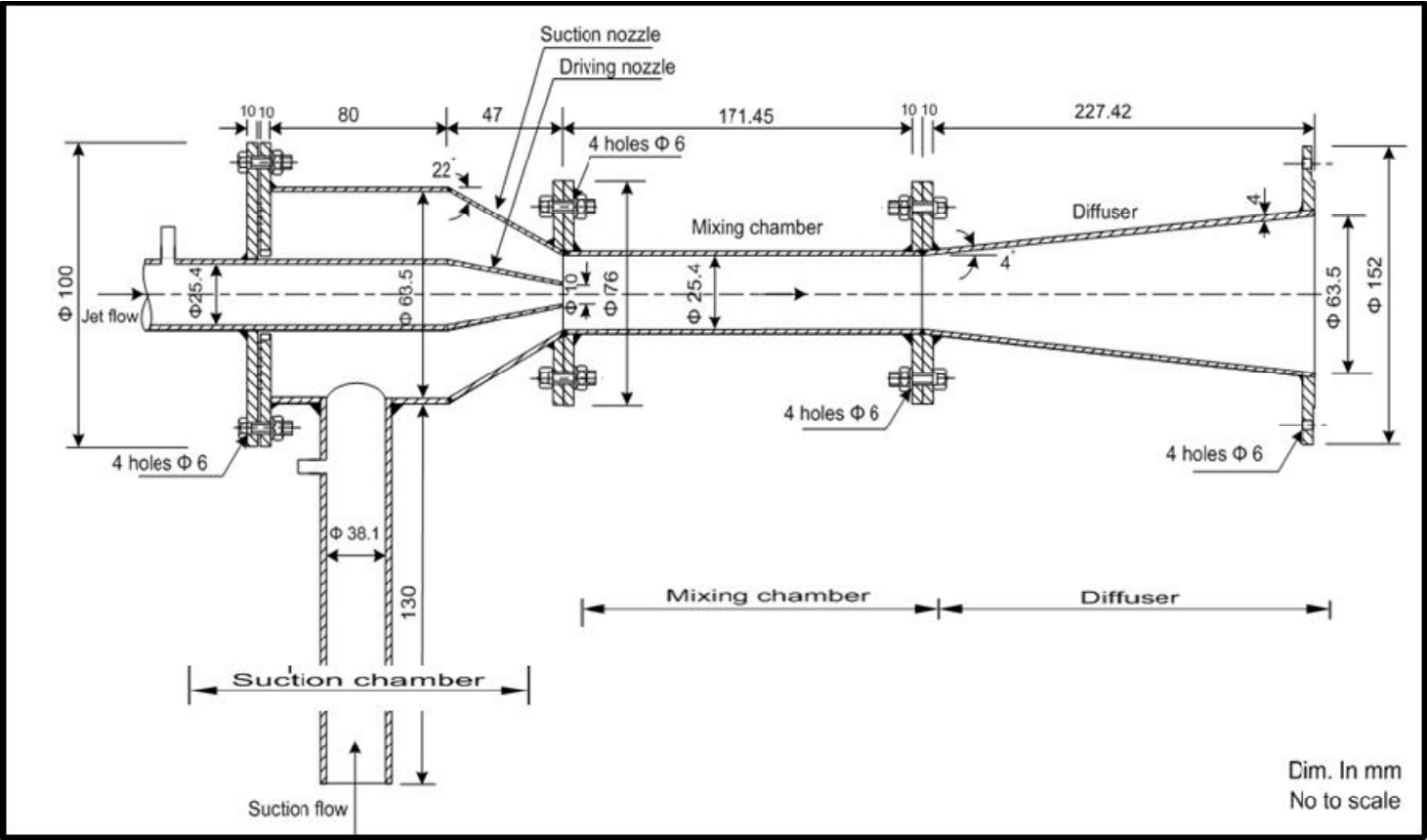12 Under ground reservoir
13 Current flow meter
14 Sand basin

Fig. 2. Principal components of the used jet-pump [11]

An experimental model was built up, the jet pump and the sand basin were attached to the hydraulic flume. The main components and dimensions of the used jet is shown in Fig. 2. The output mixture of sand and water was collected in 4 m^3 sediment basin. The collecting basin is provided with geo textile membrane filter at its drainage hole to prevent sand from escaping. Five discharges were selected to pass through the flume (30, 35, 40, 45, and 50 l/s). For each discharge, three water depths were applied (25, 30, and 35 cm). For each run both discharges and water depths were adjusted and both the volumes of mixture and sand in the collecting basin were measured. Fig. 3 shows the components of the experimental model. The variables of the experimental program runs showed in (Table 1).

Table 1. Variables of the experimental program runs

Discharge l/sec	Water depth cm	Velocity cm/sec	D_{50} mm
30	20	18.7	0.41 , 0.47 and 0.58
	25	14.1	0.41 , 0.47 and 0.58
	30	11.1	0.41 , 0.47 and 0.58
35	20	21.8	0.41 , 0.47 and 0.58
	25	16.4	0.41 , 0.47 and 0.58
	30	12.9	0.41 , 0.47 and 0.58
40	20	25	0.41 , 0.47 and 0.58
	25	18.8	0.41 , 0.47 and 0.58
	30	14.8	0.41 , 0.47 and 0.58
45	20	28.1	0.41 , 0.47 and 0.58
	25	21.1	0.41 , 0.47 and 0.58
	30	16.6	0.41 , 0.47 and 0.58
50	20	31.2	0.41 , 0.47 and 0.58
	25	23.5	0.41 , 0.47 and 0.58
	30	18.5	0.41 , 0.47 and 0.58

NB: (l/sec) : (liter / second) unit of the discharge; (cm): (centimeter) unit of water depth; (cm/sec): (centimeter / second) unit of flow velocity in the flume; (D_{50}): median grain size; (mm):(millimeter)unit of D_{50}

Fig. 3. Components of the experimental model

4. THEORETICAL APPROACH

Dimensional analysis is used in the derivation of general equation to determine the efficiency of the used experimental jet pump.

$$\varepsilon = f \left\{ \left(\frac{D_{50}}{V_t^{0.33}} \right), \left(\frac{Y}{V_t^{0.33}} \right), \left(\frac{V_s}{(Q*T)} \right) \right\} \quad (1)$$

those relations according to Buckingham's π-theorem [12-13].

Where (ε) is jet pump soil removal efficiency = (V_s/V_t), (V_s) is volume of removed soil, (V_t) total volume of jet pump out put (mixture sand / water), (Q) is the discharge of the flume, (V) is the flow mean velocity of the flume, (T) is the time of run, (Y) is the water depth of the flume, (D_{50}) is the median grain size of the used soil.

5. ANALYSIS OF RESULTS AND DISCUSSION

Forty-five runs were applied on the physical model using small prototype of jet pump to identify the effect of changing water depth, discharges, and soil gradation on the efficiency of jet pump in removing soil.

5.1 Effect of Water Depth on Jet Pump Sand Removal`s Efficiency

Three water depths were applied through the experiment with five flow discharges and three-soil gradation. The used jet pump prototype is the same for all runs. Fig. 4 represents a sample of experimental results. It shows a comparison between the efficiency of different water depths when passing different discharges for coarse sand removal. Maximum values for the efficiency were obtained at water depth of 30 cm. Fig. 5 shows the relation between the efficiency of jet pump in removing sand (Ɛ) = (V_s/V_t) and the term $(Y/V_t^{0.33})$. The curve representing the relationship did not show a definite trend. The efficiency was increased with increasing $(Y/V_t^{0.33})$ to a certain value then it started to decrease. This may be due the fact that for each jet pump (size, geometric dimensions, and feeding pump properties) an ideal water depth, which gives maximum efficiency.

5.2 Effect of Soil Gradation on Jet Pump Sand Removal Efficiency

The efficiency of jet pump in removing sand was determined when using three soil gradations. Fig. 6 represents a sample of experimental results. It shows comparison between the
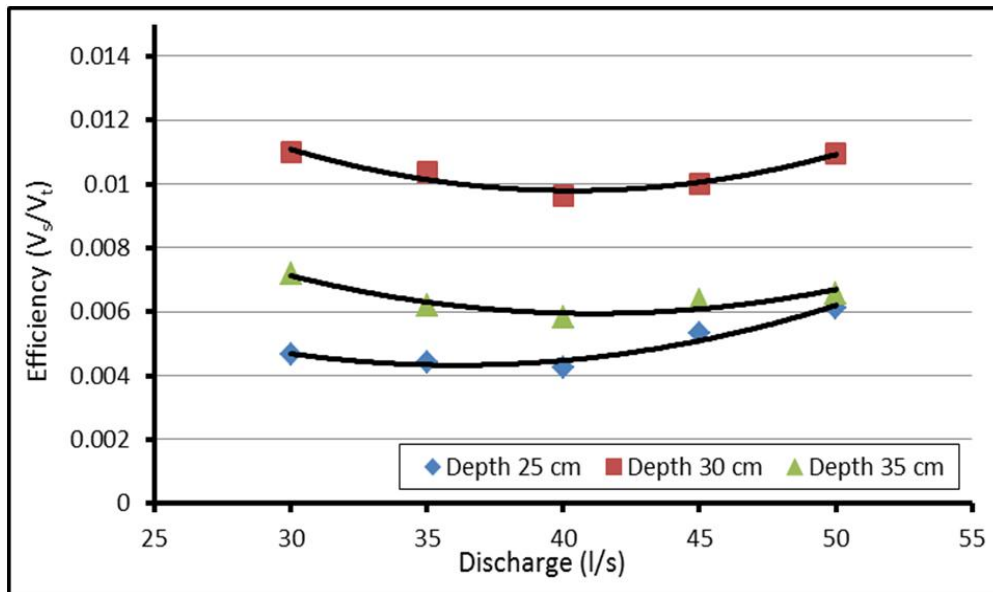

Fig. 4. The relation between jet pump sand removal`s efficiency (Vs/Vt) and discharge for different water depths
NB: These results are results from analyzing the experimental data. (Vs/Vt): Jet pump sand removal`s efficiency as (Vs): Volume of removed soil; (Vt): Total volume of jet pump out put (mixture sand / water)
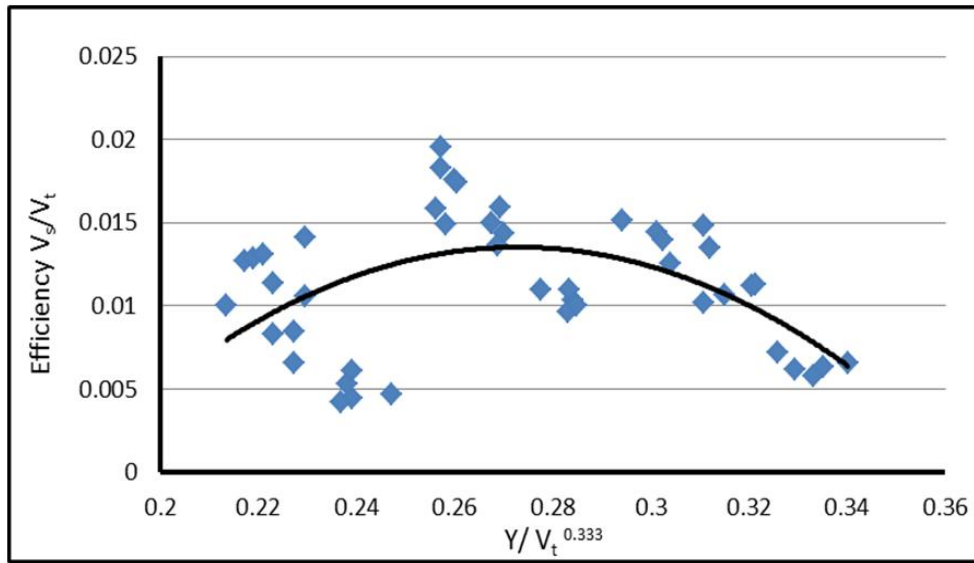
Fig. 5. The relation between jet pump sand removal`s efficiency (V_s/V_t) and ($Y/V_t^{0.33}$)
NB: Those results are results from analyzing the experimental data. (V_s/V_t): Jet pump sand removal`s efficiency as (V_s): Volume of removed soil; (V_t): Total volume of jet pump out put (mixture sand / water); (Y) is the water depth of the flume
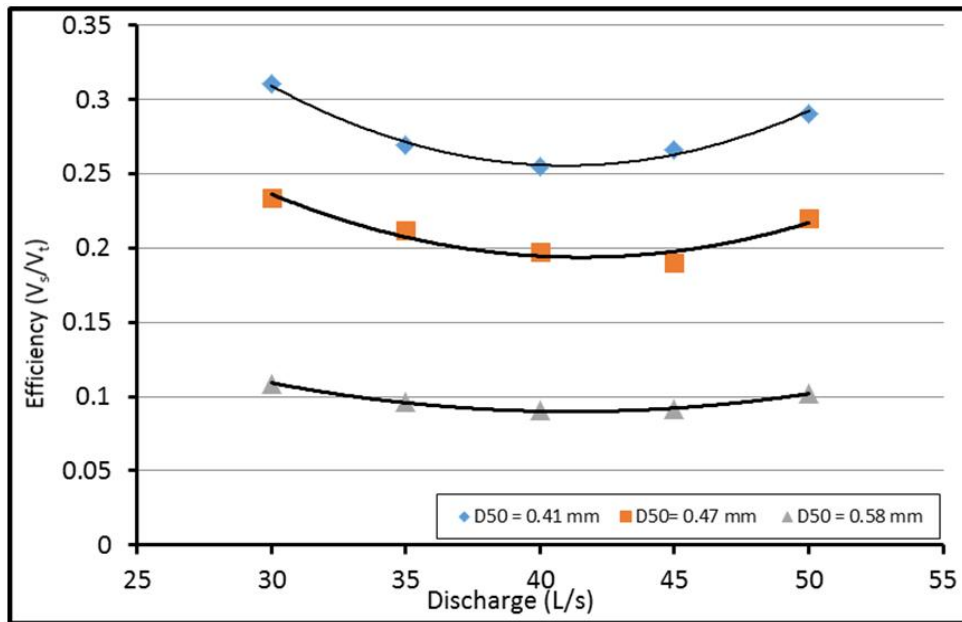

Fig. 6. The relation between jet pump sand removal`s efficiency (V_s/V_t) and discharge for different sand gradations
NB: those results are results from analyzing the experimental data. (V_s/V_t): jet pump sand removal`s efficiency as (V_s): volume of removed soil;(V_t) :total volume of jet pump out put (mixture sand / water).

efficiency of different soil gradations when passing different discharges for water depth 35 cm. The efficiency of removing sand is decreased with increasing soil particle size.

Fig. 7 shows the relation between the efficiency of jet pump in removing sand (ε) and the term ($D_{50}/V_t^{0.33}$). The efficiency is inversely proportional to the term ($D_{50}/V_t^{0.33}$).

7

5.3 Relation between Jet Pump Sand Removal`s Efficiency (V_s/V_t) and the Term (V_s/QT)

The Relation between jet pump sand removal`s efficiency and the term (V_s/QT) is represented in the Fig. 8. The removal efficiency is increasing with increasing the value of the term (V_s/ QT). The rate of increasing is high for smaller values of the term (V_s/QT). For higher values, the rate of increasing getting lesser. The relation between the two terms could be stated in the following equation:-

$$\varepsilon = 0.59 \left[\frac{V_s}{Q \times T}\right]^2 + 0.20 \left(\frac{V_s}{Q \times T}\right) \qquad (2)$$

The equation was based on analyzing the experimental data using Microsoft office excel program.

Where (ε) is jet pump soil removal efficiency = (V_s/V_t), (V_s) is volume of removed soil, (V_t) total volume of jet pump out put (mixture sand / water), (Q) is the discharge of the flume, (T) is the time of run.
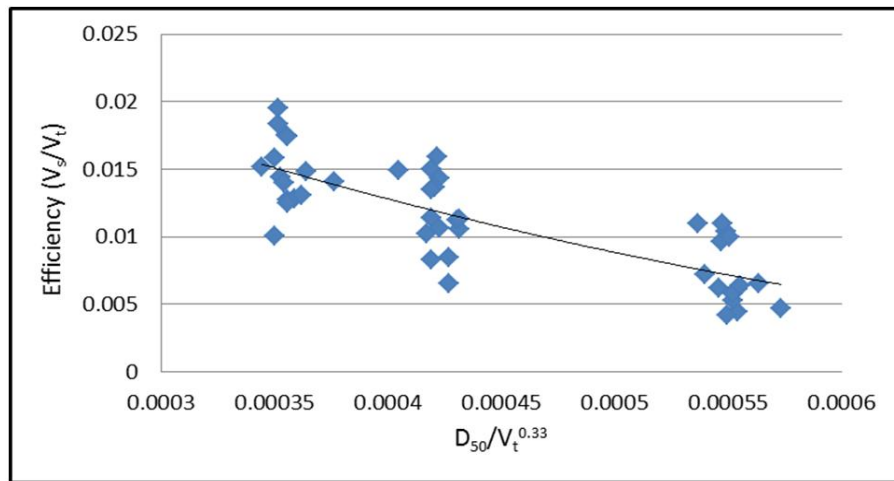

Fig. 7. The relation between jet pump sand removal`s efficiency (V_s/V_t) and (D_{50}/V_t^{0.33})
NB: Those results are results from analyzing the experimental data. (V_s/V_t): Jet pump sand removal`s efficiency as (V_s): Volume of removed soil; (V_t): Total volume of jet pump out put (mixture sand / water); (D_{50}) is the median grain size of the used soil
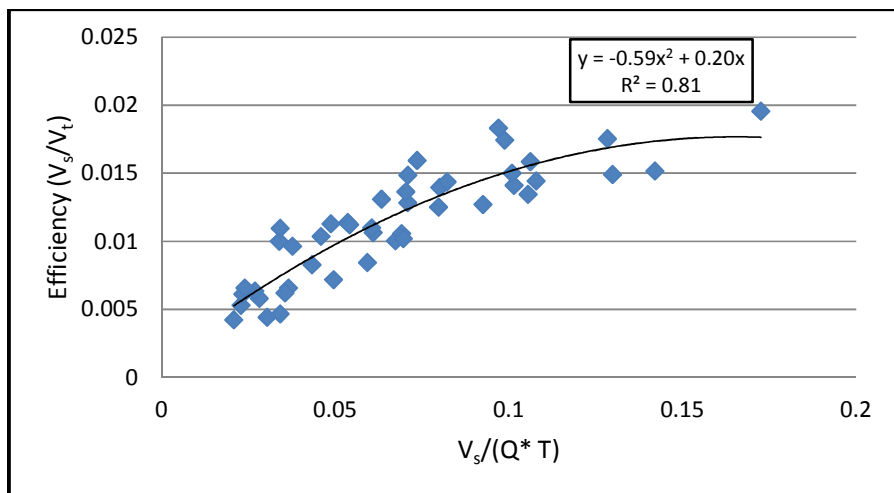

Fig. 8. The relation between jet pump sand removal`s efficiency (V_s/V_t) and (V_s/QT)
NB: Those results are results from analyzing the experimental data. (V_s/V_t): Jet pump sand removal`s efficiency as (V_s): Volume of removed soil; (V_t): Total volume of jet pump out put (mixture sand / water); (Q): the discharge of the flume; (T) is the time of run

The research is interested in studying the effect of open channel hydraulic parameters on Jet pump sand removal`s efficiency. The same prototype of jet pump was used in all runs. The experimental result showed that the efficiency decreased with increasing discharges to a certain point then start to increase again. Also efficiency increased with increasing depth to a certain point then start to decrease. This may be related to the jet pump dimensions. The observed trend may be due to that for each inner dimensions of jet pump there is optimum water depth and shear velocity that gives maximum efficiency. The efficiency of removing sand is decreased with increasing soil particle size.

6. CONCLUSIONS

The experimental investigation focused on exploring the effect of the change in open channel hydraulic parameters and soil gradation on the efficiency of jet pump in removing loose deposit. The conclusion of the experimental investigation could be summarized in the following statements.

1. Both of water depth and discharge of open channel had no direct effect on jet pump efficiency of removing loose deposits. This may be related to that for each inner dimensions of the jet pump there is optimum water depth and shear velocity that gives maximum efficiency.
2. The efficiency of jet pump is inversely proportion to soil gradation. It increased by average percent of 67% when using sand of D_{50} = 0.47 mm instead of sand of D_{50} = 0.58 mm. The increase reaches an average percent of 116% when using sand of D_{50} = 0.41 mm.
3. The jet pump is more effective in removing sandy soil deposition of small size particles of sand than the large-size particles. It is recommended to use it where the soil is loose.

There are some considerations, which could be recommended for future studies as studying the relation between different hydraulic parameters of open channel to the properties and different geometrical parameters of jet pump.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Langland M, Cronin T, editors. A summary report of sediment processes in Chesapeake bay and watershed in water resources investigations. Report 03-4123. New Cumberland, PA: U S Geological Survey; 2003.
   Available:http://pa.water.usgs.gov/reports/wrir03-4123.pdf
2. International Sediment Initiative (ISI). Sediment issues & sediment management in large river basins interim case study synthesis report. Technical documents in hydrology UNESCO office in Beijing & IRTCES; 2011.
   Available:http://www.engr.colostate.edu/~pierre/ce_old/Projects/linkfiles/UNESCO-ISI.pdf
3. Environment Agency (EA). Key recommendations for sediment management – A synthesis of river sediments & habitats (Phase 2). (EA) science report SC040015/R2; 2011.
4. Hammoud AH. Effect of design and operational parameters on jet pump performance. Proceedings of the 4th WSEAS International Conference on Fluid Mechanics and Aerodynamics, Elounda. 21-23 August 2006;245-252.
5. Richardson TW, McNair EC, Jr. A guide to the planning and hydraulic design of jet pump remedial sand bypassing systems. Instruction Report HL-81-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS; 1981.
6. Bosman DE, Prestedge GK, Rooseboom A, Slatter PT. An investigation into the removable of sediments from water intakes on rivers by means of jet – type dredge pumps. The Water Research Commission, ISBN 1 868 45 876 8, South Africa, report No. 1187/1/02; 2002.
7. El-Sawaf A, Halawa MA, Younes MA, Teaima IR. Study of the different parameters that influence on the performance of water jet pump. Fifteenth Inter-national Water Technology Conference, Alexandria, Egypt; 2011.
8. Saker AA, Hassan HZ. Study of the different factors that influence jet pump performance. Open Journal of Fluid Dynamics. 2013;44-49.
   Available: http://www.scirp.org/journal/ojfd
9. Mueller NHG. Water jet pump. Journal of Hydraulic Division. 1964;90(3):83-113.

10. El-Sibaie AM, El-Haggar SM. Performance characteristics of a slurry jet pump aided by a centrifugal pump. Ain Shams University, Egypt. 1987;2(2):149-160. Available:http://publications.environmentagency.gov.uk

11. Mechanical & Electric Research Institute and Channel Maintenance Research Institute .Using the modern technique for removing sedimentation. (Technical report), National Water Research Center, Egypt; 2015. (in Arabic)

12. Buckingham E. The principle of similitude. Nature. 1915;96(2406)396–397. Bibcode: 1915Natur..96..396B.
DOI: 10.1038/096396d0

13. Buckingham E. Model experiments and the forms of empirical equations. Transactions of the American Society of Mechanical Engineers. 1915;37:263–296.