THE EFFECT OF AIR INJECTION ON SEDIMENT TRANSPORT EFFICIENCY IN EJECTOR PUMP DREDGER SYSTEM

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INTRODUCTION

During last decades, a great number of dams have been constructed in river systems. These dams interrupt the balance of sediment transport and lead to sedimentation in reservoirs. Reservoir sedimentation has some drastic consequences on our life and environment such as: reduction of water storage capacity, aggradation of riverbed at the upstream area, degradation of riverbed at downstream area, erosion of coastal deltas and decrease of biodiversity. Having in mind the relatively high capital cost for constructing new reservoirs, it is imperative for water resources managers to develop and implement new strategies to control sedimentation in reservoirs. The excavation of deposited sediments is one of the methods to regain lost storage due to sedimentation. Dredging is a highly specialized technology and is mostly used in ports, waterways and mining. The present study focuses on one new concept of suction dredger system developed in Japan, named Ejector Pump Dredger System (EPDS). This system is based on a special ejector device that creates a negative pressure domain for suction of the underwater sediments. By using a pump, high velocity water jet will be discharged through a nozzle into an inner pipeline, resulting in the negative pressure region will be formed in an ejector house and sediments with water will be sucked up, and transported to the downstream area. In some cases, blockage may occur by sediment deposition in the downstream transport pipeline and EPDS cannot suck sediments up anymore. In such condition, air injection into the transport pipeline may solve or prevent blockage. As a consequence, complex interaction between water, air and sediments as multiphase flow will form in this system. This paper mainly deals with laboratory tests to investigate the effect of air injection (AI) into the transport pipeline on suction power (Q_{Suc}) and transport efficiency of sediments in the Ejector Pump Dredger System (E_{EPDS}).

FUNCTIONAL PRINCIPAL OF EPDS

Concept of EPDS

The high pressure water jet injected from the upstream nozzle creates a negative pressure in the ejector house and produces the energy required to suck sediment and water slurry through suction pipeline. Then, sediments entered to the ejector house would be washed out into the transport pipeline by force of the high pressure water jet. EPDS is equipped with a specially designed ejector house which is well illustrated in the previous paper published by authors (Temmyo et al, 2009, Temmyo et al, 2011). Fig. 1 shows the schematic view of EPDS and its ejector house used in this study.

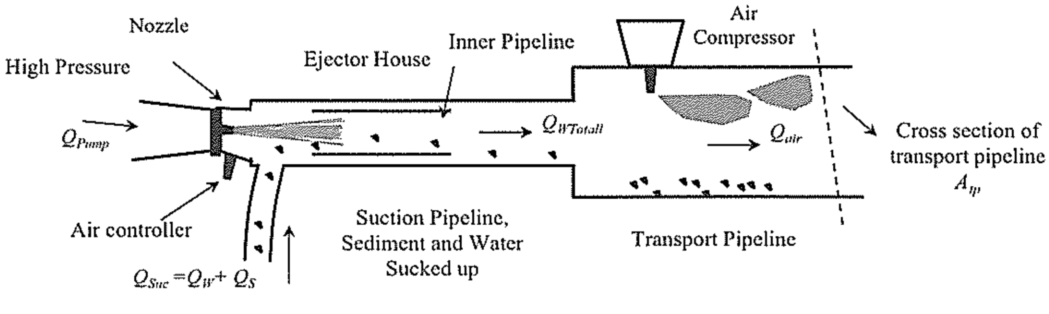

Fig. 1: The schematic view of ejector house in EPDS.

Multi-phase flow pattern in the horizontal pipeline

Air injection causes fluctuation of flow along to the x axis of transport pipeline and creates intermittent-periodic changes in which the flow is very similar to the wave. Fig. 2 shows the reference flow pattern map for two-phase flow and possible flow patterns in a horizontal pipeline (Taitel, 2000). In this figure, J_A and J_w denote air and water superficial velocities respectively which are defined as below:

$$J_A = Q_{air}/A_{tp} \quad (1)$$

$$J_W = (Q_{WTotall})/A_{tp} \quad (2)$$

where Q_{air} is the air concentration injected into the system, $Q_{WTotall}$ is sum of the pump discharge (Q_{Pump}) and sucked water (Q_w) and A_{tp} is the cross section of transport pipeline (Fig. 1). Furthermore, the total superficial velocity of flow in the pipeline (J) is equivalent to the process of summing two above-mentioned superficial velocities:

$$J = J_A + J_W \quad (3)$$

As can be seen in Fig. 2, all data analyzed in this study lies mainly at a region between *plug* and *slug flow*.

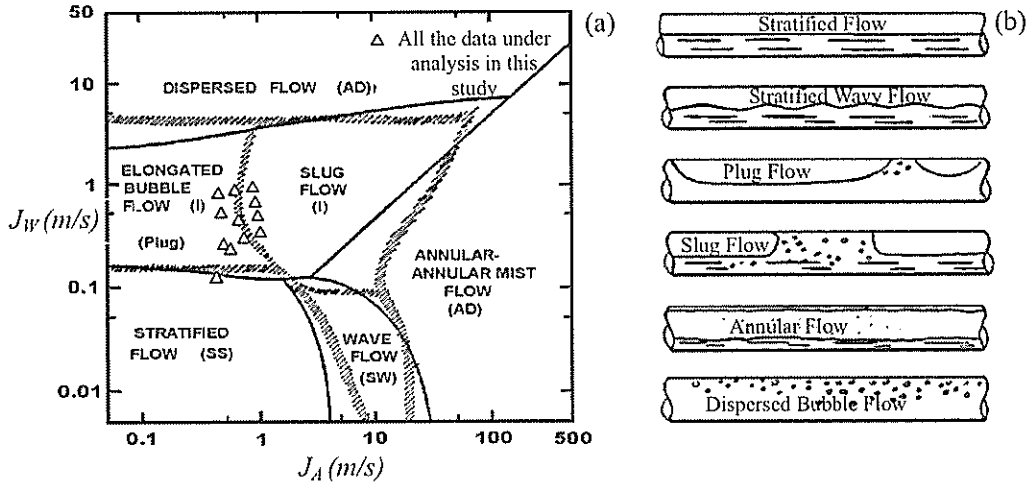

Fig. 2: The reference flow pattern map for two-phase flow in horizontal pipeline.

EXPRIMENTATION

Experimental set-up and measurements

This experimental model consists of three components: initial force section, suction section, and transport section. A schematic view of the experimental set-up is shown in Fig. 3 (not to scale). The initial force section includes a high pressure pump and its water storage tank. The suction section composed of an ejector house and a vertical suction pipeline with height of 2 m (H_{sp}=2 m) and inner diameter of 25 mm (D_{sp}=25 mm). Finally, the transport section consists of an air compressor and 10 m horizontal transparent pipeline (L_{tp}=10 m) with an inner diameter of 36 mm (D_{tp}=36 mm).

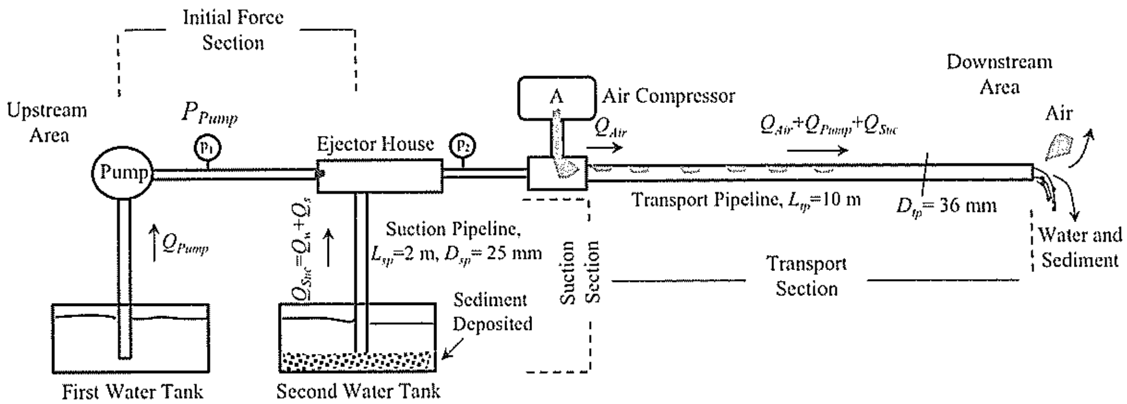

Fig. 3: EPDS system and laboratory installations.

Test procedure and Governing Parameters

The following test strategy was employed for characterizing the three-phase flow in EPDS, and obtaining suction power (Q_{Suc}) and sediment transport efficiency (E_{EPDS}). At first, a certain amount of sediments (V_s=2 liter) was placed at the bottom of second water tank and then experiment was started. The time needed for excavating, sucking up and pushing out of this amount of sediments was recorded (T_{ws}) for each test case. Sediment discharge (Q_s) in EPDS can be defined as the ratio of V_s to T_{ws} (Eq. 4).

$$Q_s = V_s / T_{ws} \tag{4}$$

By measuring the water level in the second water tank before and after each test, the volume of water and sediments released (V_{ws}) is obtained. The suction power (Q_{Suc}) can be easily calculated by Equation 5:

$$Q_{Suc} = V_{ws} / T_{ws} \tag{5}$$

The suction power (Q_{Suc}) is influenced by several parameters such as: the inherent properties of water (ρ_w) and sediment density (ρ_s), sediment grain size (d_s), pump pressure (P_{Pump}), air concentration (Q_{air}) injected to the pipeline, length of transport pipeline (L_{tp}), height of suction pipeline (H_{sp}), diameter of transport pipeline (D_{tp}), diameter of suction pipeline (D_{sp}) and gravity acceleration (g).

$$Q_{Suc} = f(\rho_w, \rho_s, d_s, P_{Pump}, Q_{air}, L_{tp}, H_{sp}, D_{tp}, D_{sp}, g) \tag{6}$$

Since the ρ_w, ρ_s, L_{tp}, H_{sp}, D_{tp}, D_{sp} and g are constant values in this paper; they can be neglected without significantly affecting the results of the analysis. Thus, Eq. 6 can be simplified as follows:

$$Q_{Suc} = f(d_s, P_{Pump}, Q_{air}) \tag{7}$$

And sediment transport efficiency (E_{EPDS}) of EPDS is defined as Eq. 8:

$$E_{\mathrm{EPDS}} = Q_s / Q_{Pump} \tag{8}$$

It is noteworthy to mention that suction power (Q_{Suc}) and sediment transport efficiency (E_{EPDS}) of EPDS could be reliable criteria to evaluate the function of EPDS and find its optimal design

RESULTS AND DISCUSSIONS

Fig. 4a and 4b show the variation of suction power (Q_{Suc}) versus the pump pressure (P_{Pump}) for different grain size of sediments. The cases shown in Fig. 4a are related to the sediment transport in pipeline just by the force of pump pressure without any air injection into the EPDS (AI= 0 *nL/min*). However for the cases illustrated in Fig. 4b, in addition to the pump pressure, 40 *nL/min* air was injected into the system. Comparing these two figures revealed that when the pump pressure is low (P_{Pump}=2 kg/cm^2) and no air injected into the system (AI= 0 *nL/min*), sediment transport capacity was almost zero for d_s=2, 5mm. In these cases, sediment easily deposited in the transport pipe line and blockage may occur and consequently sediment transport is stopped (Q_{Suc}=0 *l/min*). On the contrary, injecting 40 *nL/min* air solved the blockage problem in the system and drastically increased the Q_{Suc}. In this case, by injecting the air into the system the total superficial velocity (J) increased. Thereby, the sediments had less chance for deposition and then risk of blockage in the system is reduced. Fig. 4a shows that, in low pressure pump condition (P_{Pump}=2 kg/cm^2) when the sediments are relatively fine (d_s= 2, 5 mm and Mixed), the risk of blockage in the system is more high compare to cases with coarse sediments (d_s= 10 and Large). Pattern of sediments transport in EPDS is completely different in case of fine and coarse particles. Fine sediments sometimes formed sand dunes along the transport pipeline and air injection will easily flush them.

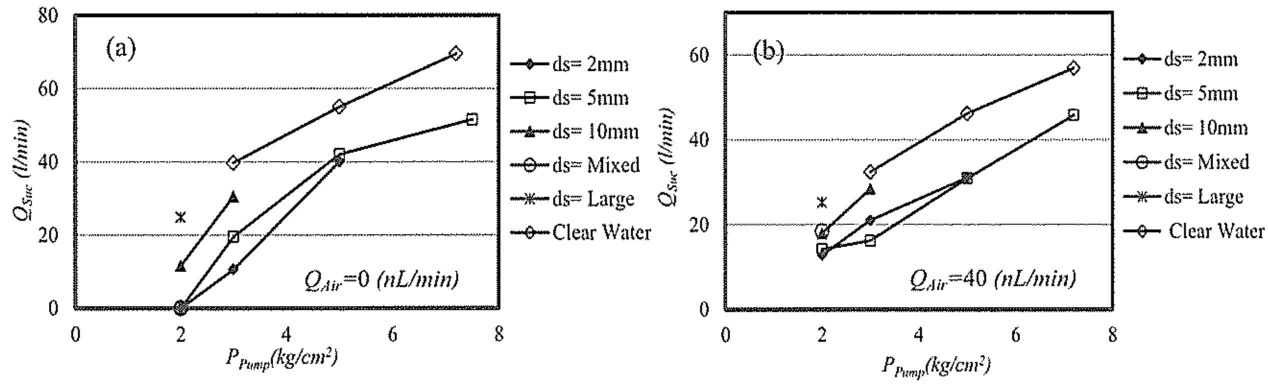

Fig. 4 (a, b): Q_{Suc} versus the P_{Pump} for different sediments grain sizes.

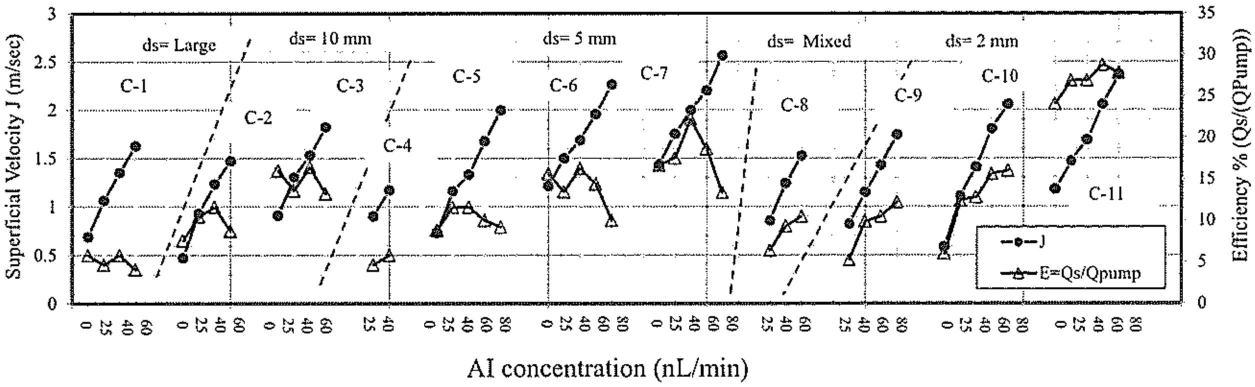

Fig. 5: Variation of transport efficiency (E_{EPDS}) and total superficial velocity (J) versus the different air concentration (Q_{air}) for all data under analysis in this study specified by 11 cases.

While coarse sediments were transported more individually. In low pressure pump condition, fine sediments have more tendencies to be deposited in a group than individual coarse sediments. Not so long after deposition of fine sediments, dunes will be created which it causes more loss of energy and consequently blockage will occur. From engineering point of view, using low pressure pump is more favorable due to the lowest costs. Additionally the sediments deposited in reservoirs are almost fine, therefore injection of air into the transport pipeline can be applicable solution to enhance the Q_{Suc} and prevent the blockage in EPDS.

Fig. 5 simultaneously shows the variation of transport efficiency (E_{EPDS}) and total superficial velocity (J) versus AI concentration for the different test cases. All measured data in the laboratory were classified into the 11 cases (C-1 to C-11) regarding to the sediment grain size (d_s) and pump pressure (P_{Pump}). As can be seen for all cases in Fig. 5, increasing the AI concentration has direct relation to the increase of total superficial velocity (J). Increasing the AI concentration (Q_{air}) for coarse sediments (case number 1 to 7) reduced the efficiency of EPDS (E_{EPDS}). Adversely, for fine sediments (case number 8 to 11) increasing the AI concentration causes increasing of E_{EPDS}. As above mentioned, during transportation of fine particles by EPDS, several dunes were created along the pipeline. By injecting air into the transport pipeline, these dunes were periodically flushed by slug flow and sediments were transported in the suspended manner. Increasing the amount of air concentration helped to increase suspension of fine sediments in water body, resulting in reduce of loss of energy. While, for coarse sediments, each particle makes its own friction against the drag force of flow and, by increasing the air concentration, turbulence of flow drastically increased means high loss of energy. Therefore, in case of coarse sediments, the E_{EPDS} decreased by increasing AI concentration.

CONCLUSIONS

A newly upgraded suction dredger system (EPDS) was introduced that used a special ejector pump. Injection of air into the transport pipeline was proposed to prevent the sediment blockage in EPDS transport section. Results show that air injection into the EPDS for low pump pressure and fine sediments initiate higher suction power (Q_{Suc}) and greater transport efficiency (E_{EPDS}). Effects of the air injection can be evaluated by the total superficial velocity (J) and classification of air-water two phase flows. Slug flow will transport fine sediments in the optimum condition.

REFERENCES

Temmyo, T., Yoshikoshi, I., Ohya, M., and Sumi, T.: Enhancement of Hydrological Safety of Dams by New Sediments Transportation System, "Sand Storm", 6th International symposium on Climate Change, Future Challenge of Dams, 25-31, pp 183-190, South Korea, 2009,.

Temmyo, T., Miura, N., Okabe, T., Kaku, M., Kammera, T., Yamagami, Y. and Sumi, T.: Trial dredging by a new ejector - pump system for the reservoir sedimentation, 79th Annual Meeting of ICOLD, Luzern, 2011.

Taitel, Y.: Two-phase gas-liquid flow short course and Fundamentals of multiphase flow modeling, Department of Fluid Mechanics and Heat Transfer, Tel Aviv University, 2000.