EXPERIMENTAL STUDY ON FLOW CHARACTERISTICS FOR THE HIGH EFFICIENCY TRANSPORTING OF THE DREDGED SOIL

Y.S. Kim[1], C.S. Yeo[2], G.L. Yoon[3] and S.B Kim[4]

ABSTRACT

To evaluate the effects of magnetic force for transporting the dredged soil, magnetic energy inducing device was installed at the dredge. The whole length of transporting pipeline reaches more than 8.5km and the efficiency of the system and the characteristics of the flow are critical factors. The main parameters which govern the flow are flow-rate, velocity, concentration and slip-layer's condition, so in the field test monitoring system was applied to check the real time conditions of the closed circuit flow and the main parameters. From analyzing the relation between the dredged soil amounts and the pump power, it can be concluded that the magnetic forces effect on the transporting system, increase the transporting quantities of dredged soil and decrease power consumption of the pump.

Keywords: Electro magnetic force, Slurry flow efficiency, Velocity profile, Soil transport, Dredging transport..

INTRODUCTION

An increase in the distance of soil transport in a dredging process comprises a number of issues including transport cost, method, efficiency and feasibility and numerous research projects are ongoing to solve these problems. Currently, the surest alternative is to use a relay pump for soil transport via multistage pressurized transport.

However, as it is widely known, a significant amount of additional cost is needed for the control and maintenance of multistage pumps and, also, due to a high degree of technical difficulty, the expenses for construction naturally and necessarily increase when applied to actual construction sites.

The study was conducted for development of high-efficiency dredged soil transport technology as a part of the "Securing and reclaiming of eco-friendly dredged soil and development of transport technology for transport distances of 30km or longer" project, which was overseen by the Ministry of Land, Infrastructure & Transport. The results generated from an effect assessment on improvement of flow efficiency when permitting electromagnetic waves at existing small-scale sites (Kim et al., 2014) were verified through an experiment at the scale of an actual site and, also, the effects were analyzed to review the effect of electromagnetic waves permission on site.

Looking at the results of previous studies, over a long period of time, there have been a countless number of studies performed by researchers to permit electromagnetic waves into a fluid in motion and control its flow, and this can be said to be a rather prevalent technology (Choi et al., 2014, Yu et al., 1998, Su and Wu, 2003, Afshin et al., 2010).

The study by Brown et al. (2000) presented meaningful results, which proved that the properties of a fluid may control the changing efficiency through frequency modulation of specific electromagnetic pulse.

Although most of these advance studies presented meaningful values, they are primarily focused on experiments at small-sized labs or on determining the effect only on extremely fine particles, thus failing to produce meaningful results to be applied to actual fields and commercialization.

[1] Researcher, Institution, KTMG Inc., 220 Seoun-ro, Seocho-gu, Seoul, Republic of Korea, T: +82-2-595-2258, Email: nocontrol@hanmail.net.

[2] General Manager, KTMG Inc., 220 220 Seoun-ro, Seocho-gu, Seoul, Republic of Korea, T: +82-2-595-2258, Email: lovesya76@naver.com.

[3] Principal Researcher, Korea Institute of Ocean Science & Technology, 787 Haean-ro, Ansan, Republic of Korea, T: +82-31-400-6348, Email : glyoon@kiost.ac.kr.

[4] Researcher, Korea Institute of Ocean Science & Technology, 787 Haean-ro, Ansan, Republic of Korea, T: +82-31-400-7620, Email : ksb9677@kiost.ac.kr.

Based on field experiments at a scale of 1km conducted previously by the authors, this study performed field experiments at a scale of 8.5km to review the possibility of commercializing the relevant technology, and also verify the experimental design and data by considering the field parameters..

RELEVANT THEORIES

Effect of Electromagnetic Pulse

Previous advance studies have utilized permanent magnets, etc. to permit an electromagnetic field and, based on this, improved the efficiency in transport of slurries by varying the viscosity and surface tension, etc. of a working fluid(Yu et al., 1998, Su and Wu, 2003, Afshin et al., 2010). However, there are limitations in influencing a fluid by using permanent magnets to influence an electromagnetic field, and the effect is also insignificant. For this, United Kingdom's A.B.D. Brown et. al. invented an experimental device as shown in Figure. 1 to consider the effect of a specific electromagnetic pulse when permitted into a fluid(Brown et al., 2000).

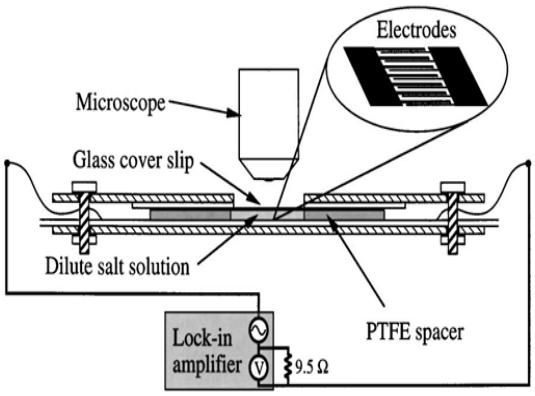


Figure. 1. Test equipment of electric pulsation.

An electromagnetic pulse was permitted through electrodes and how the characteristics of the fluid changes within the electromagnetic field was observed. It revealed that the changes of a fluid's characteristics show a significant dependence on the frequency, as shown in Figure. 2.

The left side of Fig. 2 displays the values that measure the trends after a uniform voltage potential is re-permitted into a fluid before, during and after the experiment, while the right side shows that measure the change in fluid velocity when varying each of the voltage potentials and, subsequently, pulse frequency of electrodes. Looking at the results of this experiment, it is understood that the effect would be maximized when permitting not only any electromagnetic field but also that of a specific frequency component to pipes.

Flow Characteristics of Slurries

Through an advance study, our group of researchers defined flow characteristics of slurries and, to determine this, performed a flow characteristic analysis experiment(Kim et al., 2014). The most important element in determining flow conditions is whether or not a flow is homogeneous or heterogeneous.

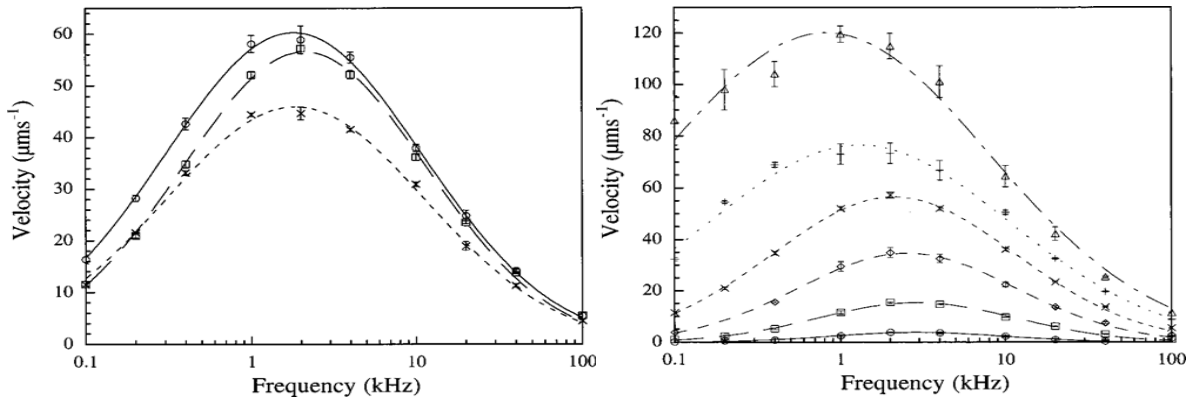


Figure. 2. Test Result under the Electric pulsation

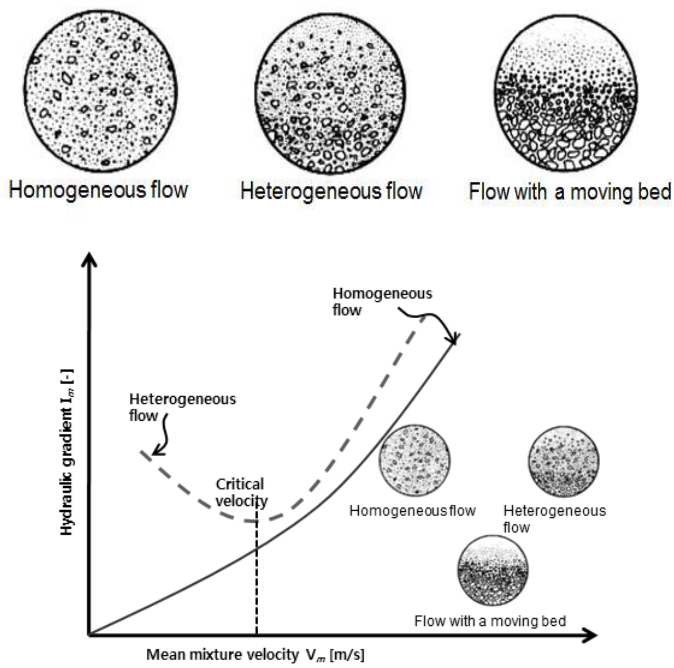


Figure. 3. Closed channel flow states classification

The equation related to the velocity of a flow, which is well developed inside a pipe as shown in Figure. 3, is experimentally proposed and, first of all, the pressure drop due to a fixed charge bed is expressed as follows using the Ergun equation.

$$\frac{\Delta p}{L} = \frac{150\mu\overline{V_o}}{\psi_s^2 D_s^2}\frac{(1-\epsilon)^2}{\epsilon^3} + \frac{1.75\rho\overline{V_o^2}}{\psi_s^2 D_s^2}\frac{(1-\epsilon)}{\epsilon^3} \qquad (1)$$

Here, Δp: Pressure drop (bar)

L : Unit length (m)

μ: Viscosity

$\overline{V_o}$: Average fluid velocity (m/sec)

ϵ: Porosity

ψ_s: Particle shape factor

D_s: Diameter of particle (mm)

ρ: Density (kg/m^3)

When applying this equation to the moment of initial fluidization at which particles of dredged soil begins to be transported,

$$g(\rho_s - \rho) = \frac{150\mu \overline{V_{oM}}}{\psi_s^2 D_s^2} \frac{(1-\epsilon)^2}{\epsilon_M^2} + \frac{1.75\rho \overline{V_{oM}^2}}{\psi_s^2 D_s^2} \frac{1}{\epsilon_M^3} \qquad (2)$$

It can be expressed as above and, for a dense charge bed constituted of extremely small particles or, in other words, Rep < 1, it can be expressed as the following empirical equation.

Here, $\overline{V_{oM}}$: Sedimentation velocity of particle (m/sec)

$$\overline{V_{oM}} \approx \frac{g(\rho_s - \rho)}{150\mu} \frac{\epsilon_M^3}{1-\epsilon_M} \psi_s^2 D_s^2 \qquad (3)$$

Based on the above equation, the speed of sedimentation for a fluid charge bed to be developed can be estimated and the critical speed at the time of dredged soil transport can be determined (Kim et al., 2014).

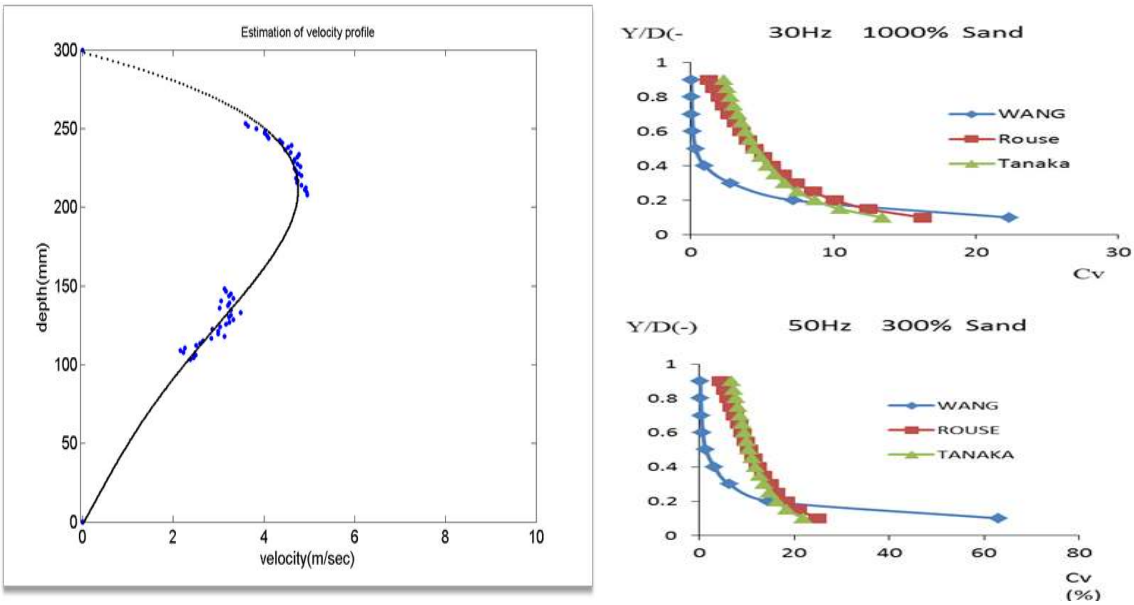
A more important item here is the concentration profile of particles inside a pipe, along with velocity distribution.

In comparison with fluid velocity, concentration is much more difficult to measure and the concentration profile, in particular, is nearly impossible to acquire real-time data by using today's measuring devices or systems. Thus, the concentration profile must be conjectured by a measured fluid velocity distribution in order to define the characteristics of a flow

To define a relation equation between the fluid velocity and the concentration profile, the equation proposed by Durand and Condolios is used, which helps conjecture the relationship between the fluid velocity distribution and the concentration profile (Durand, 1953).

$$J_m = J_0 + 82 C_{vd} \left[\frac{v_m^2}{gD}\left(\frac{\rho_s - \rho}{\rho}\right)^{-1} * \sqrt{(C_D)}\right]^{-1.5} J_0 \qquad (4)$$

Here, J_m , J_0 are the amount of pressure drop of water and slurry, respectively, and is the concentration of transported slurry..



(a) Velocity profile **(b) Concentration profile**

Figure. 4. Flow profile in the pipe flow

For the selection of pipes and pumps to transport dredged soil, critical speed and flow characteristics, or whether or not a flow is homogeneous or heterogeneous based on the concentration profile, are very important and the design must be carried out by considering this. If the velocity of fluids inside all pipes drops below the critical speed, the particles would sink before they are discharged, which leads to discoloration of the pipe.

Even if the average velocity is higher than the critical speed, however, the velocity of a viscous boundary layer is always less than the critical speed so sinking surely occurs on the surfaces of pipes, which then results in formation of a moving bed. For such flows, one of the representative fluid velocity profiles within a pipe is as shown in Figure. 4(a).

As Figure. 4 shows, once a flow is formed within a pipe, the lower portion of the pipe experiences a phenomenon in which the fluid velocity significantly reduces due to the effect of the moving bed. The concentration profile at this time is developed as shown in Figure. 4(b).

EXPERIMENT CONDITIONS

Experiment Site

Figure. 5. Test site

The site for this study is the Gunjanghang Port route maintenance dredging operation section and soil was transported over an 8.5km-long pipe that reaches the Saemangeum landfill. A cutter head type with 20,000 HP, the target dredging vessel, reviewed the geological conditions of the target site and studied the conditions and state of dredging before conducting an experiment. Also, parameters related to the experiment were specified and stations and measurement systems to acquire these parameters were established to analyze the experiment data of each case.

Experiment Devices

Dredging Ship

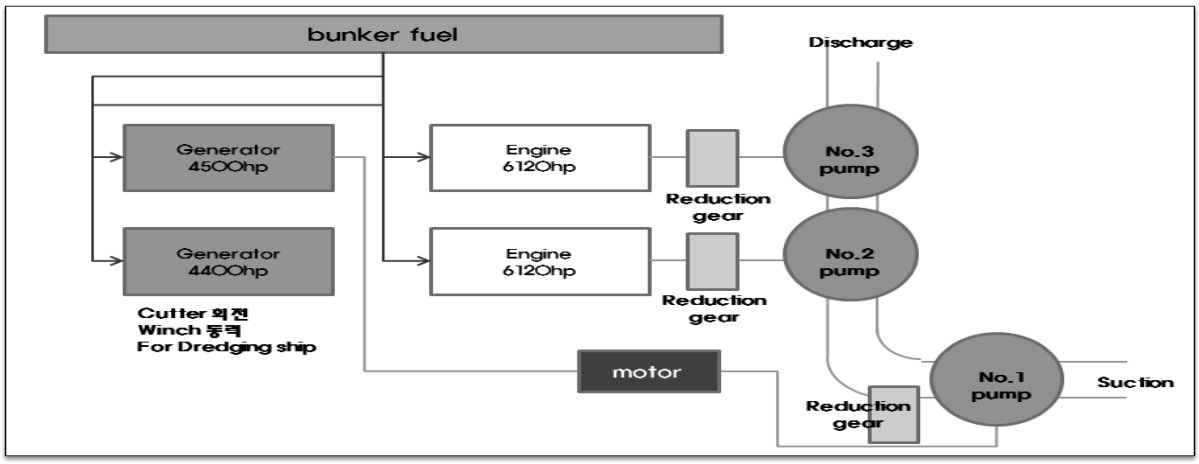


Figure. 6. Power circuit diagram

The dredging vessel used for this study is a cutter head type with 20,000 HP, and uses 3 pumps for suction and transport of dredging soil. The power system of each pump is shown in Figure. 6.

Electro-Magnetic Force Generator

As a means to reduce the flow resistance inside a pipe, a device that permits electromagnetic force within the pipe was used while the system was constituted by installing an inductor in the pipe on board (internal diameter: 900mm / external diameter: 950mm) the dredging vessel. The specifications of this device are as shown in Table 1.

The device is Fluid-Liner 19256S model manufactured by a Germany company, IFT, which enables permission of maximum 10A and 1kHz of electric pulse and also inductor connection through a maximum of 6 outputs.(Kim et al., 2014).

Table 1. Specific Performance of EMF Device

Specific Performance
Power with 6 outputs : 750VA
Output stages : 3
Inductors each output : 6
pipe diameter : <250mm per exit
Max. pipe diameter : 900mm = 3 outputs for 1 line
Case sizes : 9 U
Dimensions(W x H x D)[mm] : 600x497x450
Control unit Supply voltage : ± 12V, + 5V
Power no-load operation : 250 mW
Output current : ± 100mA
Alarm unit (x2) Voltage : ±12V

Measurement and Monitoring

he most important parameters in evaluating fluid conditions and determining the effect of an electromagnetic field are dynamic measurement of the dredging vessel and subsequent changes in fluid parameters within a pipe. Since the dredging vessel causes variations in time-dependent shipping conditions and changes in the constituents of the dredge materials, it is difficult to control these parameters with the experiment method. Thus, this study has chosen a method in which the number of experiment cases is increased to measure the fluid state corresponding to each operating condition and perform a comparison analysis of the data.

For an analysis of the operating conditions, parameters under a driving state were recorded every hour and compared with the data measured at the corresponding time, thus acquiring a condition curve between power vs. amount of dredging before and after permitting an electromagnetic field. The primary data in this experiment can largely be divided into input and output data.

1) Operating conditions (input): Motor RPM, power, pipe pressure

2) Fluid conditions (output): fluid velocity profile, flux, etc.

Here, the operating condition data were acquired using a CCTV camera to analyze the data for each time slot.

Figure. 7. Dredging ship for test

Figure. 8. EMF Generator for test

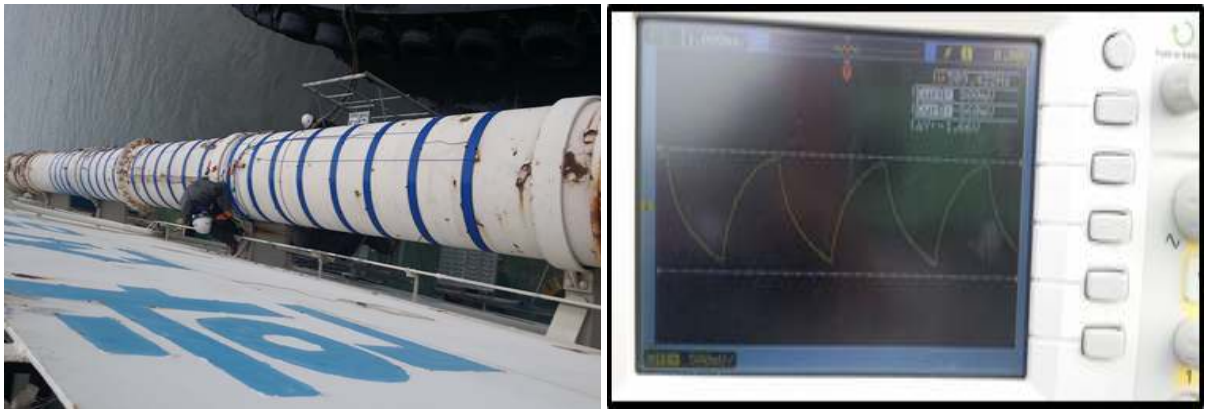


Figure. 9. Inductor installation for EMF

Figure. 10. Operating condition monitoring

As shown in Table 2, the operating condition parameters include driving variables of a pump for each time, the amount of pressure drop applied to the pump at the actual time, and operating conditions of a cutter head.

Table 2. Operation parameter of dredging ship

Time	D pump					Suction pressure	interm. Pressure1	interm. Pressure2	discharge pressure	Cutter head Depths	Cutter Direction
	MHCP	Motor RPM	PUMP RPM	Current	Torque						

A measuring station was installed at the outlet to obtain the parameters related to the flow conditions and a measurement system was set up, as shown in Figure. 11, to secure the data related to these conditions.

(a) Velocity profile (b) Density flowrate

c) Data logging (d) Surface tension

Figure. 11. perating Condition Monitoring

Primary parameters of the outlet are fluid velocity profile and flux density, which are related to the amount of dredging. Here, the flux density calculates the total amount of dredging through density and the amount of the fluid. Also, by monitoring the particle size and viscosity of the dredging fluid, which had been sampled by a stalagmometer, parameters of a fluid condition equation were obtained.

TEST RESULTS

Experiment Results

This experiment aims to control the conditions of a fluid that flows inside an actual pipe by applying an EMF device, and also evaluates the on-site application of the technology, which was applied to small-sized dredging and transport sites (500~1,000m). Although the basic data processing method is identical, it is different from previous experiments in that the operating conditions cannot be controlled at an actual site so a problem exists in having to compare the data under the same operating conditions. Considering this, the sampled fluid data and operating condition data were compared and only those under the identical operating conditions were obtained for data analysis.

The experiment proceeded from November 2015 to January 2016, and the analysis primarily focused on the resulting data obtained on 4th, 19th and 20th, when the soil (silt) and operating conditions were the most similar, as well as on January 5th, 2016, when the gravel content was high.

The following Figure. 12 is the plot that shows daily data trends. For the first two hours of an operation, the dredging operation proceeded without permission of EMF and, after 40 minutes, EMF was permitted before measuring changes in the amount of dredging.

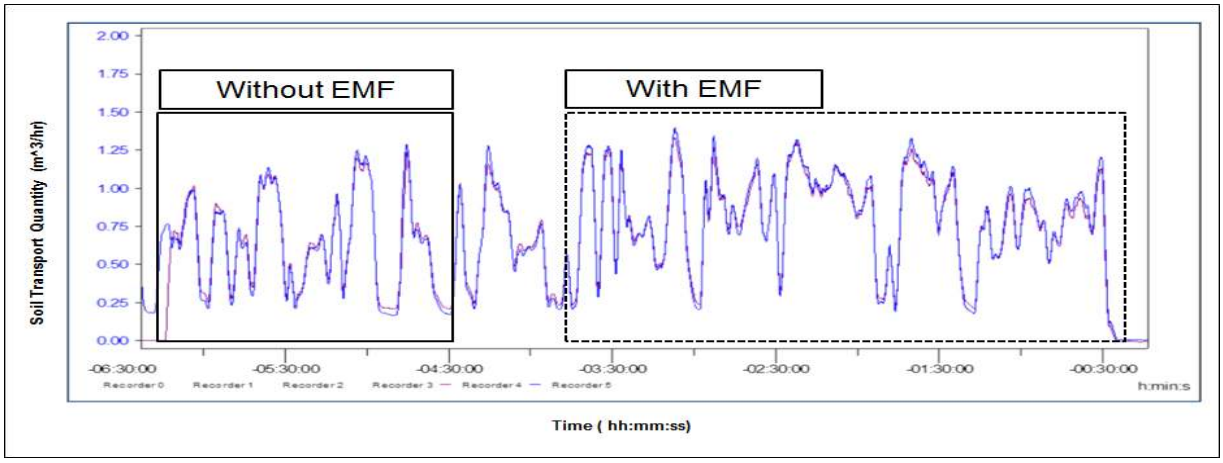


Figure. 12. Day dredging quantity trend

Data sampling

Identical to previous experiments, data is sampled based on the amount of dredging for 2 minutes near the peak value, as shown in Figure. 13, among all single-day sampling data, which is to obtain the average amount of dredging. By comparing the power values at this time, the relationship between power and amount of dredging is grasped (Kim et al., 2014).

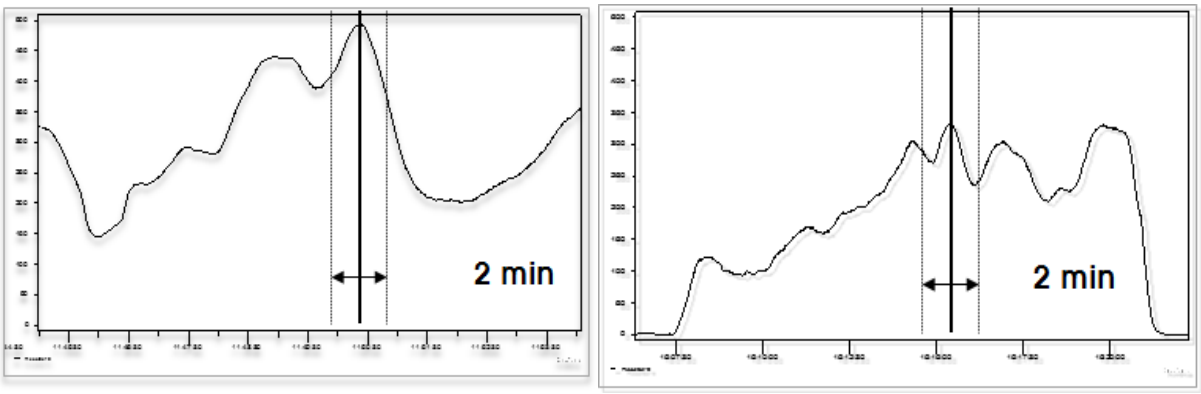


Figure. 13. Peak data sample extraction

Analyzing Experiment Results

Test data from November 2015

Among the experiment results, the tests conducted on November 4th, 19th and 20th were trial cases performed in areas with shallow dredge depths and not much gravel in the soil. The single-day data was reviewed and the relationship between the amount of dredging and power of dredging vessel was compared before and after permitting EMF.

Having analyzed the experiment results as shown in Figure. 14, it can be known that, after EMF is permitted, the power consumption reduces in comparison with an identical amount of dredging while the amount of dredging increases when permitting the identical power. In other words, when EMF is permitted, the slope of the regression equation on the power vs. amount of dredging plot is shown to increase after permission of EMF.

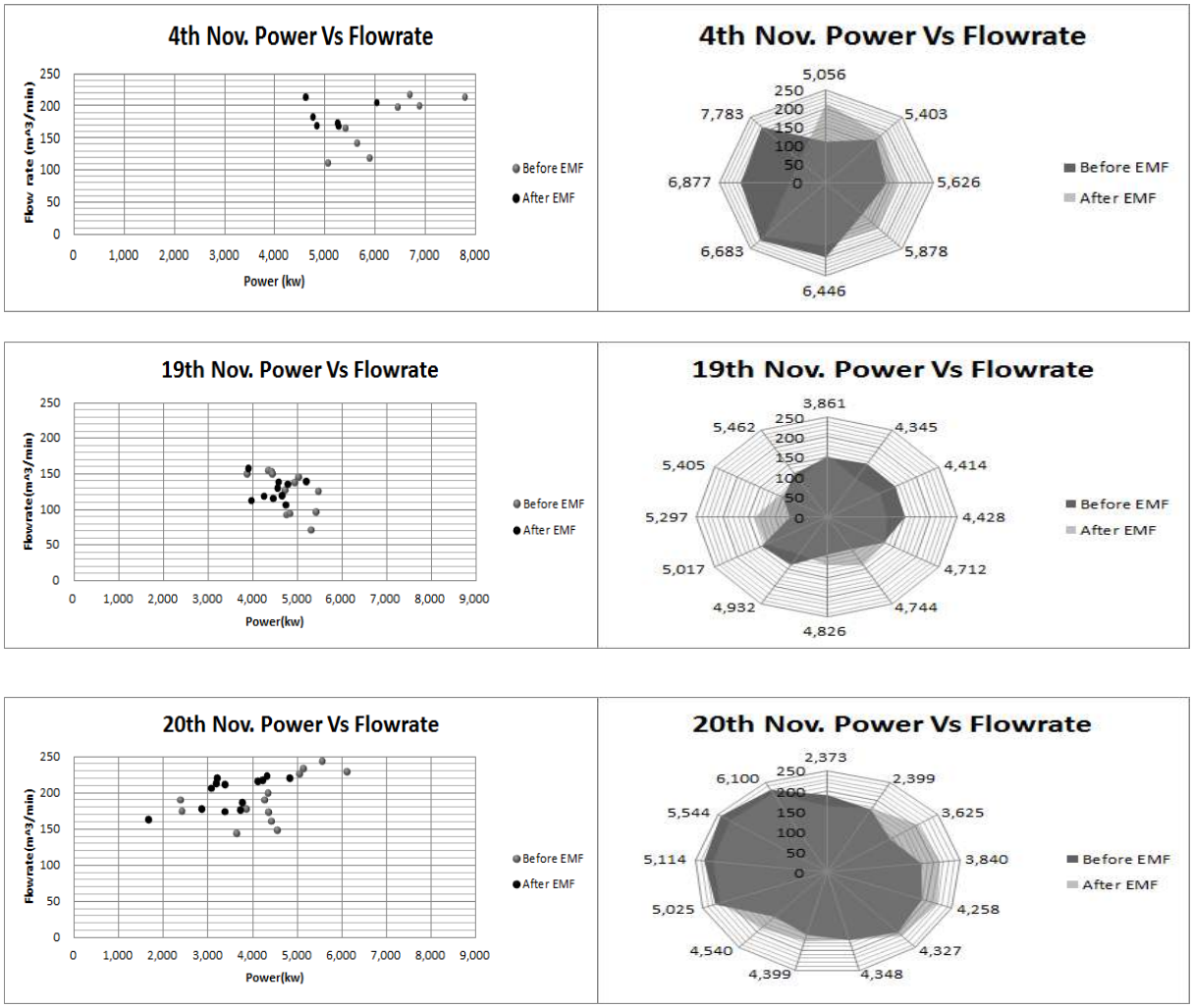


Figure. 14. Power Vs Flowrate

Table 3. Operation parameter of dredging ship

	4th Nov.	19th Nov.	20th Nov.
Efficiency Increasing	29.96%	10.19%	28.30%

A summary of these results reveal that the power efficiency increased as shown in Table 3

Test data from January 2016

Similar to the November test, January 2016 test data went through a data sampling process for comparison. One difference is that the number of samples was increased, securing about 50 samples, to analyze the data through an average data sampling of one week.

Figure. 15, the correlation plot between power and amount of dredging, shows a similar trend as the data of November 2015. Because the site for January 2016 test had much gravel and a significantly high density, a greater

amount of permitted power for the fluid velocity and amount of dredging was consumed compared to the case in November.

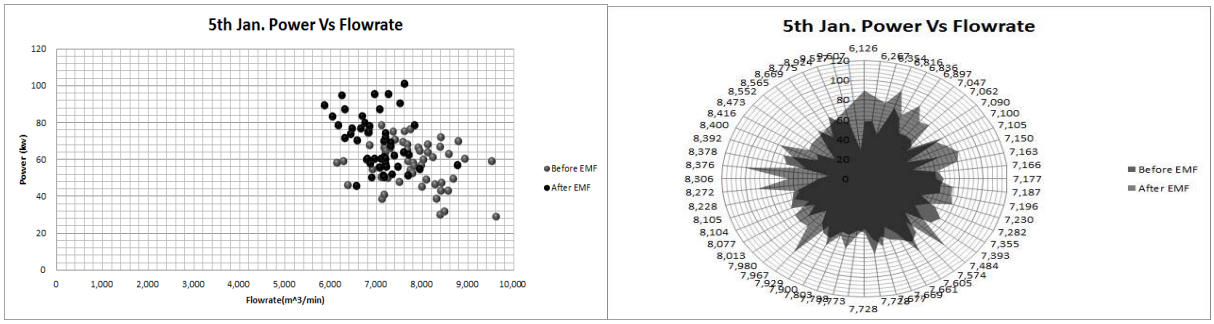


Figure. 15. Power Vs Flowrate

The relevant parameters clearly changed before and after permission of EMF and, as shown in Figure. 16 as follows, the average flux and density increased while the pressure gradient due to friction looks to be reduced after EMF permission.

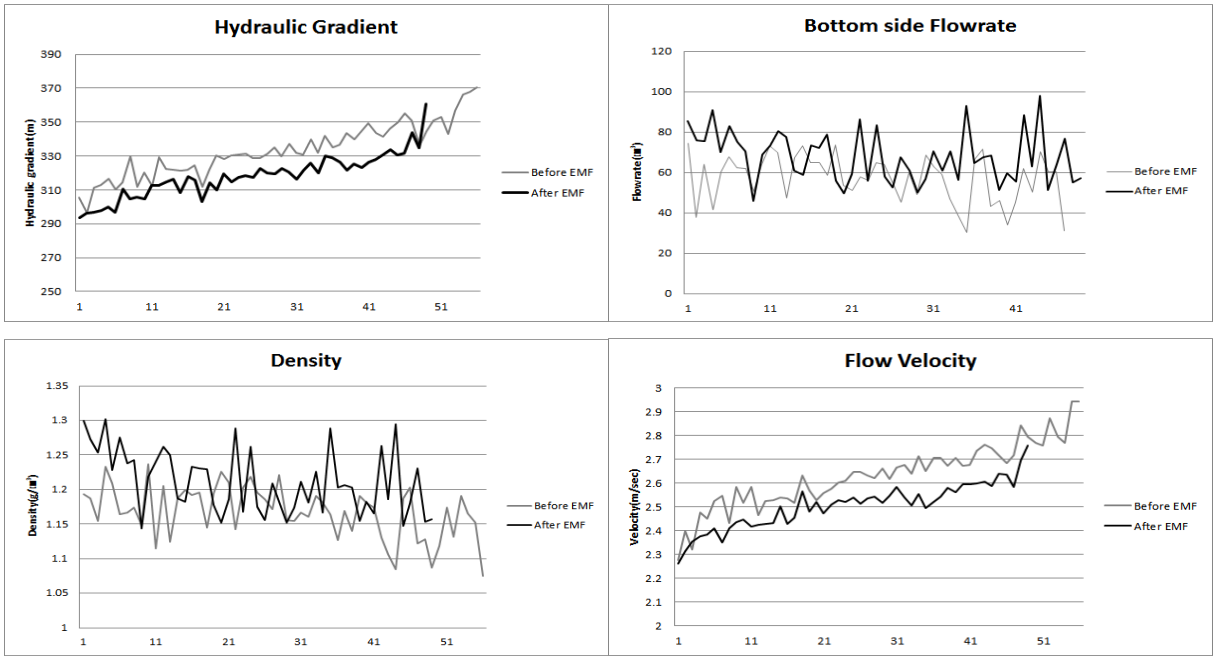


Figure. 16. Flow parameter

However, the fluid velocity at the bottom section is faster when EMF has not been permitted yet compared to after EMF permission. In other words, once EMF is permitted, the fluid velocity slows down but, due to an increase in density, the total flux, or the amount of soil being dredged and transported, increases. If the amount of soil within an operating fluid in a pipe increases, its density also increases while the velocity of the entire fluid decreases. The element that is affected the greatest by EMF is the change in flux, as shown in Table 4.

Such effect of increased fluid velocity in the lower section is displayed in an identical manner in previous experiments(Kim et al., 2014), and, as shown in Fig. 17, the effect of EMF induces what is known as a clean flow in the lower section. Once the velocity of flow in the bottom section increases, once-sedimented soil particles rise again, resulting in an increased amount of soil throughout a pipe.

Moreover, looking at the fluid velocity in the slip layer section, the effect of electromagnetic force is clearly present. The above plot is the time history data of the fluid velocity in a 12mm-deep section, and shows changes in fluid velocity data before and after an electromagnetic force is permitted.

Table 4. Flow parameter of Fluid

	Hydraulic Gradient (m)	Flowrate (m^3/min)	Density (kg/m^3)	Fluid Velocity (m/sec)
Before	336	55.78	1.16	2.64
After	318	69.73	1.21	2.5
Ratio	5.38%	25.0%	3.73%	-5.43%

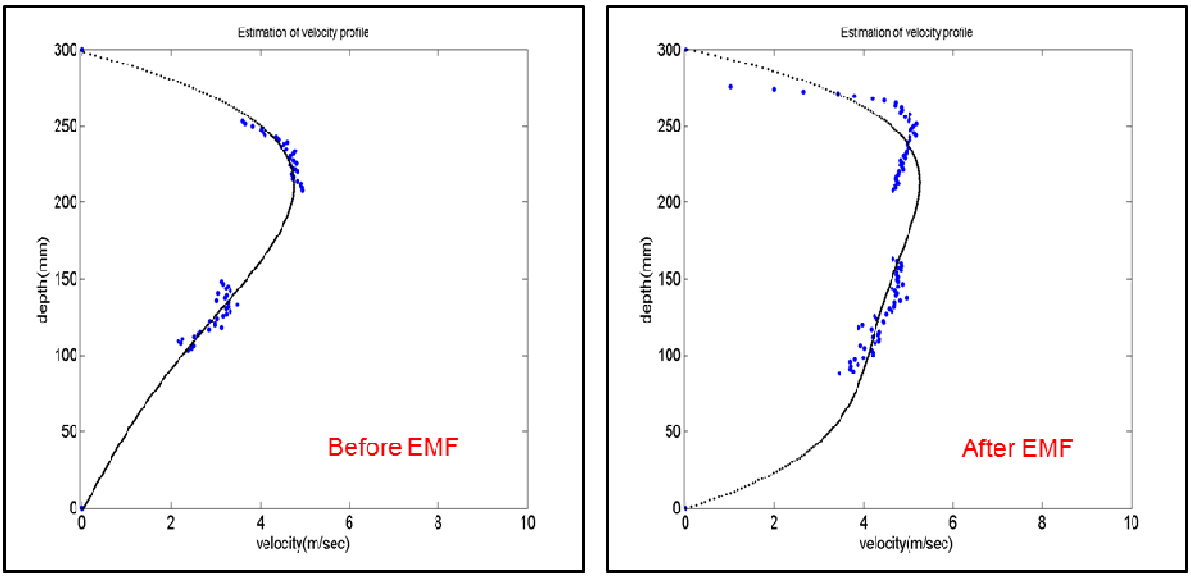


Figure. 17. Velocity profile before and after EMF

RESULTS ANALYSIS AND CONCLUSIONS

This experiment has applied the results of a study, which examined what effect EMF has on a fluid inside a pipe within a short distance (500~1,000m), to a real-life case (8,500m) in the field(Kim et al., 2014). While previous studies focused on the transported flux and changes in fluid velocity in the slip layer, this experiment investigated the relationship between power permitted into an actual fluid and the amount of dredge transported in order to deduce the following results that show the effect of EMF on dredge transport.

For an identical amount of transport, the transported flux increased by more than 30% once electromagnetic force is permitted. If an identical power is permitted, the amount of transport also increased by more than 30% once electromagnetic force is permitted. Pressure in the pipe was shown to decrease by about 5.35%, and flux increased by about 20% overall.

From the above, it can be concluded that power is reduced when electromagnetic force is applied to a transport pipe and, subsequently, the efficiency in transport is expected to increase by 30%.

This experiment was a field test conducted as a part of the development of an efficient dredged soil transport device and, from now, more data from actual sites will be collected based on a test bed to perform trend analyses.

REFERENCES

Kim, Y. S., Lee, M. H., Lee, Y. J. (2014), "Test study about electro magnetic force effect to apply dredging soil transport", Journal of academia-industrial technology, Vol. 8, No .6, pp2883-2890.

Choi, M. S., Kim, Y. S., Kim, J. H., Kim, J. S., Kwon, S. H. (2014), “Effects of an externally imposed electromagnetic field on the formation of a lubrication layer in concrete pumping”, Construction and Building Materials, Vol.61 pp.18-23.

Yu, Q., Sugita S., Sawayama K., Isojima, Y. (1998), “Effect of electron water curing and electron charging curing on concrete strength”, Cement and Concrete Research, Vol. 28, No. 9, pp. 1201–1208.

Su, N., Wu, C. F. (2003), "Effect of magnetic field treated water on mortar and concrete containing fly ash", Cement and Concrete Composites, Vol. 25, No. 7 pp.681–688.

Afshin, H., Gholizadeh, M., Khorshidi, N. (2010), “Improving Mechanical Properties of High Strength Concrete by Magnetic Water Technology", Scientia Iranica, Transaction A, Civil, Vol. 17, No. 1, pp. 74

BROWN, A. B. D., SMITH, C. G., RENNIE, A. R. (2000), " Pumping of water with ac electric fields applied to asymmetric pairs of microelectrodes", Physical review E, Vol.63, No.1.

Durand, R. (1953), "Basic Relationships Of The Transportation Of Solids In Pipes — Experimental Research", Proceedings@ sMinnesota International Hydraulic Convention. ASCE, p.89-103.

ACKNOWLEDGEMENTS

This research was supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) as part of the " Reserach on Eco-friendly Procurement Reclamation and Transferring Technology of Transport Distance more than 30km of Dredged Materials" research project.