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Sediment Treatment by a Centrifugal Device

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The present work is to introduce the preliminary experimental results for a primary hydrocyclones process in lake sediment thickening. A few cyclones based on the Rietema standard geometry were prepared. The test particles were sediments from a local lake and waste coal fly ash for a reference test. As a result of the chemical analysis, organic contaminants were abundantly found in smaller particles in overflow. Experimental results showed that the physical characteristics of particles, configuration of the cyclone and operating variables including feed solids concentration and volumetric flow rate could affect the separation efficiency. The limiting feeding velocity for the separation and enrichment of particles was 1.5 m/s, higher separation efficiency, in general, was obtained under the high velocity with the small cyclones.

Key words : Centrifugal separation, Hydrocyclone, Lake sediment, Separation efficiency, Sediment concentration

INTRODUCTION

In order to secure the irrigation water and to reduce the internal loading by the bottom sediment in domestic lakes of Korea, dredging method including settling process for dehydration has often been applied prior to dumping into the ocean or landfill. But it has some problems in space and treatment time, and also the odorous dredged mud can be re-entrained into the public hydrosphere causing environmental troubles. However, the mud containing large volume of organic matters can be utilized as phase of fine sands for fertilizer or coarse sands for building materials throughout the appropriate treatment. The solid-liquid hydrocyclones have been used in mining, pulp and juice industries, and recently being applied to a part of dredged system. In this work, a basic study for hydrocyclones as a pre-treatment for separation and thickening of lake sediments was carried out focusing mainly on the optimum operation condition.

As like any conventional centrifugal forced devices, the hydrocyclone consists of inlet tube, apex bottom outlet, and over flow through vortex finder. Major parameters regarding hycrocyclone configuration and operation conditions are cyclone body size, inlet shape, depth of vortex finder, geometrical structure of over and under flow discharges, cyclone length, and cone angles, besides the concentration of feed sludge and inlet velocity.

MATERIALS AND METHOD

Test cyclones were designed according to the Rietema's standard; 30 mm and 50 mm in body diameter, and summarized in Fig. 1. The shape and size of a hydrocyclone has a decisive effect on the separation or classification of solid particles. Amongst many geometric parameters, therefore, two different body size hydrocyclones

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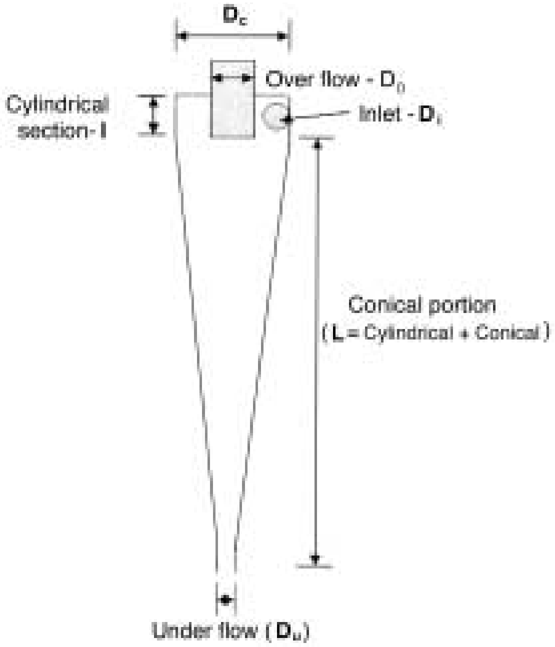

Fig. 1. Geometry of test hydrocyclones.

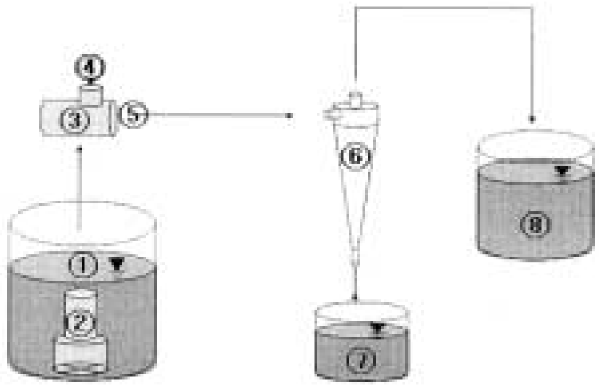

Fig. 2. Schematic diagram of experimental set-up.

with the same standard configuration were prepared in this work. An additional set was prepared with a different geometry in body length and apex diameter. Malvern Master Sizer (Malvern instrument, MSS)was used for the evaluation of the Grade separation efficiency with particle size. The efficiency is defined as Eq. (1) and Eq. (2).

■ Overall efficiency

$$E = \frac{C_u \times Q_u}{C_f \times Q_f}$$

■ Grade efficiency

$$G(x) = \frac{x(dp_i)_u \times C_u \times Q_u}{x(dp_i)_f \times C_f \times Q_f}$$

Where

C_f : Concentration of the feed inlet (g/cm^3)
C_u : Concentration of solid particles of underflow (g/cm^3)
Q_f : Flow rate of the feed inlet (l/min)
Q_u : Flow rate of the underflow (l/min)
$x(dp_i)_f$: Mass fraction of i-particles in feed flow
$x(dp_i)_u$: Mass fraction of i-particles in underflow

The current hydrocyclones were similar in structure to the conventional gas-solid cyclones. It consists of upper cylindrical section and lower conical section. Feed inlet is connected to the upper cylindrical column and vortex finder is positioned on the top of the cylinder. Concentrated slurry would be discharged through the under flow apex in lower cone. Separation is principally achieved by centrifugal force in between particles and fluid. The coarser and heavier particles are, the more frequently separated. The experimental set-up is schematically depicted in Fig. 2.

Test sediment particles were collected from Giheung reservoir near of which watershed area is 53 km^2, and supplies irrigation water to the area is in the vicinity of Suwon and Osan. It was composed of Al, Si, Na, Mg, Mn, F, S, N, P, Org-C, and the specific gravity was 1.5 with the median size, 5 μm. Feeding flow rate was adjusted by flow controller of a screw pump (MV 3400 F4, PCM POMPES France). A mixing pump was sunk in the test slurry tank in order to ensure the complete dispersion of test particles. The characteristics of separation and concentration of particles were examined through the mass balance before and after drying at 105°C for 4 hours.

In this work, feed concentration varied 3% to 20% in mass basis, the flow was fed at 1.0 m/s~5.0 m/s. In order to assess the reusing capability of separated particles, the test sediments were classified into raw as received, ~53 μm, ~106 μm, ~212 μm, ~450 μm and ~850 μm by using Tylor standard stainless sieves. Under the running condition as 6% of inlet concentration and 3 m/s of inlet velocity, pH, VSS, COD, T-N and T-P of the discharged particles from over and under flow were also analyzed according to the Korean

Standard Test Method of Water Quality.

RESULTS AND DISCUSSION

Concentration by using hydrocyclones

Selection and operation of hydrocyclones depend critically on the relationship between the aiming efficiency and treatment flow rate. The fraction of underflow to the feed flow, Rf, thus, was investigated with the inlet velocity and feed concentration ranging from 3% to 20 % vol Fig. 3 shows the effect of inlet velocity on the clllection of concentrated slurry through the underflow. Under a certain point of velocity. The particles and water of this portion flew down along the conical wall of the cyclone, but seldom upward to the vortex finder. For both cyclones, small (30 mm in body diameter) and medium (50 mm), the absolute underflow rate was not changed with the increase of inlet velocity beyond of the critical velocity.

The critical velocity herein means a threshold velocity being able to create the vortex flow inside the cyclones. As can be observed from Fig. 3, it was about 1.5 m/s. Due to the limited range of pressure adjustment the screw pump, the more sufficient data for the cyclone S could not be collected in lower velocities. Nevertheless the formulated value, Rf, on right side of the figure provides a clue to ensure the pressure of the critical velocity. In otherwords, in the velocity range of less than 1.0m/s, only little swirl should be generated and cause a large amount of downward flow. Fractional underflow decreased steeply as increasing the feed velocity, maintained almost constant. Approximately 20% of inlet flow could be consistently discharged through the apex of under cone.

The extent of underflow concentration was observed as a function of inlet sediment concentration. Figs. 4 and 5 show the thickening tendency of underflow with inlet flow velocity at different inlet concentration. As the inlet flow velocity increased, the underflow concentration increased linearly, and higher feeding concentration resulted in denser discharge. The sediment materials including fine sticky mud, various impurities and organic matters affect the viscosity of the liquid, which is closely related to the centrifugal separation of hydrocyclone. In general, it has been widely noticed that the cut diameter (d_{50}) of hydrocyclone is proportional to 0.5 to 0.6^{th} power of viscosity. The effect of feeding concentration was found to be more significant in a larger cyclone. On the other hand, the concentrating rate was greater in less feeding concentration. The velocity influenced the concentration more greatly for diluter feed flow. In order to collect more reliable data, the medium sized cyclone (M) requires further experiments with the aid of

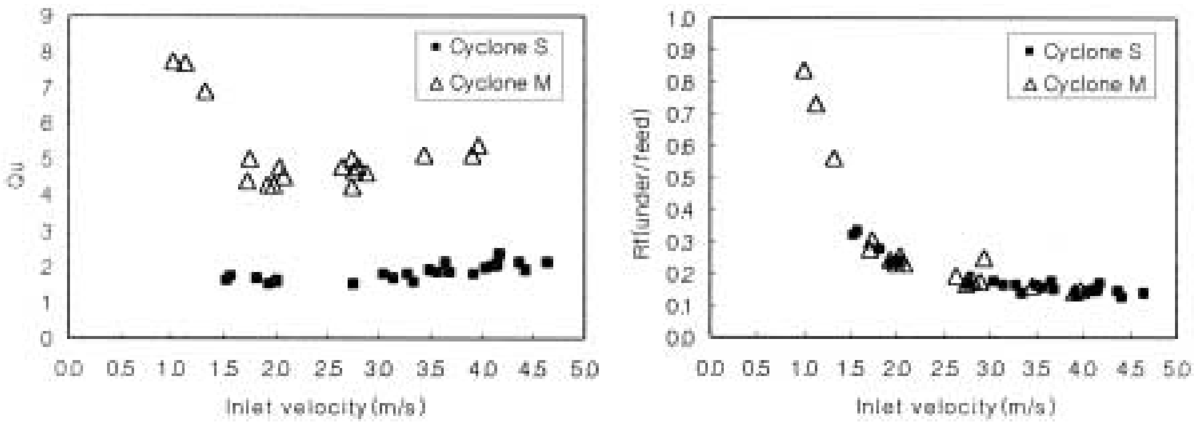

Fig. 3. Effect of inlet velocity.

Table 1. Geometry of test hydrocyclones. (Unit : mm)

Cyclone	Cyclone Dia. (Dc)	Inlet dia.(Di)	Under flow (Du)	Over flow (Do)	Body length (L)	Cone angle
S	30	8.4	6.0	10.2	150	10
M	50	14.0	10.0	17.0	250	10

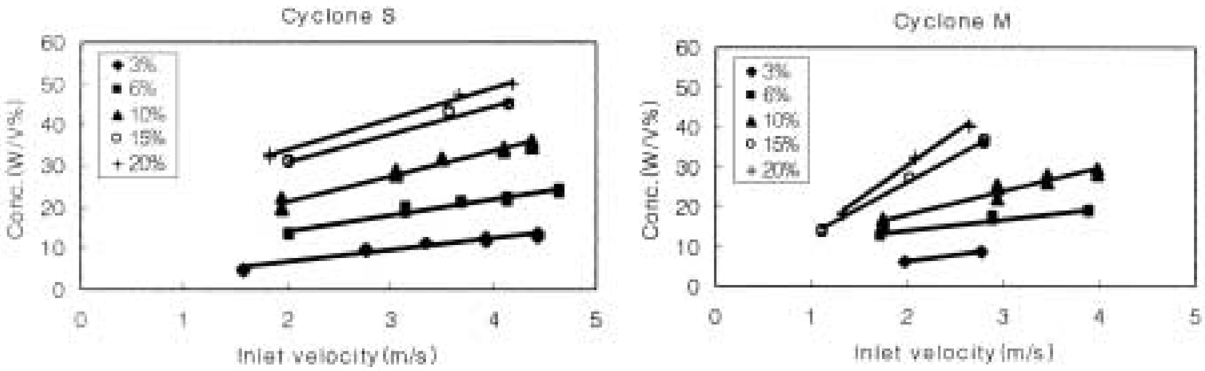

Fig. 4. Variation of underflow concentration as a function of inlet concentration.

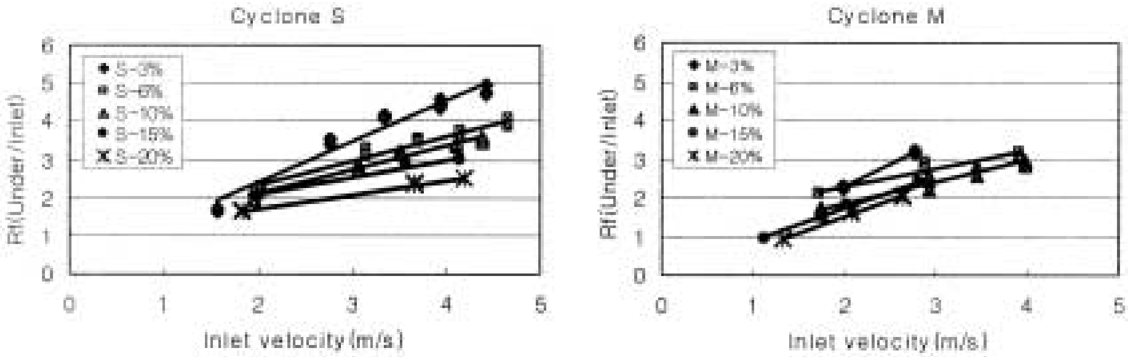

Fig. 5. Characteristics of underflow as a function of inlet concentration.

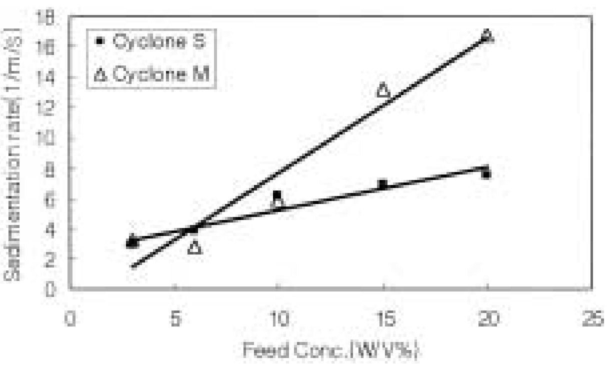

Fig. 6. Overall recovery rate with feed conc.

advanced and more powerful pump.

It is well known that the inlet fluid velocity obviously affects the separation characteristics and the extent of underflow enrichment. Feed concentration of the slurry also exerts a clear effect on the classification behavior of fluid. In accordance, the effect of feed concentration on the sedimentation of slurry particles, so called specific sedimentation rate, needs to be observed. It gives a simple clue to understand how fast the underflow is thickened.

Specific sedimentation rate in the underflow, which is a sort of the classification index or overall recovery rate depending on inlet velocity, could be evaluated from the slope of Fig. 4. Fig. 6 shows it with the feed concentration. From a simple linear correlation, it was consequently found that the larger cyclones were influenced greatly by inlet velocity and percent solid concentration.

Separation of individual particles

The grade efficiency of separation was evaluated at 6% and 10% of feed concentration with 4.0 m/s of inlet velocity. Since the exerted centrifugal force inside the hydrocyclone is inversely proportional to the body diameter, less separation force could exert on the particles in a large cyclone. The present work obviously revealed a larger cut diameter (d_{50}) for a bigger cyclone as long as under the same configuration. Cyclone S gave 16 μm and M did 20 μm of d_{50}. However, the d_{50} depends on some other variables; vortex finder diameter, apex size, flow rate and slurry density. Meanwhile, as can be seen from Fig. 7, the inlet concentration has a limited effect on the shape of the grade efficiency curve. As noted in other inertial separators, separation efficiency increased as particle size increased. Smaller hydrocyclones seemed to be more useful in its fractional efficiency. An open literature, however, revealed that too small body diameter may cause strong centrifugal force and thereby carry over most particles. In addition, small cyclones induces a great frictional loss and energy consumption. Thus, the optimum design standard must be found by consideration between separation efficiency and total energy loss.

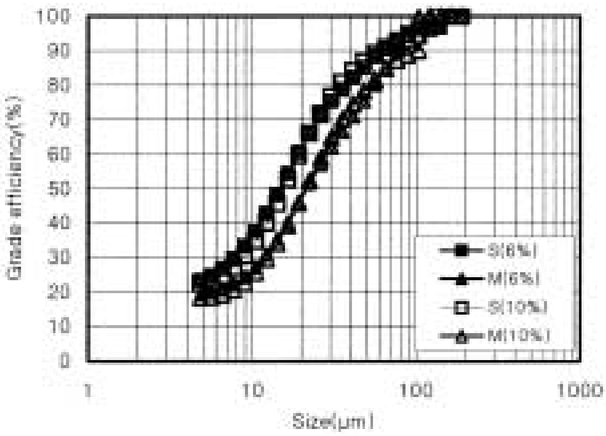

Fig. 7. Grade efficiency as a function of inlet concentration (inlet velocity: 4m/s).

Physicochemical characteristics of solid particles

The content of organic contaminants in natural sediments was analyzed and summarized in Table 2. In general, smaller particles show the large specific surface area and thereby include a great amount of organic elements. A similar result was obtained in this work as can be seen in Table 2. During the size classification by using stainless sieves, a certain amount of organic impurities including wood chips, lump of various organics and ashes could be removed. Thus, the organic contents could be deviated from the common sense between classified and raw sediment samples. It was found that pH was nothing to do with the content of organic materials, and the finer particles were significantly contaminated by various organics.

The separation of organic contaminants by the hydrocyclone was examined and displayed in Fig. 8. As previously predicted, the overflow mainly composed of fine particles contained more organic material. In particular, the variation of COD clearly indicator the quantitative contamination of fine sediments in overflow. The pH value remained nearly same as 7.0 for both dis-

Table 2. Contaminants in the sediment according to particle size.

Size	pH	VSS (%)	COD (O_2 g/kg)	T-N (mg/kg)	T-P (mg/kg)
Raw	7.03	9.80	19.9	1,482	1,052
~50 μm	7.16	9.67	19.2	1,620	1,078
~100 μm	7.05	7.98	17.8	1,228	871
~250 μm	6.93	7.29	16.4	894	589
~500 μm	7.12	4.94	11.6	856	260
~1,000 μm	7.05	1.80	3.6	580	249

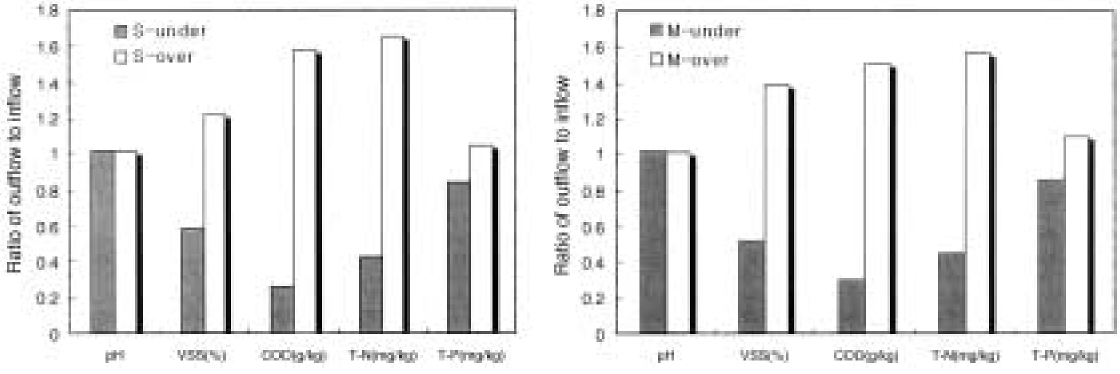

Fig. 8. Comparison of outflow organics based on inflow.

charges. Thus, it can be concluded that the hydrocyclone technology could be a quite acceptable alternative for recycling of the process wastes when the concern on waste prevention is being increased.

CONCLUSIONS

The present study was carried out as a basic research in order to apply the hydrocyclone system to the primary process of particulate separation or concentration in the dredging operation system of the lakes. Application of the hydrocyclone to the in−situ treatment can provide the rapid treatment and require narrow area. The current result showed that small size hydrocyclones might be better in the separation and concentration of the lake sediments, and higher inlet flow velocity would increase the thickening rate of under flow and absolute concentration of sediment particles. The threshold feeding velocity was found about 1.0 m/s. The best performance for thickening was achieved in a small cyclone (body diameter: 30 mm) with up to 51% from 20% feed. It was found that finer particles of lake sediment were more contaminated, and the hydrocyclone system could contribute the reduction of organic contaminants. In accordance, hydrocyclones can be used for both purposes of separation and concentration, concentration including dehydration can be plausibly achieved by parallel arrangement of small size cyclones. Size classification must be more useful with the adjustment of inlet velocity.

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< **국문적요** >

원심분리 장치를 이용한 퇴적물 처리

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본 연구는 호소내 오염된 퇴적물 처리를 위한 분리 및 농축을 위한 전처리 장치로서 hydrocyclone의 이용 가능성을 평가하는 실험이다. 외국의 선행 연구자인 Rietema의 표준 규격을 참고하여 제작된 Hydrocyclone을 이용하여 분리 및 농축 실험과 유입 및 배출 시료의 물리화학적 특성을 조사하였다. 실험결과 Hydrocyclone의 장치특성 실험에서 분리 및 농축에 가장 큰 영향요소는 몸통직경이며, 유입속도, 유입시료의 농도에 영향을 받는 것으로 조사되었다. 분리 및 농축에 필요한 한계 유입속도는 1.5 m/s로 조사되었으며, Cyclone의 몸통 직경이 작고, 유입 속도가 빠르며, 유입되는 시료의 농도가 낮을수록 분리 및 농축 효율이 높은 것으로 조사되었다. 재활용 가능성 평가를 위한 오염도 평가 결과 입자의 입경이 작을수록 오염도가 높은 것으로 조사되었으며, 분리 처리 결과 현저하게 높은 유기물 제거율을 보였다.