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Investigation of the Operational Principle and Flow Analysis of a Newly Developed Dry Separator

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Abstract**—**Mineral product, waste concrete (fine aggregates), waste in the optical field, industry, and construction employ separators to separate solids and classify them according to their size. Various sorting machines are used in the industrial field such as those operating under electrical properties, centrifugal force, wind power, vibration, and magnetic force. Study on separators has been carried out to contribute to the environmental industry. In this study, we perform CFD analysis for understanding the basic mechanism of the separation of waste concrete (fine aggregate) particles from air with a machine built with a rotor with blades. In CFD, we first performed two-dimensional particle tracking for various particle sizes for the model with 1 degree, 1.5 degree, and 2 degree angle between each blade to verify the boundary conditions and the method of rotating domain method to be used in 3D. Then we developed 3D numerical model with ANSYS CFX to calculate the air flow and track the particles. We judged the capability of particle separation for given size by counting the number of particles escaping from the domain toward the exit among 10 particles issued at the inlet. We confirm that particles experience stagnant behavior near the exit of the rotating blades where the centrifugal force acting on the particles is in balance with the air drag force. It was also found that the minimum particle size that can be separated by the machine with the rotor is determined by its capability to stay at the outlet of the rotor channels.

Keywords**—**Environmental industry, Separator, CFD, Fine aggregate.

I. Introduction

ACCORDING to the statistics of the ministry of environment, in 2012, total amount of waste generated per day in South Korea is 382000 tons out of which 187,000 tons belongs to construction waste. The waste concrete accounted for the greatest proportion, as high as 61% of the total construction waste [1]. Waste concrete which occur in the industrial field is reusable to the extent of 85%, and it is called as cyclic aggregate. Through a recent research report [2], it has been promoted a study about recycling policy of construction waste through the foreign cases and vitalization study of circulation aggregate. There are various types of separators used to segregate concrete aggregates. Separation of particles could be made possible by vibration, wind force, or centrifugal force. Advances in technology to recycle concrete debris have been reported in literature [3], [4]. Presently in Korea, rotary separator has not been developed for industrial separation of concrete aggregates.

In this study, a computerized numerical analysis of dry separation by rotating blades is carried out. Numerical analysis of both two-dimensional and three-dimensional models was done by using ANSYS-CFX commercial program. Separation of particles is simulated to understand the underlying mechanism of particle separation in rotary separator.

II. Two-Dimensional Model

A. Modeling

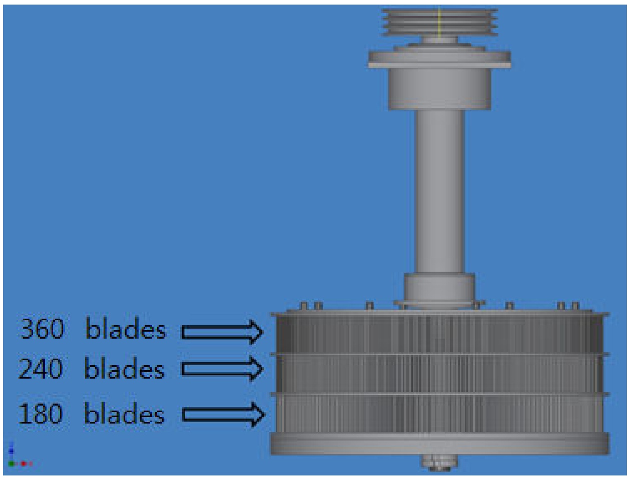

Fig. 1 Detailed view of the rotor composed of three stages with different number of blades

The rotor considered in this study is shown in Fig 1. The rotor has three stages of blades. The first stage has a total of 360 blades installed radially at 1 ° intervals, second stage has 240 blades at 1.5 ° interval and the final stage has 180 blades at 2 °. Before developing a 3-D model, 2-D models were developed and simulations were carried out to understand the movement of particles and to check the validity of separating the flow domain in to rotary and stationary. Separate 2-D models were developed for each stages of rotor blades. Because of the axisymmetric of the geometry under consideration, rotor area corresponding to an angle of 6° only is considered for the modeling. Therefore, this two-dimensional model includes 6 blades of first stage which is shown in Fig. 2 (a), 4 blades of second stage, Fig. 2 (b), and 3 blades of third stage, Fig. 2 (c).

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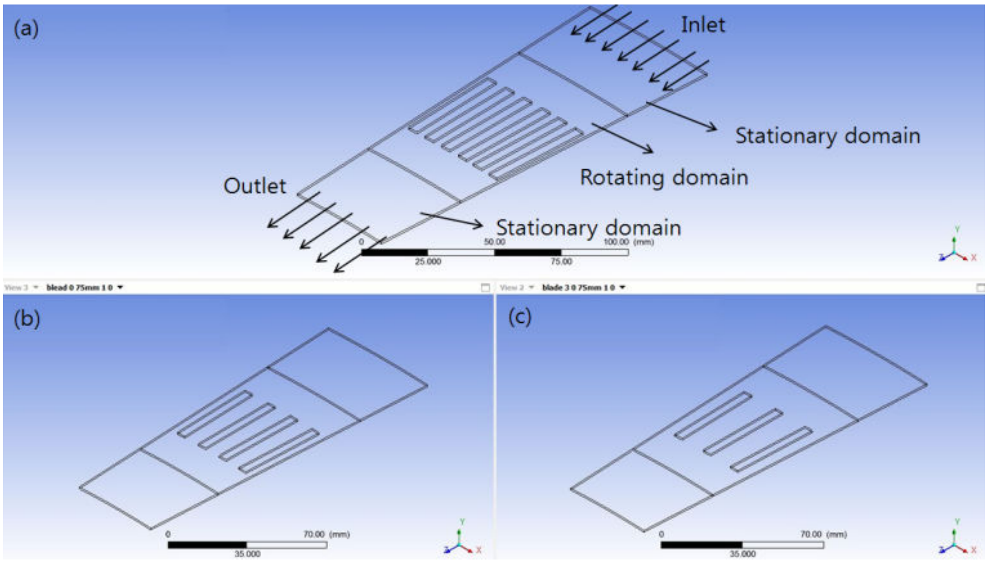

Fig. 2 Three kinds of 2D modeling of the domain around the (a) six blades for the stage 1 with 1°-spacing, (b) four blades for the stage 2 with 1.5°-spacing and (c) three blades for the stage 3 with 2°-spacing

B. Conditions for Numerical Analysis

Conditions for analyzing two -dimensional model are summarized in Table I. Applied boundary conditions are as shown in Fig. 2 (a). Air, containing particles, flows into a rectangular domain under consideration. This model has two domains, one is stationary, and the other one is rotating. Periodic boundary condition is applied along both circumferential boundaries. The applied flow rate is 8m^3/s and the velocity of the inlet can be obtained through (1):

$$V_{IN} = \frac{Q}{2\pi H R_i} \quad (1)$$

Q is the flow rate; H is the length of the wing and R_i is radius of the inlet area. From calculation, velocity of inlet is found to be 6m/s.

TABLE I
ANALYSIS CONDITION OF FOR 2D CFD

materials	air + sand (mixture)
turbulence model	κ-ε[5]
inlet velocity	6 m/s
outlet pressure	0 Pa
rotating velocity	102rpm
particle diameter	1, 0.1, 0.01, 0.001 mm
domain set	stationary domain
domain set	rotating domain
other set	rotating periodicity
parallel restitution coefficient	1.0
perpendicular restitution coefficient	0.5

C. The Wall Collision Model

Rate of impingement when the particles collide with the walls can be calculated from (2) & (3) by using parallel and perpendicular coefficients of restitution [6].

$$U_r = C_u U_i \quad (2)$$

$$V_r = C_v V_i \quad (3)$$

The definition of velocity component is shown in Fig. 3. If the collision of particle on the wall is elastic, vertical coefficient restitution is close to 1.0, and if particle sticks to the wall, vertical coefficient restitution is close to 0.

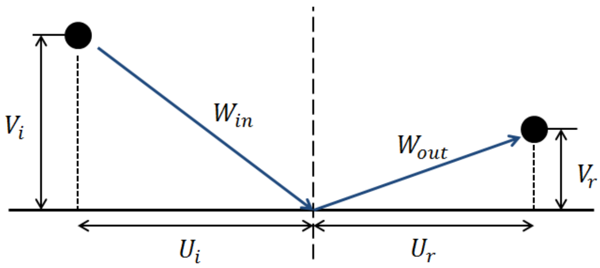

Fig. 3 Sketch of incident and reflective velocities [6]

III. Three-Dimensional Model

A. Modeling

A three-dimensional model was developed, which includes the flow path of particles from the bottom of the rotor to the upper outflow region. The model is axisymmetric except for blades. Unlike the 2-D modeling, where separate models are made for each stages of rotor, a single 3-D model includes all stages. Fig. 4 shows the 3-D model developed for the problem.

B. Conditions for 3-D Analysis

Condition for the analysis of the three-dimensional model is summarized in Table II. Fluid material is the same as in the case of 2-D model and the volume flow rate is 4m^3/s. Segregation of particles in the separator was confirmed and the trajectories of the particles having diameter of 0.5mm, 0.3mm, 0.2mm, and 0.1mm were visualized by the simulation.

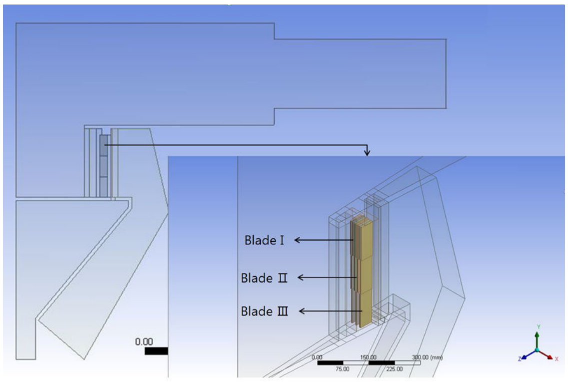

Fig. 4 3-D model for the problem under consideration

TABLE II
CONDITIONS FOR 3-D ANALYSIS

materials	air + sand (mixture)
turbulence model	κ-ε[5]
inlet velocity	6.8 m/s
outlet pressure	0 Pa
rotating velocity	100rpm
particle diameter	0.5, 0.3, 0.2, 0.1 mm
domain set	stationary domain
domain set	rotating domain
other set	rotating periodicity
parallel restitution coefficient	1.0
perpendicular restitution coefficient	0.5

IV. RESULTS OF ANALYSIS

A. Results of Two-Dimensional Model Analysis

Fig. 5 shows the trajectory of particles with the diameter of 1mm, obtained from the analysis of 2-D model. The color of the lines indicates the particle tracking time from the inlet point. After 0.01s, particles enter the region of blades, and a few particles, after impinging the blades get pushed back to the inlet region again. Remaining particles move through the gap between the blades.

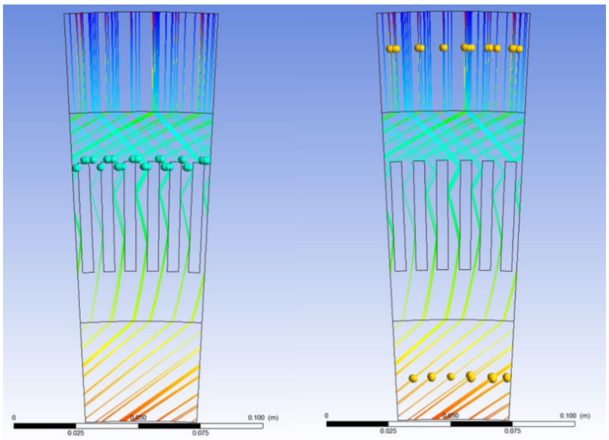

Fig. 5 Trajectories of 50 particles of 1mm diameter obtained from 2D analysis; color indicates the tracking time.

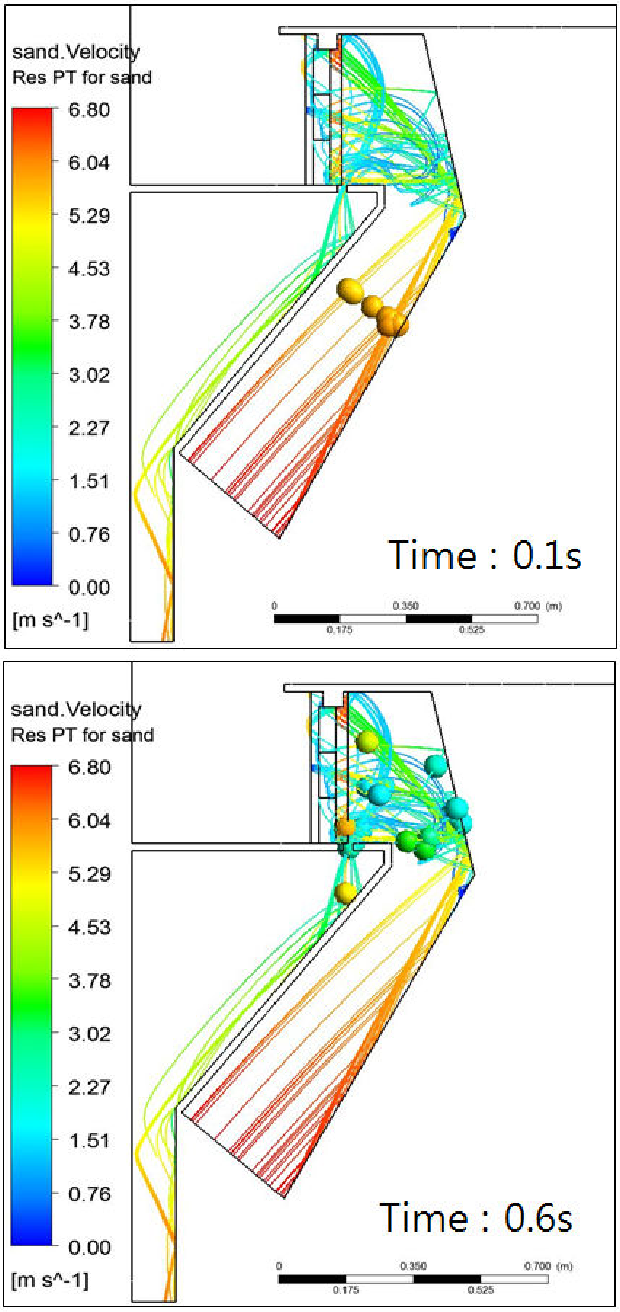

Fig. 6 Trajectories of 25 particles of 0.5mm diameter obtained from the analysis of 3-D model; color indicates the local velocity of the particle

B. Results of Three-Dimensional Model Analysis

Trajectories of particles of size 0.5mm, obtained from analysis of 3-D model are shown in Fig. 6. Particles flowing from the lower inlet has the same speed as that of air, after colliding with the walls of the sides, move to the blades. Some of the particles are pushed back after impact with the tips of the rotor blades. The remaining particles moves through the passageway and the heavier particles fall down due to gravity. Fallen particles at the bottom of the rotor exit through a hole in the bottom region, at around 0.6s. Particles, which have not been separated, circulate again, together with the inflowing air mixture particles progressed towards the side wall once again, and thus repeating the previous process.

Fig. 7 shows the trajectories of particles of size 0.1mm. After passing through the blades, particles get collected at the central region. These particles are then filtered out at the top.

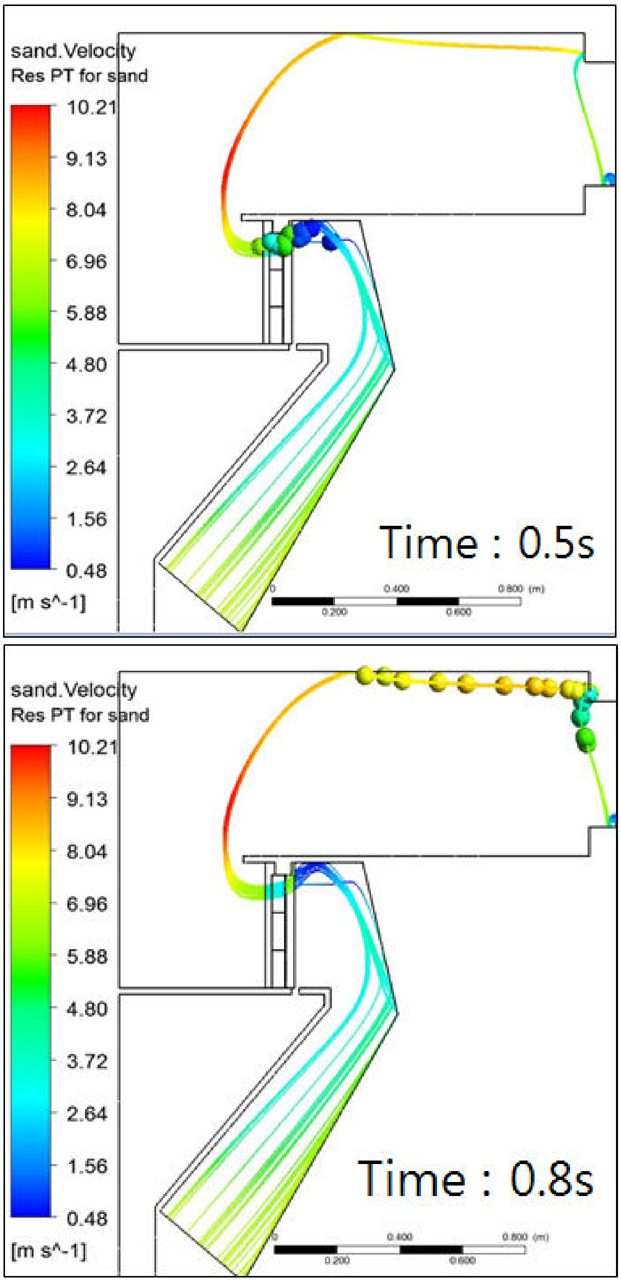

Fig. 7 Trajectories of 25 particles of 0.1mm diameter from 3-D model analysis; color indicates the local velocity of the particle

V. CONCLUSION

In this study, both 2-D and 3-D models of a 3-stage rotary separator were developed and simulations were performed to understand the mechanisms of separation of particles. Effect of particles size on the segregation of the same is also studied. Followings are our conclusions:

(a) The validity of dividing the flow region to rotating domain and stationary domain is confirmed in the 2-D model.

(b) In the 3-D model analysis, segregation of significant quantity of particles in a rotary separator is observed.

(c) Separation of particles with a diameter of 0.1mm, at a rotational speed of 100 rpm and at a flow rate of $4m^3/s$ is confirmed in the 3-D model analysis.

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