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Deep seawater flow characteristics around the manganese nodule collecting device

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Abstract

Flow field characteristics with outflow discharge from a collecting device in deep seawater while gathering manganese nodules have been analyzed by CFD. Numerical model is used for the analysis with CFD program of FLUENT. It is assumed that the collecting device is 4.5 × 5.4 × 6.7 m with outflow speed = 1.75 m/s and the current speed = 0.1 m/s. Overall seawater flow field characteristics are largely influenced by the outflow discharge from the collecting device and manganese nodule particle behavior. The outflow discharge effect reaches to about few times of the collecting device in back. As simulation results, flow velocity and streamline distributions are compared including turbulence kinetic energy variation. This study will be useful for optimal design for manganese nodule collecting device system in deep sea.

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Keywords: Manganese nodule collecting device; Seawater flow; Computational Fluid Dynamics

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1. Introduction

Recently, many concerns of terrestrial mineral depletion have been seriously raised, and thus the interests in marine mineral resources which can replace is rapidly increasing. Among various marine mineral resources, manganese nodule is the typical mineral resource that is located in depth of 4000 ~ 6000 m on the seabed as a large quantity. Manganese nodule contains various rare metals such as manganese, nickel, copper, cobalt and etc. and it is very valuable. It is also known that manganese nodule is mainly in Clarion-Clipperton zone where is southeast of Hawaii (LRET Collegium 2012). Currently, Korea obtained the 75,000 km mining rights in the zone, which has more than few million tons of manganese nodules. Most collecting device systems are usually composed of manganese nodule collecting and the lifting parts. The collecting part is for gathering manganese nodules at seabed, and the lifting one is to draw up the manganese nodules on the surface of the sea. Continuous interaction of these parts is very important for efficient system operation in deep seabed with minimized malignant effects on the ecosystem.

A lot of researches and developments with the collecting device system in the sea depth of 4000 ~ 6000 m have been widely carried out. In Korea, presently developed collecting device is tested successfully on the seabed at about 1,400 m depth with experimental studies. As recent studies of the collecting device system, Taguchi robust design method of tracked vehicle for manganese nodule test miner in collecting operation considering deep-sea noise factors was applied by Cho et al. (2012). Choi et al. (2010) performed inshore tests with specific design concepts of deep sea manganese nodule miner system. Total dynamic analysis of deep-seabed integrated mining system is also carried out by Kim et al. (2010). Lee et al. (2013) investigated design optimization method of a hydraulic deep-sea manganese pick-up device using Coanda effect. Experimental tests of the underwater mining system with flexible riser were conducted by Deepak et al. (2001). Although many researches associated with the collecting device system have been actively carried out in various ways, there is not sufficient studies on seawater flow field around the collecting device in the deep sea. Especially it is necessary to investigate the characteristics of seawater flow field around the devices with manganese nodules behavior, since it seriously affects the ecosystem of the deep sea.

In this study, the seawater flow characteristics around the collecting device, including fluid velocity distribution and turbulent kinetic energy variation, are numerically analyzed by CFD. The simulated results from this study can be applicable to the prediction of the effects caused by the collecting device operation on the deep-sea ecosystem.

Nomenclature

D	Diameter (m)
L	length of collecting device (m)
u	velocity (m/s)
k	turbulent kinetic energy (m^2/s^2)
$\bar{k}$	cross-sectional averaged turbulent kinetic energy (m^2/s^2)
μ	viscosity (P·s)
ρ	density of seawater (kg/m^3)
x, y, z	coordinate axis (m)

Subscripts

cd	collecting device
mn	manganese nodule
i, j	general spatial indices
s	seawater

2. Numerical Model

In this study, it is assumed that seawater flow around the manganese nodule collecting device is turbulent flow at steady state. Also, ANSYS Fluent 14.5 as a CFD code is employed for this numerical analysis. Fig. 1 shows CAD model of the manganese nodule collecting device. Length, height, and width of the collecting device are about 6.7 m, 4.5 m, and 5.4 m respectively. Computational domain of this analysis is shown in Fig. 2. The collecting device aligned with seawater flow is located in the middle of the bottom seabed plane in Cartesian coordinate system. Longitudinal distance of the computational domain is about 7 times of the collecting device length. Fig. 3 also shows numerical grid generation in the analysis domain using HYPERMESH. Dense grid is clustered near the collecting device where there is large variation of seawater flow.

Boundary conditions and fluid properties for computational analysis are set with deep-sea environment. Seawater flow velocity far from the collecting device is assumed to be $u_s = 0.1$ m/s, and moving speed of the collecting device is $u_{cd} = 0.5 \sim 2.0$ m/s with discharging nozzle velocity of 0.75 m/s,. Both sides and the top of the computational domain are set as symmetry. Density and viscosity of seawater are $\rho_s = 1{,}025$ kg/m^3 and $\mu_s = 1.08 \times 10^{-3}$ Pa · s respectively. For nodule particle behavior analysis averaged diameter and density of manganese nodule generated at seabed are $D_{mn} = 4.5 \times 10^{-2}$ m and $\rho_{mn} = 2{,}100$ kg/m^3 respectively (Yoon et al. 2013).

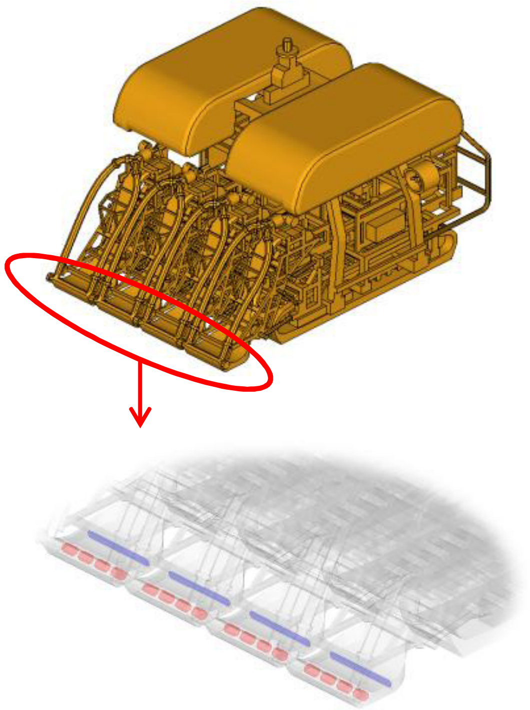


Fig. 1 Manganese nodule collecting device geometry

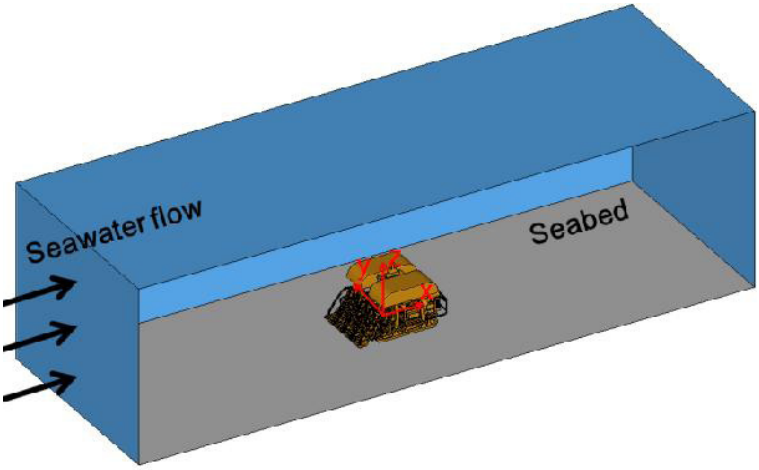


Fig. 2 Domain for computational analysis

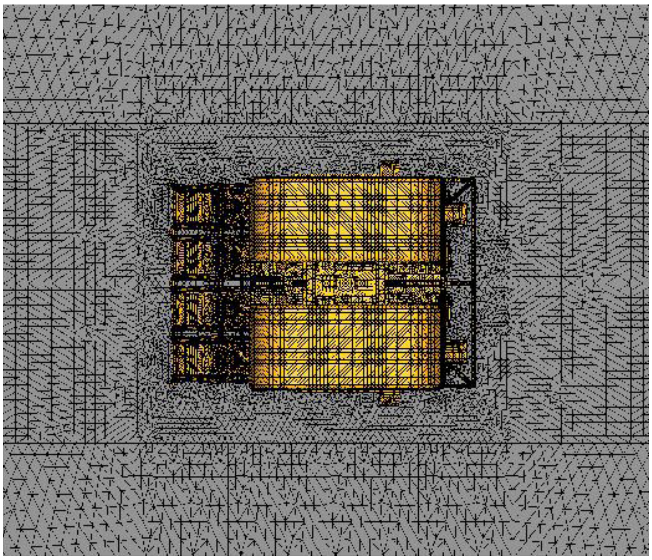
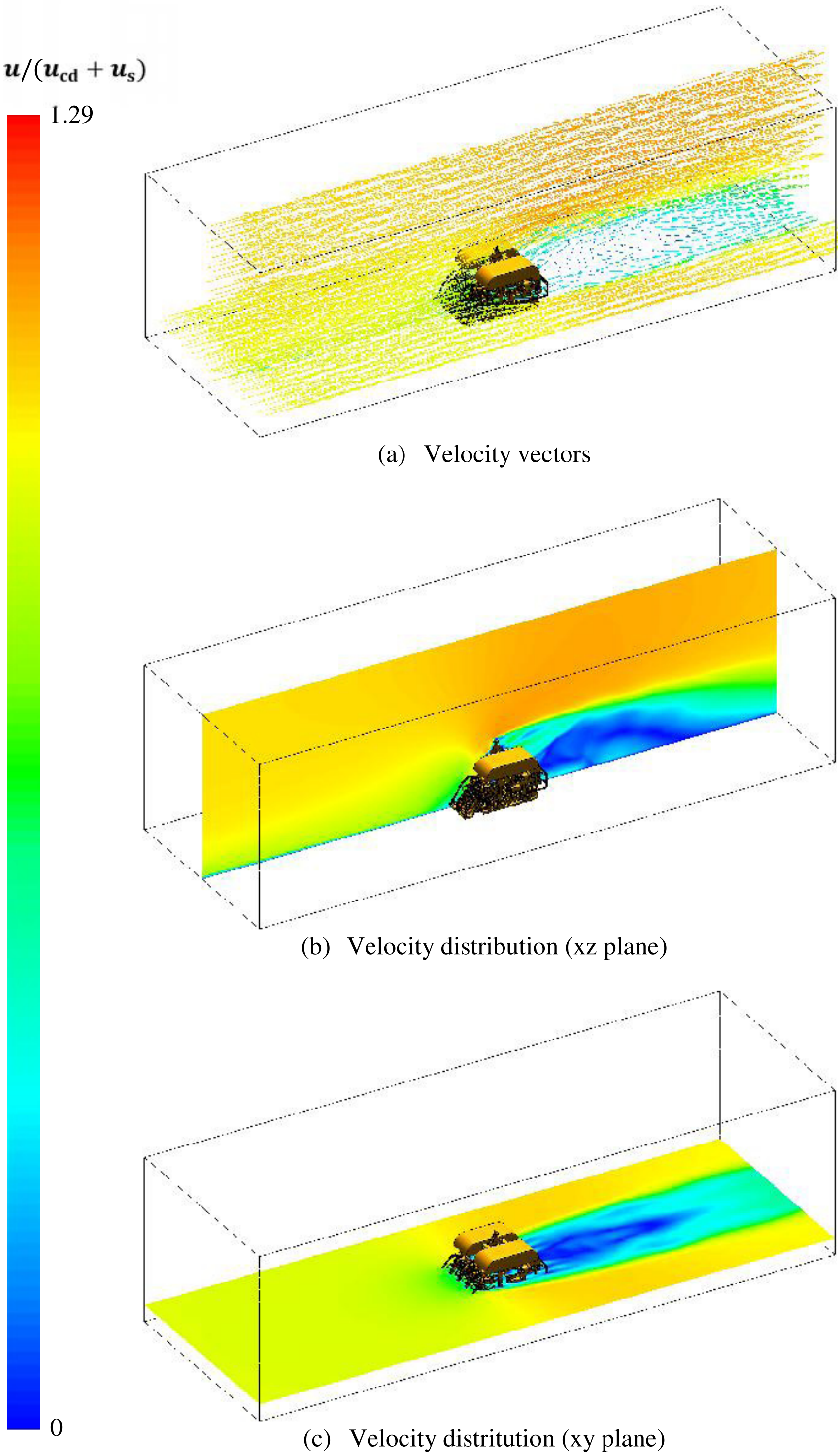


Fig. 3 Numerical grid generation near the collecting device

3. Results and Discussion

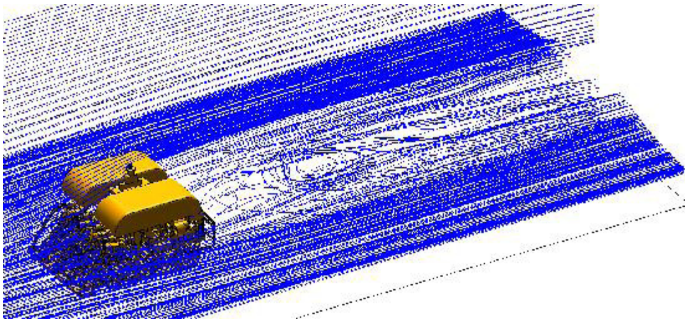
Seawater flow is severely affected by the collecting device with manganese nodule particles. As shown in Fig. 4 (a) - (e), flow velocity and streamline distributions with particles behavior in the seawater flow field are largely influenced by the outflow discharge from the collecting device. The outflow discharge effect reaches to about 2~3 times of the collecting device in the back while the front flow field of device was slightly affected by the outflow discharge. Meanwhile, with water jet from the collecting device, overall flow field is changed with manganese nodules behavior. There is also large variation in seawater velocity near the rear of the collecting device, and stagnation region with flow recirculation is about 2 times of the collecting device. Manganese particles from seabed mostly move into the front of the collector sections, and some of them gradually spread out as time passes.



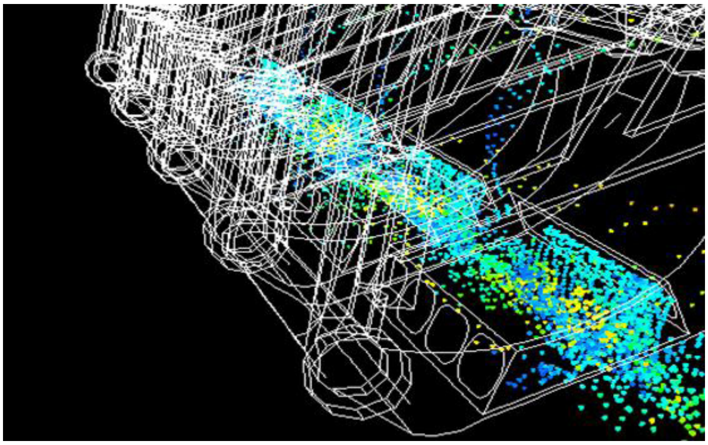
(a) Velocity vectors

(b) Velocity distribution (xz plane)

(c) Velocity distritution (xy plane)



(d) Streamlines distribution



(e) Particles behavior

Fig. 4 Flow velocity and streamline distributions with particles behavior in the seawater flow field

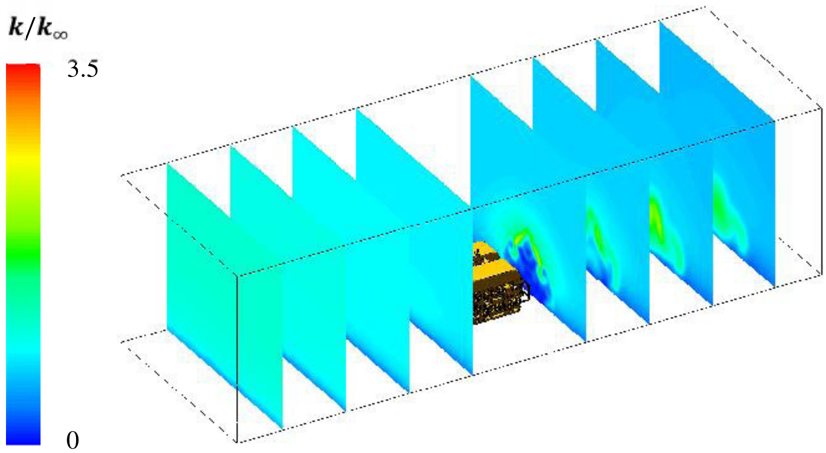
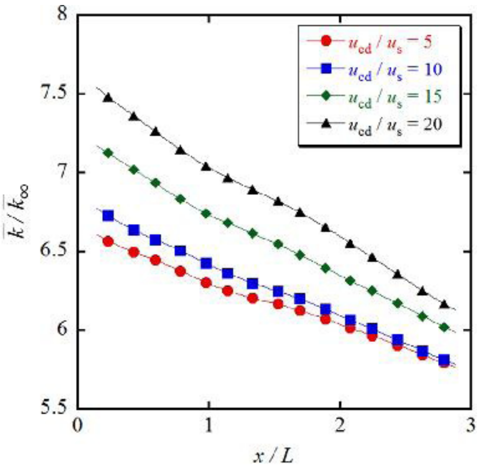
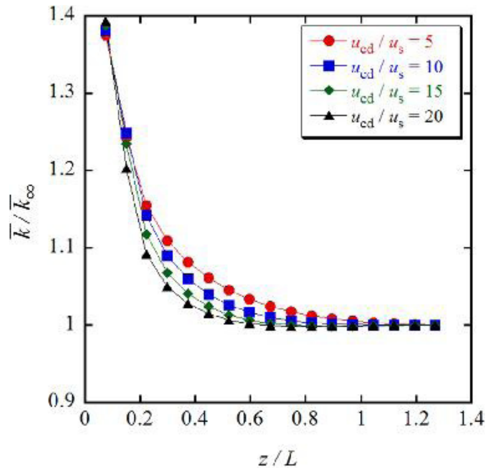


Fig. 5 Variation of turbulent kinetic energy distribution from the front and rear of the collecting device for u_{cd}/u_s= 20

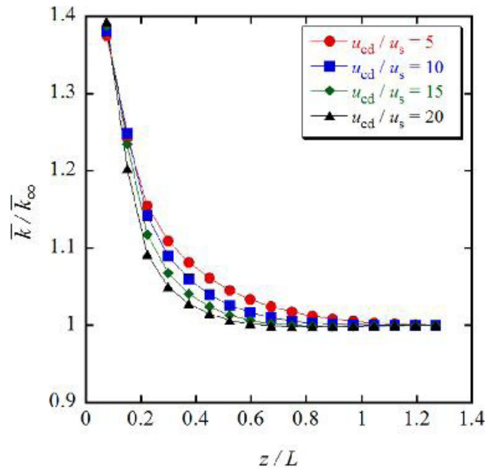
Fig. 5 shows the variation of k at several planes of the front and rear from the collecting device. It can be seen that there is severe variation of k from the rear part of the device and its distribution becomes more complicated along the downstream. And then it gradually dissipates from the device with seawater flow field. Fig. 6 shows the $\bar{k}$ variation from the device in each direction. $\bar{k}$ gradually decreases with the distance from the collecting device, and it depends on the speed of the collecting device in each direction. And k variation is more severe in the rear direction than vertical and side directions. With complicated flow field in the rear part of the device due to the vortex flow generated by operating the pick-up device, $\bar{k}$ is rather high, and it is up to about 7.5 times larger than that of far region where flow is not influenced by the device. It is also shown that k decreases steeply as the device speed increases while it increases about 4% when u_{cd}/u_s increases by 5. As shown in Fig. 6 (b) - (c), there is not much variation of $\bar{k}$ for $y/L > 0$ and $z/L > 1.5$ in vertical and side directions respectively. $\bar{k}$ in the above collecting device is relatively lower because outflow discharge effect hardly reaches there, while $\bar{k}$ at the side of the collecting device is about 1.4 times higher than $\bar{k}_\infty$ due to the strong influence of the water injected from water-jet on the seawater flow in the area. $\bar{k}$ slightly decreases with u_{cd}/u_s for $z/L \leq 1.2$.



(a) Behind the collecting device



(b) Above the collecting device



(c) Side of the collecting device

Fig. 6 Averaged turbulent kinetic energy variation

4. Conclusion

Seawater flow characteristics near the manganese nodule collecting device are analyzed through numerical simulation. This analysis revealed seawater velocity and streamline distributions along with complicated flow characteristics downstream including nodule particles behavior, which are largely influenced by the outflow discharge from the collecting device. The seawater flow is severely affected by the collecting device with water jet and nodule particle behavior, and it strongly depends on the device speed. Complicated flow field of velocity and streamline is generated from the device with considerable amount of k in the rear downstream of the device with vortex. $\bar{k}$ is up to 7.5 times higher than that of other areas where flow is not influenced by the device while its variation in vertical and side directions is rather limited near the collecting device. Since the simulation results in this numerical study could be largely influenced by modeling methods such as turbulence models and boundary conditions, they might be different from real flow situations. Thus, these predicted results are to be compared and correlated with experimental data for exact calibration hereafter.

Acknowledgements

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