Effects of Density Current Generator In Semi-Enclosed Bay

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Abstract **- A research on "Density Current Generator (DCG)" which is a new concept machine to agitate the stratified water area widely and calmly by using a density current has been carried out. The machine draws the water from both surface and bottom layer in a stratified water area, and mixes and discharges it on the middle layer. The discharged water is spreading and staying on a same density layer horizontally as a density current driven by the gravity. By making use of the machine, the hypoxic water that appears quite often in the bottom of semi-enclosed bay is pumped up and may be eliminated. The prototype machine, which discharges the density current of 120,000m3/day driven by 5kw electric motor impeller was developed and set up in Gokasho Bay, Mie Prefecture Japan, in June 1997. Since then, the machine is running for ten years continuously except winter season when the stratification disappears. After 3 years continuous running of the machine, an effectiveness of the machine such as the prevention of red tide at the bay end, outstanding increase of clams inside of the bay, etc. have been observed. Furthermore, after 9 years, the outstanding increase of seaweeds on the seafloor of the whole area of the experimental region is confirmed by the on-site investigations. These results lead us to believe that the DCG has excellent potential in terms of agitating and purifying stratified water of very large area, and also in terms of increasing seaweeds and benthos on the seafloor by eliminating the hypoxic water.**

Ⅰ. INTROCTION

In a stratified water, a water of certain density plunges into the same density layer as itself and makes very wide horizontal flow. This is a density current driven by the gravity, and we can see this phenomenon in many places in the nature. But there are no means to create a density current artificially until today. The authors are trying to create the artificial density current and to agitate a stratified water area widely, for the purpose of avoiding red tides, water blooms, and a hypoxic water in a enclosed bay.

The Density Current Generator (DCG) which sucks and mixes the low density upper water and high density lower water and discharges the average middle density water into the middle layer, have been developed by the authors [1]. It has been running for 10 years in the Gokasho Bay, Mie Prefecture Japan very successfully. In the first half of this paper, the concept and design of the DCG is introduced, and in the second half, the seafloor investigation results which show the remarkable DCG effects on increasing seaweed bed and benthos is discussed

Ⅱ. DENSITY CURRENT

In the liquid stratified with density, we can see the phenomenon that the fluid of a certain density tend to flow into the layer of identical density and spread over great distances along the horizontal layer. This kind of current has been known as a density current or a gravity current. Fig.1 shows an example of the density current in the middle layer [2]. When a comparatively cold water from a river flows into a lake, the river water sinks for a while within the lake until it reaches the layer of equal density and then starts flowing, changing its direction of flow to horizontal, along the layer.

In this way, the gravity induces the density current through the difference of density potential between the upper and lower liquid layers. Thus the gravity provides the energy source for this movement, so that induction of this flow does not require any energy cost. This feature conceivably recommends an extensive use of this phenomenon.

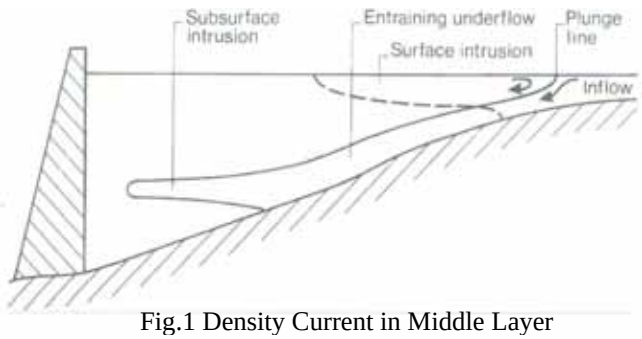


Fig.1 Density Current in Middle Layer

III. DENSITY CURRENT GENERATOR (DCG)

The prototype machine for generating the density current was researched and made by the authors [1]. The purpose of the machine is to make a density current and agitate the stratified sea water in the enclosed bay calmly, so that it prevents the pollution such as the formation of the hypoxic water, red tide, water blooms, and etc.

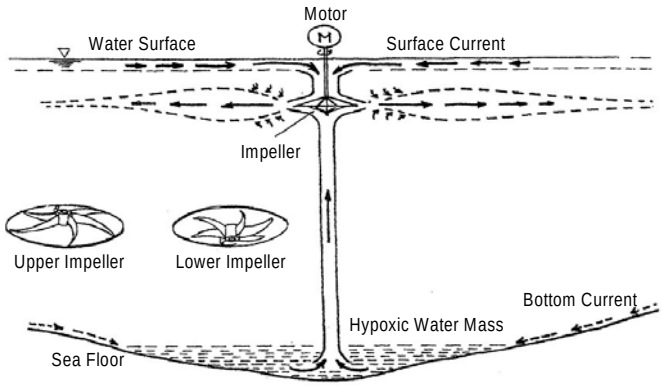


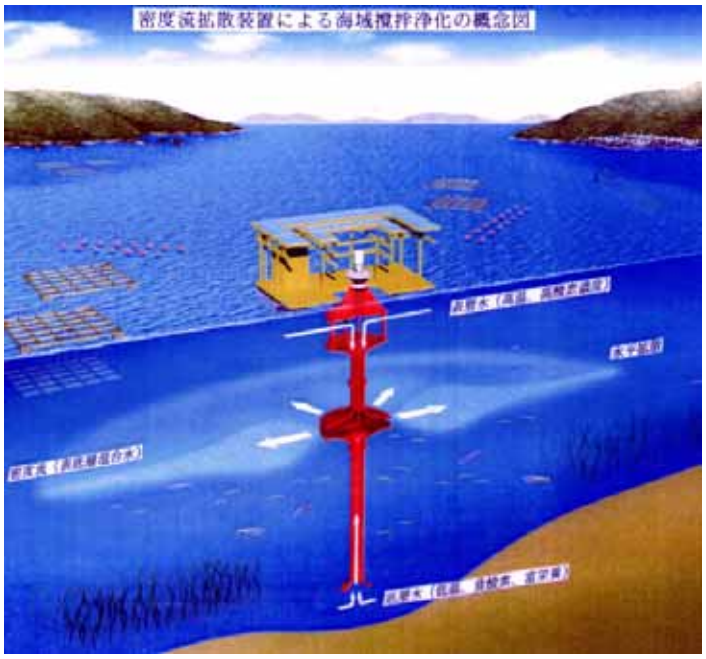
Fig.2 Concept of DCG

Fig.2 shows a conceptual schema of the DCG. Waters from the surface and bottom layers of the sea are sucked through bell-mouths and vertical pipes, then they mixed up by the motor-driven impeller which has blades on both sides of a disc. The mixed water is discharged horizontally toward all directions within the middle layer form the ring-nozzle formed in the pump casing, whereupon the water spreads through the layer as a density current. The electric power for driving the impeller motor is supplied by solar batteries at daytime and a diesel generator at night on the supporting pontoon. The machine has been installed at Hasamaura of Gokasho Bay, Mie Prefecture Japan (about 100km southward from Nagoya City, shown in Fig.6) since June 1977, and has been working continuously at the point of 15m water depth.

This sea area is an enclosed bay with a length of approximately 2km and a width of about 500m. The total amount of sea water is approximately 12,000,000m3. To achieve a turnover of this amount of the water during summer in a period of about 100days, we designed that the machine can create and discharge a mixed water of approximately 120,000m3/day. The mixture rate of surface and bottom layers was set to be 4:1, considering the temperature of the thermocline on the level of about 3m depth. Principal Particulars and the picture of the machine on operation is shown in Fig.3. The required power of the machine is only 5kw, therefore it is possible to be driven by not only electric power from the land but also solar cell on the top of the pontoon in day time.

IV. INVESTIGATION OF WATER QUALITY

The flow field around the DCG was measured in the sea, and the scale model test in tank and the computer simulations were also carried out, and reported [1] [3] [5].



Principal Particulars

Total Height	16.4 m
Max. Diameter	2.3 m
Diameter of Upp. Pipe	0.8 m
Diameter of Lower Pipe	0.5 m
Lower Water Intake	24,000 m3/day
Lower Water Level	15 m
Surface Water Intake	96,000 m3/day
Surface Water Level	0.5 m
Mixed Water Discharge	120,000 m3/Day
Mixed Water Level	3 m
Impeller Revolution	64 rpm
Power of Driving Motor	5 kw
Displacement of Pontoon	25 ton

Fig.3 DCG Design for the Experiment of Gokasyo Bay

Fig.4 DCG running in Gokasyo Bay

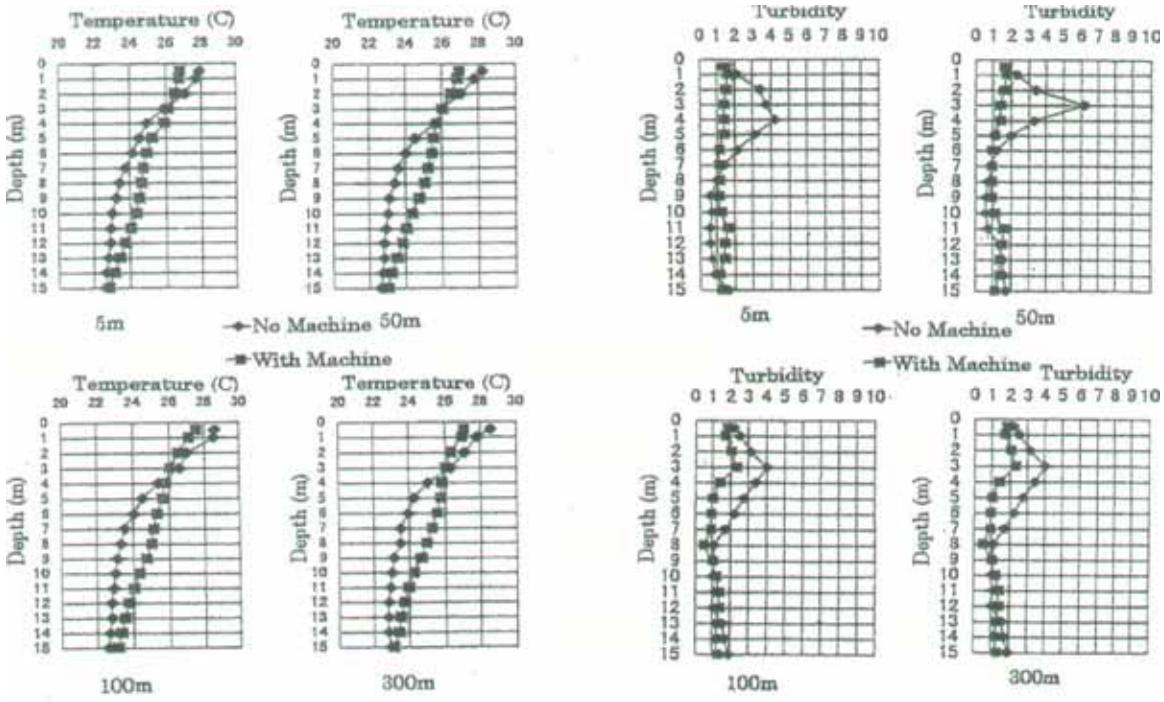


Fig.5 Change of Water Quality

The measurement of the water quality change around the machine was carried out the summer of 1997 [1] [3]. For this investigation, we stopped the machine for 4days from Aug.19 until Aug.23. The measurements in case of no machine running were carried out on Aug.23, and the measurements in case of machine running were carried out on Aug.26.

Regarding the water quality, Fig.5 shows the measurement results of water temperature and turbidity at 4 measuring points; distance of 5m, 50m, 100m and 300m from the machine. Fig.5 reveals a decrease of the surface layer temperature by 1 to 2degrees C. and an increase of the water temperature within the intermediate layers by 1 to 2degrees C. At the same time we could confirm that the thermocline, that was formed at a water depth of 2 to 4m, had been eliminated. Fig.5 also shows that turbidity reached a peak in the water depth of 3m while the machine was out of operation. After starting the machine the peak disappeared and the water became more transparent. This phenomenon reveals that the machine eliminated the rich phytoplankton layer by making the certain flow field, so it is expected that the machine has an effect of red tide prevention.

After two years of the continuous DCG running, a clam catch inside Hasamaura is increasing to 9-15 tons/year which is more than 10 times in comparison with the years before the DCG was set up. And no red tides occurred in the bay end, where we had them in summer season before setting the DCG. They suggest that the machine made remarkable improve of sea bed quality that had been very hypoxic, and the continuous flow field made by the density current eliminated the red tides which is an explosive increase of phytoplanktons.

Fig.6 Location of Experimental Site

Ⅴ. INVESTIGATION OF SEAFLOOR

In the year of 2006, nine years of continuous running of the DCG except every winter season, the wide area survey of

seafloor was carried out to confirm the DCG effect of avoiding the hypoxic water and improving the seaweed bed and benthos [4]. Fig.6 shows the geographic position of Hasamaura (the experiment region) and Shimotsuura (the reference region) in Gokasho Bay. Both regions have almost same condition of size, depth, and other boundaries. To obtain the total seafloor data, these regions are divided into proper areas as shown in Fig.7, 16 areas in Hasamaura, 19 areas in Shimotsuura, and mean depth of the each areas are also shownin Fig.7. The DCG is located at the point of H15 in Hasamaura. Using a under water TV camera and Diver's observation, every point (H1-16, S1-19) was surveyed in terms of the characteristic of seafloor material and the density of seaweed increase.

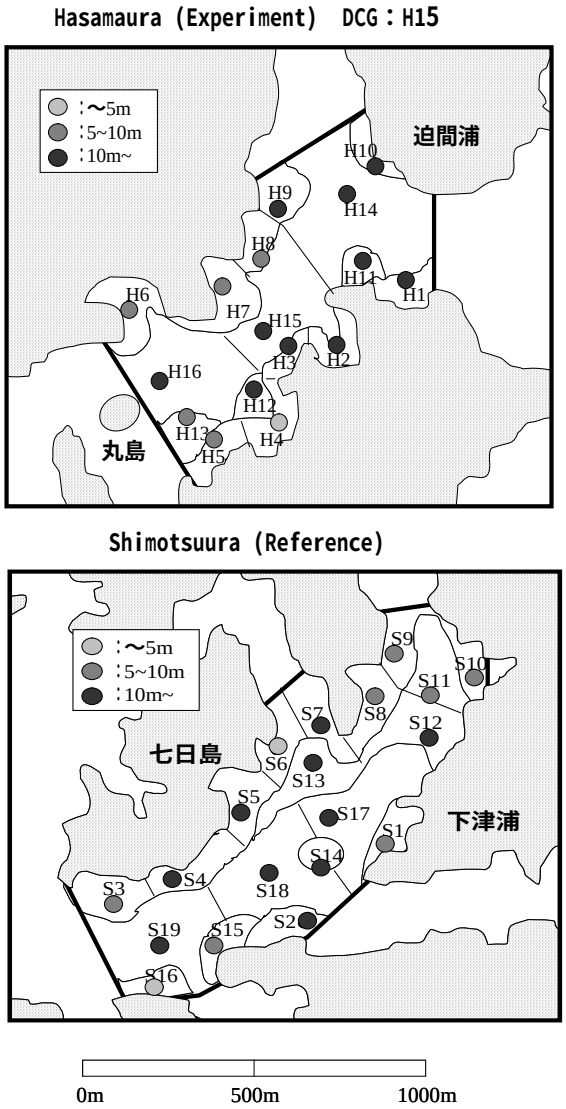


Fig.7 Depth of the Investigation Areas

Fig.8 shows the characteristics of the seafloor materials of the representative points of every investigation area. It is very remarkable that the seafloor in the experimental region is covered mostly with sand, but in the reference region mostly mud, which is called Hedoro (silt of organic matter). The thick Hedoro is observed in the point of H15, but Hedoro exists just only underneath the DCG and another place has sand seafloor.

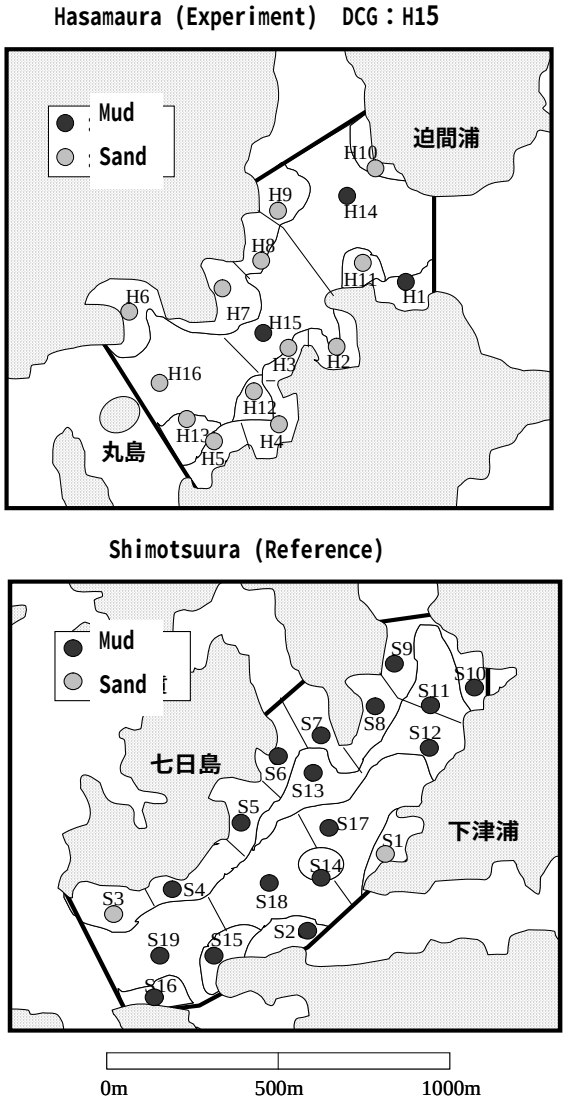


Fig.8 Characteristics of the Seafloor material

Fig.9 shows the density distribution of seaweed bed prosperity on the seafloor. It is very clear that the density level of seaweed bed in Hasamaura is remarkably better than that in Shimotsuura. From the obtained data of the seaweed weight per square meter in each area, the average weight per square meter is calculated as 230g/m2 in Hasamaura and as 20g/m2 per square meter in each area, the average weight per square meter is calculated as 230g/m2 in Hasamaura and as 20g/m2 in Shimotsuura respectively. So that the density of the seaweed bed prosperity in Hasamaura is more than 10 times higher than Shimotsuura.

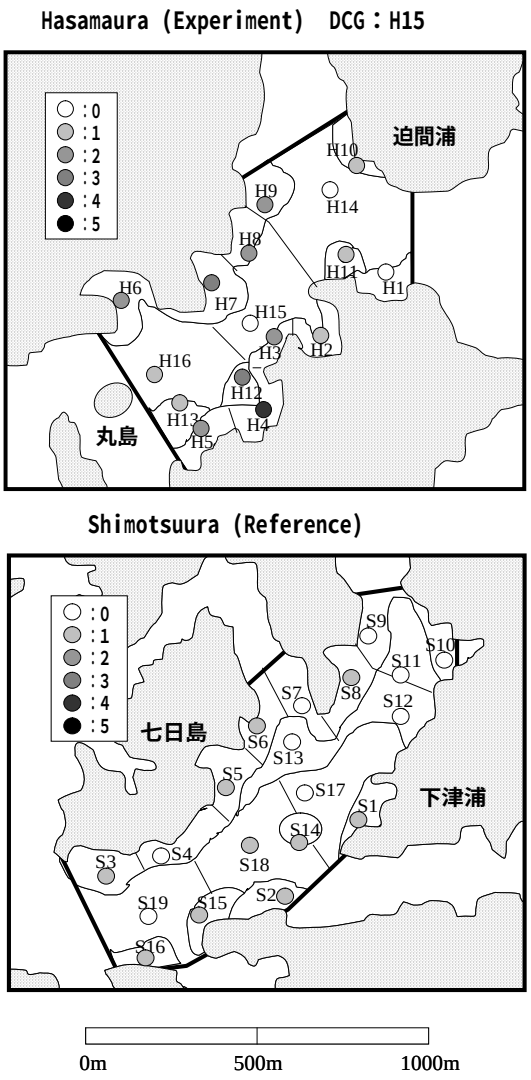


Fig.9 Density of Seaweed bed Prosperity

VI. CONCLUSIONS

The prototype machine of the DCG was developed, and about ten years continuous running except every winter season has been achieved successfully. As the results of such a long term experiment in the enclosed bay, the followings were found in terms of environmental improvement in the sea.

- Stratification of the sea is weakened.
- Hypoxic water in the bottom layer is avoided.
- Red tides in the bay end are avoided.
- Clam carch around the shore of the bay increases
- Hedoro (Silt of organic matter) is eliminated.
- Seaweeds and benthos on the seafloor increase.

ACKNOWLEDGEMENTS

This research was supported by Marino-Forum 21. Authors would like to thank to them.

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