Breakup of marine aggregates under laminar shear flow

*Yasuhito Hayashi[1], Shigeki Wada[1], Yasuhisa Adachi[1]

1. University of Tsukuba

Marine sinking particles are the major carrier of organic carbon originating from phytoplankton from surface to the ocean interior. This process regulates both oceanic and atmospheric CO_2 concentration. The efficiency of this process is determined by the settling velocity, carbon content, and the remineralization rate of particles. Since settling velocity is considerably controlled by the particle size, the coagulation of small particles into large aggregates in the flow field is important in the transport process of the organic carbon. On the other hand, fluid shear resulting from variations in fluid velocity around the aggregates could induce breakup due to erosion or fragmentation. While field observation in the previous study conducted in ocean surface and coastal benthic boundary layer suggested that turbulence causes aggregate breakup, experimental assessment for breakup of aggregates had been carried out by only Alldredge (1990), in which breakup of marine aggregates rarely occur even under the storm condition (energy dissipation rates > 10^{-4} W kg^{-1}). Their method of collecting aggregates from the ocean could overestimate the strength of the aggregates.

In our study, a Couette device which consists of two concentric cylinders with different diameters (inner cylinder is fixed, and outer one rotates) was used to examine the breakup of aggregates derived from natural phytoplankton communities, which were cultured in seawater collected from a eutrophic coastal sea (Tokyo bay, Japan). A stable laminar shear flow was generated in the gap between two cylinders. Shear rates were from 3.2 to 22 s^{-1} adjusted by the rotational speed of the outer cylinder. Durations of the experiments were one to two hours because the sizes of particles were mostly stable within these periods. The size of the aggregates were 309, 182, 129, 128 μm at a shear rate of 3.2, 6.9, 10.1, 22 s^{-1}, respectively. Size and shear rate were described by the following theoretical scaling relation,

$D \approx G^{-\gamma}$ (1)

where D, G and γ denote aggregate’s size, shear rate, and aggregate strength constant respectively. The value of γ is theoretically 0.50 when the cohesive strength of aggregate is constant irrespective of the size. In this study, the calculated γ value of 0.48 was similar to the theoretical value. The relationship between the shear rate and the commonly measured energy dissipation rate (ε) is,

$G = (\varepsilon / \nu)^{1/2}$. (2)

The values of ε were 9.7×10^{-6} to 4.4×10^{-4} W kg^{-1} which is within the range of the turbulence generated by the wind and zooplankton community. Therefore, the breakup of marine aggregates by the fluid shear would occur under natural environment.

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