Flocculation in turbulent flow – a view into particle network

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Introduction

Cohesive sediment is prone to form aggregated particle network, and consequently its transport, settling, deposition, resuspension, and interaction between fine particles and flow are to large extent determined by intrinsic strength of particle network. In the estuarine environment suspended particles are mostly flocculated, and are continuously moving through estuarine zones of varying salinity, suspended sediment concentration and turbulence intensity, and as a result, they are subject to a continuous process of flocculation and de-flocculation. The aim of this study is to investigate floc formation at various locations within the Scheldt Estuary (Belgium, the Netherlands) through field measurements and laboratory experiments and to get insight into the longitudinal variability of flocculation and to contribute to improved understanding of sediment transport dynamics.

Field investigation and laboratory simulation experiment

Flocculation *in-situ* field measurements were carried out following the salinity gradient along the Scheldt Estuary. *In-situ* benthic camera, floc-sampler and Environmental Scanning Electron Microscope Wet-mode (ESEM-WM) were used to sample and observe flocs. Simulation experiments were performed in an attempt to reproduce the observed natural phenomena in terms of the variability of floc formation with respect to the suspended particle locality from areas varying in salinity and situated above, within, and below the estuarine turbidity maximum (ETM) zone. These simulation experiments were focused on three main influential parameters: suspended sediment concentrations (SSC), salinity and temperature, and were completed on natural estuarine suspension under controlled turbulence.

Every individual floc image acquired from ESEM-WM was analysed using the image software to determine the floc size (length, width and height) and the floc median length. Floc volume is presented as parts per thousand (ppt), which represents the volume units of flocs per thousand volume units of suspension. The *in-situ* floc shape is described by the floc sphericity that is determined by the floc length to width ratio.

In situ suspended particle flocculation and characteristics

Direct field investigations in the Scheldt Estuary show that suspended particles are intensively flocculated. Evolution of floc formation within a tidal cycle is governed by different phases of tidal related current velocity and suspended particle concentration. The longitudinal *in-situ* particle-size spectra demonstrate an important pattern. Large flocs (up to 1400μm) are repeatedly found at low or no salinity areas and further upstream. Flocs become smaller toward downstream showing least size, with average floc size around 50μm, in a zone where the most important ETM locates. This persistent pattern of average floc-size distribution in the Scheldt Estuary suggests that the increment of SSC to a certain extent leads to a probable increment of the particle collision frequency resulting in floc break-up or floc abrasion within the ETM. In this study no evidence was found for an intensified flocculation in the low salinity transitional zone where fresh and salt water meets and is conventionally considered as the most favourable locality for flocculation because of the optimal salinity range. An overview of aggregated particle network shows distinctive differences of floc structure from the freshwater zone to the downstream high salinity zone (Fig. 1).

Flocculation capability

Observations from the simulation experiments reveal that in a low turbulent flow field flocculation takes place on 3-hour time scales with estuarine reality SSC (around and below 300mg/l). The SSC affects the flocculation at different scales and is particle source dependent. Some intrinsic particle properties such as primary grain compositions, specific surface area and cation exchange capacity as well as biological factors indispensably determine the ultimate size and settling behaviour of floc. Increment in floc size is not necessarily accompanied by an enhanced floc settling behaviour. Floc shape is a significant parameter determining floc settling, and spherical shape is favourable. Introducing particles from the freshwater part of the estuary into a saline environment yields a two-stage effect on floc formation. An initial stage of dense and spherical floc formation associated with fast settling and a second stage of large low-density organic floc growth and very slow settling. The effect of water property (including salinity) on flocculation is particle property dependent. The

impact of temperature increment on flocculation is SSC dependent. High temperature limits floc size but positively affects the formation of spherical-shaped floc.
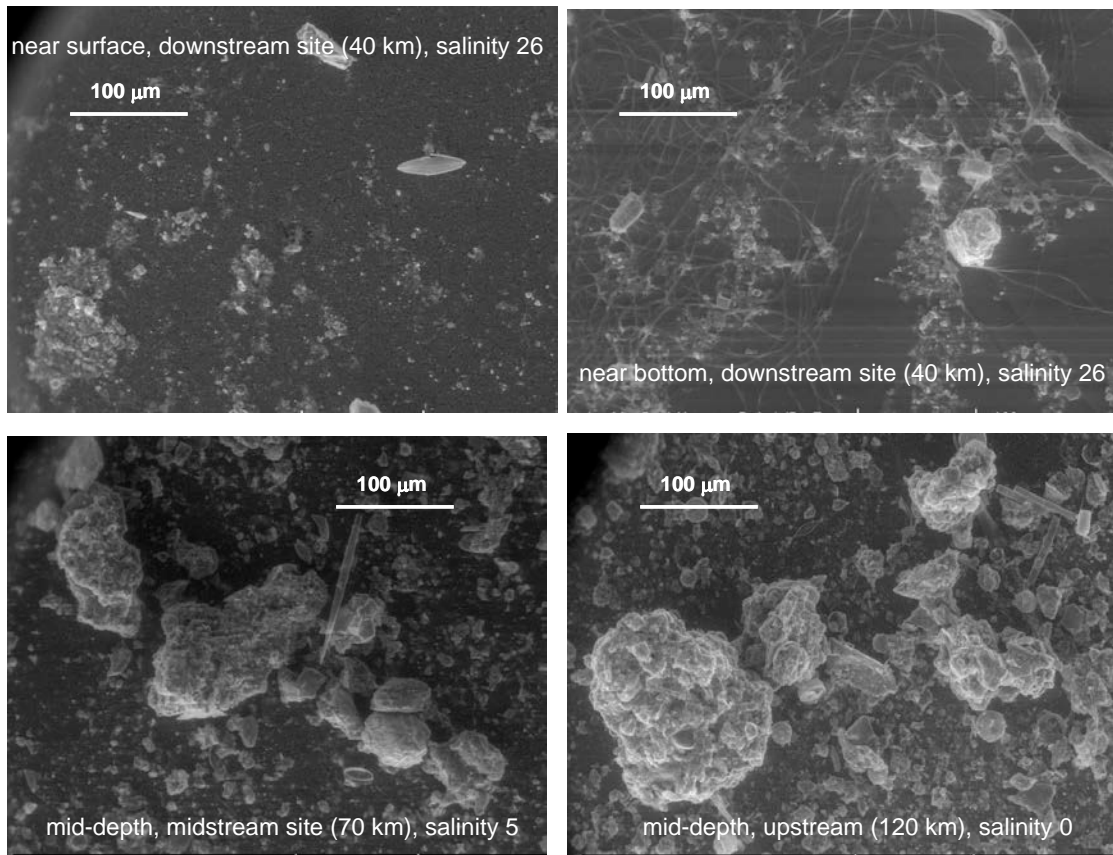

Fig. 1. Particle networks representing flocculated sediments with irregular form and open structure.

Conclusions

The findings of this study show the effect of process parameters on flocculation and floc characteristics as well as compatibility between *in-situ* observations and simulation experiments. Direct field investigations demonstrate an important pattern of longitudinal *in-situ* particle-size spectra. Flocculation simulation experiments have successfully reproduced the observed spatial variation pattern of floc size in nature. Suspended particles from different localities even within the same estuary do show different variability in flocculation. In this study, suspended particles from the upstream of ETM show the strongest flocculation capability, while those from within the ETM show the least capability in floc forming. In addition to local hydraulic flow and local SSC, the biological, physical and chemical components associated with the particle locality are at the root of the variability of flocculation and the resulting floc distribution and settling.