Coagulation, Flocculation and Agglomeration

Agglomeration

Agglomeration refers to the formation of more or less firmly bound primary particles by collision processes between primary particles, primary particles and agglomerates, as well as pre-existing agglomerates.

The agglomeration consists of a destabilization and a transport process. The destabilization is divided into coagulation and flocculation. In general, both mechanisms occur in parallel.

Coagulation

Before a suspension is at all able to form flocks or agglomerates, it must be destabilized. In this context stable refers to a suspension that if at all only slightly tends to self flocculate and thus settles very slowly. Unstable refers to a suspension that forms flocks very quickly and thus the solids settle very fast. In the so-called coagulation the self flocculation of the solids is caused by interparticle interactions. Electrostatic repulsion, van der Waals attraction and possibly electric or magnetic forces are acting between the particles. Depending on which force prevails flocks are formed or not. The physical background of the forces are discussed intensely in literature frequently under the section DLVO theory. These intermolecular forces can be manipulated to achieve the particular desired effect of destabilization by the addition of salts and/or by changing the pH of the suspension. The destabilization is most usually observed at a zeta potential $\zeta = 0$, which is also known as the isoelectric point. The zeta potential is a measure of the surface charge of particles and is largely responsible for the electrostatic repulsion forces.

Flocculation

Flocculation refers to the accumulation of high molecular weight flocculants on the surface of particles. The destabilization is achieved by reactive cationic or anionic groups and can be controlled by the pH of the suspension. Flocculants are roughly divided into natural organic flocculants (eg starch, glucose) or synthetic polymeric flocculants. The attachment of particles to the polymer molecules takes place by hydrogen bonds, electrostatic interactions, ion bonding and gel formation.

There are two mechanisms (see Fig. 1). First, the charge mechanism for short-chain polymers, which attach themselves only to a particle and move its surface charge such that there is interaction with other particles and the other is the bond model in which multiple solid particles are grouped together by a polymer network of long-chain polymeric flocculants to agglomerate.

Figure 1: charge model (left) und bond formation (right)

To reach an actual agglomeration the destabilized particles need to collide with each other or get in range of mutual attraction.
During the transport process, depending on whether diffusive transport of small particles (x<1μm) or inertial transport of large particles (x>1μm) predominates, one talks of perikinetic or orthokinetic transport. Responsible for the movement during perikinetic transport is the Brownian motion. In the case of orthokinetic transport the larger particles cannot follow the liquid flow due to their inertia and collide with each other.
Macroscopically destabilization and transport are happening simultaneous. The result of a flocculation experiment is difficult to predict. The mechanisms depend on the material system and treatment of the sample. They are highly variable and have many influencing parameters such as amount and duration of energy input, concentration and addition mode of flocculant, stirrer, pH, etc..
The life span and size of a flake is primarily determined by the entry of shear forces and centrifugal forces and the nature of the formation of the flake. The strength is influenced by the formation mechanism. The lowest binding forces have flakes, which were generated by changing the physico-chemistry, the highest strength flakes result from the addition of polymeric flocculants.

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