One theory of Alum Coagulation - sweep floc

Aluminum sulfate, a.k.a. "filter alum", is commonly used as a coagulant in water treatment systems and less frequently in waste treatment systems. In water treatment it is used primarily for the removal of tiny particles (called colloids, measured as total suspended solids) in the raw water which are too small to settle by gravity in a reasonable length of time. Another contributing factor as to why small particles are difficult to settle out is that VERY small particles commonly possess a negative surface charge. As a result, they will not adhere to each other if brought into contact since like charges repel. Such colloidal systems are termed "stable". The process of causing the colloidal particles to settle out is called "destabilization". "Coagulation" is defined as any process used to destabilize colloidal systems.

There are two primary theories regarding the exact mechanism by which coagulants actually cause the removal of colloids in water (or wastewater). One theory involves neutralization of the surface charge on the particle so that they can adhere to each other forming particles large enough to settle by gravity in a reasonable time. This theory is rather complex and somewhat esoteric. It will not be covered here. The other mechanism, which we will discuss, is often referred to as the "sweep floc" theory. This theory simply postulates that the coagulant(s) added form a precipitate (a solubility product is exceeded) which settles by gravity in a reasonable time. These coagulant floc particles then collide with and drag colloids down with them.

From an operational standpoint the process of coagulation is divided into several steps. These are (1.) flash mixing (2.) flocculation and (3.) settling.

Flash mixing is the process by which the coagulant is added to the water or wastewater and then thoroughly mixed so that it is distributed as evenly as possible in the water. Obviously coagulation isn't going to occur in regions of the water where the coagulant doesn't get distributed.

The second stage in the process is flocculation. During flocculation the water-colloid-coagulant mixture is stirred in order to enhance contact between floc particles and colloids as well as between floc particles themselves. This allows the floc particles to grow in size so they will settle faster.

Finally, once the floc particles have grown large enough they are allowed to settle, hopefully dragging out most of the colloids with them. Each of these processes have specific design procedures and limitations which must be met.

The chemistry of alum coagulation

When alum is added to water it undergoes the reaction below. The alum reacts with bicarbonate to form aluminum hydroxide, a precipitate.

1. \( \text{Al}_2(\text{SO}_4)_{3} * 18\text{H}_2\text{O} + 3\text{Ca(}\text{HCO}_3\text{)}_2 \rightleftharpoons 2\text{Al(OH)}_3 + 6\text{CO}_2 + 3\text{CaSO}_4 + 18\text{H}_2\text{O} \)

"alum or filter alum"  alkalinity as CaCO3  precipitate gas salt

The solubility product of aluminum hydroxide, \( \text{Al(OH)}_3 \) is : 

\[
\frac{[\text{Al}^3\text{+}] [\text{OH}^-]_3}{[\text{Al(OH)}_3]} = 1.26 \times 10^{-33}
\]
The equation can also be written as shown below which recognizes that calcium bicarbonate and calcium sulfate are soluble and do not necessarily exist as distinct molecules but only as ions.

2. \( \text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O} + 3\text{Ca}^{+2} + 6\text{HCO}_3^- \rightleftharpoons 2\text{Al(OH)}_3 + 6\text{CO}_2 + 3\text{Ca}^{+2} + 3\text{SO}_4^{2-} + 18\text{H}_2\text{O} \)

The term "alum" refers to aluminum sulfate \( \text{Al}_2(\text{SO}_4)_3 \). However the number of water molecules bound to the central molecule can vary substantially (3 to 24 waters). While this has no effect on the behavior of the coagulant it is necessary to know in order how much bound water is present in order to compute the number of moles or equivalents of alum.

The alum reacts with the bicarbonate molecule. In the reaction above bicarbonate is shown associated with \( \text{Ca}^{+2} \) in order to preserve charge neutrality. For most waters with a pH of 6-8 the bicarbonate is measured as alkalinity.

The reaction produces carbon dioxide, CO\(_2\), as a gas. This CO\(_2\) will then react with water producing carbonic acid H\(_2\)CO\(_3\). The carbonic acid will partially dissociate producing bicarbonate, carbonate and H\(^+\). Thus, the pH of water to which alum is added will drop, but not very greatly, since carbonic is a weak acid.

**MONROE WTP**

Recall that alum is added at the Monroe water treatment plant for just the purpose described above. Recall also that the pH of the raw water is about 7.0 but after alum addition it drops to about 6.0. Monroe uses NaOH (sodium hydroxide) to raise the pH to about 8.3. The Monroe WTP does not have a classic flash mix basin. However it does have a flocculation chamber where the mixture is gently stirred to promote collisions between floc particles. It also has a settling basin to allow the floc particle to settle out. The settled sludge is pumped to the Ouchita (sp) River.