Practical Course: Drinking Water Treatment

Coagulation & Flocculation of suspensions with the coagulant Aluminium Sulphate and the Flocculant Polyacrylamid

Background

Coagulation and flocculation with subsequent sedimentation is widely employed in the purification of water (e. g. drinking water treatment, waste water treatment). It is used to remove water turbidity as well as dissolved organic matter, inorganic trace compounds (e.g. heavy metals and phosphorus) and microorganisms. The main causes of turbidity of water are fine particles, like suspended or colloidal particles. The latter have a size from 1 nm to 1 µm, hence they are not visible to the naked eye. You can see them only with the help of an optical microscope (wavelength of visual light: 400…800 nm). Colloids are too small to settle in a reasonable time. For example a colloidal particle of 10 nm usually needs over 30 years for its sedimentation in a 1 m water column.

In addition these particles have got negative surface charges. The similar-charged particles repulse and do not aggregate into larger and heavy particles. Therefore, a neutralization of the surface charges of colloids is required. For this process coagulants and flocculants are used. Coagulants and flocculants are chemicals that promote the process of coagulation or flocculation. During this process the fine particulates are clumped together and form flocs or "flakes”. The flocs may then settle in a short time, or they can be readily filtered out of the liquid.

Colloids and other suspended particles aggregate and form flocs in different ways.
The three main mechanisms are:

1. Destabilization of colloids by adsorption of positively charged ions
   the so-called **specific coagulation**
2. Adsorption of polymers and bridging *called* **flocculation**
3. Precipitation with entrapping of particles *known as* **sweep coagulation**

The mechanisms of **specific coagulation and flocculation** are quite similar and are based on the neutralization of surface charges. For the specific coagulation inorganic positively charged hydroxo complexes of multivalent metal cations are used. These complexes are mostly Al or Fe ones. For the flocculation organic positively charged polymers are applied. These positively charged ions interact with negatively charged colloid surfaces and reduce the barriers of aggregation. Thanks to the Van de Waals forces the colloids (now with neutral surface charges) aggregate and form flocs. The concentration of coagulants and flocculants plays a significant role in these processes. If the concentration of coagulants is too high, the colloids adsorb too many of the positively charged ions and so they have positive surface charges. Colloidal particles are repulsed and remain in the liquid. This process is called restabilization. If the concentration is lower than necessary, the removal of turbidity is not complete. That is why the selection of a precise concentration of coagulants and flocculants is decisive for an optimal removal of turbidity.

The **sweep coagulation** mechanism is based on the formation of insoluble hydroxides which physically trap small particles into larger flocs and precipitate. For example, the coagulant aluminium sulphate is precipitated at pH = 6 as aluminium hydroxide. The bulky precipitation includes small colloidal particles and settles down to the bottom of the liquid.

Summarizing**:** The removal of turbidity has got 3 stages:

1. The neutralization of the surface charges of colloids
2. Formation of microflocs
3. Formation of macroflocs

[A] Determination of the optimal dosage of the coagulant *aluminium sulphate* and the settling time

1. Preparation of the SiO_2-suspensions

To carry out a flocculation experiment you have to generate a model solution with a known concentration of turbidity (10 g/l SiO_2 suspension).
Add 850 ml of tap water and 50 ml of the 10 g/l SiO_2 suspension into each of the five flocculation reactors. These suspensions should be stirred constantly at a speed of 200 rpm. After an agitation time of 5 min the suspensions are ready for further experimental application.

2. The experimental procedure consists of 5 steps:

2.1. Preparation and Addition of the coagulant

At the beginning we have to add different quantities of 5 % aluminium sulphate stock solution to 20 ml beakers (see Table 1). Then we fill the beakers with tap water up to the 20 ml marks.
After that we simultaneously add the aluminium solution into the flocculation reactors. By adding the aluminium sulfate solution to the model solution different concentrations of aluminium are produced (see Table 1)

Table 1

beaker number	**1**	**2**	**3**	**4**	**5**
aluminium sulfate stock solution (ml)	0	0.7	1.5	8	20
β(Al) (mg/l)	0	3	7	35	88

2.2 ***Agitation phase 1:*** *growth of microflocs*

At this step the stirrer moves at a constant speed of 200 rpm. The agitation time is 2 minutes. During this time, the coagulant distributes evenly in the solution and neutralizes the negative charges of the colloids. Microflocks are formed.

2.3 ***Agitation phase 2:*** *growth of macroflocs*

At this step, we reduce the speed of the stirrer from 200 rpm to 50 rpm for the next 10 minutes. During this time macroflocks are formed. If the agitation speed is not reduced, the aggregated flocks will be destroyed.

2.4 ***Sedimentation phase****:*

After 10 minutes we turn the stirrers off. The formed flocks settle to the bottom. We take two samples from each reactor, after 5 and 20 minutes respectively.The samples are taken with the help of a pipette. It’s very important, that all the samples are taken at the same depth of immersion. We take the samples at the 500 ml marks. The samples are filled into sample cups with labels of P1 to P5.

2.5 ***Determination of the turbidity***

Turbidity is measured with the help of a turbidity meter. The cuvette is filled with a sample up to the mark. Then we place the cuvette in the cuvette compartment. As soon as a star symbol appears, you can read the values. These values should be entered in Table 2 in the corresponding boxes in accordance with the sampling time.

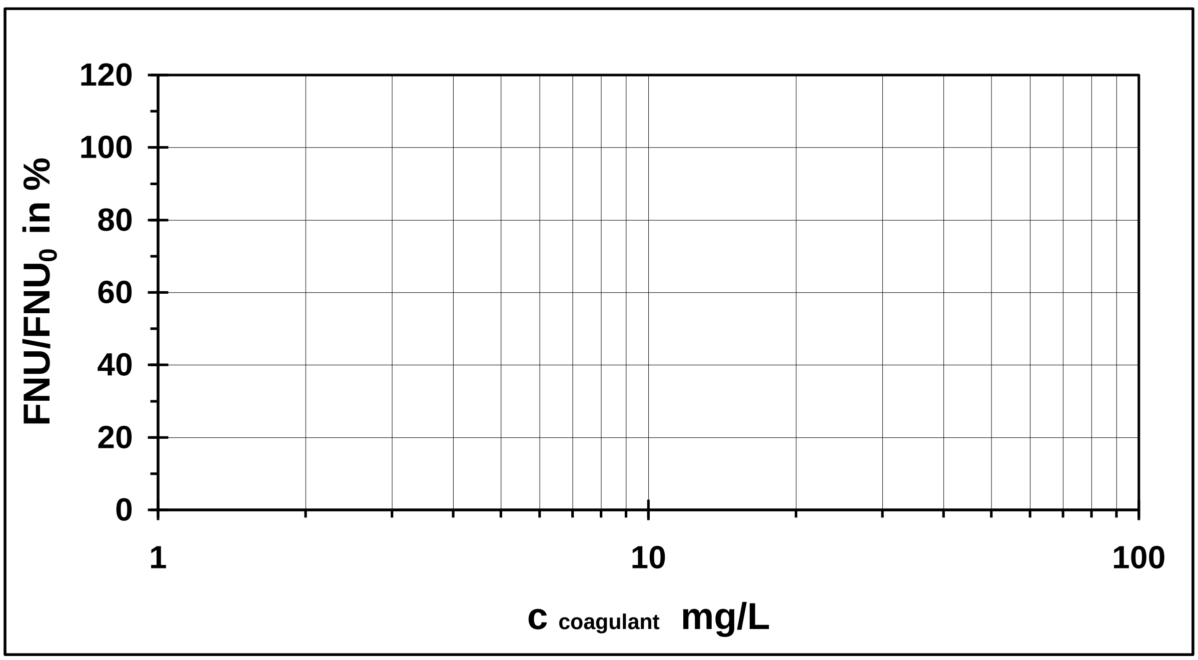
3. Evaluation

3.1 Determination of the relationship FNU/FNU_0

The turbidity of the non treated sample (without any addition of flocculant) is marked with FNU_0 and corresponds 100 %. For the remaining samples the relationship FNU/FNU_0 in percent ($FNU/FNU_0 * 100$) should be calculated.

Table 2

number of the sample	aluminium sulfate	sedimentation 5 min.		sedimentation 20 min.	
	in mg/L	turbidity FNU	FNU/FNU_0 (%)	turbidity FNU	FNU/FNU_0 (%)
1	0		100		
2	3				
3	7				
4	35				
5	88				



Graph 1: Dependence of the coagulation effect on the dose of the coagulant

Questions:

[1] What is the coagulant concentration for the optimal removal of turbidity? **β =**

[2] What is the difference of the turbidity after 5 and 20 min of sedimentation by using this concentration? **ΔFNU=**

[3] Explain the dependency of the coagulation on concentration of the coagulant.

[B] Determination of the optimal concentration of the non-ionic flocculant *polyacrylamid*

4. Preparation of the SiO_2-suspensions

To carry out a flocculation experiment you have to generate a model solution with a known concentration of turbidity (10 g/l SiO_2 suspension).
850 ml of tap water and 50 ml of the 10 g/l SiO_2 suspension is to add into each of the five flocculation reactors. These suspensions should be stirred constantly at a speed of 200 rpm. After an agitation time of 5 min the suspensions are ready for further experimental application.

5. Preparation of the *of the* coagulant *aluminium sulphate and flocculant polyacrilamid*

For this experiment use the beakers with labels from Al1 to Al5 and add the optimal quantity of ***aluminium sulfate***, wich we have determined in experiment A, only into the beakers from Al1 to Al3 (see Table 3). Then fill up every beaker with tap water up to the 20 ml marks.

In the beakers with labels of FHM 1 to FHM 5 add different quantities of the ***flocculant polyacrilamid*** (see Table 3). Then fill up every beaker with tap water up to the 20 ml marks.

Table 3

beaker number	1	2	3	4	5
aluminium sulfate solution (5 %) (mL)				**0**	**0**
dosage $c_{flocculating\ agent}$ (mg/L)				**0**	**0**
0.5 g/L flocculant solution in mL	0.2	1	2	**0**	**1**
flocculant solution in mg/L	0.1	0.5	1	**0**	**0.5**
FNU after 5 min.					

6. The experimental procedure

6.1. ***Addition of the* coagulant** *aluminium sulphate to the flocculation reactors*

At this step the stirrers in reactors moves at a constant speed of 200 rpm. We add simultaneously the aluminium solution (Al1…Al5) into the flocculation reactors.

6.2 ***Agitation phase 1:*** *growth of microflocs*

The agitation time is 1 minute. During this time, the coagulant distributes evenly in the solution and neutralizes the negative charges of the colloids. Microflocks are formed.

6.3 ***Addition of the flocculant*** *polyacrilamid*

We add simultaneously the polyacrilamid solution (FHM1…FHM5) into the flocculation reactors. At this step the stirrer moves continue at a constant speed of 200 rpm. During this time, the flocculant distributes evenly in the solution and adsorptions on microflocks.

6.4 ***Agitation phase 2:*** *growth of macroflocs*

At this step, we reduce the speed of the stirrer from 200 rpm to 50 rpm for the next 10 minutes. During this time macroflocks are formed by bridging. If the agitation speed is not reduced, the aggregated flocks will be destroyed.

6.5 ***Sedimentation phase****:*

After 10 minutes we turn the stirrers off. The formed flocks settle to the bottom of beakers. We take samples from each reactor, after 5 minutes.The samples are by pipette. It’s very important, that all the samples are taken at the same depth of immersion. We take the samples at the 500 ml marks. The samples are filled into sample cups with labels of P1 to P5.

6.6 ***Determination of the sample turbidity***

The turbidity is measured with the help of a turbidity meter. The cuvette is filled with a sample up to the mark. Then we place the cuvette in the cuvette compartment. As soon as a star symbol appears, you can read the values. These values should be entered in Table 3 in the corresponding boxes in accordance with the sampling time.

<u>Questions:</u>

[1] Explain the function of the flocculant.

[2] Summarize the determined results! What are the optimal conditions for the flocculation of the SiO_2-suspension? Name the optimal concentration of coagulant and flocculant as well as the optimal settling time!

Resuming literature:

DVGW (1985) Flockung in der Wasseraufbereitung. DVGW-Schriftenreihe Nr. 42, 386 S. [20/3517/42]
Kermer, K. (1991) Physikalisch-chemische Verfahren zur Wasser-, Abwasser-, Schlammbehandlung und Wertstoffrückgewinnung. Teil 1, 3. Aufl., Verlag für Bauwesen GmbH, Berlin, 189 S. [20/4028/1]
Kittner, H.; Starke, W.; Wissel, D. (1985) Wasserversorgung. VEB Verlag für Bauwesen Berlin, 5. Aufl., S. 183-190 [20/101]
Mutschmann, J.; Stimmelmayer, F. (1995) Taschenbuch der Wasserversorgung- 11- Aufl., S. 221-224 [20/1828]
Walther, H.-J.; Winkler, F. (1981) Wasserbehandlung durch Flockungsprozesse. Akademie-Verlag Berlin, 250 S. [20/3170]
Winkler, F.; Worch, E. (1989) Verfahrenschemie und Umweltschutz. VEB Deutscher Verlag der Wissenschaften, S. 113-122 [20/4366]
Winzenbacher, R.; Faißt, M.; Schick, R.; Stabel, H.-H. (1998) Effiziente Partikelentfernung bei der Aufbereitung von Bodenseewasser mit geringen Mengen an Fe(III)-Salzen. gwf Wasser Abwasser *139* (3), 137-144.