ASSESSMENT OF THE DRINKING WATER CLARIFICATION UNDER CONDITION OF SLUDGE RETURN TO FLOCCULATOR

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ABSTRACT

Natural surface water contains a wide range of impurities, mostly arising from weathering and human activities. The availability of safe water, and in particular safe drinking water, is one of the most important determinants of our general health.
The removal of suspended matter from water is one of the major goals of drinking water treatment. Effective clarification is really necessary for completely reliable disinfection because microorganisms are shielded by particles in the water.
Coagulation, flocculation and clarification, followed by rapid gravity sand filtration, are the main steps in conventional water treatment systems. Colloidal particles and other finely divided matter are brought together and agglomerated to form larger size particles that can subsequently be removed in a more efficient fashion. The increase in the contact mass increases the probability that collisions will take place inside the flocculator resulting in a more efficient flocculation. Therefore, the intentional introduction of preformed floc or sludge into the mixing and flocculation stage is a feature of most proprietary water treatment equipment.
The aim of study is to explore the wealth of literature to present the new trends of the conventional drinking water treatment that is continuously evolving, especially clarification enhancement and acceleration by solids contact increase. The study will experimentally demonstrate the possibility of turbidity removal enhancement, by increasing the contact mass with adding a sludge dosage during flocculation process. The raw water turbidity removal was investigated under conditions that the destabilized colloids and sludge dosage are mixed during flocculation process. This will simulate the actual condition in which the performed sludge is recycled from the clarifier bottom to the flocculation zone by submersible pumps mainly for sludge blanket establishment.

Key Words: water treatment, flocculation, solid contact, optimization

1. INTRODUCTION

The contaminants which mainly cause turbidity in water are colloidal particles that have extremely large surface area and carry a surface charge making them repel each other. Colloidal particles are larger than atoms and ions but are small enough that they are usually not visible to the naked eye. They range in size from 0.001 to 10 μm resulting in a very small ratio of mass to surface area. The consequence of this smallness in size and mass and largeness in surface area is that in colloidal suspensions, i.e., gravitational effects are negligible, and surface phenomena predominate, [1].

Coagulation and flocculation constitute the backbone processes in most water and advanced wastewater treatment plants. Their objective is to enhance the separation of particulate species in downstream processes such as sedimentation and filtration, [1].
Coagulation is a physical and chemical reaction occurring between the alkalinity of the water and the coagulant added to the water, which results in the formation of insoluble flocs. The most important consideration is the selection of the proper type and amount of coagulant chemical to be added to the water to be treated. Overdosing as well as underdosing of coagulants may lead to reduced solids removal efficiency, [2]. Also, there are important considerations for optimum coagulation to occur: pH of the processing water, duration of coagulation dispersion, and that no other chemical which directly react with coagulant be fed at the flash mixer, [3]. The process water will then enter a flocculation chamber, during which gentle mixing allows particles to agglomerate and form settleable flocs. Optimum flocculation is mainly achieved under the conditions of proper coagulation, optimum pH range, proper level of mixing intensity and adequate net mixing time, [3].

In conventional water treatment systems, coagulation, flocculation and clarification, followed by rapid gravity sand filtration are well-proven technology for the significant removal of colour and particulate matter including protozoa, viruses, bacteria, and other micro-organisms. Iron, manganese, tastes and odors may also be removed from the water by these processes. Some dissolved material can also be removed through the formation of particles in the coagulation and flocculation processes. The importance of dissolved material removal has become much more critical in recent years with increased regulatory emphasis on disinfection by-products and total organic carbon removal, [4]. With respect to coagulation and flocculation, most bacteria and protozoa can be considered as particles, and most viruses as colloidal organic particles, [5]. More recently, coagulation has been shown to be an effective process for the removal of many other contaminants that can be adsorbed by colloids such as metals, toxic organic matter, and viruses, [1]. Enhanced coagulation is an effective method to prepare the water for the removal of certain contaminants in order to achieve compliance with the EPA (Environmental Protection Agency) newly proposed standards. These contaminants include arsenic, emerging pathogens such as *Cryptosporidium* and *Giardia*, and humic materials. Humic substances are the precursors of THMs (trihalomethanes) and other DBPs (disinfection byproducts) formed by disinfection processes, [1].

The increase in the contact mass increases the probability that collisions will take place inside the flocculator resulting in a more efficient flocculation. Therefore, the intentional introduction of preformed floc or sludge into the mixing and flocculation stage is a feature of most proprietary water treatment equipment. High concentrations of suspended solids in the flocculation process can provide improved efficiency in reducing particulates, colloids, organics, and certain ionized chemicals, [6]. The solids contact units, which create or convey a larger mass of sludge into the flocculation area, utilize this principle, [7].

1.1 The Aim of Study

The aim of study is to explore the wealth of literature to present the new trends of the conventional drinking water treatment that is continuously evolving. A special attention is paid to clarification acceleration and enhancement by solids contact increase. The study will experimentally demonstrate the possibility of turbidity removal enhancement, by increasing the contact mass with adding a sludge dosage during flocculation process. The raw water turbidity removal was investigated under conditions that the destabilized colloids and sludge dosage are mixed during flocculation process. This will simulate the actual condition in which performed sludge is recycled from the clarifier bottom to the flocculation zone by submersible pumps mainly for sludge blanket establishment.

1.2 Solid-Contact Up-flow Clarification

High-rate clarification was first used in the 1930s, and it grew in popularity during the 1970s and 1980s. It involves using smaller basins and higher surface loading rates than conventional clarifiers, and is therefore referred to as high-rate clarification. Processes include solids-contact clarification, ballasted-floc sedimentation, and adsorption clarification. In solids-contact clarification, a fluidized blanket increases the particle concentration, thus increasing the rate of flocculation and sedimentation. Ballasted-floc systems combine coagulation with sand, clay, magnetite or carbon to increase the particle sedimentation rate. Adsorption clarification involves passing coagulated water through a bed where particles attach to previously adsorbed material, [5].
Solids contact units offer a great number of advantages, [7]:

- Enhanced flocculation: absence of finely divided particles, homogeneous floc, and a shorter flocculation time,
- Higher settling rate, hence smaller units,
- Completion of specific reactions (precipitation, adsorption, etc.),
- Higher organic matter removal by adsorption on the floc, - savings on chemical reagents.

The design of up-flow solids contact clarifiers is based upon maintenance of a layer or blanket of flocculated material through which water flows in a vertical direction in the clarifier. The purpose of the layer, known as a sludge blanket, is to entrap slowly settling small particles and achieve a high level of clarification. The sludge blanket is maintained at a certain level and concentration by the controlled removal of sludge. The precise height is determined by the clarification rate. When the flow is increased, the clarification rate is greater and the level of the blanket rises, [8].

Effectively, incoming destabilized particles passing through the sludge blanket gives a greatly enhanced flocculation rate. Another point is that floc growth in the blanket is by the attachment of small particles to existing flocs, which gives denser flocs than those produced by cluster-cluster aggregation. This means that the flocs will have a higher settling rate, so higher up-flow rates are possible. The combination of flocculation and sedimentation in a single clarifier unit has great advantages. There are many different commercial designs of flocculator-clarifiers (also called clariflocculators), and these are widely used in practice, [9].

The up-flow clarifier, specifically the sludge-blanket clarifier, is often used in water softening operations. This system combines mixing and sludge recirculation. The recirculated settled sludge provides additional particles that increase the probability of particle contact and forms a dense sludge blanket. The sludge blanket concentrates, traps, and settles out suspended particles and floc before they are discharged over the effluent weir, [6].

1.3 Operational Considerations

Optimizing water treatment plant operation is a concept should be applied by all plant operators to have continuous operational improvements. El-Nahhas [10] concluded that global optimization for the water treatment plant operation can be obtained by understanding and control of physicochemical environment of the colloidal suspension. The characteristics of a suspension can be tailored by understanding the particle-to-particle interactions. The attractive forces should prevail for colloids removal to form large flocs, while it should be minimized keeping each particle discrete during sludge hydrotransport, [10].

When feeding coagulant, the pH of the raw water is obviously important because the coagulation process requires an adequate amount of trivalent or even high ionic species in order to effectively reduce the electrical charge of the colloidal particles. When using alum sulfate as a coagulant, there is an interrelation between pH and the type of aluminum hydroxide formed. This in turn determines the charge on the hydrous oxide complex. Another important aspect of pH is its effect on solubility of the aluminum (Al^{+3}) ion, [1]. Because the raw water pH value is a very important factor for adjusting the suspension physicochemical environment and colloids removal, it should take into consideration any additive effect that can alter this value either positively or negatively. This can led to obtain optimum turbidity removal and/or economic coagulant dose. The presence of powdered activated carbon among the colloidal particles also affects the suspension physicochemical environment. It enhances the flocculation performance and turbidity removal, [11].

Sludge control is very important in the operation of up-flow clariflocculators that operate using a sludge blanket. The reactor section of the basin must be monitored daily, and the appropriate amount of sludge must be removed from the basin to maintain the optimum reactor concentration and sludge blanket depth. Inadequate monitoring of the basin can lead to a loss of the sludge blanket over the weirs, which significantly degrades unit process performance and, ultimately, filter performance. A 100 mL graduated cylinder has been used to monitor sludge mass in a reactor type basin. A volume of 18 - 25 mL of sludge in a 100 mL cylinder, after five minutes of settling, has provided satisfactory performance at one location, [12]. Another issue to consider is the possibility of floc breakup after the settled water leaves the sedimentation basins. Depending on the chemical conditioning used in the plant, coagulated particles may break apart because of turbulence when the settled water is conveyed to the filtration process. If floc breakup is suspected, operational changes, such as flooding the effluent weirs, can be tried to assess if performance improves. Additionally, the use of a filter aid can assist in overcoming the detrimental impacts of floc breakup, [12].

Design dosages for chemicals should be based on experience with similar types of waters or, preferably, with bench-scale and pilot tests. The effectiveness of coagulation and flocculation can also be monitored by several parameters, including turbidity, zeta potential, streaming current, and particle counts, [6].

1.4 Assessment of the Processes

Because the practical processes is so complex and the number of variables is so large, in most cases it is not feasible either to predict the best type of coagulant and optimum dosage or the best operating pH. The most practical approach is to simulate the process in a laboratory setting using the jar test, [1]. The jar test has been and is still the most widely used method employed to evaluate the coagulation process and to aid the plant operator in optimizing the coagulation, flocculation and clarification processes. From the turbidity values of the settled water, settling velocity distribution curves can be drawn. These curves have been found to correlate well with the plant operating data and yield useful information in evaluating pretreatment, such as optimizing of velocity gradient and agitation and flocculation, pH, coagulation dosage and coagulant solution strength. Such curves cannot be generalized and are relevant to the plant for which the data have been collected through the Jar tests, [2].

A jar test apparatus is a variable speed, multiple station or gang unit that varies in configuration depending on the manufacturer. The differences, such as the number of test stations (usually six), the size (commonly 1000 mL) and shape of test jars (round or square), method of mixing (paddles, magnetic bars, or plungers), stirrer controls, and integral illumination, do not have an appreciable impact on the performance of the unit. Other available alternatives and/or supplementary techniques include the zetameter (electrophoretic measurement) and the streaming current detector.

2. BENCH-SCALE LABORATORY TESTS

For the study the effect of the return sludge addition, during flocculation stage, on the processes efficacy, a bench-scale laboratory testing was carried out conducting with the standard jar test procedure. The laboratory Floc tester, model AL 46-6 with 6 stirring places had been used as floc testers and universal agitators. A photo for this apparatus and its schematic diagram are shown in Figure 1. The stirring rate is infinitely variable between 20-300 rpm. The stirring rate is shown in LED display. The stirring time is also set and shown via an LED display. The high position of the agitator blades can be adjusted during operation, the rear panel is illuminated to allow a perfect observation of the samples.

(A)

(B)

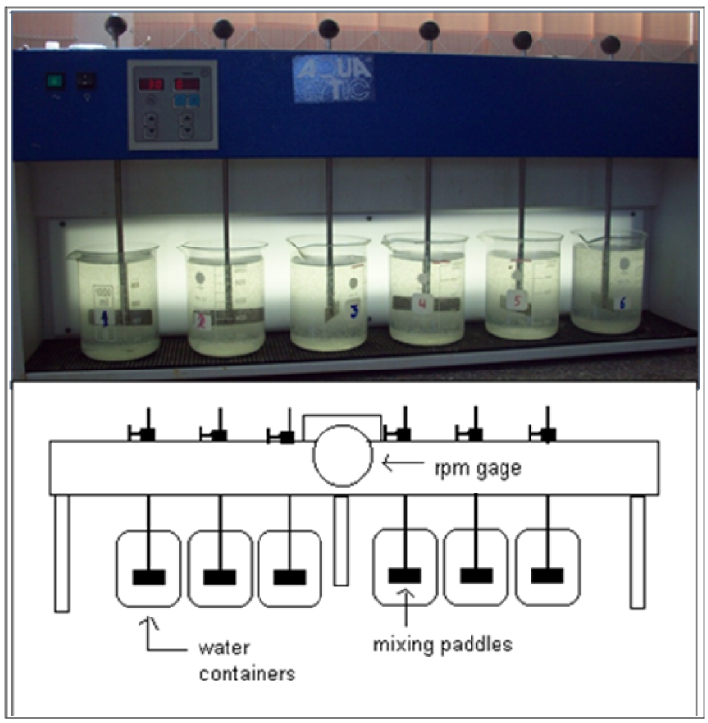

Fig. 1 The laboratory floc tester: (A) photo, (B) schematic diagram

The instrument is driven by one common motor for all stirring position to ensure a uniform stirring rate for all stirring positions. The individual stirring positions are connected with the motor by means of pulley belts. The speed of the motor is directly calculated with the aid of an incremental transducer and after electronic evaluation transmitted to the indicator. Presetting of the stirring time is made possible through the time-LED-display. The stirring time can be entered in increment of one minute each. When this preset time has elapsed the stirring is switched-off automatically. The shafts of the agitator blades are fitted with slip clutches close to the bearings, this allows the manual stopping of individual stirring positions as well as high adjustments during operation.

The turbidity of the water at different stages had been measured using a turbidity meter model LAB-VIS, manufactured by HF scientic inc. it conforms to specifications set forth in EPA method 180.1 (Nephelometric Method). The measuring range is 0-1000 NTU with resolution 0.01 NTU in the range

0.00 – 9.99 NTU, 0.1NTU in the range 10.0 – 99.9 NTU and 1 NTU in the range 100 – 1000 NTU. The accuracy is ± 2% of reading or ± 0.01 NTU whichever is greater.
The pH measurements were made by the compact precision pH 315i handheld meter, manufactured by WTW GmbH, whose error is ±0.01 and resolution is adjustable (0.01or 0.001).

Samples of raw water were dosed with varying amounts of coagulant under standard rapid mix conditions, in order to distribute the additive evenly. The samples are then given a standard period of slow stirring at a fixed speed, during which flocs may form. A certain period of sedimentation is then allowed, after which samples of water are withdrawn for turbidity measurement. The residual turbidity of the settled samples was measured for giving a good indication of the degree of clarification obtained and can be used to locate the optimum flocculation conditions. The tests were normally conducted in above mentioned apparatus with multiple stirrers so that six samples can be tested simultaneously. A typical procedure involved 1 min of rapid mix at 100 rpm, 19 min of slow stirring at 30 rpm and 15 min sedimentation. The experiment was repeated with adding a fixed sludge dosage (30 mg/l) to all jars at the beginning of the flocculation period. Another two sets of experiments with two different coagulant fixed dosages (25 and 40 mg/l) were carried out while different sludge dosages were added to the six jars for each case. The used sludge is extracted from the actually return-sludge in an up-flow sludge blanket clariflucculator. The appearance and size of the floc, the time for floc formation, and the settling characteristics were noted. The clarified water is analyzed for turbidity and pH.

3. RESULTS AND DISCUSSIONS

The intentional introduction of preformed floc or sludge into the flocculation stage is a feature of the high-rate solid-contact clarification systems. The purpose of conveying the sludge into the flocculation zone is mainly to maintain a layer or blanket of flocculated material through which water flows in a vertical direction in the clarifier. Figure (2) shows the effect of return-sludge on the clarification processes itself, regardless its main purpose. A certain sludge dosage (30 mg/l) was added at the beginning of the flocculation period, during the jar test procedures. The sludge dosages were added to the six vessels that had different coagulant dosages (25-45 mg/l). Figure (2) also shows the normal case, without return-sludge, for comparison.
It could be noticed that the return sludge enhanced the clarification processes for the all coagulant dosages. It raised the maximum possible turbidity removal from about 95% to about 97% where obtained at 40 mg/l coagulant-dosage in the two cases. This could be due to the increase in the contact mass that increases the probability of particles collisions taking place inside the flocculator and resulting in a more efficient flocculation process.

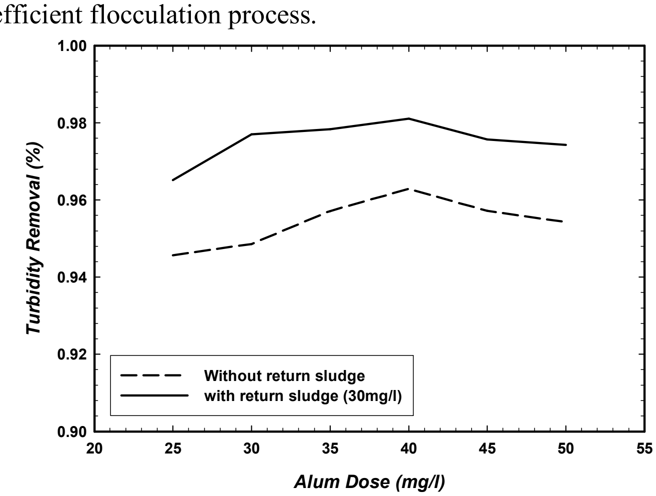

Fig. 2 Turbidity removals with and without sludge dosing at different alum dosages

To demonstrate the effect of the quantity of added return-sludge, two sets of experiments were carried out for two coagulant dosages (25 and 40 mg/l). Sludge was added for each case in the six vessels with different dosages. Figure (3) shows generally that the turbidity removals increase as the return-sludge dosage increase reaching a maximum value, and then decrease. For the alum dosage of 40 mg/l the turbidity removals increase as the return-sludge dosage increases up to 30 mg/l, then it goes with more or less the same value for the two following successive sludge dosage (35 and 40 mg/l). More increasing of sludge dosage (to 45mg/l) caused the turbidity removals to begin decreasing. It could be noticed the same behavior for the case of lower alum dosage (25 mg/l) but with earlier actions as following: the turbidity removals increase as the return-sludge dosage increases up to 25 mg/l, then it goes with more or less the same value for the two following successive sludge dosage (30 and 35 mg/l). More increasing of sludge dosage (to 40 gm/l) caused the turbidity removals to begin decreasing. This could be explained as the lower alum dosage has not the capability to act with the higher solids content caused by higher return-sludge dosages.

As discussed previously, there is a strong relation between pH and turbidity removal performance. It should take into consideration any other additives (rather than the coagulant) that could be added in the different stages of the processes and its effects on the environment pH value. Figure 4 shows the effect of the return-sludge addition on the pH values of the media. It could be noticed that the return-sludge causes lowering the pH values that are normally decrease with increasing the alum dosages.

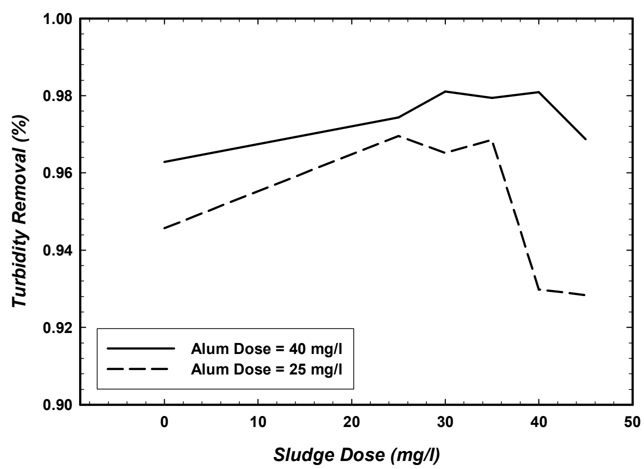

Fig. 3 Turbidity removals at different sludge dosing with two different alum dosages

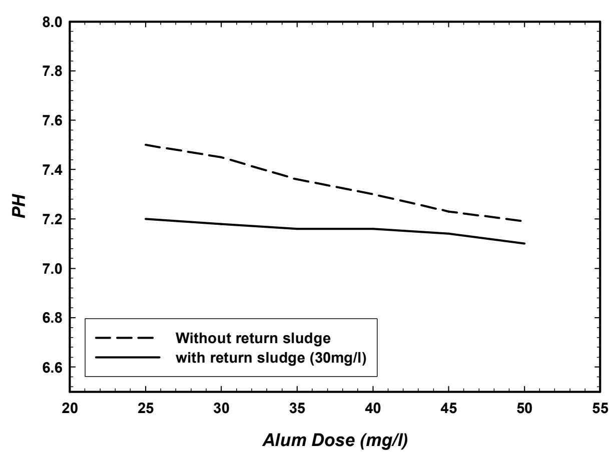

Fig. 4 pH values with and without sludge dosing at different alum dosages

4. CONCLUSIONS

The conclusions can be summarized and presented as the following:

- It has been confirmed that the performed floc that is intentionally introduced into the flocculation zone, essentially to maintain a flocs blanket through which water up-flows in the clarifier, also enhances the flocculation process.
- As the return-sludge dosage increases the turbidity removals increase reaching a maximum value, after which it remains nearly constant and then decreases. The performance and behaviour are dependent on the alum dosage.
- Adding the performed flocs into the flocculation stage causes the media pH values to decrease.
- It is recommended that the up-flow clariflocculator should be monitored daily to control the appropriate amount of sludge to be removed maintaining the optimum reactor concentration and sludge blanket depth.
- To obtain optimum turbidity removal and/or economic coagulant dose, it should take into consideration any other additives (rather than the coagulant) in the different clarification stages and its effects on the physicochemical environment. This should be included with the periodically simulating laboratory bench-scale tests.

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