A

DISSERTATION REPORT

On

“Comparison of Pulsator and Conventional Clariflocculator for Residual Aluminium levels”

By

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Abbreviations

DAF: Dissolved Air Floatation

PAC: PolyAluminium chloride

RPM: Rotations per minute

ACH: Aluminium chlorohydrate

IPFs: Inorganic polymeric flocculants

Lpm: liters per minute

BWSP: Bisalpur Water Supply Project

ppm: parts per million

Abstract

Coagulation and flocculation play a dominant role in many water and wastewater schemes. The success of treatment plant depends on the effectiveness of the coagulant and the clarifier. Clariflocculators have been used conventionally for the removal of suspended solids. These days, it is common to use a high rate modification of conventional systems like sludge blanket clarifiers. Superpulsator® manufactured and designed by Inflico Degremont, is one such proven clarification technology that results in a better effluent quality with minimal operating costs. However, this technology was yet to be examined for various applications like reducing the residual Aluminium levels. Therefore, a pilot plant based on Superpulsator® was designed and fabricated for a capacity of handling 8000 liters of water per day. For this, treatment plant of PHED at Surajpura was surveyed to understand the functioning of Superpulsator®. To analyse the performance of pulsator, a conventional clariflocculator model was also designed and fabricated.

Alum, the most widely used coagulant is well known for its poor performance in treating water with low turbidity and less alkalinity. PolyAluminium chloride, a relatively new polymeric Aluminium coagulant is increasingly being used in the treatment plants, is found to be more advantageous than alum. In this research, both the models were run at various turbidities in the range 2-30 NTU and their efficacy in reducing the residual Aluminium were compared.

The results of the research indicated that both the models yielded relatively lower residual aluminum levels. However, residual Aluminium in treated water by Pulsator was more close to the standard value of 0.030 mg/L as set by Indian regulations (IS 10500:2012).

1. Introduction

1.1 Background

Water is a fundamental human need. It is necessary for humans to have clean drinking water. This is why water treatment plants have to go through a series of purification where coagulation and flocculation processes play a significant role. These processes are necessary to remove particulate matter which is too small in size to settle by gravity in sufficient time frame.

Chemical treatment typically is applied before sedimentation and filtration to enhance the ability of a treatment process to remove particles. Typically two steps are employed: coagulation and flocculation. Coagulation is a process to neutralize surface charges and then to form a gelatinous mass to trap (or bridge) particles thus forming a mass large enough to settle under gravity or be trapped in the filter. Flocculation is gentle stirring or agitation to promote the particles thus formed to agglomerate into masses large enough to settle or be filtered from the solution (Engelhardt, Terry L., 2014).

Traditionally, Coagulants such as alum, ferric sulphate are added to the water to be treated. Alum is effective in treating a broad range of water types but is less efficient in treating water with low turbidity and low alkalinity. However, alum can be subject to significant deterioration of treatment efficiency in some waters, especially in certain ranges of pH and temperature(C Ye. Et al,2007).

Polyaluminum Chlorides(PACl), a relatively new polymeric coagulant increasingly in use in water treatment plants is found to have more advantageous than conventional alum like low dosage requirement, high efficiency, low cost and convenient usage (Zhang et al.,2008)(Yi Geng ,2005). An important property of poly aluminium coagulants is their *basicity*. It is the ratio of hydroxyl ions to aluminium ions in the hydrated complex and in general the higher the basicity, the lower will be the alkalinity requirement in the treatment process and hence impact on pH(Gebbie, Peter, 2001). The poly aluminium coagulants,in general,consume relatively less alkalinity than alum. They are effective over a wider pH range compared to alum and studies shows that PACl works satisfactorily over a pH range of 5.0 to 8.0 (Gebbie, Peter, 2001) (David, Yonge,E.I., 2012). Although the use of inorganic pre-polymerized flocculants (IPFs) has significantly increased, studies of the coagulation process using polyaluminium chloride (PACl) have indicated that the chemical species of PACl and their activities lead it to be more effective in coagulation in some cases(Xiaohong et al.,2009).

Conventionally, coagulation and flocculation occur in successive tanks intended to overcome the forces stabilizing the colloidal particles, allowing particle collision and formation of flocs, which then can be settled and removed out of the water. Most of the water and wastewater treatment plant are based on the conventional designs.

However, The Superpulsator®, a proven clarification technology is a high solids contact clarifier. Its unique design combines the flocculation and clarification functions in one basin for optimal use of space. The Vacuum generated pulses create a homogeneous blanket that results in a better effluent quality at minimal operating costs. This design results in optimal solid removal with low maintenance and minimal operation attention.

Bisalpur water supply Project is a state of the art plant, only one in Rajasthan that has employed SuperPulsator clarifier. The Bisalpur-Jaipur Water Supply Project (BWSP) has been designed to deliver water from the existing Bisalpur Dam headworks up to Balawala on the south edge of Jaipur City to reduce the city's reliability on its ground water resources and includes complementary provisions for supplying water to nearby areas. The conceptual planning for the BWSP is to utilize the water of Bisalpur Dam in a phased manner to meet the ever increasing water demands of Jaipur City and reduce the groundwater abstraction to sustainable limits. With the completion of the phase-II expansion, the project will achieve a total capacity of 1020 MLD clear water production.

The plant receives very low turbid water mostly below 15 NTU. Hence, a better clarification technique i.e. Pulsator accompanied with a coagulant working on bridging mechanism i.e. poly aluminium chloride is administered in the plant. At present, 100% PAC is being used as the coagulant which costs around Rs 1 lakh while the chlorine costs around 15,000 INR on the daily basis. Also, the plant is successful in restricting the residual aluminum levels equal to less than 0.005 mg/L.

The presence of Al in treated water or as a precipitate in the distribution system has been considered for many years as an undesirable aspect of treatment practice, and it has been associated with numerous problems, including increased turbidity, reduced disinfection efficiency, and a loss in hydraulic capacity (Yang et al., 2010).

Issues have been raised that the use of alum may increase aluminum concentrations in treated water (Kimura et al., 2013).However, because high aluminum levels in treated water are associated with increased turbidity and because aluminum exerts undeniable human health effects, its concentration must be controlled in water treatment plants, especially in plants that use aluminum coagulants. The effect of poly aluminum chloride (PACl) coagulant characteristics on dissolved residual aluminum concentrations after coagulation and filtration are being investigated. Many factors influence the concentration of residual aluminium remaining in water treated with aluminum coagulants.

Therefore, the development of coagulants that can easily decrease residual aluminum concentrations to <0.03mg/L ,even for treated water in which coagulation pH is not optimized, is highly desired as per the Indian standards (IS 10500:2012).

There is a considerable concern throughout the world over the level of aluminum in drinking water sources (raw water) and treated water. The ingestion of high concentrations of Al is also of concern because of potential adverse health effects (G.Eric et al.,2000). Furthermore, scientific issues about the association between Al and Alzheimer’s disease are pending resolution (Srinivasan et al., 1999). From the standpoint of treatment plant performance, high levels of residual dissolved Al indicate incorrect coagulant dosing, inefficient coagulant use, or problems in the chemistry of treatment process(B.guy et al.,2002). High levels of particulate Al may cause problems in solid–liquid separation of postprecipitation of Al. Thus, Al fractionation measurements can provide the treatment plant operator with important information about various aspects of plant performance (John et al., 1990).

1.2 Need of the study:

Despite the various researches on coagulation and flocculation in water treatment, no theoretical and experimental analysis has been reported in the literature to describe the sludge blanket formation and operation of the pulsator clarifier.

The pulsed sludge blanket technology is a result of latest developments in the field of water and wastewater treatment. Growing environmental concern pertaining increased Al concentrations in fresh and treated waters led to the development of ways by which residual aluminum can be reduced. However, this technology is yet to be examined for various applications like in lowering residual aluminium levels.

The water treatment plant at Surajpura incurs a cost of around 1Lakh rupees per day on coagulant Poly aluminium chloride. The other cost for chemical included chlorine for disinfection for Rs 15000 on a daily basis. Thus, it is important to suggest a better and economical way of reducing the cost of chemicals required for coagulation and disinfection. Therefore, it is necessary to examine the optimum dose of PAC which can bring down the turbidity to desired value without compromising on residual aluminium levels.

The present study is carried out by a group of four students of MNIT, Jaipur. The complete study work consisting of design, fabrication and experimentation was done as a team and individual studies are then taken up by each student for detailed investigation. The work was divided into following four thesis titles:

- Comparative analysis of turbidity removal in pulsator pilot scale model vs. conventional clariflocculator by Megha Gupta.
- Comparative analysis of aluminium removal in pulsator pilot scale model vs. conventional clariflocculator by Neelam Kothari.
- Comparative analysis of the effect on performance of the pulsator pilot plant and conventional clariflocculator when polyaluminium chloride and alum are used as coagulants by Shashank Srivastava.
- Performance Analysis of Surajpura WTP of Bisalpur Jaipur Water Supply Project and Cost Optimization Study using a Pulsator Clarifier Pilot Plant by Suparshve Kumar Jain.

1.3 Objectives of the study:

1. To develop a pilot scale model on Superpulsator and Conventional Clariflocculator.

2. To run the models at different turbidities ranging from 2-30 NTU using PAC as a coagulant and measure residual aluminium in treated water.

3. To examine the species of residual aluminium .i.e dissolved or suspended.

4. To compare the effectiveness of both the models concerning residual aluminium levels.

2. Literature Review

2.1 Coagulation and Flocculation

In water treatment, coagulation is the important process through which suspended, colloidal and dissolved matter are destabilized by the addition of a chemical (coagulant). The Coagulant is key to flocculation efficiency (Alberto et al,2014).Chemical treatment is applied before sedimentation and filtration to enhance the ability of a treatment process to remove particles. Two steps which are employed: coagulation and flocculation (Engelhardt, Terry L., 2014).

Coagulation is a process to neutralize charges and to form a gelatinous mass to sweep (or bridge) particles thus forming a mass large enough to settle under gravity or be trapped in the filter. Flocculation is a gentle stirring or agitation to encourage the particles formed to agglomerate into masses large enough to settle or be filtered from solution. Particles in water, smaller than 10 μ, are difficult to remove by plain sedimentation or by filtration. This is primarily true for particles smaller than 1 micron – colloids.

Coagulation is, “the effect produced by the addition of a chemical to a colloidal suspension resulting in destabilization of particles by the reduction of the forces tending to keep the particles apart” (Engelhardt, Terry L., 2014). Table 1 shows various particles sizes along with their terminal settling velocity. From these values, it is evident that plain sedimentation will not be very efficient for the smaller suspended particles (Peave Rowe, 1985).

Table 2.1: Settling Velocities of various size particles (Source: Peave Rowe, 1985)

Particle diameter,mm	Size typical of	Settling velocity
10	Pebble	0.73m/s
1	Coarse sand	0.23m/s
0.1	Fine sand	1.0×10^{-2} m/s (0.6m/min)
0.01	Silt	1.0×10^{-4}m/s (8.6m/d)
0.0001	Large Colloid	1.0×10^{-8}m/s (0.3m/yr)
0.000001	Small colloid	1.0×10^{-13}m/s(3m/million yr)

2.2 Clarification/Sedimentation

After coagulation and flocculation, water containing flocs usually passes to a settlement/clarification phase.

Clarification has more than one roles in water treatment plant.In a conventional treatment process its usual purpose is to reduce the solids load after coagulation and flocculation. Another application is the removal of heavy settleable solids from turbid water sources to lessen the solids load on treatment plant processes (John F.Willis, 2005).

Criteria for design of clarifiers/settling basins have evolved as much from practice as from theory. One way of designing the clarifiers is to maximize solids removal which generally requires lower clarifier loadings and larger, more cost intensive units. On the other hand, the clarifier may be designed to remove only sufficient solids to provide reasonable filter run times and to enhance the quality of filtered water. This latter approach optimizes the entire plant and generally leads to smaller, less expensive facilities. Typical loading rates can be conservatively selected for optimization of the clarifier-filter combination to provide high-clarity water (John F.willis, 2005).

2.3 Types of clarifiers/settling basins

Earlier, the only process used was some form of settlement basin in which the flocs settled out. These days,it is common to use either DAF or a sludge-blanket clarifier which are better described as clarifiers and not as settlement basins (George Smethrust, 2002).

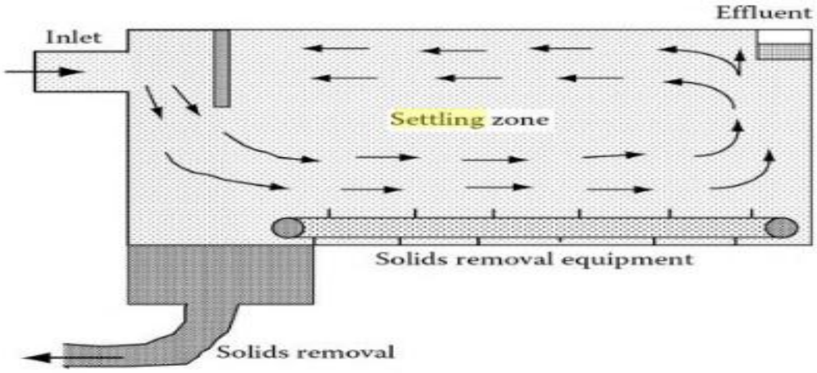

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Figure 2.1: Conventional rectangular settling basin Source: David Hendricks,2011

There are two basic categories of settling basins: horizontal flow and vertical flow; and two other categories of clarifiers: vertical-flow solids contact tanks; and DAF tanks.

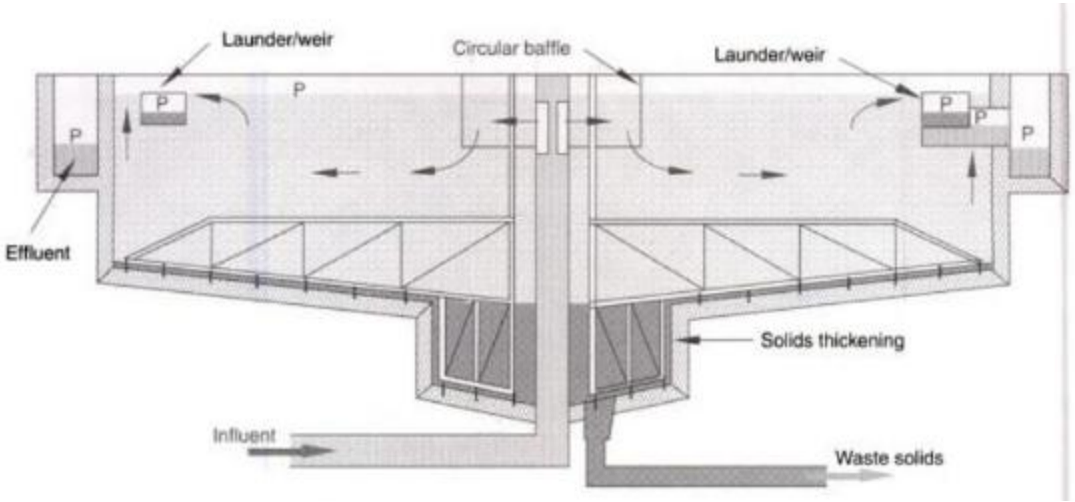


Figure 2.2 : Circular settling basin Source:David Hendriks,2011

Horizontal- and vertical-flow tanks predominantly remove already flocculated particles; there is some additional flocculation, but this is not a major factor. Horizontal-flow tanks are generally rectangular or circular. Long rectangular basins , shown in figure 2.1, are generally used in treatment plants treating large flows. Circular settling basins, shown in figure 2.2, have the similar functional zones as the long rectangular, but their flow regime is a bit different. When the flow enters at the center and is baffled to flow radially towards the circumference, the horizontal velocity of the water continuously decreases as the distance from the center increases. Circular tanks have certain advantages. Sludge removing mechanisms are simpler and require less maintenance. Vertical-flow tanks are usually square hopper-bottomed tanks (Peave Rowe,1985).

Clarifiers fall into two basic categories: the ones used only to remove settleable solids, either by plain sedimentation or after flocculation, and the ones that combine flocculation and clarification processes into a single unit, better known as clariflocculators shown in figure 2.3. The first category includes conventional sedimentation basins and high-rate modifications such as dissolved air flotation (DAF) shown in figure 2.4 and tube or plate settlers. The second type includes solids contact units such as slurry recirculation clarifiers and sludge blanket clarifiers (John F.willis, 2005).

Figure 2.3: Conventional Clariflocculator Source:Sapient Consultants

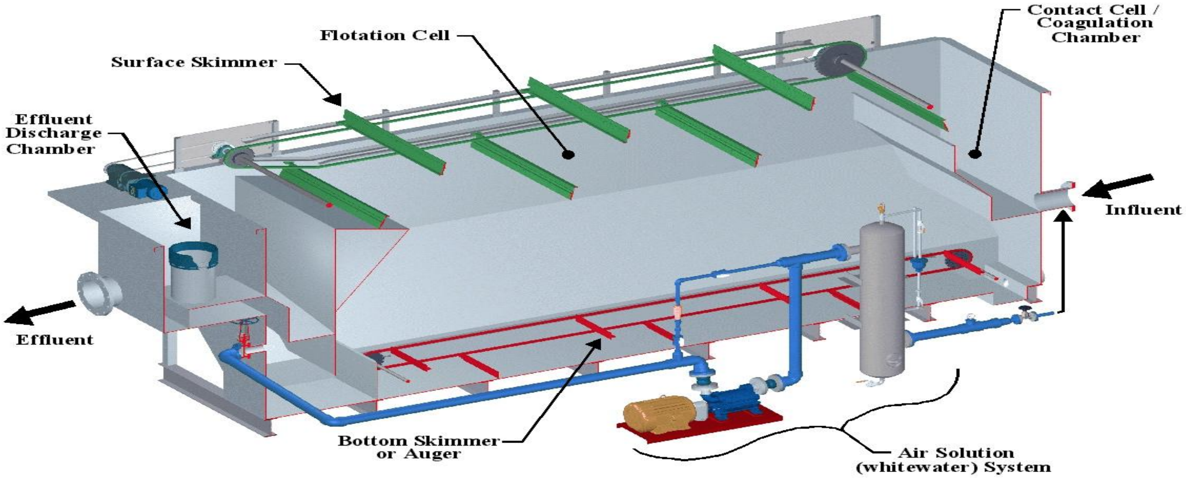


Figure 2.4: Dissolved Air floatation Source: C.Ross et al., 2000

Vertical-flow solids contact tanks/sludge blanket clarifiers, as shown in figure 2.5, achieve much higher efficiencies partly by passing flow through a sludge blanket .These particles, which would otherwise rise and continue to pass on, are retained within the floc layer as the flow passes through the sludge blanket resulting in flocculation and entrapment of fine particles. They have been evolved from hopper-bottomed vertical-flow tanks, which are very deep, and have developed into flat-bottomed upward-flow clarifiers that have a relatively shallow depth of construction (Smethrust, 2002).

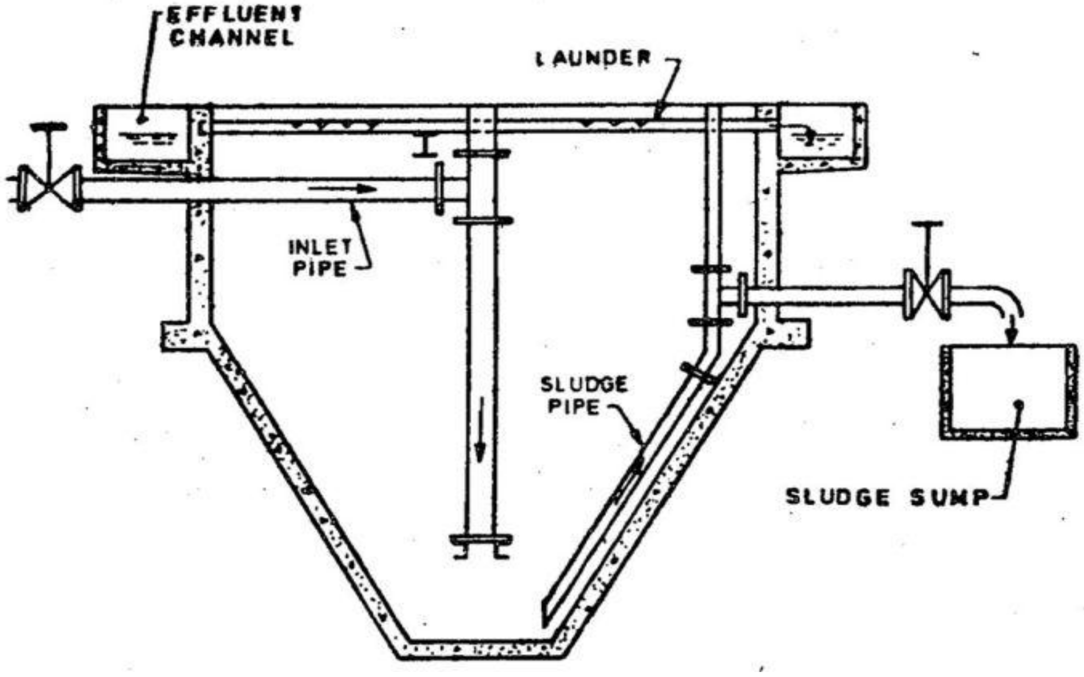


Figure 2.5: Hopper bottomed settling tank , Source : IS 10261:2005: Indian standards for requirements for settling tanks

Pulsator clarifier is a simple type of upward flow tank whose effectiveness depends on a sludge blanket. It is most widely used clarifier in the world because it is highly reliable and flexible. In a pulsator clarifier, the water flows upward through the sludge blanket in a cycling or pulsating flow. During surging flow, the bed expands uniformly. During subsiding flow, the bed settles uniformly. As a result of pulsating flow, the sludge blanket remains homogeneous throughout, with no stratification, facilitating continuous, effective contact between water and sludge. Flocculation rate is one of the most important characteristics in the operation of a pulsator clarifier. This rate is influenced by a number of physical parameters and operating conditions: sludge blanket height, upflow velocity of coagulated water, the volume concentration of sludge blanket and physical properties of flocs. All these factors are highly interactive and control the clarifier performance. Superpulsator® , a proprietary technology , designed and manufactured by Inflico Degremont is shown in figure 2.6.

Despite the pulsator clarifier is most widely used in the world in many water treatment stations, no theoretical and experimental analysis has been reported yet in the literature to describe the operation of a pulsator clarifier.

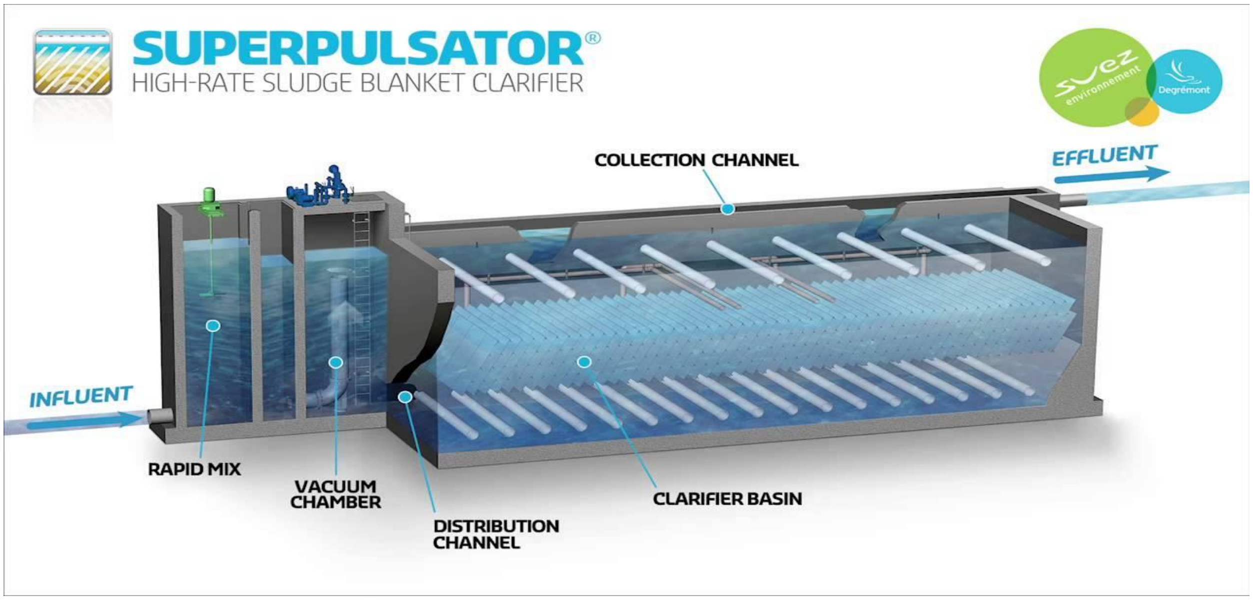


Figure 2.6: Superpulsator® Clarifier Source: Infilco Degremont

In a typical water-treatment plant, the filtration stage is often considered as the fundamental of the process. The influent to the filters was clearly non-potable, but after disinfection the filtered water was virtually potable water. As standards for water quality have become more stringent this perception is no longer true in many cases, but filtration still exists to be a critical stage in water treatment plant and many modifications in the conventional have been made over the years to be able to produce water which can meet higher water-quality standards. Earlier, filtration referred only to granular filtration, using sand or other granular material. Nowadays, where their use is appropriate, non-granular filters are becoming increasingly popular.

Basically, the filtration process consists of passing water through a granular bed, of sand or another suitable medium, at low speed which retains most suspended solids while allowing the water to pass, and the effluent from a filter performing well will be crystal clear with a turbidity of less than 0.2 NTU. Filtration almost always follows a clarification stage except for treatment of high-quality groundwaters. Hence, there is a trade-off between the performance of the clarification and the performance of the filters; the more efficient the clarification, the less the filters have to do and vice versa(Smethrust,2002).

2.4 Types of Coagulants

The traditionally used metal coagulants fall into two general categories: iron based and aluminium- based coagulants.The aluminum coagulants include aluminum sulphate, aluminum chloride and sodium aluminate, polyaluminium chloride. The iron coagulants include ferric sulfate, ferrous sulfate, ferric chloride and ferric chloride sulfate.

Colloidal particles which do not agglomerate naturally are termed as stable .The most important factor contributing to the stability of colloidal suspensions is the excessively large surface to volume ratio resulting from their very small size. Most of the colloidal particles have a static negative electrical charge.The greater the surface area with respect to the particle mass, the greater is the effect of the charge.

The particles do not agglomerate into larger particles and settle naturally because the force of repulsion exceeds the force of gravity.The charged particles attract a cluster of other charges to surround the colloidal particle with greater concentrations of positive or counter ions close to the colloidal particles.This is often known as the ‘double-layer theory” or double-layer model.So, colloids repel one another and are kept apart by this double-layer effect.

The purpose of adding a coagulant is to neutralize the charge. As most of the colloidal particles in water are negatively charged, any positive ion (cation) can be therefore used as a coagulant. A sodium compound (like sodium hydroxide), gives a monovalent ion, Na+ and a calcium compound (like calcium hydroxide) gives a divalent ion, Ca2+ and Aluminum and iron coagulants contribute trivalent aluminum ions, Al3+ and trivalent iron ions, Fe3+, respectively(Engelhardt, Terry L., 2014).

The efficacy of aluminum and iron coagulants arises predominantly from their ability to form multi-charged polynuclear complexes with improved adsorption characteristics. The pH of the water regulates the nature of the complexes formed in water.

When metal coagulants are added to water the metal ions (Al and Fe) hydrolyze quickly but in a somewhat uncontrolled way, forming a series of metal hydrolysis species. The effectiveness of rapid mixing, the coagulant dosage and the pH govern which hydrolysis species is effective for treatment.

Nowadays, prehydrolyzed inorganic polymeric coagulants , based on both aluminum and iron have been considerably developed which produces the correct hydrolysis species regardless of the process conditions during treatment. Inorganic polymeric coagulants mainly include aluminum chlorohydrate, polyaluminium chloride ,polyaluminium silicate chloride and forms of polyaluminium chloride with organic polymers. Iron forms include ferric salts and polyferric sulfate with polymers. The principal advantages include effective functioning over wide ranges of pH and raw water temperatures ,requirement of lower dosages; lesser chemical residuals and lower chloride or sulfate residuals, resulting in lower final water TDS.

2.5 Polyaluminium chloride

PAC is an effectual & useful substitute for solid alum which is conventionally used as a coagulant in many water treatment plants in India. It can cause effective coagulation of water at various turbidities, producing less sludge & leaving less amount of residual aluminium (Sonu Malhotra, 1994).

Other advantages of polyaluminium chloride include the following:

- low levels of residual aluminium can be achieved in treated water, typically in the range of 0.01-0.05 mg/L,
- PACl work extremely well at low raw water temperatures. Flocs formed by alum at low temperatures settle very slowly, whereas flocs formed from polyaluminium chloride tend to settle equally well at low and at normal water temperatures,
- less sludge is produced in comparison to alum at an equivalent dose,
- much lower doses are required to achieve desired turbidity in comparison to alum.
- results in less overall increase in TDS.

However, Alum has various disadvantages:

- limited coagulation pH range: 5.5 to 6.5,
- to attain the optimum pH for coagulation, supplemental addition of alkalinity to the raw water is often required.
- residual aluminium concentrations in the treated water can often exceed desirable limits,
- alum floc produced is particularly fragile primarily important if a coagulant is required to maximise colour removal in a microfiltration-based water treatment process(Gebbie, Peter, 2001).

PAC is made by partial hydrolysis of aluminum chloride acid solution using a specific reactor. These compounds have the common formula $Al_n(OH)_mCl_{(3n-m))x}$ and have a polymeric structure which is entirely soluble in water. The length of the polymerized chain, molecular weight and number of ionic charges is determined by the degree of polymerization. Polyaluminum chloride, one form of inorganic polymer coagulants, contains monomeric Al, polymeric Al, and aluminum hydroxide.

2.6 Destabilisation Mechanisms

Earlier studies considered that hydrolyzing iron and aluminum metal coagulants were efficient in forming enormous flocs which can be separated eventually by sedimentation and filtration. Later, chemical aspects of coagulation demonstrated that the hydrolysis products of polynuclear hydroxyl complexes were the active species responsible for charge neutralization and destabilization. Despite various progressive viewpoints in understanding interactions between particles and coagulants, four primary mechanisms were commonly recognized, i.e. double layer compression, charge-neutralization, sweep-flocculation and bridge-aggregation (X. Wu et al.,2007). Coagulation mechanisms may be different under different coagulation conditions for metal salt coagulants. Charge neutralization and sweep coagulation are the most important coagulation processes. Double-layer compression is not a feasible method for wastewater treatment and is only important at low pH . The dominant mechanism depends on solution pH and coagulant dosage, and is apparently determined by the diphase equilibrium state between soluble metal species and hydroxide precipitation(Ning Wei et al.,2015).

It is generally seen that by increasing the ionic strength of the solution, compression of the double layer occurs thereby reducing the range of interparticle repulsion. For a given suspension, as the ionic strength is incrementally increased, the transition from stability to destabilization occurs over a narrow range of coagulant concentration. (Bratby, 1980).Some chemical species are capable of being adsorbed at the surface of colloidal particles. The nature, rather than the quantity, of the ions is of prime importance in the theory of adsorption and charge neutralization(Peave Rowe,1985). Adsorbed species carry a charge opposite to that of the colloids, which causes a reduction of surface potential and therefore results in destabilization of the colloidal particle. Adsorption and charge neutralization is a much different mechanism than ionic layer compression. The sorbable species are capable of destabilizing colloids at much lower dosage than nonsorbable "ionic layer compressing" ions. Destabilization caused by adsorption is stoichiometric. Thus, the coagulant dose required increases as the concentration of colloids increases. Furthermore, there is no effect on destabilization if an excess of coagulant is applied because restabilization of a suspension often takes place . Furthermore, the efficacy of a coagulant is strongly dependent on the valency of the counter-ions such that for mono-, di-and trivalent counter-ions, the concentration of coagulant required would be in the ratio 800:12:1 respectively(Bratby,1980).

The third mechanism considered, again as a result of adsorption of coagulant species at the particle-solution interface, is that described as -a *bridging* mechanism. The metal coagulants during hydrolysis reactions have a pronounced tendency to polymerization .As the extent of hydrolysis increases, progressively higher polynuclear species form. On adsorption of such polymeric species to particles a coagulant bridge spanning between adjacent particles is formed thereby promoting destabilization.

Another significant mechanism of destabilization by metal coagulants is that of precipitate enmeshment. Under appropriate conditions of coagulant concentration and pH, metal coagulants in aqueous solution form metal-hydroxide precipitates. Such species serve to enmesh particulate material thus affecting destabilization substantially by a *sweep* action. Destabilization is visualized as being the result of metal ion - functional group - hydroxide precipitate formation. From these characteristics it is evident that destabilization with metal coagulants cannot be exclusively attributed to any one particular mechanism; In a particular instance, destabilization may be contributed to by one or several mechanisms.(Bratby,1980)

2.7 Residual Aluminium in treated water

Aluminium is one of the trace inorganic metals found in the drinking water. Other than the naturally occurring Al in water, use of Al-based coagulants especially Al2(SO4)3 (alum) and others often leads to an increase in treated water aluminium concentrations (WHO,2003).

Al is also a suspected causative agent of neurological disorders such as Alzheimer's disease and presenile dementia. During usual water treatment processes, Al undergoes various transformations (also called 'speciation' of Al) as shown in figure 7 which are influenced by parameters such as pH, turbidity, the temperature of the water source, and the organic and inorganic ligands present in water. A high (3.6 to 6 mg/l) concentration of Al may precipitate as aluminium hydroxide giving rise to consumer complaints. (Srinivasan et. al,1999).

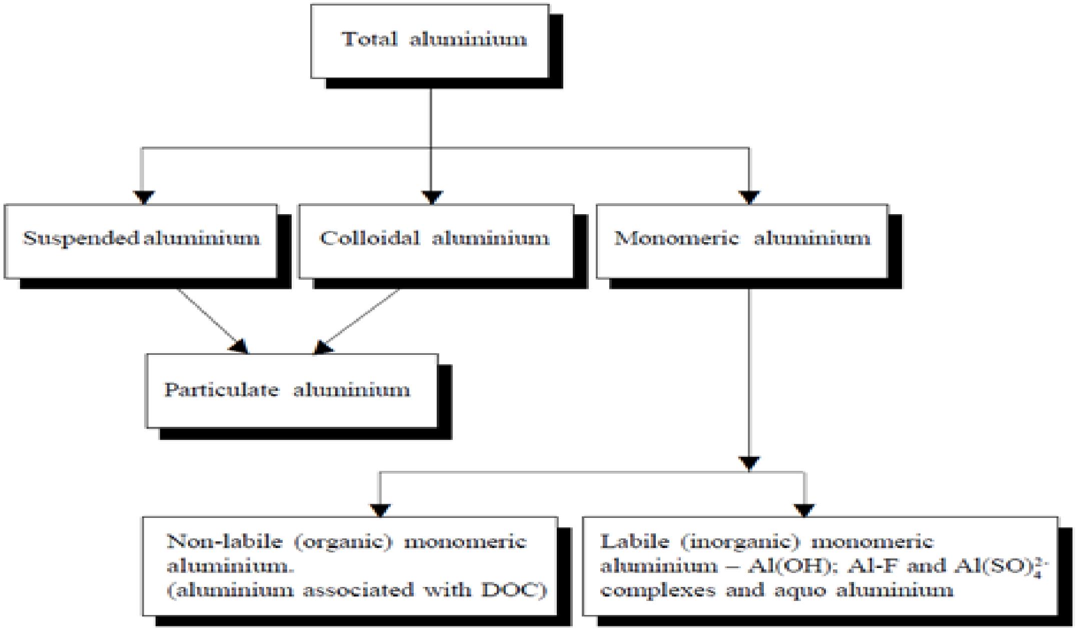


Figure 2.7: Block diagram showing various fractions of Al Source: Srinivasan et. al,1999.

Since Al toxicity is highly dependent on its speciation (''free'' and complexed Al) and mobility (soluble, colloidal or precipitated Al), the fractionation and measurement of different Al speciation in treated water are conducted, in order to discuss the effect of PAC dosage on content and speciation of residual Al of different PAC samples with respect to the treatment of a specific low turbidity, low DOC concentration (Yang et al,2012).

Al fractionation can provide the valuable information about how the treatment plant is operating .Also, from a research perspective, the Al speciation can provide insights into coagulation chemistry and the mechanisms for contaminant removal (Benschoten, Edzwald, 1990).

Growing environmental concern pertaining increased Al concentrations in fresh and treated waters have resulted in the development of various analytical techniques for the examination of Al species. Aluminium has a very complex chemistry that is significantly influenced by pH. There are various methods for examining Al fractions in water (J Scanscar, 2006). Because of its toxic effects on living beings, Al may represent an environmental hazard, particularly under increased acidic conditions. Different Al species are found in environmental solutions, and many of them are unstable. Contamination of samples and reagents by extraneous Al represents an additional problem in speciation of Al at trace concentrations (J Ščančar ,2006).

Coagulants such as Alum and polyaluminum chloride (PACl) are widely used at water treatment plants for turbidity, and dissolved substances removal from water have led to increasing concerns that the use of these coagulants may increase aluminum concentrations in treated water (Ohno et al., 2009). The treatment of surface water with alum has been in operation for over a hundred years all over the world. Alum as a coagulant in water treatment often results in higher concentrations of aluminium the treated water than in the raw water itself. Typically, some amount of alum added to the raw water is not removed during treatment which is left as residual aluminium in the treated water (Schintu et al., 2000).

The occurrence of aluminium in treated water has been considered for many years to be an undesirable aspect of treatment practice. There is a considerable concern throughout the world over the concentrations of aluminium present in raw water sources and treated drinking water(Othman et al.,2010). The possibility of an association between aluminium and neuropathological diseases including presenile dementia and Alzheimer's disease is frequently hypothesised (Othman et al, 2010).

High aluminum concentrations in treated water are linked with several problems, including increased turbidity due to the formation of aluminum pre- capitates; Also are of concern are human health hazards (WHO, 2003; Gupta et al., 2005). Further, Al is widely dispersed in natural waters in which various Al species exhibit different toxicity . Thus, the knowledge of Al speciation is very important from the standpoint of human and ecosystem health (Benschoten et al., 1990). The distri-bution of Al species in coagulants have great effects on the residual Al in treated water.(D. Shu-xuan et al. ,2014)

The desirable limit of Aluminium is 0.03 mg / L and permissible limit in the absence of alternate source is 0.2 mg / L as per IS 10500(2012). However, meeting such stringent values is often difficult, especially when the pH of raw water is high due to algae growth. In alkaline conditions, high concen- trations of residual aluminum often remain after water treatment. Therefore, the development of coagulants that can easily decrease residual aluminum concentrations to <0.05 mg/L, even for treated water in which coagulation pH is not optimized, is highly desired (Kimura et al., 2013). However, it should be emphasized that all guidelines refer to total Al and most of the water treatment plants and researchers consider only dissolved Al. That is to say, profiles of various forms of Al in raw and treated water are rarely examined .So reports of compliance with standards may have less toxicological significance. Thus, from a research perspective, knowledge of Al speciation can provide insights into coagulation chemistry and the mechanisms for contaminant removal (Yang et al, 2010).

Residual Al comprises of dissolved and particulate species. Particulate Al can be easily removed by efficient operation of solid -liquid separation facilities such as clarifiers and filters. Dissolved Al species are complex, which can form complexes with natural organic matter, fluoride, phosphate, sulphate, and hydroxyl ion.

Temperature, turbidity and pH of the water are the important parameters in determining Al solubility and consequently the levels of residual Al in treated water. Aluminium is soluble at extremely acidic(pH <6) and alkaline(pH >7.5)conditions, but is insoluble in neutral pH values(7.0-7.5). At lower temperature (4°C), the pH of minimum solubility increases, resulting in alum coagulation and hence resulting in higher residual Al levels. A corelation was reported between residual Al and effluent turbidity. Specifically, residual Al concentrations were less than 0.1 mg/l when the turbidity in the treated water was less than 0.15 NTU. This shows that low effluent turbidity would yield low particulate Al, leading to a reduction in residual Al (Srinivasan1 et al., 1999).

3. Methodology

This chapter presents the process for the development of laboratory scale models of a pulsator and a conventional clariflocculator and describes the experimental procedures followed for the assessment of their efficiencies.

3.1 Pulsator Pilot Scale model

A pilot plant was constructed as per design recommendations given by Infilco Degremont Ltd mainly consisting of rise rate and the flow rate of continuous and the pulsed flow. Its fabrication and operational procedures are described in the following sections.

3.1.1 Design and Fabrication

The main parameters which govern the design of the pulsator are the upflow velocity of the coagulated water , sludge blanket height, volume concentration of sludge and properties of flocs.

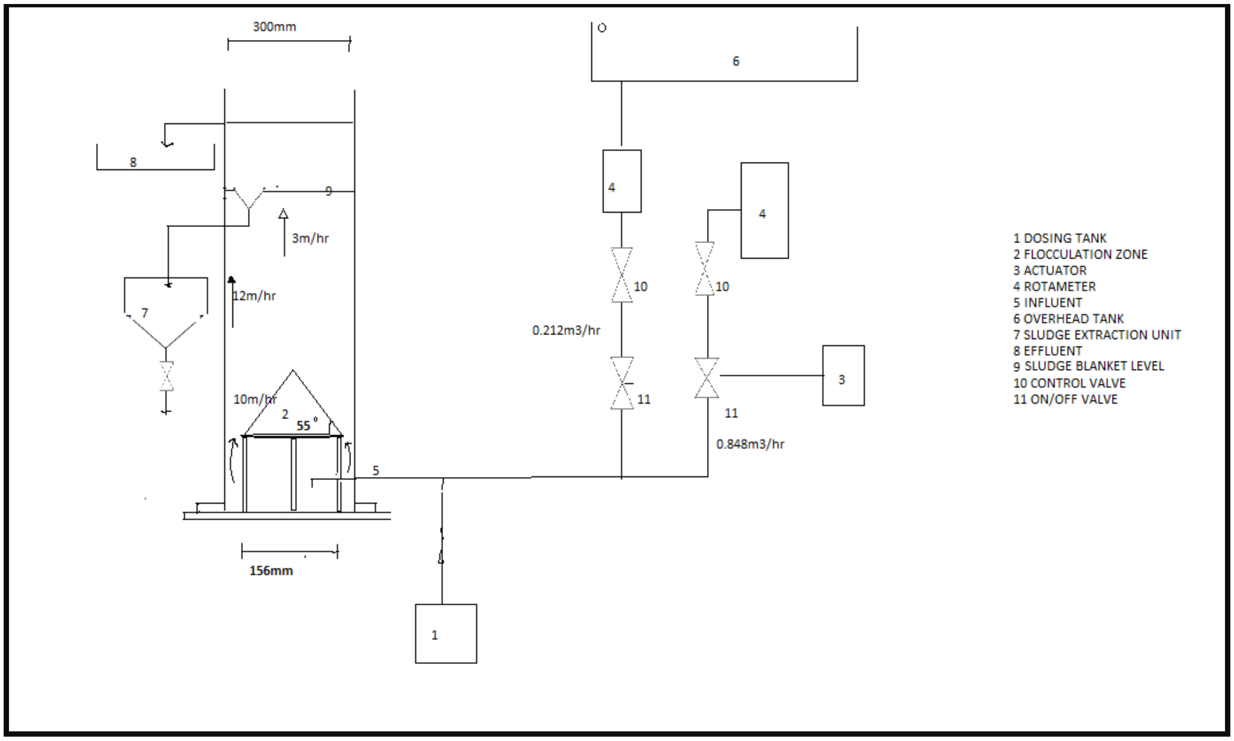


Figure 3.1: Schematic diagram of Pulsator pilot model

The other factor influencing the operation of pulsator is the pulsed flow, its duration, and frequency, which in turn, depend on the raw water and the sludge blanket characteristics. If the flocs forming sludge blanket is light, the pulsed flow can be kept low with frequency on a higher side. Similarly, for a heavy blanket, the frequency can be reduced, the duration and the flow can be increased to maintain the homogeneity of the blanket.

The rise rates and the dimensions of the model are shown in the schematic diagram in figure 3.1.

As per the specified rise rates and flow rate, the column diameter was calculated. A cone, a sort of tranquilizer plate, is provided, which acts as a flocculator that uses the energy imparted by the pulse for perfect distribution of pulsation energy without disturbing the blanket above. The cone also prevents channeling in a sludge blanket. The cone diameter is slightly lesser than the column diameter, providing a space for flocs to fall and mix with the coagulated water to form flocs of larger size. The cone angle provided is such that the particles do not settle on its top surface and rather slide down.

Figure 3.2: The Pilot plant of Pulsator installed at Hydraulics lab, MNIT Jaipur .

The model consists of a hollow cylinder of perspex of 300 mm diameter of 8 feet height made by joining four 2 feet high pieces available in the market as shown in figure 3.2. A cone mentioned above was also made of perspex sheet to have a direct visualization of the effect of pulse and the mixing regime inside. A sludge extraction unit is provided at 1.2 m from the bottom of the column to withdraw the sludge to maintain a constant height of the sludge blanket.

The water fed into the model was supplied by an overhead tank near Hydraulics Lab, MNIT campus, giving an effective head of about 8 m. The inlet pipe of the model receives water from two supply lines, one for continuous flow and the other for pulsed flow. Both the flows are regulated by the rotameters of 5lpm and 15 lpm capacity.

An actuator valve with its assembly as shown in figure 3.3 was the main element of the model responsible for generating the pulse. It was run at its default settings in which it allows the flow for 10 seconds and stops the flow for 45 seconds with a complete cycle of 55 seconds. Thus, for 10 seconds, the model receives both the continuous flow and the pulse flow while only the continuous flow for the 45 seconds.

Figure 3.3: Actuator valve with its assembly

Two tanks for storing turbid stock solution (bentonite clay suspension) and coagulant solution were placed near the models. Peristaltic pumps were used to deliver the artificial turbidity and coagulant solution. These solutions were fed into the inlet pipe.

3.1.2 Operation

The foremost task for efficient operation of the Pulsator model was to develop a homogenous and a stable blanket, which provides a high solids contact time to the incoming particles in the water. To develop the sludge blanket at a fast rate, a concentrated suspension of bentonite clay was prepared in the storage tank, was pumped to the model at a high delivery rate and supplemented by a high PAC dosage in order to form large flocs.

Figure 3.4: Fully functional Pilot plant with established sludge blanket

During the development of the blanket, the model was run at the designed flow rates. The blanket slowly started to develop. Initially, it was more of a non-uniform blanket with clear gradation. But with time, a homogeneous blanket was observed with a clear interface between the blanket and clarified water as shown in figure 3.4. Once the sludge blanket reached the desired height, the trial runs were started to optimize the flow rate for which the blanket remains homogeneous and stabilized. By various hit and trials, flow was fixed at 2.2 lpm and 8.8 lpm for continuous and pulsed flow respectively. Accounting both the flows, the pulsator was run on a flow rate equivalent to 3.745 litres per minute.

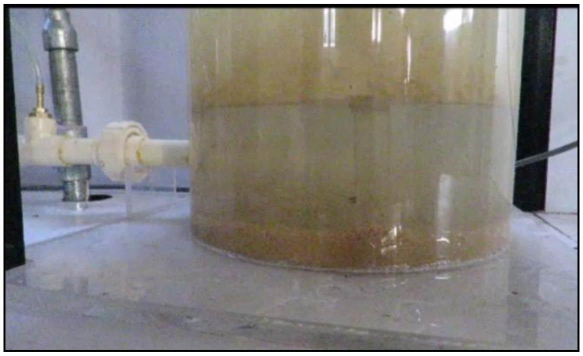


Figure 3.5: Blanket settlement in case of a power failure

In the event of power outage or absence of pulse, the blanket settled as shown in figure 3.5. Due to the absence of a continuous source of water, the model was run for 6-7 hours daily. The first two hours of operation were used for again establishing the settled blanket and the next two hours for stabilizing the blanket with the modified turbidity.

After some runs of the model and due to the exposure to sunlight, algal growth was observed in the model which led to sliming of bentonite and algal at the inside of the column.. 2, 3 and 5 NTU turbidity were run during algal growth. Further, the model was cleaned by feeding in bleaching powder solution at a rate to avail a constant chlorine dose of 5 ppm. Later, the model was cleaned manually.

3.2 Conventional Clariflocculator Model

A vertical flow clariflocculator was designed and fabricated to compare its performance with Superpulsator Model on various grounds.

3.2.1 Design and Fabrication

The model consists of a rapid mix unit and two concentric tanks with inner tank serving as flocculator and outer one as a clarifier as shown in figure 3.6.

Figure 3.6: Flocculator and Clarifier of Conventional clariflocculator model

A mechanical rapid unit was provided to mix coagulant rapidly and uniformly throughout the volume of the water. A stirrer with a motor for mixing at 100-120 rpm was employed. Detention time provided was 30 seconds. After the rapid mixer, the influent enters at the bottom of the unit where flocculation takes place as particles join into aggregates. The upflow velocity decreases with increased cross-sectional area of the tank. There is a formation of a blanket of floc through which the rising floc must pass. The clarified water is withdrawn through the circumferential weir. The diameters of clariflocculator and clarifier were 60cm and 72 cm respectively. A sludge drain line with a valve was provided at the bottom of the clarifier basin to remove sludge at regular intervals. The clarified water was collected through an outlet provided near the top of the clarifier basin.The major dimensions of the model are shown in the schematic diagram in figure 3.7. Detailed design calculations are enclosed at Annexure.

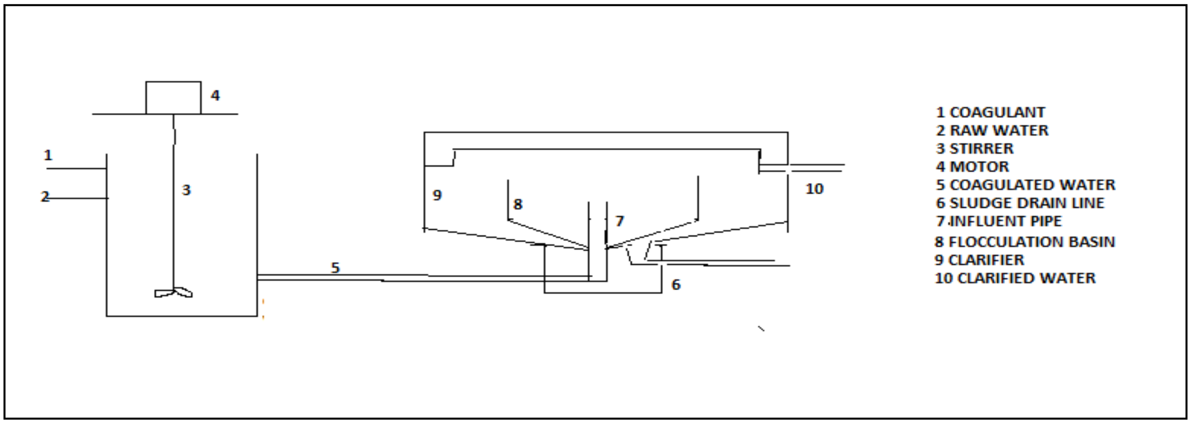


Figure 3.7: Schematic diagram of Conventional clariflocculator

3.2.2 Operation

The flow rate was kept fixed equal to the flow rate of the Pulsator model .i.e 3.745 litres per minute. Water fed into the model was taken from the same supply line from the overhead tank. A rotameter of 5lpm capacity was provided to regulate the flow rate. Similar to the pulsator model, two peristaltic pumps were employed to draw the coagulant solution and turbid solution from same dosing tanks used for the Pulsator model. The Peristaltic pump was run at different RPMs for various turbidities. Figure 3.8 shows the fully functional conventional clariflocculator model installed at the Hydraulics lab, MNIT Jaipur.

After 2 hours of the model run, the effluent water was withdrawn and taken for analysis.

Figure 3.8: Fully functional conventional clariflocculator installed at Hydraulics lab, MNIT Jaipur

3.3 Preliminary Work

Before the experimental analysis preliminary work like field visits, preparation of stock solutions and analysis of weekly reports obtained from water treatment was done as described in the following sections.

3.3.1 Water treatment plant visits:

Water treatment plant of PHED at Surajpura of 1020 MLD capacity designed by Infilco Degremont Ltd. and constructed as well as currently operated by L&T Ltd., was surveyed and studied to identify the sampling points and water quality parameters which need to be further investigated.

The six points identified as shown in figure 3.9 were:

- Raw water at inlet
- immediately after prechlorination and PAC dosage
- Before hydraulic jump
- after the hydraulic jump but before Pulsator
- Pulsator outlet before Filter
- filter outlet

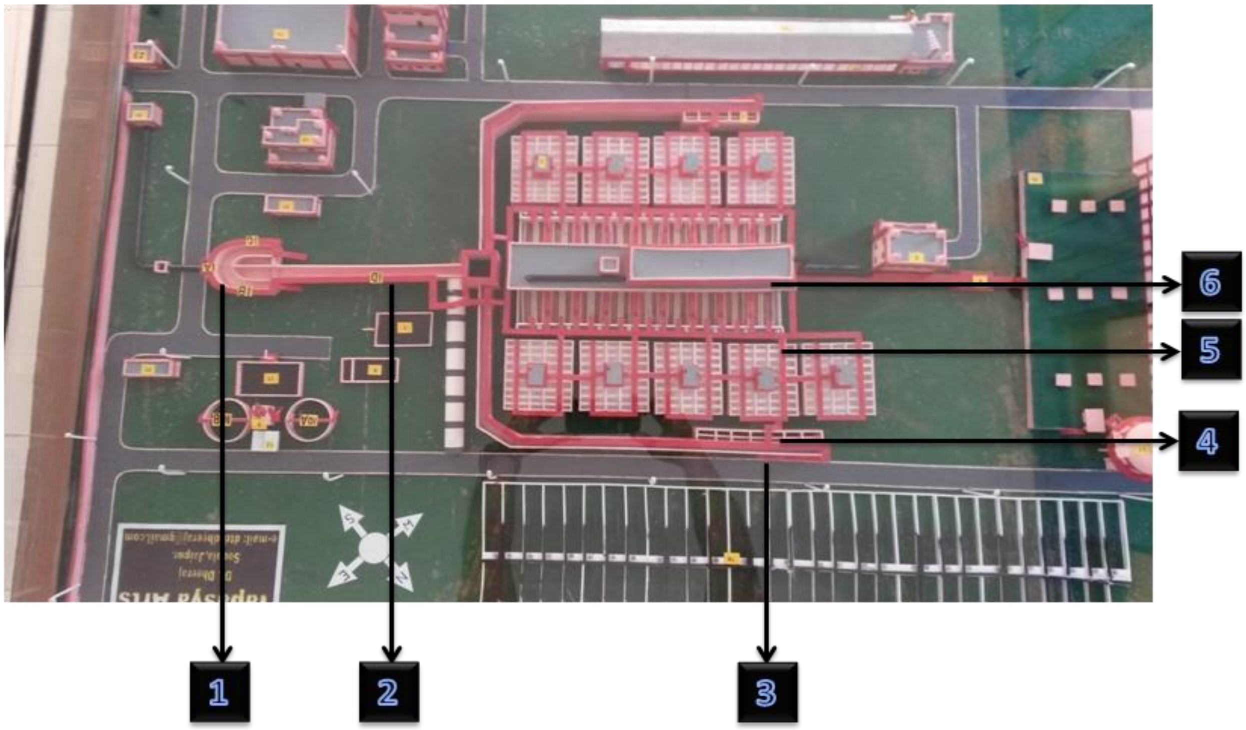


Figure 3.9: Sampling Points identified at treatment plant at Surajpura

Residual Free chlorine was measured at the above- mentioned sampling points with Hannah portable Chlorine Kit photometer shown in figure 3.10 to analyze the chlorine consumption with respect to the chlorine dosage. Samples from raw water inlet were collected in 5 L cans and brought to PHE lab, MNIT for analysis.

Figure 3.10: Hannah UV photometer

3.3.2 Weekly Reports analysis:

The water treatment plant prepares a weekly report for parameters like Turbidity, pH, Suspended solids (SS), residual aluminium in raw, clarified and treated water. Such reports were collected for June 2015 to July 2016 i.e. for 35 weeks and analysed for the range of turbidity the plant receives round the year and the treatment quality in terms of residual turbidity and aluminium levels.

Also, the study of these report provided the basis for selecting the coagulant dosage and turbidities to be run in the models. The model was run at following turbidities with fixed coagulant PAC dosage of 25 mg/L as shown in table 3.1.

Table 3.1: Turbdity selected with PAC dose for model runs

Turbidity in NTU	2	3	5	8	10	20	30
Coagulant Dose of pac in mg/L	25	25	25	25	25	25	25

In 35 weeks, for about 99% times, the treatment plant was receiving raw water of turbidity less than 14 NTU. Thus out of the 7 turbidities selected, 5 were below 14 NTU. Only 2 turbidities were taken outside 14 NTU for research purposes.

For the reason , 60% of the weeks the treatment plant was dosing PAC equal to 25 ppm, Both the models were run at a constant dosage of 25 mg/l as PAC.

3.3.3 Preparation of synthetic water

The water used for pilot model experimentation was supplied by an overhead tank near Hydraulics lab, MNIT, Jaipur. Since the tank water had negligible turbidity, Synthetic water was prepared by adding bentonite clay in water. Bentonite is used to impart turbidity in water and is a colloidal native hydrated Aluminium silicate principally of montmorillonite. To achieve the desired turbidities in the inlet pipe of the pilot model, a relation was developed between the turbidity in NTU and the weight required to achieve that turbidity in mg/L. For this, A known amount of bentonite clay ($Al_2O_3.4SiO_2.H_2O$) by Ases Chemical Works, was added to 1 L of tap water. The suspension was stirred, and its turbidity was noted using Digital Nephelometer. The table 3.2 shows the bentonite suspension required to achieve the corresponding turbidities.

Table 3.2: Bentonite suspension vs. Turbidity in NTU

Turbidity in NTU	2	3	5	8	10	20	30
Bentonite Suspesnion(mg/L)	5	10	20	30	40	75	100

3.3.4 Stock solutions

Stock Solutions for turbidity and coagulant were prepared as described in the following sections.

3.3.4.1 Turbidity

Table 3.3: Peristaltic pumps settings for the corresponding Turbidity

Turbidity in NTU	Bentonite Suspension	Volume required to pump in ml/min	Rpm
2	5	18.72	6.2
3	10	37.45	12.5
5	20	74.90	25.0
8	30	112.35	37.4
10	45	168.52	56.1
20	75	280.87	93.6
30	100	374.5	124.8

60-70 L of 1g/L Bentonite suspension was prepared and stored in the 100 L tank daily in the hydraulics lab. A stirrer was employed to keep the clay particles in suspension. For the fixed flow rate, a peristaltic pump was run at different RPMs to introduce the selected turbidities in the model. For instance, to run 30 NTU equivalent to 100ppm suspension, for 3.745 lpm flow rate, the peristaltic pump was made to run at 112.35ml/min at 37.4 rpm. Table 3.3 shows the turbidity and volume required to pump the turbidity solution and the rpm.

3.3.4.2 Coagulant

Poly Aluminium chloride used was supplied by the treatment plant in 5 L cans. The liquid grade used was Arya PAC manufactured by Aditya Birla Ltd with physical properties shown in the table 3.4.

Table 3.4: PAC Liquid grade Specifications, Source: Aditya Birla Chemicals

Property	**Value**
Aluminium as Al_2O_3% by mass, min.	10.2
Specific gravity at 25°C, min	1.20
Basicity, percent by mass, min	64.0
Sulphate, percent mass, max	2.7
Chloride as Cl, percent by mass, max	10.5

Constant PAC Dosage of 25 mg/L was run in both the models for all the turbidities. 20 L of 0.1% (v/v) PAC was prepared and stored in a dosing tank of 100 L capacity daily. The peristaltic pump was made to run at 77.9ml/minute or 26rpm to dose 25mg/L of PAC or 20.8ml/L taking into account specific gravity of 1.20.

3.4 Laboratory Analysis:

This section describes the procedures followed in laboratory for assessment of various parameters like pH, alkalinity, turbidity and Residual Al.

3.4.1 Turbidity

Turbidity is one of the important aesthetic properties of potable water, and it is also very useful in defining drinking water quality. A digital Nephelometer Model 341E by Hach shown in figure 3.11 was used to measure turbidity.

Figure 3.11: Digital Nephelometer by Hach

- Range:0-200NTU
- Direct digital readout in NTU
- Calibration carried out by using standard turbidity solutions of formazine.
- Manual adjustments for calibration of the instrument.

3.4.2 Preliminary Jar tests

Raw water:

20 L volume of the sample was collected from raw water channel of the Surajpura Treatment plant and brought to PHE lab, MNIT, Jaipur. Initially, Turbidity, pH, and Alkalinity of raw water were measured. Two sets of Jar test were performed for 5mg/l to 30 mg/l and 35mg/l to 60mg/l of PAC dosage at 5mg/l intervals. Other than Residual turbidity, pH , alkalinity and residual aluminium were also measured.

Coagulant:

Poly Aluminium chloride used was supplied by the treatment plant. The liquid grade used was Arya PAC manufactured by Aditya Birla Chemicals.

PAC, to be dosed, was prepared by diluting the PAC received from plant to 1%. Following volumes of diluted PAC were added to get the corresponding dosage as shown in table 3.5.

Table 3.5: PAC dose vs. Volume required for 1L and 500 ml

PAC dose in ppm	5	10	15	20	25	30	35	40	45	50	55	60
Vol to be dosed in 1 L water in ml	0.42	0.83	1.245	1.660	2.06	2.49	2.90	3.33	3.75	4.16	4.58	5.0
Vol in 500 ml water in ml	0.21	0.42	0.62	0.83	1.04	1.245	1.45	1.66	1.87	2.08	2.29	2.5

Procedure:

Jar test apparatus (Accumax India) available in PHE lab was used. 500 ml sample was added in 6 beakers of 1L capacity and coagulants prepared were added to the jars during rapid mixing. The coagulants were mixed rapidly for about one minute and then, the stirring speed was reduced to 20-30 rpm for 20-30 minutes. The stirring process was stopped to provide a settling time for flocs formed for about 30 minutes. The water sample is drawn from a specific fixed distance below the water level in the jar and tested for the residual turbidity and other parameters. In this study, residual turbidity and residual aluminium were analysed to evaluate the optimum coagulant dose which results in the minimum Residual turbidity without compromising on residual aluminum levels.

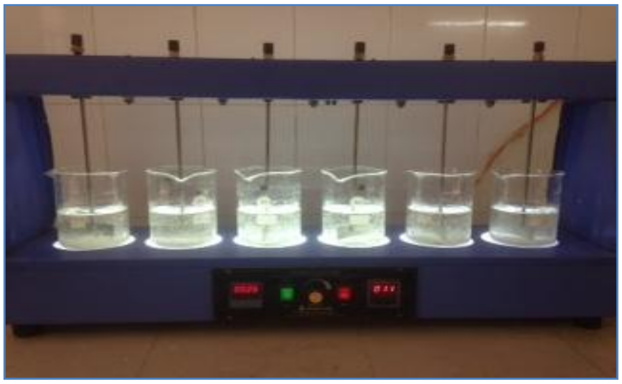


Figure 3.12: Jar test apparatus

3.4.3 Alkalinity

The titration method was used as per **(APHA, Standard Methods for the Examination of Water and Wastewater 1999)*(*2320 B. Titration Method*)***.

Procedure

- 25ml of treated wastewater sample was used for testing.
- 2- 3 drops of *Phenolphthalein solution, alcoholic,* pH 8.3 indicator was added. Pink color is observed.
- Sample was titrated with 0.02 N H2SO4 till the color disappeared. The reading was noted and phenolphthalein alkalinity (P) was calculated.
  Alkalinity , mg/L CaCo3/L = A x N x 50000/mL sample
  Where, A = ml of acid used N = normality of the acid
- Then, 2-3 drops of *methyl orange solution*, pH 4.5 indicator was added. A pale yellow color was observed.
- Again the sample was titrated with 0.02 N H2SO4 till bright yellow color appeared. .The reading was noted and total alkalinity (T) was calculated.
  Alkalinity, mg CaCo3/L = B x N x 50000/ml sample

Where, B = ml of acid used N = normality of the acid

Calculation of alkalinity relationships: The results obtained from the phenolphthalein and total alkalinity determinations provides a means for stoichiometric classification of the three main forms of alkalinity present in water. i. e. carbonate , bicarbonate, and hydroxide alkalinity.

The classification divides the entire alkalinity to bicarbonate, carbonate, and hydroxide. According to this :

1. Carbonate (CO32–) alkalinity is present when phenolphthalein alkalinity is not zero but is less than total alkalinity (P<T).

2. Hydroxide (OH-) alkalinity is present when phenolphthalein alkalinity is more than half the total alkalinity (P>=1/2 T).

3. Bicarbonate (HCO3–) alkalinity is present when phenolphthalein alkalinity is less than half the total alkalinity (P < =1/2)

3.4.4 pH

pH: pH of the treated wastewater sample was measured using pH meter (Labtronics Model LT-11) available in the PHE laboratory, MNIT, Jaipur.

Procedure

- The pH meter was calibrated by immersing the electrode in the buffer solution of known pH, normally 4.0 and 7.0.
- The electrode was rinsed with distilled water.
- Then, the pH of the treated water sample was read.

Figure 3.13: Digital ph meter

3.4.5 Residual Aluminium

Residual Aluminium was measured with Eriochrome Cyanine R method as per 3500-AlB APHA 1995 Manual. Eriochrome Cyanine R method provides a means for estimating Aluminium with simpler instrumentation. The minimum aluminium concentration detectable by this method is 6 µg/L.

Principle:

With Eriochrome cyanine R dye, dilute aluminum solutions are buffered to a pH of 6.0 which produces a red to pink complex that exhibits maximum absorption at 535 nm. The intensity of the developed color is governed by the concentration of aluminium, reaction time, temperature, pH, alkalinity, and concentration of other ions present in the sample(APHA Manual -3500-Al B). To compensate for color and turbidity, the aluminum in one portion of the sample is complexed with EDTA to provide a blank. Ascorbic acid is added to remove interference due to the iron and manganese(APHA Manual -3500-Al B).

Interference: Negative errors are caused by both fluoride and polyphosphates. Both the parameters were zero in the sample water.

Apparatus:

1) *Spectrophotometer(Schimadzu UV-1800),* for use at wavelength 535 nm

2) Glassware: All glassware were treated with warm 1 + 1 HCl and rinsed with aluminum-free

distilled water to avoid errors due to materials absorbed on the glass.

Reagents:
All reagents were made with aluminum-free distilled water.

a. Stock aluminum solution: 8.791 g aluminum potassium sulfate (also called potassium alum), AlK(SO4)2·12H2O, was added in water and diluted to 1L. Therefore, 1.00 mL = 500 µg Al:

b. Standard aluminum solution: 10.00 mL stock aluminum solution was diluted and made to 1 L with water; 1.00 mL = 5.00 µg Al.

c. Sulfuric acid, H2SO4, 0.02*N*

d. Ascorbic acid solution: 0.1g of ascorbic acid(Sarabhai M Chemicals) was added in water and dissolved in 100 mL in a volumetric flask. This solution was prepared fresh daily.

e. Buffer reagent: 136 g sodium acetate, NaC2H3O2·3H2O(Merck), was dissolved in water, and 40 mL of 1*N* acetic acid was added, and diluted to 1000mL.

f. Stock dye solution: 300 mg Eriochrome Cyanine R dye(Merck) was dissolved in about 50 mL water. pH was adjusted from about 9 to about 2.9 with 1 + 1 acetic acid and Diluted with water to 100 mL. Stock solutions can be kept for at least a year.

g. Working dye solution: 10.0 mL of stock dye solution was diluted to 100 mL in a volumetric flask with water. Working solutions are stable for at least 6 months.

h. Methyl orange indicator

i. EDTA (sodium salt of ethylenediamine-tetraacetic acid dihydrate), 0.01*M*: 3.7 g of EDTA was added in water, and diluted to 1 L.

j. Sodium hydroxide, NaOH, 1*N* and 0.1*N*

Figure 3.14: Water samples testing for Residual Aluminium

Procedure:

a. Preparation of calibration curve: The calibration curve was prepared as per the procedure mentioned in APHA Manual using known amount of the standard aluminum solution and recording its transmittance at 535 nm in the spectrophotometer.

b. *Measuring Residual Aluminium*: 25.0 mL sample was placed, or a portion diluted to 25 mL, in a flask or a test tube, a few drops of methyl orange indicator was added and the sample was titrated with 0.02*N* H2SO4 to a faint pink color. The reading was recorded and sample was discarded. To two similar samples at room temperature the same amount of 0.02*N* H2SO4 used in the titration was added and then 1 mL in excess was added. To one sample 1 mL of EDTA solution was added which will serve as a blank by complexing any aluminum present and compensating for color and turbidity then to both the samples 1 mL ascorbic acid, 10 mL buffer reagent and 5.00 mL working dye reagent was added.The test tubes containing water sampleand reagents for measurement of Al is shown in the figure 4.13.

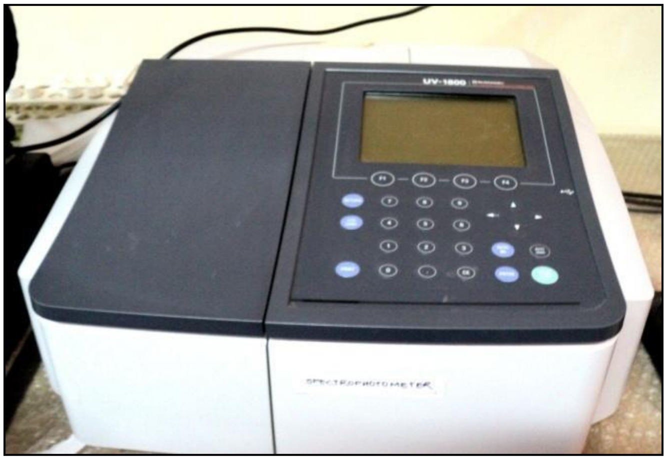


Figure 3.15: UV Spectrophotometer

Instrument was set to zero absorbance or 100% transmittance using the EDTA blank. After 5 to 10 min contact time, transmittance or absorbance was read and aluminum concentration from the calibration curve previously prepared was determined.

3.4.6 Residual Aluminium after filtration:

Treated sample collected from models was brought to PHE lab and filtered through filter paper (Whatman paper 42) with a pore size of 20 µ. Around 80 ml filtrate was collected and its residual aluminium was measured as mentioned above. 20 µ pore size was selected as the rapid sand filter generally removes particles of size 20 µ which gave an idea of the level of residual aluminium after the filtration treatment.

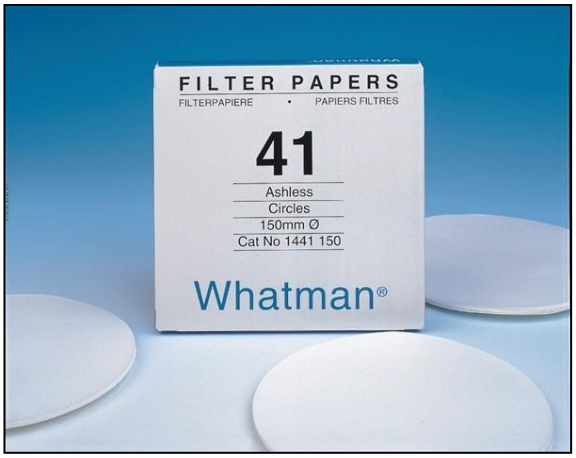


Figure 3.16: Whatman 41 filter paper having 20 µ pore size

3.4.7 Dissolved Residual Aluminium:

Figure 3.17: Dissolved Al measurement with 0.45 µ filter paper and vacuum filter

Further, it was important to differentiate the form of aluminium .i.e. whether the aluminium is present in suspended or dissolved form. Therefore, the treated sample collected from the model was filtered by 0.45 µ pore size filter using vacuum filter (APHA manual 3500-Al B). The filtrate was collected and immediately tested for residual aluminium as mentioned above.

3.4.8 Instruments used

Table 3.6: Instruments used

SNO.	Instrument used	Company	Model
1.	UV Spectrophotometer	Schimadzu	UV-1800
2.	Nephelometer	Hach	341-E
3.	pH meter	Labtronics	LT-11
4.	Weighing balance	CAS	CAUW220D
5.	Microwave		
6.	Chlorine Photometer	Hannah	
7.	Distillation water unit		

4. Results and Discussions

This chapter discusses the efficiency of both the models in lowering the residual aluminium levels. It also presents the analysis of the filterable and dissolved fraction of aluminium present in treated water.

4.1 Coagulant Properties

Polyaluminum chloride (Arya PAC grade) provided by Aditya Birla Pvt Ltd. has 10.2% Al_2O_3 (w/v) equivalent to 5.38% Al (w/v). The percentage of aluminium present in Polyaluminum chloride, as determined by Spectrophotometric method, was observed to be 5.39% nearly similar to the theoretical value by the manufacturer.

4.2. Jar test

The Jar test was performed on water collected from raw water channel from the treatment plant. Table 8 shows the results of the jar test carried out with coagulant dose of PAC varying from 5mg/l to 60 mg/L (equivalent to PAC dose ranging from 0.269 mg-Al/L to 3.228 mg-Al/L) for residual turbidity, pH, alkalinity and residual Aluminium.

Table 4.1: Jar test results on Bisalpur raw water with PAC dose ranging from 5 ppm to 60ppm equivalent to 0.269mg-Al/l to 30228mg-Al/l

PAC dose	Equivalent Al dose	pH	Turbidity	Vol of H2SO4 added (T)	Alkalinity in	Residual Aluminium
in ppm	as PAC mg/L		in NTU	in ml	As mg/l as CaCo3	In mg/l
5	0.269	7.86	0.4	0.8	32	0.009
10	0.538	7.85	0.3	0.7	28	0.011
15	0.807	7.68	0.4	0.7	28	0.013
20	1.076	7.46	0.2	0.5	20	0.018
25	1.345	7.36	0.1	0.7	28	0.020
30	1.614	6.84	0.1	0.6	24	0.019
35	1.883	7.00	0	0.6	24	0.022
40	2.152	7.39	0	0.6	24	0.024
45	2.421	7.45	0.1	0.6	24	0.018
50	2.69	7.42	0.2	0.5	20	0.012
55	2.959	7.25	0.1	0.6	24	0.022
60	3.228	7.34	0.2	0.4	16	0.023
Raw	-	7.54	0.6	0.8	32	0.000

4.2.1. Residual Turbidity

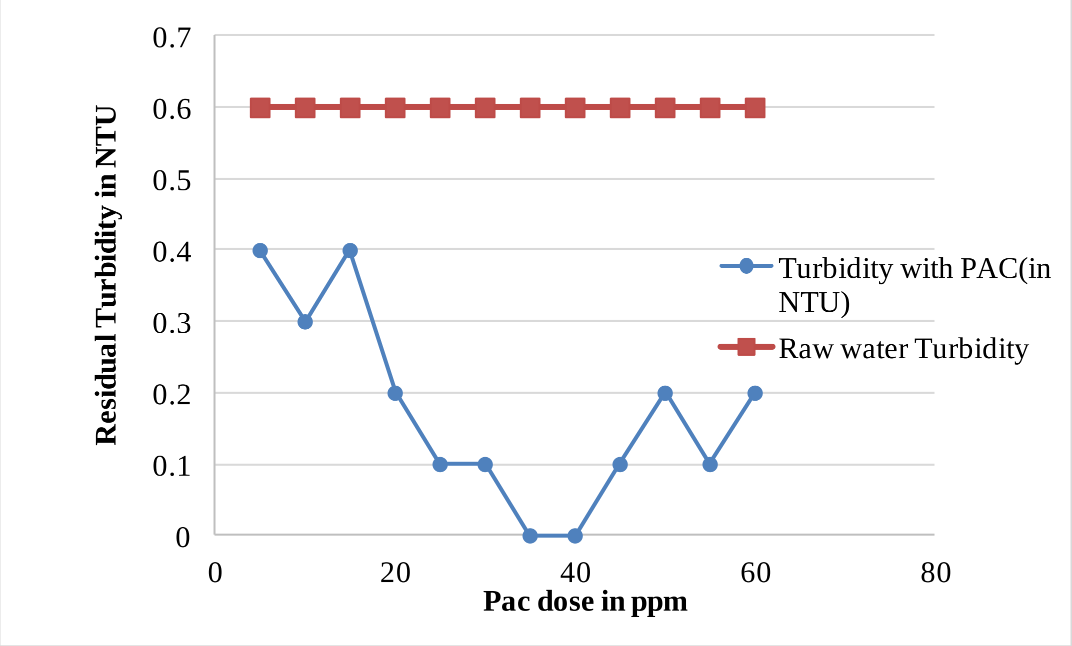


Figure 4.1: Jar test: PAC dose in ppm vs. Residual turbidity in NTU

The figure 4.1 shows the Residual Turbidity plotted vs. PAC dose varying from 0-60ppm. The coagulant dose which resulted in lowest residual turbidity, almost not detectable, is 35 mg/l to 40 mg/l. But, as it can be seen in the figure 4.1 the raw water had a very low turbidity of 0.6 NTU which gets reduced to 0.4 NTU even at a very low dose of 5 mg/L, there seems to be no reason for increasing the dose any further as this can be achieved in the subsequent filtration stage in the treatment plant. Also, at 10, 15 and 20 mg/l PAC dose the turbidity of less than or equal to 0.4 NTU is achieved. Thus, the treatment plant at Surajpura is a highly overdosed system operating at 25ppm of PAC dose, which is further increased to 35-45 ppm when some color is observed in the raw water. Currently,100% PAC is administered at the treatment plant leading to a cost of more than 1 lakh INR being incurred on a daily basis. The increase in the coagulant dose of PAC not only just leads to the additional cost for operation of the plant, but it also leaves the filters underused.

4.2.2 pH and Alkalinity

Figure 4.2 shows pH and the alkalinity variation with PAC doses. Unlike Alum, PAC produces less acidity and hence does not lower pH and alkalinity of water significantly. It can be seen that the pH lies within the range of 6.5 to 7.5 for 20 to 60ppm dose. With the increase in the Al dose, the alkalinity consumed increases.

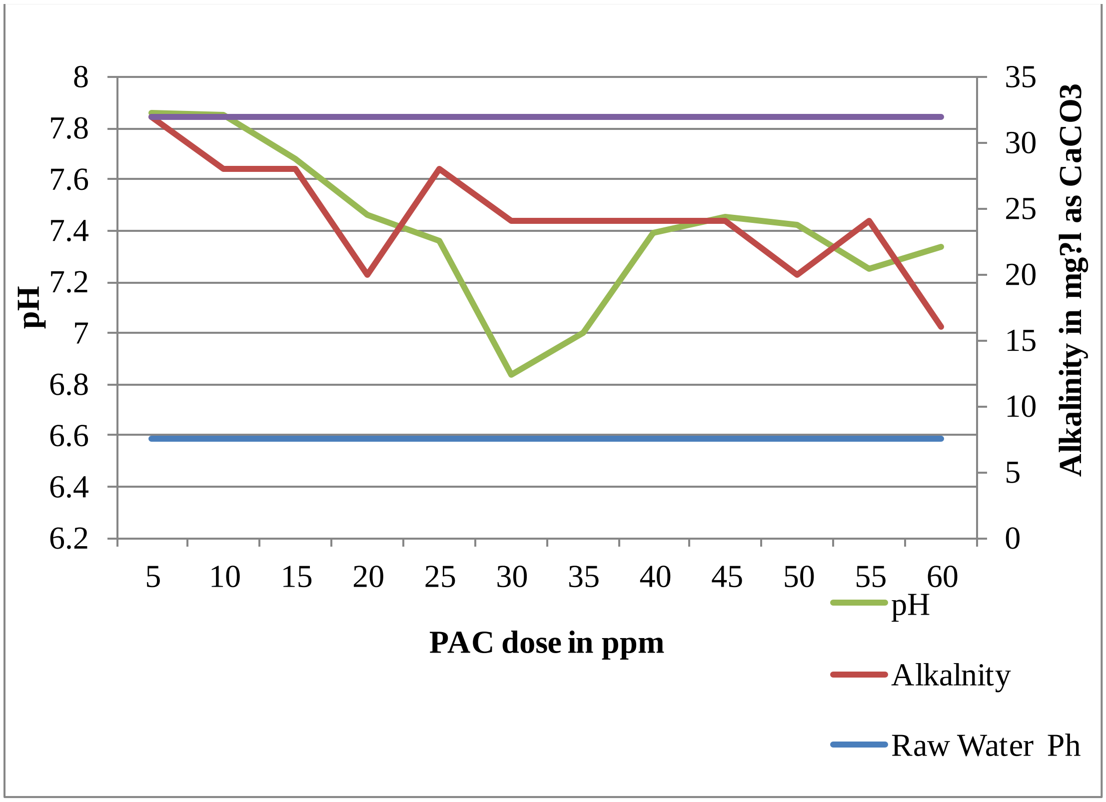


Figure 4.2: Jar test: PAC dose in ppm vs. ph and alkalinity in mg/l as $CaCO_3$

4.2.3 Residual Aluminium

It can be seen in figure 4.3 that for all the doses from 0.269mg-Al/L to 3.228 mg-Al/l of PAC, residual Aluminium remains below the desirable standard of 0.03 mg/l as per Indian regulations IS 10500, which further permits a value up to 0.2 mg/l in case no alternate source is available.

Further, as shown in figure 4.3 percentage of aluminium removal increases with the increase in the coagulant dose with the highest removal being observed at the higher dosages. The lowest residual concentration was 0.009 mg/L at 5 ppm equivalent to 0.269mg-Al/l PAC dose while the highest percentage removal was at 50 ppm equivalent to 2.69mg-l/l PAC dose.

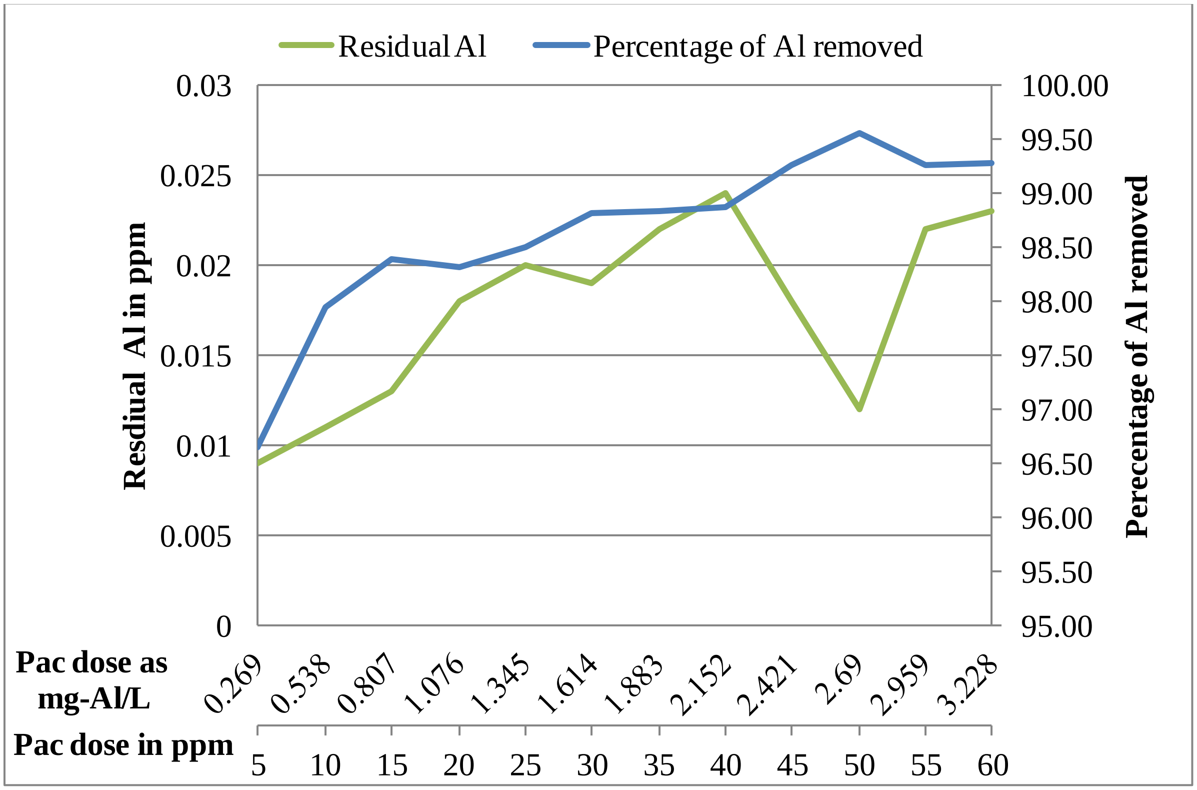


Figure 4.3: Jar test : PAC dose in mg-Al/l Vs Residual Al in mg/l

Thus, it can be inferred that all the coagulant doses are giving a residual aluminium below the standard value of 0.030 mg/L indicating that PAC is a highly effective coagulant in lowering down the residual aluminium levels. Therefore, the cost of PAC incurred in treatment plant can be reduced by lowering the coagulant dose to 5 to 10 mg/L to achieve both the desired turbidity and residual Aluminum levels. Further, some turbidity and aluminum level will be reduced in the next stage of the filtration.

4.3 Water treatment plant visits

Table 4.2 shows the values of residual free chlorine measured at various sampling points during treatment plant visits. It can be seen that immediately after prechlorination dose of 4.25 ppm, remaining chlorine in water was 2.99 ppm indicating some amount being lost to the environment. Thus, careful consideration should be given to the method of feeding the chlorine in the water.

Before the hydraulic jump, free chlorine was reported to be 1.93 ppm. After the dosing of chlorine the water travels through a long channel with a travel time of about 2-3 minutes and then gets thoroughly mixed in a hydraulic jump. Free chlorine of 0.74 ppm was available after pulsator indicating that about 1.19 ppm of chlorine was consumed either in the pulsator or lost in the hydraulic jump. Free chlorine available after the last stage of filter was 0.49 ppm indicating that prechlorination dose can be reduced.

Table 4.2: Residual free chlorine measured with portable UV photometer at treatment plant

Sampling Points	Residual Free chlorine in ppm
Raw water Channel	0.00
Immediately after Prechlorination	2.99
Before Jump	1.93
After Pulsator	0.74
After Filter	0.49

4.4. Pulsator Model

In this section, residual aluminium , Aluminium after filtration and dissolved Al in treated water by Pulsator is analyzed and discussed.

4.4.1. Residual Aluminium

Table 4.3: Pulsator model results for the first run for turbidities 2, 3,5,8,10,20 and 30 NTU

Raw Turbidity	Al in PAC	Total Al in treated water	Al after filtration with 20 microns	Dissolved Al	Suspended Al(Total – Dissolved)
NTU	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
2	1.332	0.030	0.010	0.010	0.020
3	1.332	0.021	0.015	0.018	0.003
5	1.332	0.031	0.035	0.008	0.023
8	1.332	0.040	0.044	0.032	0.008
10	1.332	0.034	0.034	0.028	0.006
20	1.332	0.019	0.002	0.000	0.019
30	1.332	0.036	0.029	0.028	0.008

Table 4.4: Pulsator model results for second run for turbidities 2, 3,5,8,10,20 and 30 NTU

Raw Turbidity	Al in PAC	Effluent Al	**Al after filtration with 20 microns**	Dissolved Al	**Suspended Al(Total – Dissolved)**
NTU	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
2	1.332	0.028	0.048	0.010	0.018
3	1.332	0.037	0.037	0.015	0.022
5	1.332	0.051	0.035	0.033	0.018
8	1.332	0.054	0.057	0.037	0.017
10	1.332	0.043	0.031	0.015	0.028
20	1.332	0.031	0.036	0.030	0.001
30	1.332	0.030	0.025	0.020	0.010

The selected turbidities were run twice in the model. The tables 4.3 and 4.4 show the results of the two sets of experiments.Since the sludge blanket characteristics varied for every run, the average results used for analysis shown in table 4.5. For a better understanding of the results, the selected seven turbidities were categorized into three heads: lower , intermediate and higher turbidity. 2, 3 and 5 NTU were taken as lower, 5 and 8 NTU as intermediate while 20 and 30 NTU as high turbidity

Table 4.5: Average Results for two runs on pulsator for 2,3,5,8,10,20 and 30 NTU

Raw Turbidity	**Al in PAC**	**Effluent Al**	**Al after filtration with 20 microns**	Dissolved Al	**Suspended Al(Total – Dissolved)**
NTU	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
2	1.332	0.029	0.029	0.010	0.019
3	1.332	0.029	0.026	0.017	0.012
5	1.332	0.031	0.035	0.021	0.010
8	1.332	0.038	0.040	0.035	0.003
10	1.332	0.039	0.033	0.022	0.017
20	1.332	0.025	0.019	0.015	0.010
30	1.332	0.033	0.027	0.024	0.009

The lowest total residual aluminum observed in the effluent of Pulsator pilot plant was 0.025 mg/L at 20 NTU while the highest concentration was 0.039mg/L at 10 NTU. Out of 7 turbidities, at three turbidities i.e. 2 NTU, 3 NTU and 20 NTU, the residual aluminium was below 0.03mg/L(IS 10500).

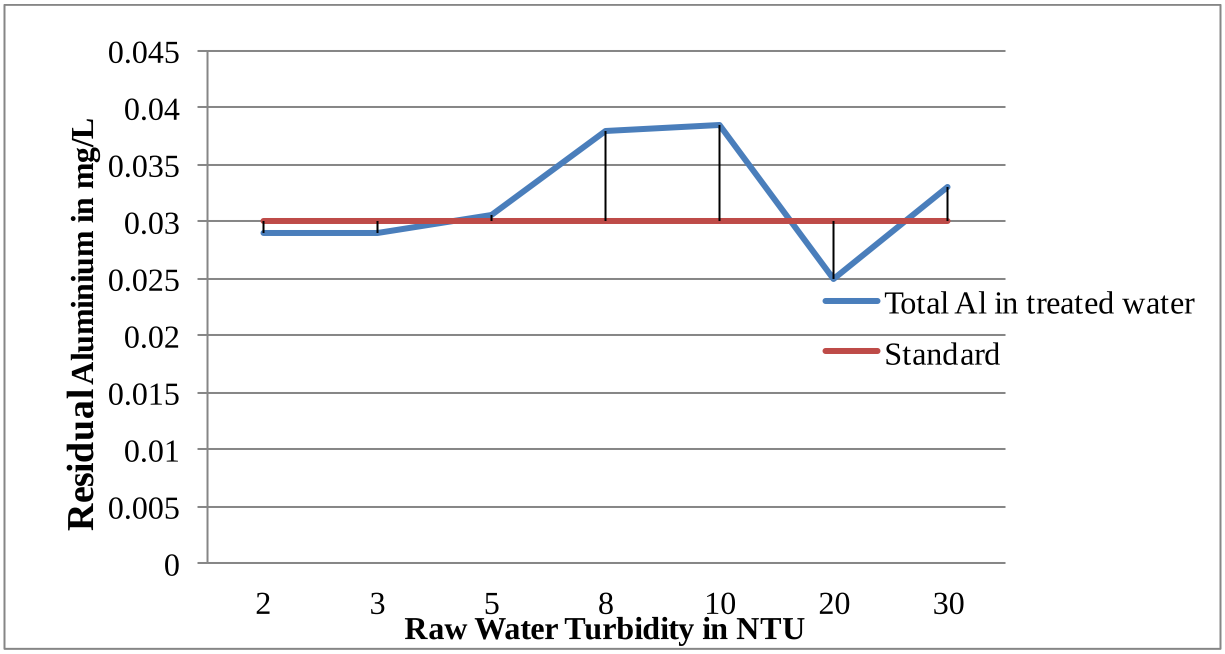


Figure 4.4: Residual Aluminium in mg/L in treated water by Pulsator model for selected turbidities

The performance of pulsator was better at lower and higher turbidities that are at 2, 3, 5, 20 and 30 NTU as the residual aluminium level almost complied with Indian standards. However, at an intermediate turbidity of 8 and 10 NTU, the residual aluminium concentration was slightly higher, being 0.038mg/l and 0.039 mg/l respectively, which could be further reduced in next stage of Filtration.

The performance of Pulsator mainly depends on the formation of sludge blanket ; its stability and homogeneity .As the model was not run continuously for experimental analysis, the condition of sludge blanket varied every day,hence the performance of model also differed.

4.4.2. Residual Aluminium after filter

Table 4.6: Residual Al in water after passing the pulsator treated water through a 20 µ pore size filter

Raw water Turbidity	Total Al in Treated water	Residual Al after filtration with 20micron	Al entrapped in floc size higher than 20micron	Percentage removed in filtration
NTU	mg/L	mg/L	mg/L	%
2	0.029	0.029	0.000	0.00
3	0.029	0.026	0.003	10.34
5	0.031	0.035	0.000	0.00
8	0.038	0.040	0.000	0.00
10	0.039	0.033	0.006	15.58
20	0.025	0.019	0.006	24.00
30	0.033	0.027	0.006	18.18
Average	0.032	0.030	0.003	9.73

Table 4.6 shows the residual aluminum left after filtering the clarified water by 20 µ pore size filter. As it can be seen, most of the Aluminium left in treated water by pulsator, was entrapped in flocs of size lower than 20 microns. On an average, only 0.003 mg/l was removed during the filter. For the efficient functioning of a filter, the particles to be removed must be entrapped in a floc of size equal to or higher than 20 microns if a rapid sand filter is employed in a treatment plant(Al-Rawi,2009).

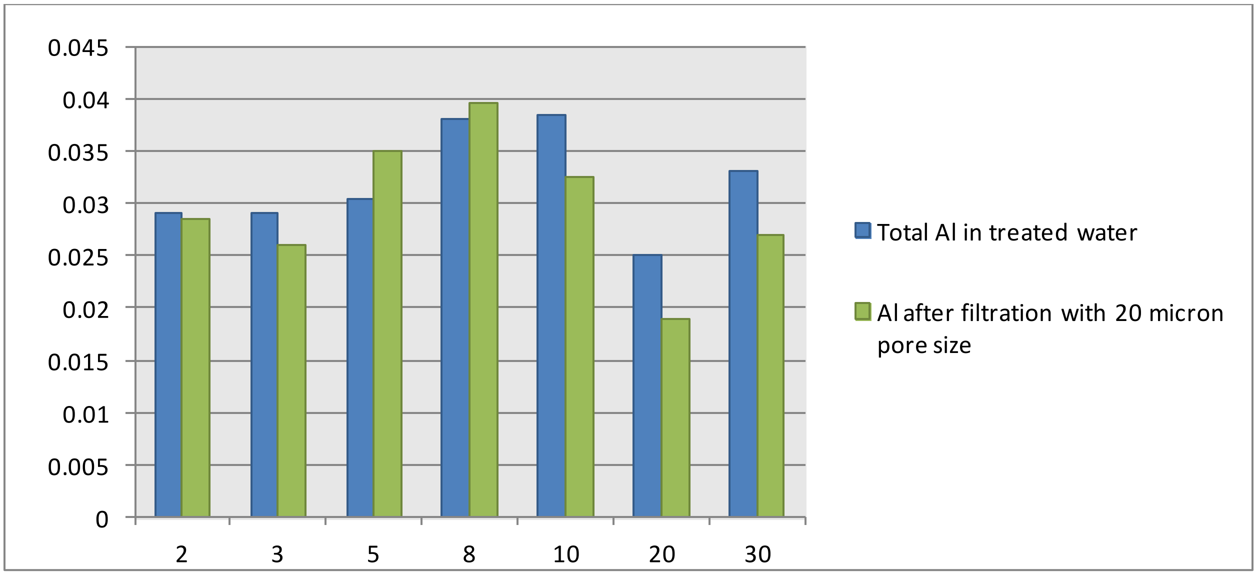


Figure 4.5: Graph showing Residual Al in Pulsator treated water and after filtration with 20 µ pore size filter

Also, it can be seen in figure 4.5 that at 5 and 8 NTU, the residual aluminium after filter was observed to be higher than the total Al which could have resulted due to some error while performing the experiment. Thus, for further analysis, the values of Al after filter were assumed to be equal to the total aluminum for the above- mentioned turbidites.

Out of 7 turbidities, at four turbidities residual aluminium after the filter was below 0.03 mg/L, while the average was equal to the standard value of 30 µg/L(IS 10500) as shown in figure 4.6.

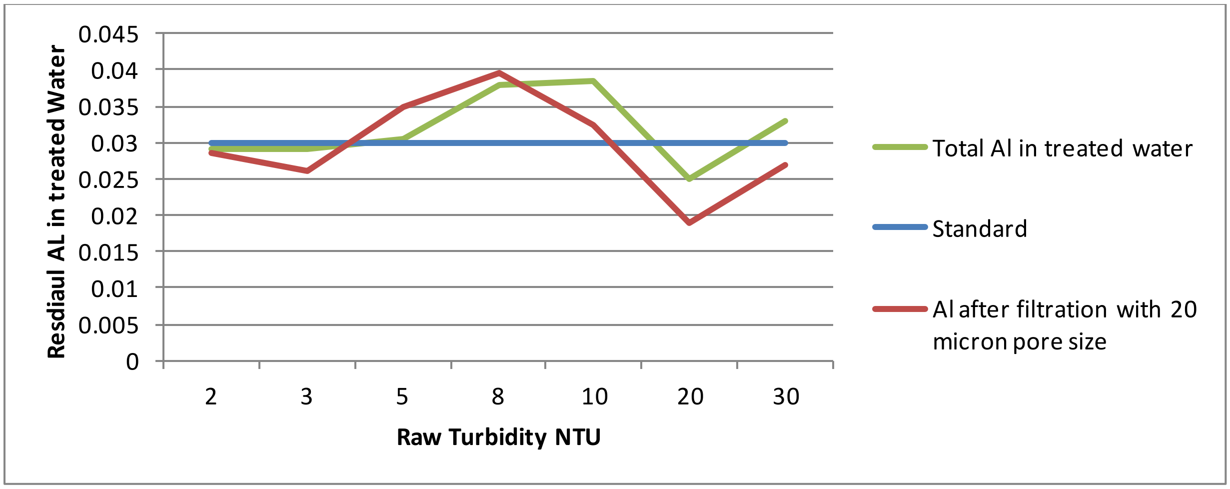


Figure 4.6: Comparison of Residual Al after treatment with Indian standards(IS 10500:2012)

Percentage of Total aluminum removed during filter was lowest at 2, 5 and 8 NTU with an average removal percentage of 9.73%. Hence, it can be said that most of the aluminium (90.27%), left after treatment with pulsator, was enmeshed in floc size lower than 20 microns. However, the percentage removal during the filter improves at higher turbidities i.e. at 20 and 30 NTU.

4.4.3. Dissolved aluminium

The Table 4.7 shows the Dissolved aluminium in treated water by pulsator model. It can be seen that for all the turbidities run in the model, except for 2 NTU, more than 50 % of aluminium was left after clarification possibly being in dissolved form.

Table 4.7: Dissolved Al in treated water by pulsator, percentage of total Al in dissolved and suspension

Raw Turbidity in NTU	Dissolved Al	Percentage of Total Al in dissolved form	Percentage of Total Al in Suspension
2	0.010	35.34	64.66
3	0.017	56.90	43.10
5	0.021	67.21	32.79
8	0.035	90.79	9.21
10	0.022	55.84	44.16
20	0.015	60.00	40.00
30	0.024	72.73	27.27
Average		62.69	37.31

Percentage of Al in dissolved form is highest at 8 NTU, next lower being at 5 NTU while the Percentage of Al in dissolved form was minimum at 2 NTU as shown in figure 4.7. This correlates well with the fact that the performance of the model for lower turbidities was better than intermediate turbidities as higher the percentage of Al in suspension higher will be the chances of removal in filtration.

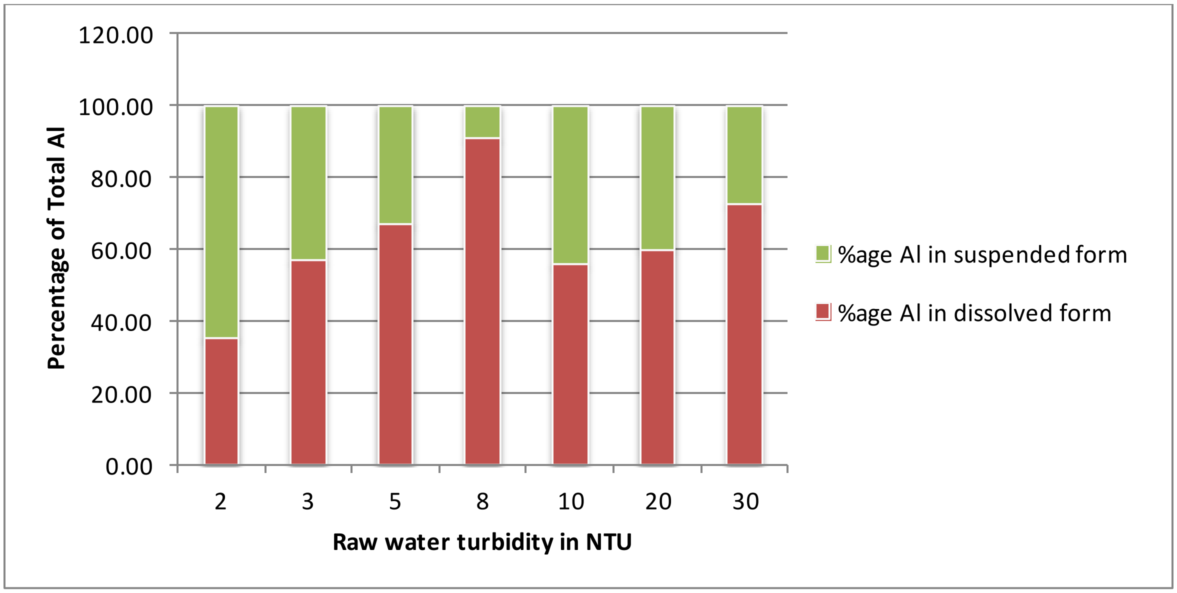


Figure 4.7: Graph showing percentage of total Al in suspension and dissolved from in pulsator treated water

4.4.4 Algal growth in model

Algal growth was observed in the model as the column was made up of Perspex sheet . A slime layer was developed on the inside of the column which degraded the model performance and resulted in unexplainable results as shown in the table 4.8. Three turbidities were run in the model with the algal growth. Both the residual aluminum after the filter and dissolved aluminium for all the three turbidities was greater than the total aluminum in the treated water. Algal cells might have caused some experimental disturbance while assessing aluminium concentration using Eriochrome cyanine R method. This can be the possible explanation of disturbance in aluminium mass balance.

Table 4.8: Pulsator model results during algal growth for 2, 3 and 5 NTU turbidity

Raw Turbidity	Al in PAC	Effluent Al	Filtered Al	Dissolved
NTU	**mg/L**	**mg/L**	**mg/L**	**mg/L**
2	1.332	0.003	0.027	0.017
3	1.332	0.03	0.043	0.015
5	1.332	0.011	0.041	0.015

4.3.5 Model cleaning by Chlorination

The curves in figure 4.8 show the chlorine demand of the algal growth witnessed in the model for the two days. Day 1 results show that there was continuous consumption of chlorine till 90 minutes. After which, the free available chlorine was equal to the chlorine supply. On second day, there was residual chlorine of 0.02 ppm left in the water. Further, it took around 125 minutes to reach the point where free residual chlorine was equal to the chlorine dose. This shows that the demand of algal growth was satisfied in 90-125 minutes. Since, there was continuous chlorine consumption even after one day, the model was put to manual cleaning.

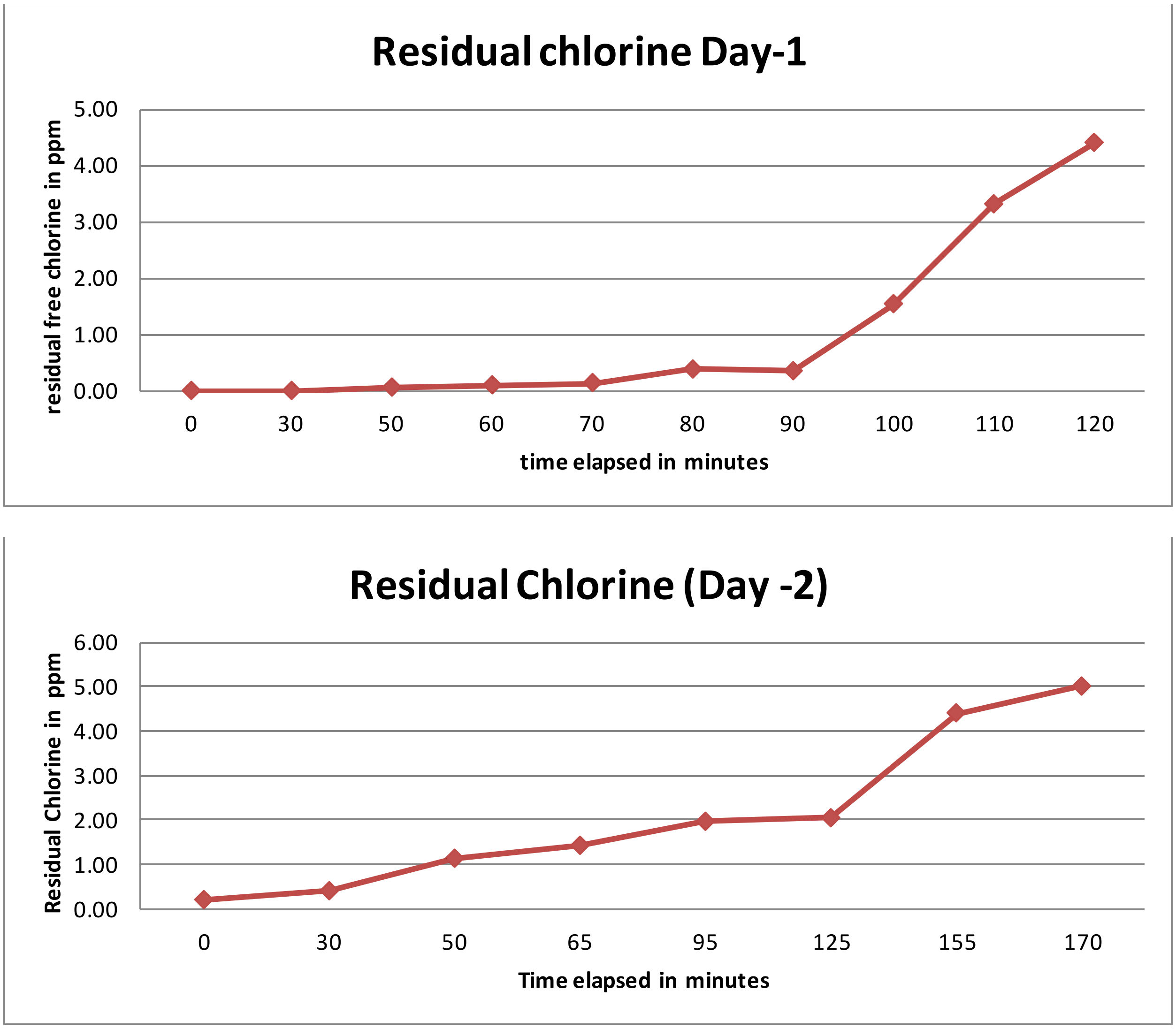


Figure 4.8: Pulsator model cleaning by chlorination with constant dose of 5ppm for day1 and day 2: Curve showing time in minutes vs free chlorine in ppm

4.5. Conventional Clariflocculator Model results

This section evaluates the performance of conventional clariflocculator model run at selected turbidities in reducing the residual Al concentrations. Similar to Pulsator model, residual Al in treated water, Al left after filter and dissolved Al shown in table 4.9, was analyzed and discussed.

4.5.1. Residual Aluminium

Table 4.9 : Conventional Clariflocculator model results for selected turbidity

Raw Turbidity	Al in PAC	Total Al in Treated water	Al after filtration with 20 microns	Dissolved Al
NTU	mg/L	mg/L	mg/L	mg/L
2	1.332	0.018	0.017	0.008
3	1.332	0.034	0.021	0.008
5	1.332	0.055	0.018	0.010
8	1.332	0.032	0.040	0.023
10	1.332	0.041	0.034	0.020
20	1.332	0.038	0.038	0.000
30	1.332	0.024	0.020	0.000

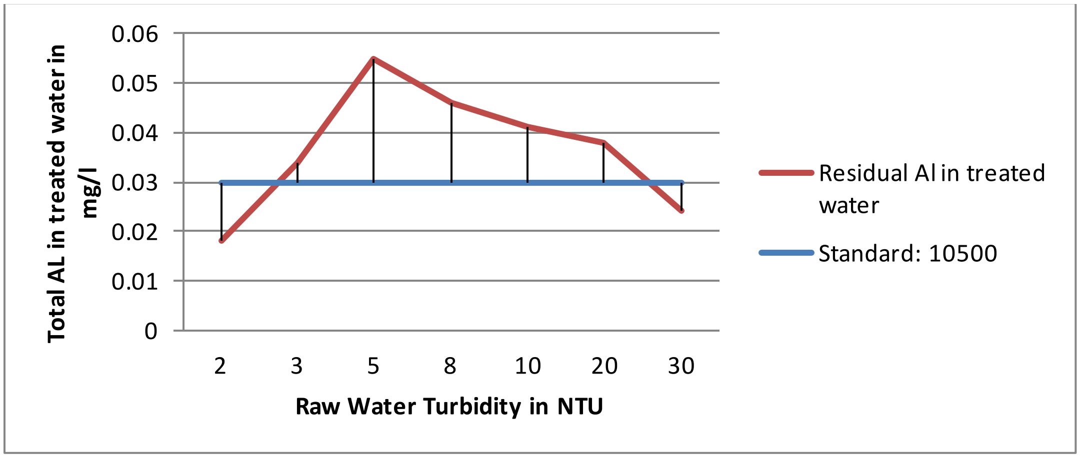


Figure 4.9: Residual Al vs turbidity in raw water in treated water by conventional clariflocculator

Figure 4.9 shows that the out of 7 turbidities run in the model, only 2 resulted in a residual aluminium below the standard of 30 µg/L(IS 10500).The concentration of Al in treated water was observed to increase with increase in turbidity till 5 NTU, after which further increase in turbidity resulted in a decrease in residual aluminum. Lowest residual aluminum was found at 2 NTU while highest at 5 NTU. Sudden increase of residual Al at 5 NTU may have resulted due to a floc being drawn while taking the sample. In the model, a piped outlet was provided to withdraw the clarified water instead of a peripheral weir. The weir load might have excessively increased, due to which small flocs were sucked up while withdrawing the sample. Thus, a need was felt for placing a weir in the model for drawing up the clarified water so that the designed detention time is provided in the model for settlement of the flocs.

4.5.2. Residual Aluminium after filter

Table 4.10 and figure 4.10 shows the total Al in treated water, Al left after filter and percentage of Al removed during filtration.

Table 4.10: Conventional Clariflocculator Model results for turbidity 2, 3,5,8,10,20 and 30 NTU

Raw water Turbidity	Total Al in Treated water	Residual Al after filtration with 20µ pore size filter	Al entrapped in floc size higher than 20	Percentage removed in filtration
NTU	mg/L	mg/L	mg/L	%
2	0.018	0.017	0.001	5.56
3	0.034	0.021	0.013	38.24
5	0.055	0.018	0.037	67.27
8	0.046	0.032	0.014	43.75
10	0.041	0.034	0.007	17.07
20	0.038	0.038	0.000	0.00
30	0.024	0.020	0.004	16.67
Average	0.036	0.027	0.011	26.94

At four turbidities, residual aluminum was brought below the standard after filtering the clarified water with 20 µ pore size filter paper as shown in figure 4.11. On an average, 0.027 mg/l was left after filtration with a mean percent of total Al removal of 25.03 %.

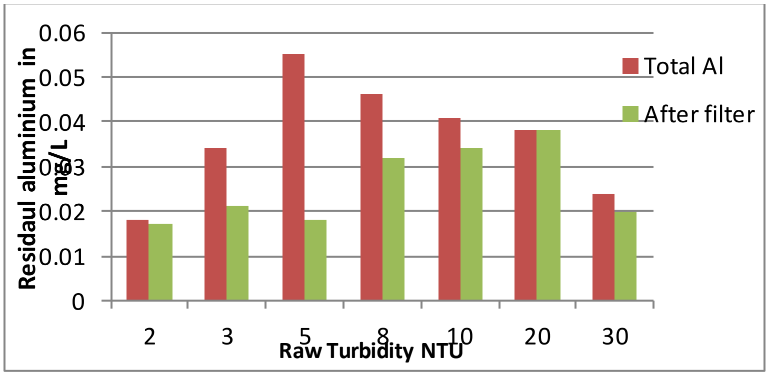


Figure 4.10: Residual Al in model treated water and after filtration with 20 µ pore size filter

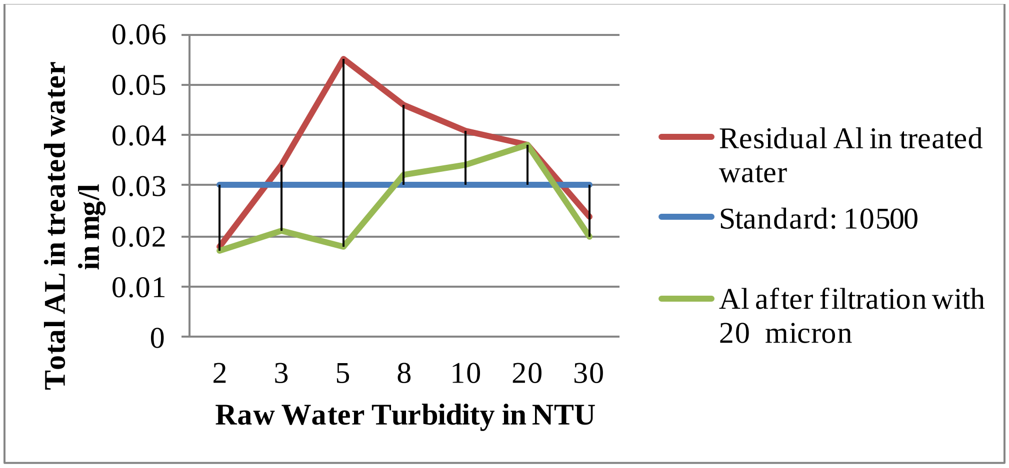


Figure 4.11: Comparison of residual Al after treatment with Indian standards

Also, the sudden increase in residual Al in treated water at 5 NTU can be explained here .Most of the Al left was entrapped in floc size equal to or greater than 20 µ which could have been removed in the case of an effective weir arrangement, proper sampling and availability of sufficient detention time in the clarifier. This also explains the high percentage removal of total Al during filter at 5 NTU.

4.5.3. Dissolved Aluminium

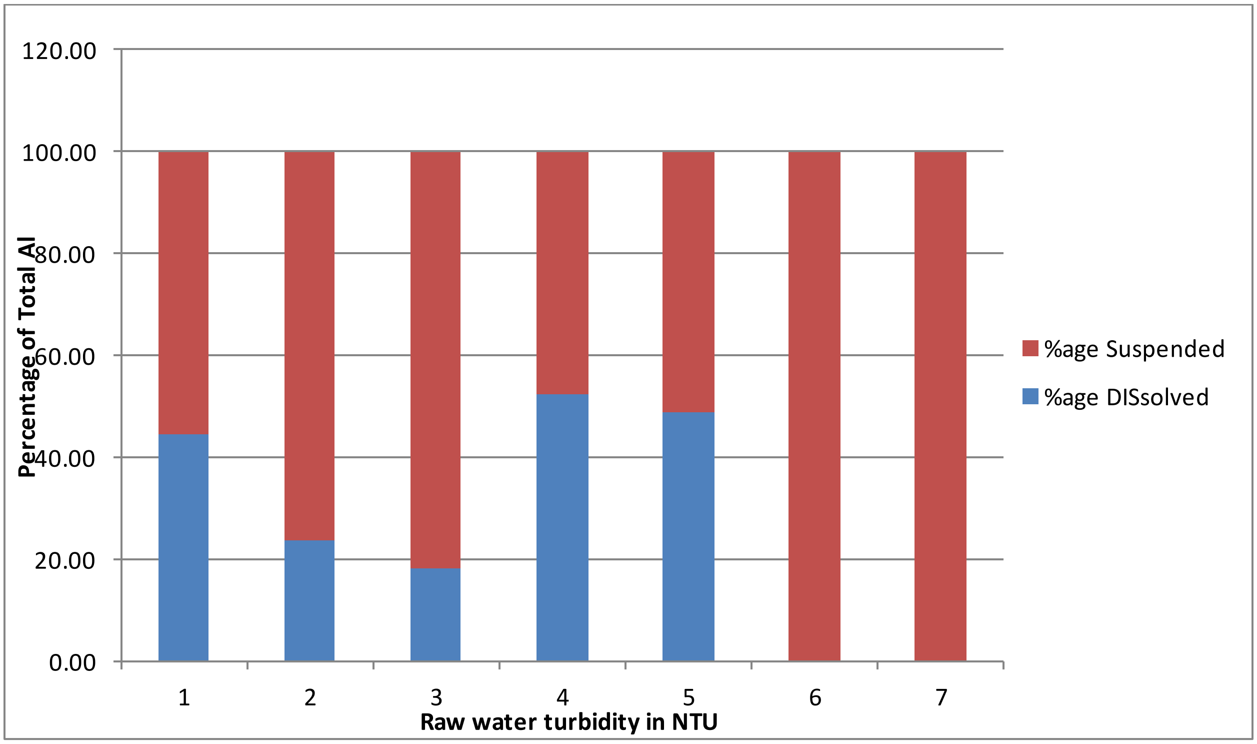
The table 4.11 shows the dissolved Al in treated water and the percentage of total Al in dissolved and suspended form. The dissolved fraction in treated water in conventional clariflocculator was very low with an average value of 0.010 mg/L.

Table 4.11: Dissolved Al in treated water by Conventional Clariflocculator, percentage of total Al in dissolved and suspension

Raw Turbidity	Dissolved Al	Percentage of total Al in dissolved form	Percentage of Total Al in suspension
NTU	**mg/L**	**%**	**%**
2	0.008	44.44	55.56
3	0.008	23.53	76.47
5	0.010	18.18	81.82
8	0.023	50.00	50.00
10	0.020	48.78	51.22
20	0.000	0.00	100.00
30	0.000	0.00	100.00
Average	0.010	26.42	73.58

It can be seen in figure 4.12 that for all the turbidites, more than 50 percentage of total Al was in suspension indicating better flocs formation in conventional clariflocculator. However, the flocs formed were not removed efficiently resulting in a higher residual Al in treated water .73.58% of total Al in treated water was in suspended form with 25.03% removable in filtration stage indicating a higher fraction of residual Al was enmeshed in floc size of 0.45-20 microns. Thus, higher detention time in flocculator can result in larger floc size.

Figure 4.12: Graph showing percentage of total Al in suspension and dissolved from in pulsator treated water



4.6. Comparison of models

- Residual Aluminium concentration in treated water by Pulsator was in range 0.025-0.039 mg/l with an average of 0.032 mg/L while in the case of Conventional clariflocculator residual Al was present in the range of 0.018 to 0.055mg/L with a mean concentration of 0.036 ppm. Thus, both the models yielded relatively low residual aluminium levels.

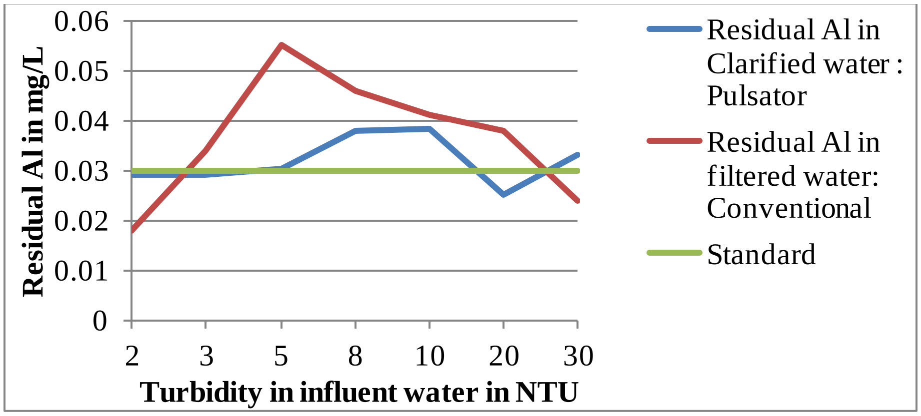


Figure 4.13: Comparison of Pulsator and Conventional clariflocculator model in terms of Residual Al

- Residual aluminum concentrations, in water treated by pulsator, were closer to or lower than the desired standard of 0.030mg/L set by Indian regulations in comparison to conventional clariflocculator as shown in figure 4.13. Hence, Pulsator seems to be a better clarification technique with high efficacy in lowering the residual Al level, requiring lesser space and minimal operating cost in comparison to conventional clariflocculator.
- It can be seen in figure 4.14 that although, residual Al levels in the clarified water were slightly lower in pulsator, after filtration with 20 µ pore size filter conventional clariflocculator yielded lower Al concentration. This was because most of the total residual Al in latter was in suspended filterable form.

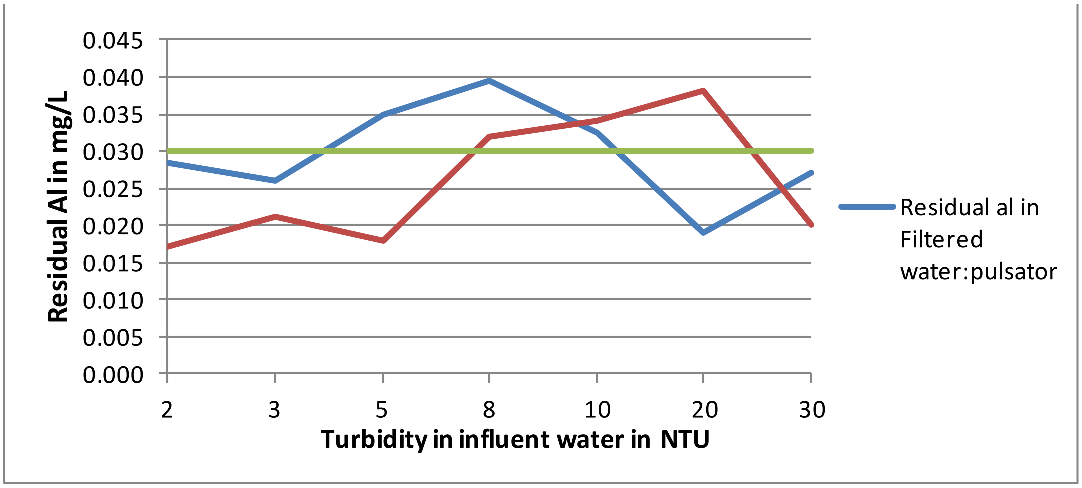


Figure 4.14 : Comparison of models in terms of residual Al after filtration

- On an average, 73.58% of total Al was in suspension in conventional clariflocculator while only 37.31% in Pulsator. Conventional clariflocculator was more efficient in forming flocs but was not able to remove them because of the above- mentioned reasons like shorter detention time in the clarifier and lack of weir arrangement in the model. The higher dissolved fraction of total Al in pulsator can be reduced either by altering the flow rates to provide more contact time to the incoming particles, in the sludge blanket or by establishing a denser blanket.

4.7. Pilot model vs. treatment plant

Weekly reports of plant performance were studied and analysed in order to compare the results of the pilot plant with those of water treatment plant at Bisalpur. The highest turbidity reported in 35 weeks was 14.08 NTU while its lowest value was 2.22 NTU. The turbidity received in treatment plant was less than 13.9 NTU for 99% of the weeks. Coagulant dose of PAC was 25 ppm in 60% of the weeks that is 24 out of 35 weeks.

For comparison of the performance of pilot plant and full- scale plant, the reports were sorted as per turbidity ranges i.e 2-3 NTU and 3-4 NTU. Since the plant receives very low turbidity, results of pilot scale models were compared at two turbidities were compared at 2 and 3 NTU. After treatment with pulsator and filtration through 20 microns pore size filter paper resulted in residual aluminium concentration of 0.029ppm and 0.026 ppm at 2 and 3 NTU respectively as shown in figure 4.15.

However, the method followed to measure residual aluminium in treated water at field laboratory has a least count of 0.050 ppm. Therefore, 99% of the times, the residual Aluminium reported in the weekly reports was equal to 0.050 ppm. The measurement of Al at field laboratory can be done by a simple instrumentation method using Eriochrome cyanine dye with a least count of 6µg/L.

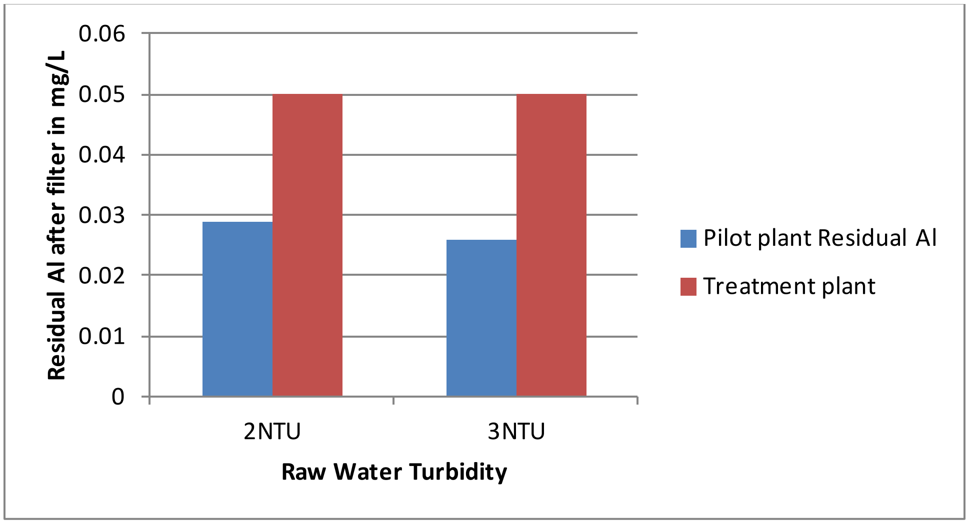


Figure 4.15: Comparison of treatment plant and Pulsator pilot plant performance at 2 and 3 NTU

5. Conclusion

- Poly Aluminium chloride is a highly effective coagulant in minimizing turbidity as well as residual aluminium concentration in treated water. As per the jar tests conducted on raw water of Bisalpur, all the coagulant doses(5-60 ppm of PAC) were giving a residual aluminium below the standard value of 0.030 mg/L. as per the standards set by Indian regulations(IS 10500:2012).Therefore, the cost of PAC incurred in treatment plant can be reduced by lowering the coagulant dose to 5 to 10 mg/l to achieve both the desired turbidity and residual Aluminum levels. Further, some turbidity and aluminum level will be reduced in the next stage of the filtration.
- During the treatment plant visits, free chlorine available at identified sampling points was measured using a portable chlorine photometer. High residual free chlorine was available at filter outlet, which indicated that the current prechlorination dose equal to 4.25-4.5 ppm at treatment plant can be reduced. Also, some amount of chlorine is lost to the environment while feeding the chlorine. Therefore, careful consideration can be given to the design of chlorinator to minimize the loss of chlorine.
- 99% of the times in 35 weeks, residual Al reported in treated water was equal to 0.05 mg/L because the least count of the method adopted in field laboratory is 0.05 mg/L. Thus, a better method for measurement of aluminium can be adopted like Eriochrome cyanine R method with a least count of 0.006mg/L.
- Both the models, pulsator and conventional clariflocculator, were efficient in bringing down the aluminium levels. However, Residual aluminum concentrations, in water treated by pulsator, were more close to or lower than the standard of 0.030mg/L set by Indian regulations in comparison to conventional clariflocculator. Hence, Pulsator proves to be a better clarification technique with high efficacy in lowering the residual Al level, requiring lesser space and minimal operating cost in comparison to conventional clariflocculator.
- The performance of pulsator was better at lower turbidities i.e. at 2 and 3 NTU as the residual aluminium level almost complied with Indian standards for aluminium.

Therefore, pulsator technology with PAC as coagulant is successful in treating low turbid waters and producing desired turbidity and residual Al levels.

- Although, residual Al levels in the clarified water were slightly less in pulsator, after filtration with 20 µ pore size filter conventional clariflocculator yielded in lower Al concentration. This was because most of the total residual Al in latter was in suspended filterable form. Thus, a peripheral weir is required in the clariflocculator model instead of a piped outlet for withdrawing the clarified water.

6. Future Recommendations

Recommendations for future research:

- **Continuous operation of model**: In this study, the pulsator model was not run continuously for 24 hours which resulted in different characteristics of sludge blanket every time the blanket was reestablished. Therefore, for more accurate and reliable results, model should be operated continuously while carrying out the experiments.
- **Synthetic wate**r: Also, in this study, bentonite clay suspension was used to introduce the turbidity in the raw water. For future research, synthetic water can be made by supplementing bentonite with some organic matter (treated sewage). This will examine the efficiency of pulsator in removing organic solids.
- **Varying Coagulant dose:** Further, the coagulant dose for PAC was fixed at 25 ppm in this study. However, jar tests results indicated that 15 ppm of PAC dose is also sufficient to bring down the turbidity levels to desired value without compromising on residual aluminium levels. So, the model can be run for a lower dose of PAC to determine the efficiency of pulsator in treating the variety of turbid water with a lower coagulant dose.Also, combination of coagulants can be used to examine the efficacy of the pulsator in treating different turbidity of water.
- **Modifications in the model:** In pulsator model, a Perspex cone was provided which acts as a flocculator. The purpose was fulfilled however a need was felt to reduce its apex angle so that the flocs do not settle on its top and slide down. In conventional clariflocculator model, Peripheral weir arrangement should be made so that the clarified water overflows uniformly.
- **Changes in Actuator settings:** In this research, actuator valve was operated on its default settings i.e 45 seconds off and 10 seconds on. The frequency and duration of pulse can be altered depending on the raw water characteristics and the properties of the flocs so formed.
- **Flow alterations:** The model was designed for a flow rate of 3.5 lpm as regular flow and 14lpm as pulsed flow (Approx 4 times the regular flow). After various trials, flow rate

was fixed at 2.2 lpm for continuous flow and 8.8 lpm as pulsed flow. This can be further altered to reach an optimum flow rate for which blanket remains stable.

- **Defluoridation of water:** The pulsed sludge blanket technology has the potential of replacing the settler and membrane combination in the ‘Nalgonda’ process equipment for the de-fluoridation of water.

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Annexure - A

Design Calculations of Conventional Clariflocculator

Flow Rate: 0.212m^3/hour

(i) **Rapid Mix unit**

Taking Detention time= 30 seconds

Volume = flow * detention time= 0.212*30/1000= $1.76*10^{-3}$ m^3

From CPHEEO MANUAL taking ratio of tank height to diameter =1:1

Volume $= \pi/4\ d^2 * d$

$1.76*10^{-3} = \frac{\pi}{4} * d^3$

d= 13.36 cm

Provide Diameter of 14 cm ; height of tank = 14cm

Free board= 2 cm ; height= 16cm

Power Requirements

Power spent = μG^2 *volume

For detention time 30 seconds, taking G velocity Gradient = $600s^{-1}$ from CPHEEO manual

Taking $\mu=1.0087*10^{-3}$

$P=1.0087*10^{-3}*600*600*1.76*10^{-3}$

P= 0.64 watts

taking N=120 rpm and Ratio of impeller dia to tank dia=0.4:1

Diameter of Impeller= 0.4*14cm= 5.6cm

Velocity of tip of impeller= $2\ \pi rN/60$ m/s = 0.35m/sec

$P= 1/2 *C_d*\ell*A_p*V_r^3$

$A_p= 0.0393m^2$

Provide 4 blades of 0.1m*0.1m

(ii) Clariflocculator:

Flow= $0.212m^3/hr$

Detention Time= 20minutes

Taking $G= 40\ s^{-1}$

Assuming Velocity of 1m/sec ; $\pi/4d^2= 0.212/3600$

d= 8.6 mm provide 1 cm influent pipe

Volume of Flocculator = 0.212*20/60= $0.07m^3$

Taking Depth = 0.25m

Plan area= $0.28m^2$

$\pi/4(D^2-D_p^2) = 0.28m^2$ where D= dia of flocculator and D_p= dia of infleunt pipe

solving D=60cm

Depth for sludge storage = 5 cm

Providing 1 cm as free board

8% slope for bottom

Total height = 5 cm +6.25cm+1cm+25cm= 37.25cm

Design of Clarifier:

Taking SOR= $40m^3/m^2/day$

Surface area= 0.212*24/10 = 0.1272m^2

$\pi/4(D_{cf2}-D_f^2) = 0.1272m^2$

D_{cf}= 72 cm

provide dia clarifier= 72 cm; flocculation basin= 60 cm; total height = 38cm