Development of Pilot Plant based on Superpulsator$^{\circledR}$ Clarifier & Comparative Analysis of Effect of Polyaluminium Chloride and Alum on the Performance of the Pilot Plant and Conventional Clariflocculator

Master of Technology
(Environmental Engineering)

Dissertation Report

by

Shashank Srivastava
(2013PCE5340)

Under the Supervision of
Dr. Urmila Brighu
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Department of Civil Engineering
Malaviya National Institute of Technology, Jaipur-302017

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CERTIFICATE

I hereby certify that the work being presented in the dissertation report entitled "**Development of Pilot Plant based on Superpulsator® Clarifier & Comparative Analysis of Effect of Polyaluminium Chloride and Alum on the Performance of the Pilot Plant and Conventional Clariflocculator"** in the partial fulfillment of the requirements for the award of the **Degree of M. Tech.** and submitted in the **Department of Civil Engineering** of Malaviya National Institute of Technology Jaipur is an authentic record of my own work under the supervision of Dr. Urmila Brighu (Associate Professor), Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur.

The matter presented in this dissertation report embodies the results of own work and studies carried out by me and has not been submitted for the award of any other degree of this or any other institute.

SHASHANK SRIVASTAVA
(2013PCE5340)

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Place: Malaviya National Institute of Technology, Jaipur

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ABSTRACT

Sustained supply of treated surface water which meets the drinking water standards is of paramount significance. Water treatment plants based on conventional technology have long been found to be uneconomical concerning usage of power, the requirement for area, dosage of chemicals and beset by non-functional mechanical components, to mention a few important markers. Superpulsators® are basically solids contact clarifiers, and are renowned for treating even low turbidity waters efficiently. However, like most of the proprietary technologies, are designed and sized by manufacturer's recommendations and rationales that explain their behavior are deficient. Therefore, water treatment plant at Surajpura, was visited for gaining insights into the design of Superpulsator® Clarifiers, and to contribute towards improvement of performance. Subsequently, a pilot plant based on Superpulsator® technology was designed and developed for a capacity of about 8000 liters per day at the Malaviya National Institute of Technology Jaipur, India. A conventional clariflocculator also designed for a capacity of about 8000 liters per day was constructed and studied in parallel.

Pre-chlorination dose 4.5ppm and post-chlorination dose of 1ppm, being currently administered at Surajpura WTP was found optimum. Zetapotential of colloidal particles in Bisalpur water was found to be -12.7mV. Zetasizing analyses indicate that the flocs are damaged due to hydraulic jump in the parshall flume of the WTP. Large D_{90} values were observed for the flocs in the clarified water from Superpulsator® pilot plant, which shows that coagulation and flocculation occur properly and result in adequate formation of sludge blanket for high solids contact. Analysis of the effect of coagulants, namely PAC and alum on the performance of Superpulsator® pilot plant and conventional clariflocculator was done. Much lower residual aluminium levels were obtained when alum was used as coagulant in the pilot plant as compared to PAC. Whereas, in case of conventional clariflocculator, PAC was found to give lower residual aluminium levels as compared to alum. However, turbidity in the filtered water was lower when alum was used for conventional clariflocculator as compared to PAC.

Keywords: Superpulsator® clarifier; conventional clariflocculator; pilot plant; particle size; zetapotential; polyaluminium chloride; alum; turbidity; residual aluminium;

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List of abbreviations

- AD: Alzheimer ’s Disease
- Al: Aluminium
- BIS: Bureau of Indian Standards
- Cl: Chlorine
- IS: Indian Standards
- PAC: Polyaluminium Chloride
- WTP: Water Treatment Plant

Chapter 1. Introduction

Coagulation and flocculation constitute the backbone processes in most water and advanced wastewater treatment plants. Their objective is to enhance the separation of particulate species in downstream processes such as sedimentation and filtration. Colloids are insoluble particles suspended in water. Their small size (less than 10 micron) makes the particles extremely stable. They can have different origins such as minerals, organics and micro-organisms such as bacteria, plankton, algae, viruses etc. Coagulation is the step where colloids are destabilized. In water treatment, coagulation is the result of the addition of chemical reagents to water suspensions where the dispersed colloidal particles are assembled in larger aggregates called flocs or microflocs (Kawamura S., 1973). Destabilization of colloidal particles is accomplished by coagulation through the addition of hydrolyzing electrolytes such as metal salts and/or synthetic organic polymers in a controlled manner (Chowdhury et al., 1991) and may occur through diverse mechanisms which are distinct for different coagulants (Wu et al., 2007).

Conventional water treatment plants often employ high doses of coagulants for treating low turbidity waters. This is a cause of concern to the environmental engineers since the coagulants used are mostly salts of aluminium and high dose of coagulants directly translates to higher residual aluminium levels in the treated drinking water, especially in conventional systems. As aluminium is notorious for its reported neuro-toxicity, efforts are being made on technological front to reduce the levels of residual aluminium (George et al., 2010).

1.1 Background and justification for the project:

Pulsed sludge blanket technology goes a step further over other solids contact clarifiers by maintaining a contracting and expanding sludge blanket which acts as a filter, without compromising flow distribution, in order to gain efficient and high rate solids contact. The pulsing sludge blanket combines flocculation, clarification and sludge collection into one compact system. This design results in improved efficiency and superior effluent quality at much lower operating costs.

The **Bisalpur-Jaipur Water Supply Project (BWSP)** is a state-of-the-art plant, only one in Rajasthan, and among the select few in India, based on the Pulsed sludge blanket technology. It 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 dependence on its ground water resources, and includes complementary provisions for supplying water to other areas. With the completion of the phase-II expansion, the project will achieve a total capacity of 1020 MLD clear water production.

The traditional use of coagulation has been primarily for the removal of turbidity from potable water. (Langelier and Ludwig, 1949) However, more **recently**, coagulation has been shown to be an effective process for the removal of many other contaminants that can be adsorbed by colloids such as metals, (Leckie and James, 1974) organic matter, (Exall and Vanloon, 2000) toxic organic matter, (Carlson et al., 1993) viruses and radionuclides. (Fox and Lytle, 1996) Enhanced coagulation is an effective method to prepare the water for the removal of certain contaminants such as fluoride, emerging pathogens such as *Cryptosporidium* and *Giardia*, (Ongerth J., 1996) and humic materials (Edzwald et al., 1977).

Moreover, the pulsed sludge blanket technology is a result of latest developments in the field of water and wastewater treatment. Few researches have been done and many realms haven't even been touched upon for this promising technology, namely removal of fluoride, residual aluminium etc.

1.2 Gaps in the present technology:

Conventionally, a zone of high solids contact to achieve a better quality effluent is accomplished in an up-flow clarifier (Su et al., 2004). However, **Pulsed sludge blanket technology** goes a step further over other solids contact clarifiers by maintaining a contracting and expanding sludge blanket which acts as a filter, without compromising flow distribution. The pulsed sludge blanket technology is a result of latest developments in the field of water and wastewater treatment.

However, this technology is yet to be examined for various applications like efficient removal of certain contaminants such as emerging pathogens, fluoride, phosphates and devising a method for control and reduction of residual aluminium levels. It would therefore be of immense utility to design and develop a pilot plant for researching into these realms.

1.3 Potential applications:

The proposed project attempts at the technology upgradation of water treatment process and has direct application for the upcoming major water supply projects based on surface sources in Rajasthan being executed for catering to rural and urban areas. Immediate beneficiary would be the Bisalpur-Jaipur Water Supply Project (BWSP) as this study will help in decoding the pulsator operation (technology being used for water treatment at BWSP) and writing down a detailed operator instruction handbook for troubleshooting, as well as hassle-free and efficient operation and maintenance. Further, the study can suggest a better and economical coagulant, as against 100% polyaluminium chloride being currently administered at the BWSP besides examining the technology for various other applications. Future prospects for research are promising once a functional pilot plant is developed and installed.

A **team of four students** from M. Tech. Environmental engineering class, namely, **Mrs. Megha Gupta, Ms. Neelam Kothari, Mr. Suparshve K. Jain** and **Shashank Srivastava** (myself) was formed for studying the Surajpura WTP, carrying out the research and development of pilot plant based on Superpulsator® Clarifier, and fabrication of a conventional clariflocculator. Thereafter, each student analyzed the different aspects of the functioning of pilot plant, conventional clariflocculator and evaluation of Surajpura WTP based on primary and secondary data, in their respective dissertation reports as follows- "Comparative analysis of turbidity removal in pulsator pilot scale model vs conventional clariflocculator vis-à-vis Surajpura treatment plant" was done by Mrs. Megha Gupta, Ms. Neelam Kothari worked on "Comparative Analysis of Pulsator and Conventional Clariflocculator Pilot scale model on residual aluminium levels vis-à-vis treatment plant at Surajpura", and "Performance Analysis of Surajpura WTP of Bisalpur Jaipur Water Supply Project and Cost Optimization Study using a Pulsator Clarifier Pilot Plant" was done by Mr. Suparshve K. Jain. I had the opportunity to work on the development of pilot plant based on Superpulsator® Clarifier and comparative analysis of the effect on performance of the pilot plant and conventional clariflocculator when polyaluminium chloride and alum are used as coagulants

1.4 Area of interest:

Coagulation and flocculation constitute the backbone processes in most water and advanced wastewater treatment plants. Their objective is to enhance the separation of particulate species in downstream processes such as sedimentation and filtration. Colloids are insoluble particles suspended in water. Their small size (less than 10 micron) makes the particles extremely stable. They can have different origins such as minerals, organics and micro-organisms such as bacteria, plankton, algae, viruses etc.

Coagulation is the step where colloids are destabilized. In water treatment, coagulation is the result of the addition of chemical reagents to water suspensions where the dispersed colloidal particles are assembled in larger aggregates called flocs or microflocs. Destabilization of colloidal particles is accomplished by coagulation through the addition of hydrolyzing electrolytes such as metal salts and/or synthetic organic polymers in a controlled manner.

Flocculation is the step where destabilized colloidal particles (or the particles formed during the coagulation step) are assembled into aggregates. The agglomeration of particles is a function of their rate of collisions. The function of flocculation is to optimize the rate of contact between the destabilized particles, hence increasing their rate of collision and bringing about the attachment and aggregation of the particles into larger and denser floc. Thus, the flocculation process allows the colloidal particles to come together and build into larger flocs that are more amenable to separation by settling or filtration (Weber at al., 1970).

Conventionally, coagulation and flocculation have been carried out in two different tanks, viz. a rapid mix tank and a flocculation basin in series, followed by settling under gravity in a clarifier. Most water and wastewater treatment plants are based on these designs. The destabilization process is achieved by the following four mechanisms of coagulation: double-layer compression; adsorption and charge neutralization; entrapment of particles in precipitate; and adsorption and bridging between particles. *However, if the water is having* ***low turbidity*** *and low alkalinity which is normally there when the intake is situated in a large impoundment/lake, the conventional systems with their sweep floc* ***mechanism*** *are less effective. (Packham R. F., 1962)* In such scenarios, the alternative is either to use the bridging mechanism by using PaCl as the coagulant (Pernitsky and Edzwald, 2000) or/and improved clarification by employing a **zone of high solids contact** to achieve a better quality effluent. This is accomplished in an up-flow clarifier, so called because the water flows upward through the clarifier as the solids settle to the bottom. Summarily solids contact clarifiers can enhance sedimentation by improving the physical characteristics of the material to be removed, can remove materials by utilization of chemical reactions because of ideal reacting environment, can maximize the use of chemicals and occupy a smaller space.

It is important to consider the principal mechanism at play for coagulation and flocculation which might be different for PAC and alum. More importantly, the different designs and conditions of Superpulsator® pilot plant and conventional clariflocculator would result in difference in performance due to different coagulants. PAC contains a high cation (aluminium) to anion (chloride or sulphate) ratio, and thus it produces significantly less sludge than would alum. In other words, alum produces more sludge and thus would give a better formation of sludge blanket in Superpulsator® pilot plant, even more so because high solids contact zone exists at the bottom of the column.

1.5 Proposed approach:

It is proposed to design and develop a continuous flow pilot plant based on the Superpulsator® clarifier and a conventional clariflocculator each of about 8000 liters per day capacity. Experiments would be carried out on the pilot plant and conventional clariflocculator in a controlled regime of flow characteristics for comparison of performance when PAC and alum are used as coagulants. It is also proposed to conduct experiments to analyse actual water samples from Bisalpur and try to develop insights to help improve the performance of Surajpura WTP.

1.6 Objectives

1. Design and development of a pilot plant of about 8000 liters per day capacity based on Superpulsator® clarifier.
2. Construction of a conventional clariflocculator also designed for a capacity of about 8000 liters per day.
3. Carry out particle size analysis on Malvern's® Mastersizer 2000™ to estimate the size and specific surface area of the flocs in the clarified water from the Superpulsator® pilot plant
4. Compare the performance of Superpulsator® pilot plant in terms of turbidity removal and levels of residual aluminium when PAC and alum are used as coagulants.

5. Compare the performance of conventional clariflocculator in terms of turbidity removal and levels of residual aluminium when PAC and alum are used as coagulants.
6. Conduct jar tests on raw water from Bisalpur for analysis of turbidity and residual aluminium levels for different doses of PAC and alum.
7. Optimization of chlorine dose for Surajpura WTP.
8. Simulation of parshall flume conditions of Surajpura WTP for analysis of zetapotential at different stages of flow.
9. Simulation of parshall flume conditions of Surajpura WTP for particle size analysis of flocs at different stages of flow.

Chapter 2. Literature review

India accounts for 2.45% of land area and 4% of water resources of the world but represents more than 16% of the world population. India's population is expected to cross1.5 billion by 2050 if the current population growth rate of 1.9% per year continues (CPCB, 2010). The water demand has been estimated to increase to almost 1180 BCM in 2050 with domestic and industrial water consumption expected to increase almost 2.5 times (Kathpalia and Kapoor, 2002). The rapid growth of population has exerted increased demand of potable water. Moreover, the raw water quality available in India varies significantly, resulting in modifications to the conventional water treatment scheme consisting of aeration, chemical coagulation, flocculation, sedimentation, filtration and disinfection. As for Rajasthan, the state of art Surajpura WTP receives water from Bisalpur head-works and in this case waters are typically low in turbidity.

Under the Indian Constitution, water supply and sanitation is a State responsibility. Three central level Ministries, namely; The Ministry of Drinking Water and Sanitation (until 2011 the Department of Drinking Water Supply in the Ministry of Rural Development) is responsible for rural water supply and sanitation; the Ministry of Housing and Urban Poverty Alleviation and the Ministry of Urban Development share the responsibility for urban water supply and sanitation. However, except for the National Capital Territory of Delhi and other Union Territories, the central Ministries only have an advisory capacity and a limited role in funding. It is the prerogative of the states to plan, design and execute water supply schemes (and often operate them) through their State Departments (of Public Health Engineering or Rural Development Engineering) or State Water Boards. Table 2.1 gives the quality standards for drinking water as laid down by the Bureau of Indian Standards directive document IS: 10500 (BIS, 2009). It should be noted that till date there is no directive regulation on the limit of aluminium.

Table 2.1: Indian standard specifications for drinking water; IS: 10500

S.NO.	Parameter	Requirement/ desirable Limit	Remarks
1.	Colour	5	May be extended up to 50 if toxic substances are suspected.
2.	Turbidity	10	May be relaxed up to 25 in the absence of alternate
3.	pH	6.5 to 8.5	May be relaxed up to 9.2 in the absence.
4.	Total Hardness	300	May be extended up to 600
5.	Calcium as Ca	75	May be extended up to 200
6.	Magnesium as Mg	30	May be extended up to 100
7.	Copper as Cu	0.05	May be relaxed up to 1.5
8.	Iron	0.3	May be extended up to 1
9.	Manganese	0.1	May be extended up to 0.5
10.	Chlorides	250	May be extended up to 1000
11.	Sulphates	150	May be extended up to 400
12.	Nitrates	45	No relaxation
13.	Fluoride	0.6 to 1.2	If the limit is below 0.6 water should be rejected, Max. Limit is extended to 1.5
14.	Phenols	0.001	May be relaxed up to 0.002
15.	Mercury	0.001	No relaxation
16.	Cadmium	0.01	No relaxation
17.	Selenium	0.01	No relaxation
18.	Arsenic	0.05	No relaxation
19.	Cyanide	0.05	No relaxation
20.	Lead	0.1	No relaxation
21.	Zinc	5.0	May be extended up to 10.0
22.	Anionic detergents	0.2	May be relaxed up to 1
23.	(MBAS)Chromium+6 as Cr	0.05	No relaxation
24.	Poly nuclear aromatic Hydrocarbons	--	--
25.	Mineral Oil	0.01	May be relaxed up to 0.03
26.	Residual free Chlorine	0.2	Applicable only when water is chlorinated
27.	Pesticides	Absent	--
28.	Radio active	--	--

Various studies on animals (Connor et al., 1988; Domingo et al., 1989; Gomez et al., 1990); Yen-Koo, 1992; Colomina et al., 1994) and humans (Clayton, 1989; Flaten, 1990; Neri & Hewitt, 1991;) have long indicated high toxicity of aluminium. However, a comprehensive study by WHO has concluded that the relative risks for development or acceleration of onset of Alzheimer disease (AD) from exposure to aluminium in drinking-water above 100µg/L are less than 2.0 (WHO, 1998). The degree of aluminium absorption depends on a number of parameters, such as the aluminium salt administered, pH (for aluminium speciation and solubility), bioavailability, and dietary factors. Due to such variety of methodological reasons, a population attributable risk has not been calculated with precision, and that is why there is no regulatory limit in India (IS 10500) and other countries.

Due to the +3 cationic charge on Al ion, relative inexpensiveness, and other beneficial properties the use of aluminium as a coagulant in water treatment is well accepted and documented. Taking this into account and considering the potential health concerns (i.e. neurotoxicity) of aluminium, a practicable level should be derived based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants, to minimize aluminium levels in treated water. According to the report by CPCB on the status of water treatment plants in India (CPCB, 2010), majority of the plants use either alum or PAC, alum being more popular.

Coagulation and flocculation constitute the backbone processes in most water and advanced wastewater treatment plants. Their objective is to enhance the separation of particulate species in downstream processes such as sedimentation and filtration. Colloids are insoluble particles suspended in water. Their small size (less than 10 micron) makes the particles extremely stable. They can have different origins such as minerals, organics and micro-organisms such as bacteria, plankton, algae, viruses etc. Coagulation is the step where colloids are destabilized. In water treatment, coagulation is the result of the addition of chemical reagents to water suspensions where the dispersed colloidal particles are assembled in larger aggregates called flocs or microflocs (Kawamura S., 1973). Destabilization of colloidal particles is accomplished by coagulation through the addition of hydrolyzing electrolytes such as metal salts and/or synthetic organic polymers in a controlled manner (Chowdhury et al., 1991) and may occur through diverse mechanisms which are distinct for different coagulants (Wu et al., 2007).

The traditional use of coagulation has been primarily for the removal of turbidity from potable water (Langelier and Ludwig, 1949). However, more recently, coagulation has been shown to be an effective process for the removal of many other contaminants that can be adsorbed by colloids such as metals (Leckie and James, 1974), organic matter (Exall and Vanloon, 2000), toxic organic matter (Carlson et al., 1993), viruses and radionuclides (Fox and Lytle, 1996). Enhanced coagulation is an effective method to prepare the water for the removal of certain contaminants such as fluoride, emerging pathogens such as Cryptosporidium and Giardia, (Ongerth, J., 1996) and humic materials. (Edzwald et al., 1977)

Flocculation is the step where destabilized colloidal particles (or the particles formed during the coagulation step) are assembled into aggregates. The agglomeration of particles is a function of their rate of collisions. The function of flocculation is to optimize the rate of contact between the destabilized particles, hence increasing their rate of collision and bringing about the attachment and aggregation of the particles into larger and denser floc (Wang et al., 2005). Thus, the flocculation process allows the colloidal particles to come together and build into larger flocs that are more amenable to separation by settling or filtration (Weber et al., 1970). In the initial growth phase of the flocs, the size which a floc attains can be basically determined by the balance between the rate of collision-induced aggregation and the rate of breakage for given shear conditions (Bouyer et al., 2005)

$$R_{floc} = \alpha\, R_{colij} - R_{br}$$

Where, R_{floc} is the overall rate of floc growth, α is the collision efficiency factor ($0 < \alpha < 1$), R_{col} is the rate of particle collision and R_{br} represents the rate of floc breakage. The larger the floc size, the better its efficiency to capture other colloidal particles, and higher the filterability and/or settleability (Gray and Ritchie, 2006; Grabsch et al., 2013).

Conventionally, coagulation and flocculation have been carried out in two different tanks, viz. a rapid mix tank and a flocculation basin in series. These plants are often marred by several operational and maintenance issues. As such they are unable to achieve the desired level of performance, and a major factor is the dependence on mechanical equipments which soon become non-functional (Rotkar, 2001). It has been observed that conventional flocculation (mechanically mixed) usually requires high energy gradients, due to which, irregular, fluffy and weak flocs are formed (Carissimi and Rubio, 2015). The process, as operated in most water treatment plants is optimized primarily for the removal of turbidity (Gregor et al., 1997) and the level of residual aluminium in the treated water is variable. Aluminium (Al) is an established neurotoxin, and since it is a highly potential environmental risk factor, it has been studied most intensively (Craun, G. F., 1990). The Al speciation in drinking water has been strongly linked with the risk of Alzheimer's disease (Gauthier et al., 2000).

The selection of the proper type and amount of coagulant chemical to be added to the water to be treated is crucial. Overdosing as well as underdosing of coagulants are undesirable and lead to reduced solids removal efficiency (Letterman, 1999). If the water is having low turbidity and low alkalinity which is normally there when the intake is situated in a large impoundment/lake, the conventional systems with their sweep floc mechanism are less effective (Packham, 1962). In such scenarios, the alternative is either to use the bridging mechanism by using PACl as the coagulant (Pernitsky and Edzwald, 2000) or/and improved clarification by employing a zone of high solids contact to achieve a better quality effluent. Conventional water treatment plants often employ high doses of coagulants for treating such waters. This is a cause of concern to the environmental engineers since the coagulants used are mostly salts of aluminium and high dose of coagulants directly translates to higher residual aluminium levels in the treated drinking water, especially in conventional systems. As aluminium is notorious for its reported neuro-toxicity, efforts are being made on technological front to reduce the levels of residual aluminium (George et al., 2010).

Now it has been established, that it is often advantageous to employ a zone of high solids contact to achieve a better quality effluent primarily because increase in the contact mass increases the probability that collisions will take place inside the flocculator resulting in a more efficient flocculation (El-Nahhas K., 2011). High concentrations of suspended solids in the flocculation process can provide improved efficiency in reducing particulates, colloids, organics, and certain ionized chemicals. It may be summarized that solids contact clarifiers can enhance sedimentation by improving the physical characteristics of the material to be removed, can remove materials by utilization of chemical reactions because of ideal reacting environment, can maximize the use of chemicals and occupy a smaller space and also may have the benefit of reduction of aluminum levels (Hemingway and Sposito, 1996; Parsons and Jefferson, 2006). Pulsed sludge blanket technology goes a step further over other solids contact clarifiers by maintaining a contracting and expanding sludge blanket which acts as a filter, without compromising flow distribution in order to gain efficient and high rate solids contact. The pulsing sludge blanket combines flocculation, clarification and sludge collection into one compact system (Ondeo Degremont, 2002). This design results in improved efficiency and superior effluent quality without the use of submerged moving parts and at lower operating costs.

Suez Environment's (formerly Infilco Degrémont) Superpulsator® is the pioneer technology based on pulsing sludge blanket. Due to simple design and better performance, these units have been successful world over. However, Superpulsators®, like most of the proprietary technologies, are designed and sized by manufacturer's recommendations and rationales that explain their behavior are deficient. Few researches have been done and many realms haven't even been touched upon for this promising technology, like removal of fluoride, residual aluminium levels and other performance parameters.

Chapter 3. Design and development

To begin with, the process of water treatment at Surajpura WTP has been outlined in this chapter to get a comprehensive idea for the development of the pilot plant. Then after, the calculations for design and safety of pilot plant and conventional clariflocculator have been discussed. The chapter finally builds up towards explaining the working of the fully functional models after describing the materials and methods for fabrication.

3.1 Process overview

Superpulsators®, like most of the proprietary technologies, are designed and sized by manufacturer's recommendations and rationales that explain their behavior are deficient. Therefore, a pilot plant based on Superpulsator® technology was designed for a capacity of about 8000 liters per day and fabricated at the Malviya National Institute of Technology Jaipur campus. For this, the state-of-the-art water treatment plant of PHED at Surajpura of 1020 MLD capacity constructed by Degrémont Limited (and currently operated by Larsen and Toubro Ltd.) was surveyed and studied for sizing the pilot plant in order to depict the functioning as closely as possible. Overall process flow of the plant is outlined in figure 3.1; however the scope of the thesis limits the area of interest to the production of clarified water. A brief functional description of the course of water treatment employed at the Surajpura plant, which is relevant towards the project, is given below.

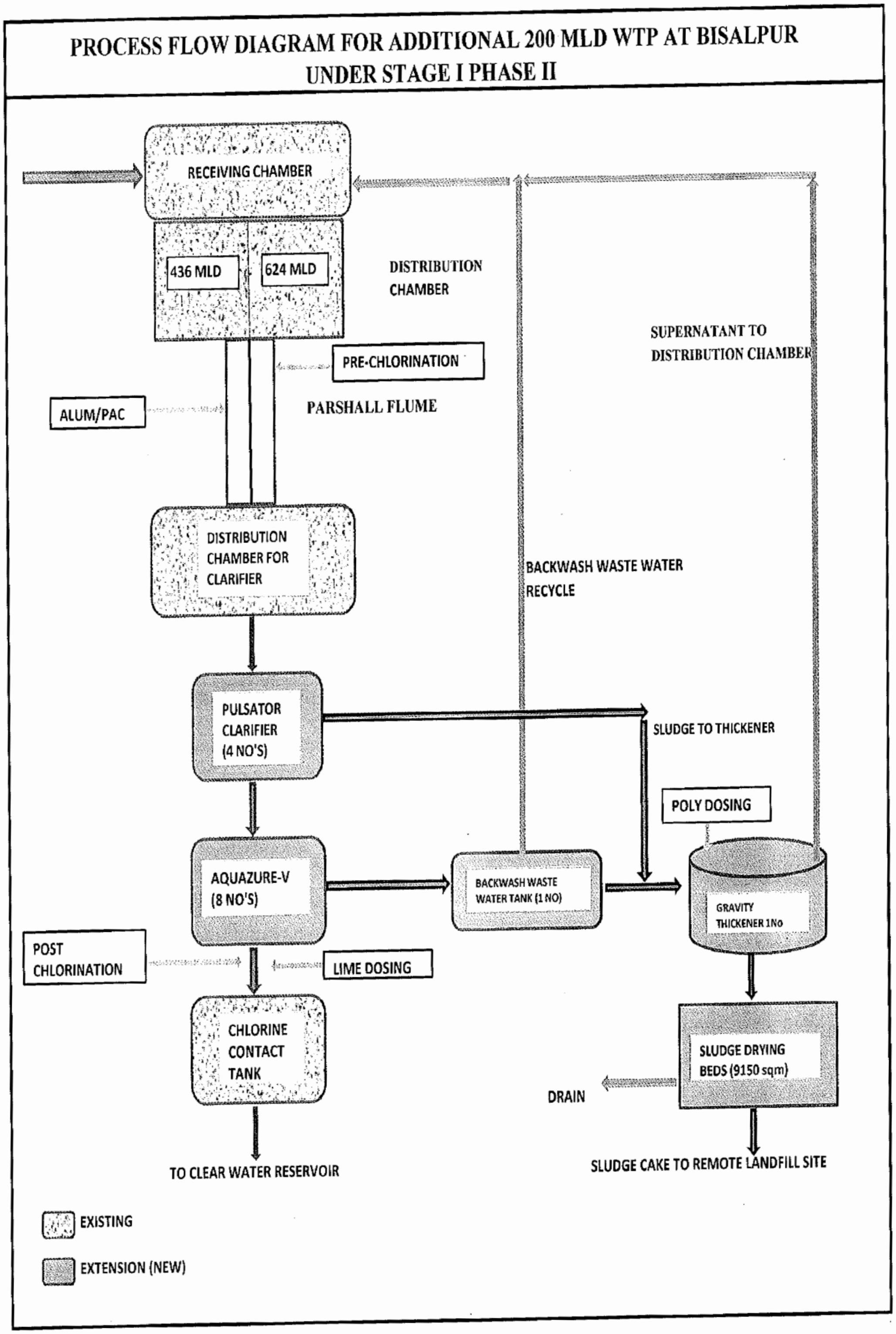


Figure 3.1: Process flow diagram for extension of WTP at Surajpura from 400 MLD to 600 MLD (source: Public Health Engineering Department, Government of Rajasthan)

Figure 3.2: View of the Parshall flume

Following the flow path, the coagulant is added to the raw water pipeline. At present, 100% Polyaluminium Chloride (PAC) is administered at the BJWSP. The aim of rapid mixing is the immediate dispersal of the required dose of chemicals throughout the mass of the pre-chlorinated raw water because both, the hydrolysis of the coagulant and the destabilisation of colloids, take short time. Hydraulic rapid mixing arrangements are used in the parshall flume (fig. 3.2); dosing of chlorine is done right at the start of the parshall flume (fig. 3.3(a)) and PAC is done at the Venturi throat (fig. 3.3(b)) and then a hydraulic jump of 0.39m (fig. 3.4) is given. Coagulated water from the pipeline is transferred to the Superpulsator vacuum chamber.

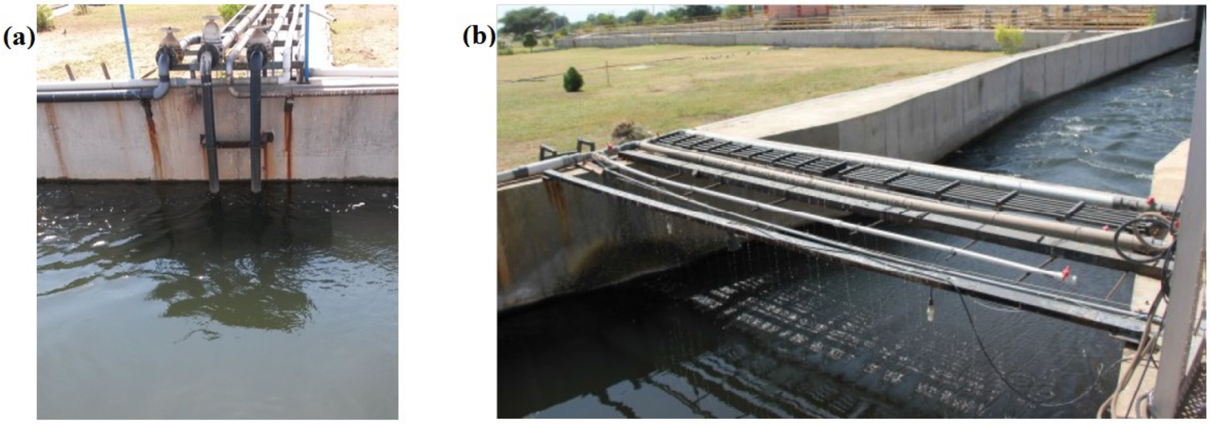


Figure 3.3: (a) Dosing of Chlorine at Parshall flume; (b) Dosing of PAC at the Venturi throat of Parshall flume

Figure 3.4: Hydraulic jump before inlet of the Superpulsator vacuum chamber

Infilco Degrémont's Superpulsator®, a proprietary technology for clariflocculation, is normally designed and sized by the manufacturer's recommendations. It functions as a solids contact basin. Perspective cut-away representation of the Superpulsator® unit is shown in figure 3.5 with its main components labeled. At present, ten Superpulsator® units are operating at the Surajpura plant (fig. 3.6).

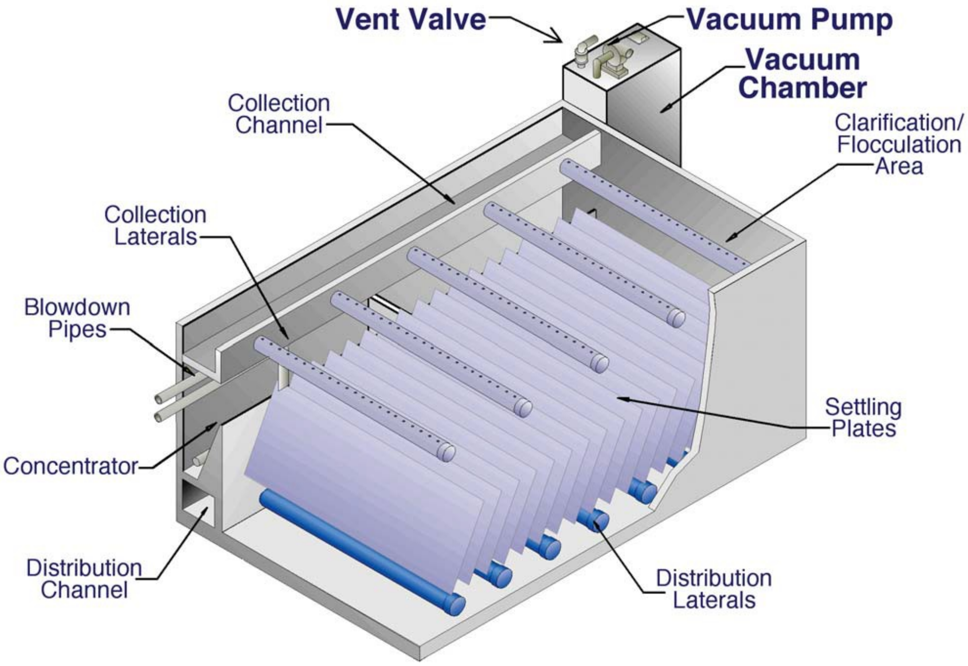


Figure 3.5: Diagram of a Superpulsator® unit (Courtesy: Degrémont Ltd.)

Figure 3.6: Series of Superpulsator® units at the Surajpura WTP

The coagulated water moves from the base of the vacuum chamber to a distribution channel and gets uniformly distributed to a perforated series of laterals. Orifices function to impart energy for flocculation and are cleverly pointed downward to ensure even distribution of water and promote scouring of the basin floor (fig. 3.7).

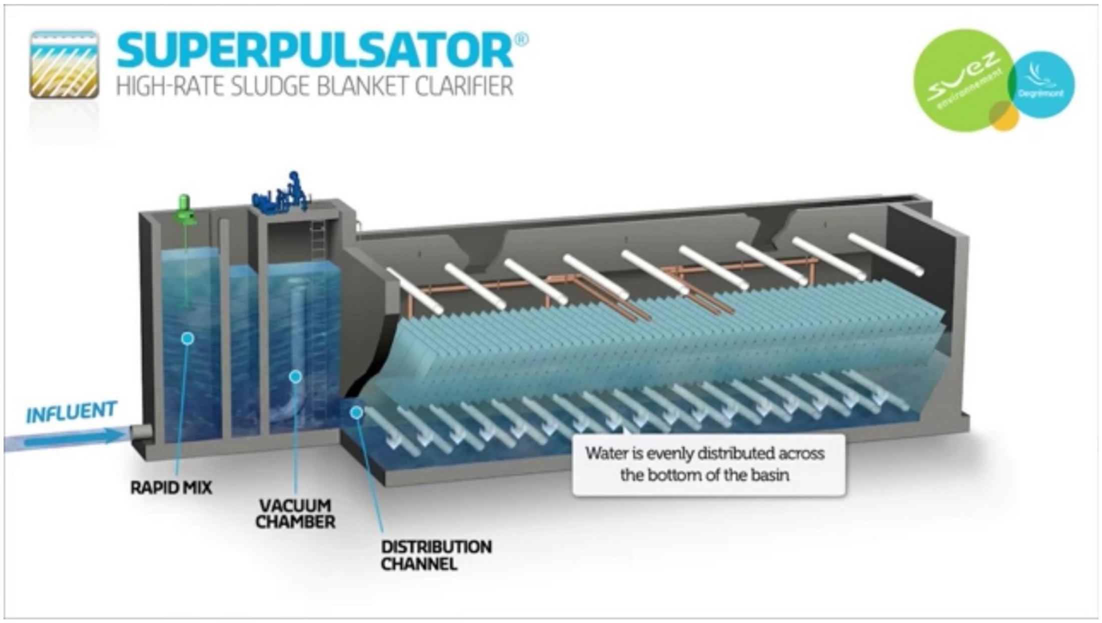


Figure 3.7: Distribution manifold (Courtesy: Degrémont Ltd.)

Flocculated water is directed upward through a series of inclined parallel plate separators, which function to hold a 10-ft high sludge blanket. The flocculated water flows through the sludge blanket and as such, the lighter particulate is circulated between the plates, and this promotes internal solids contact. Clarified water rises up and is then collected uniformly and conveyed to the center channel by means of submerged orifice laterals across the length of the settling area (fig. 3.8).

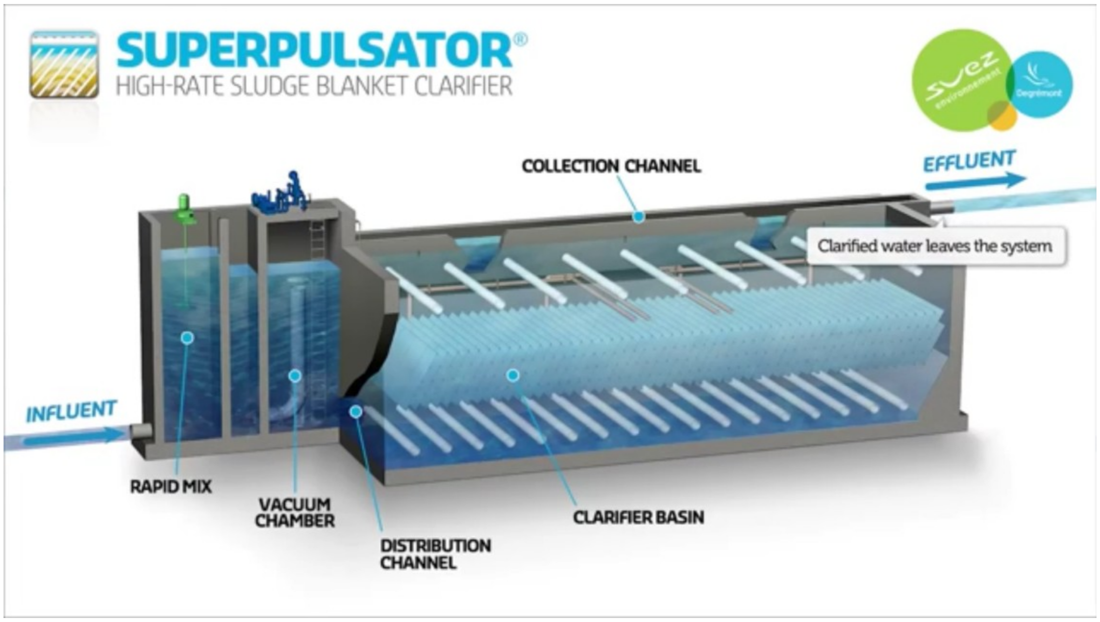


Figure 3.8: Collection of clarified water (Courtesy: Degrémont Ltd.)

The floc particles are retained by the sludge blanket and are removed following the law of mass balance, which implies that rate of removal should be equal to the rate at which they are retained. A side weir permits the overflow of the sludge to an internal concentrator, which collects sludge during sludge blanket expansion while maintaining a desired sludge blanket depth (fig. 3.9).

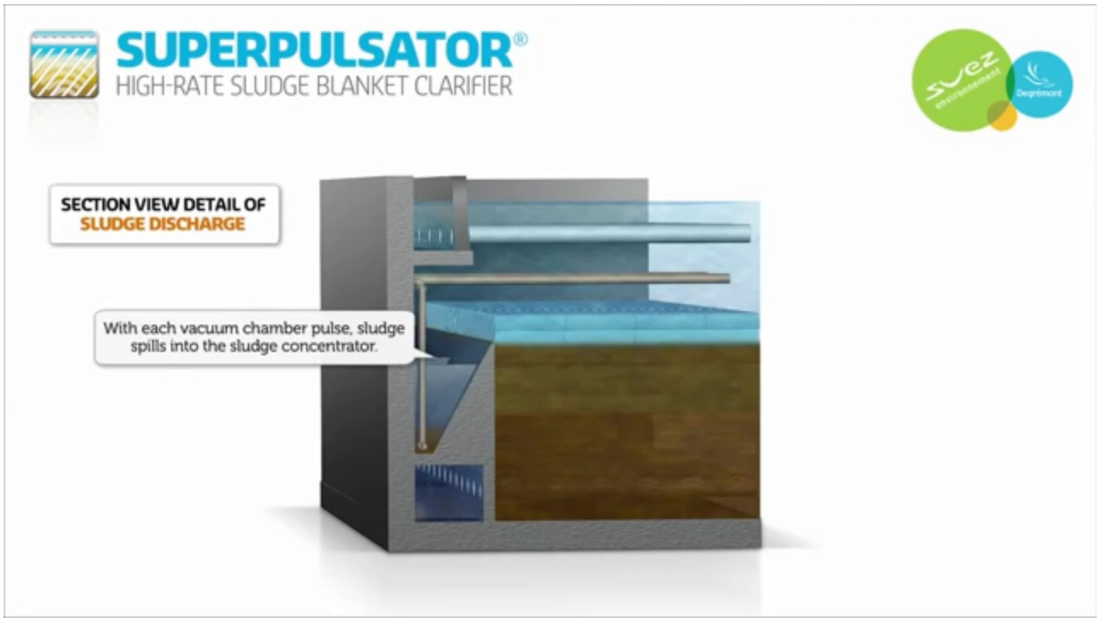


Figure 3.9: Removal of sludge (Courtesy: Degrémont Ltd.)

In order to maintain a homogeneous blanket, a means of agitation is required. This function is served by the nonsteady flow of a pulse of water created by the head of the water in the vacuum chamber. Subtle pulsations of the sludge blanket in the settling area are created by the operation of the vacuum pump and vent valve assembly at a prescribed frequency and duration. As shown in figure 3.10, when the valve atop the vacuum chamber is closed, a small column of water is drawn up by the vacuum pump. As soon as the vent is opened, the vacuum chamber is vented to atmosphere, and the water level in the chamber drops and this differential volume of water is rushed down the distribution manifold. This net result is a contraction of the sludge blanket when the vent is closed and an expansion when the valve is opened.

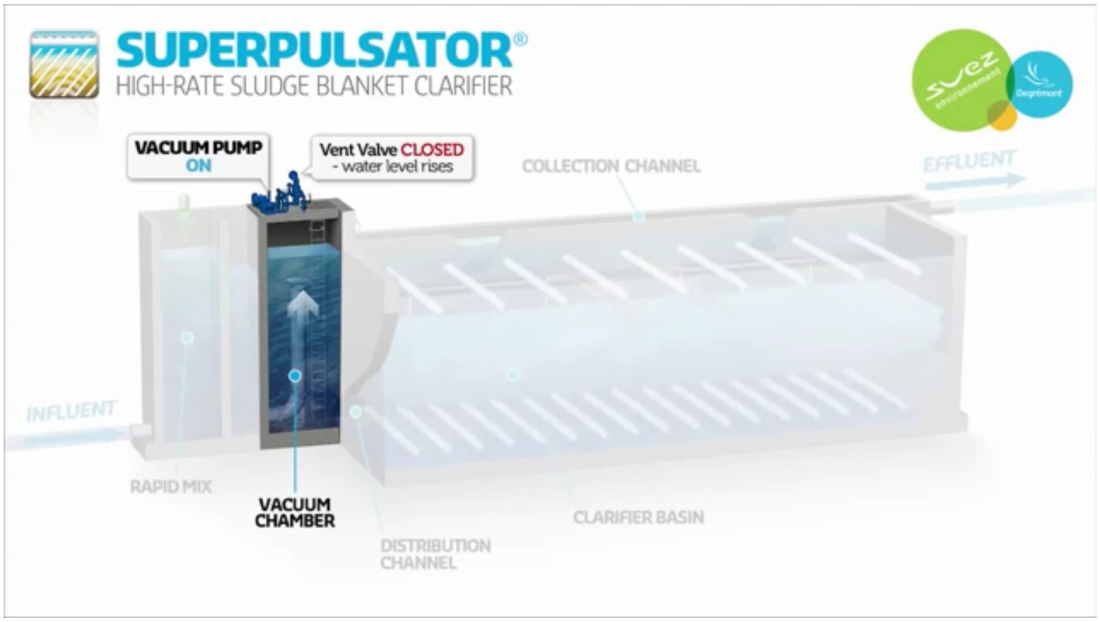


Figure 3.10: Pulsing action (Courtesy: Degrémont Ltd.)

Therefore Superpulsator® with its pulsing sludge blanket is able to combine flocculation, clarification and sludge collection into one compact system. A key design feature of the Superpulsator® unit is that short circuiting does not take place, and as such the entire basin is utilized for treatment.

3.2 Design and development of pilot plant concept

Attempts have been made to construct prototypes of Superpulsator®, however, complete success in unraveling the rationales that describe the functioning and modeling of the behavior of Superpulsator® has so far eluded the researchers (Hendricks, 2005). Another attempt recently in 2012 was made by Khezri et al, in which a pilot plant based on pulsator was constructed to experimentally determine the effect of suction head on turbidity removal. Their project nevertheless encountered difficulties due to high cost and requirement of high-tech equipments. It was concluded that the reliability and practicability of the results was not up to the mark and the pilot plant lacked flexibility (Khezri et al., 2012).

Therefore, there was a need for design and construction of a pilot plant which offered transparency, flexibility, simplistic design and other features to give unparalleled insight into the functioning of Superpulsator® and support detailed research.

It should be noted that if it is attempted to create a miniature form of the entire Superpulsator® unit installed in the field, the performance of the prototype pilot plant might be adversely affected. It can be supposed that attempts of such nature might have been unsatisfactory in performance because they perhaps were not able to depict the functional behavior of the fluid element due to lack of control. Hence, it was imperative to pay attention to geometric, kinematic and dynamic similarity of the functional aspects of the Superpulsator®. Here, geometric similarity is for the similarity of shape; kinematic similarity is for the similarity of motion; and dynamic similarity is for the similarity of forces.

3.2.1 Model laws and calculation of dimensions

Assuming flow in the column (above the flocculation cone) is laminar, which is essential to avoid short-circuiting, we can consider the dimensionless numbers.

Reynold’s Number is of significance in modeling flows through closed conduit pipes, and is given by-

$$R_e = \frac{Fi}{Fv} = \frac{\rho VL}{\mu}$$

Froude’s Number should be considered where a free surface is present and gravity force plays an important role:

$$F_r = \sqrt{\frac{Fi}{Fg}} = \frac{V}{\sqrt{gL}}$$

Applying the Reynold’s model law:

$(R_e)_m = (R_e)_p$

So, $\frac{\rho r V r L r}{\mu r} = 1$

and Froude’s model law:

$(F_r)_m = (F_r)_p$

So, $\frac{Vr}{\sqrt{grLr}} = 1$

where, F_i = Inertia force

F_v = Viscous force

F_g = Gravitational force

Therefore by comparing the corresponding dimensions of the Superpulsator® unit from its blueprint, we can calculate the model attributes as follows (fig. 3.11):

Height of column = 2.2m (measured from the base)

Point of sludge extraction = 1.2m (measured from the base)

Point of tip of flocculation cone = 0.2m (measured from the base)

Diameter of the column = 300mm

Volume of water contained in the column at any point of time, $V = \pi d^2 l/4$
So, $V = \pi(0.3)^2(2.2)/4$
We get, $V = 0.155m^3 \equiv 155l$

Rise rate = 3m/hr

Rise rate during the pulse = 13m/hr

Duration of pulse = 10s

Duration of cycle = 55s

3.2.2 Stress analysis

Constraints: Strength of material to withstand pressure

Assuming thin cylinder for analysis,

Hoop stress or Circumferential stress is given by

$\sigma_h = \frac{pd}{2t}$

Longitudinal stress is given by

$\sigma_L = \frac{pd}{4t}$

For the cylinder made of perspex®, the corresponding Hoop strain and Longitudinal strain will be, $\varepsilon_h = \frac{pd}{4tE}(2-\mu)$; $\varepsilon_L = \frac{pd}{4tE}(1-2\mu)$

Volumetric strain (ε_v) of cylinder

$\varepsilon_v = \frac{pd}{4tE}(5-4\mu)$

Maximum pressure exists at the bottom of the column, and can be calculated as,

$p_{max} = \rho \times g \times h$

$= 1000(kg/m^3) \times 9.81(m/s^2) \times 2.2(m)$

$= 21{,}582(N/m^2)$

So, maximum hoop stress, $\sigma_{h,max} = \frac{p_{max}d}{2t}$

$= \frac{21582\times0.3}{2\times0.005}$

$= 647{,}460(N/m^2)$

Maximum longitudinal stress is given by, $\sigma_{l,max} = \sigma_{h,max}/2$

$\sigma_{l,max} = 323{,}730(N/m^2)$

Hoop strain for long term use, $\sigma_h = \frac{\sigma_{h,max}}{2E}(2-\mu)$

$= \frac{647460\times(2-0.4)}{2\times1.2\times10^9}$

$= 4.316 \times 10^{-4}$

Similarly, $\varepsilon_L = 5.395 \times 10^{-5}$

and $\varepsilon_v = 9.171 \times 10^{-4}$

Apparently, all the stresses and strains are quite small even for long term use. Hence, the **design is safe.**

The initial concept of the pilot plant was developed and is shown in figure 3.11.

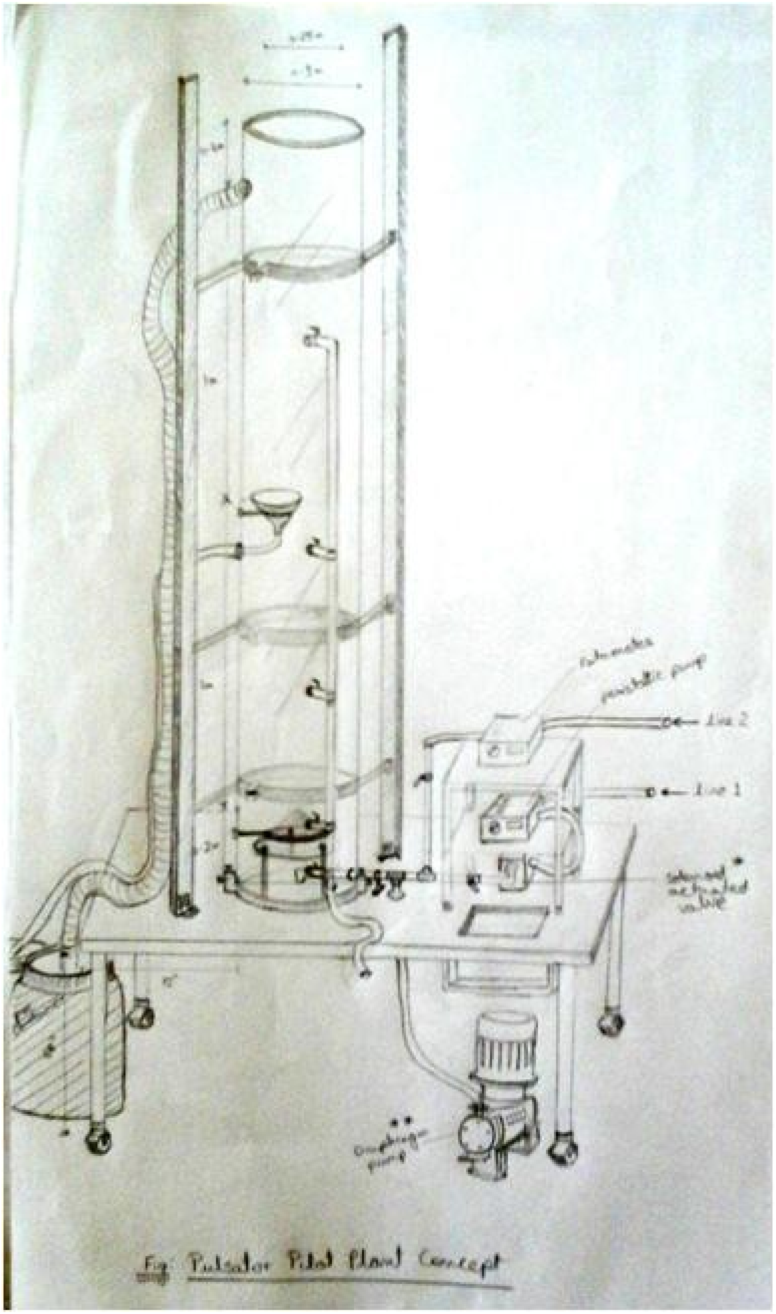


Figure 3.11: Preliminary conceptualization of pilot plant

3.3 Materials for construction of the Pilot Plant

Following components were made from Perspex® for the construction of the column (Table 3.1):

Table 3.1: Description of components used in fabrication of column for the pilot plant

S. No.	Component	Numbers used	Dimensions
1.	Hollow cylinders	4	Diameter: 300mm Length: 2ft Thickness: 5mm
2.	Flange plates	5	Length: 400mm Breadth: 500mm
3.	Flocculation cone	1	Diameter 250mm Length: 72mm
4.	Sludge collection cone	1	Diameter: 100mm Length: 70mm

For the construction of the column, all materials were chosen to be made of Perspex® because of the following reasons-

- It has exceptional light transmission with little colour bias- even in thick blocks - This was essential to ensure unparalleled insight into the functioning of Superpulsator® and support detailed research.
- Resistant to weathering- The pilot plant is of a large capacity and yet portable. Resistance to weathering would ensure long useful life for research purposes.
- Impact resistant- is again a favorable quality for longevity of the model.
- A high gloss, hard surface- This was required to keep the model maintenance free and permit the study of blanket dynamics.
- High tensile strength and rigidity- Construction of the pilot plant required the performance of various operations like drilling and cutting, for which the material must possess these attributes.
- Easily thermoformable and machinable with simple workshop tools.
- Easy to clean- In case of staining or attached biological growth, like algal bloom in presence of sunlight, it is easy to clean.
- Capable of being fully recycled- Important from environmental perspective.

Important mechanical properties of Perspex® are given in Table 3.2.

Table 3.2: Design data for Perspex® cast acrylic sheet at 20°C (Source: Lucite)

Property	Units	Short-Term / Intermittent (6 hours)	Long Term / Continuous (10 years)
Tensile strength (unexposed)	kgf/cm^2	170	88
	MPa	17	8.6
	lbf/in^2	2500	1250
Tensile strength (exposed)	kgf/cm^2	140	70
	MPa	14	7
	lbf/in^2	2000	1000
Modulus	kgf/cm^2	2.5 x 104	1.3 x 104
	GPa	2.5	1.2
	lbf/in^2	3.6 x 105	1.8 x 105
Poisson's ratio		0.39	0.40

3.4 Working on Perspex® column

For making the flocculation cone and flange plates, cutting, sawing and drilling operations had to be performed (fig. 3.12). Since Perspex is a brittle material therefore only light machining cuts were taken and feed rates were kept slow (fig. 3.13). It was also important in order to keep the temperatures low and prevent buildup of stresses as Perspex softens above 80°C. Twist drills with minimal rake angle (fig. 3.14) were chosen for drilling holes to accommodate inlet pipes and sampling ports. In order to produce bonds with good strength, durability and optical clarity, suitable acrylic cement and superglue® were used. The joints were sealed with a suitable, acrylic compatible MS polymer.

Figure 3.12: Construction of the column of the pilot plant at MNIT Jaipur campus

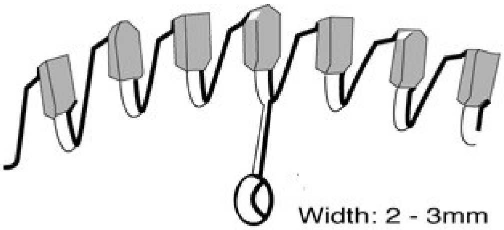


Figure 3.13: Tungsten Carbide tip circular saw blade used for cutting

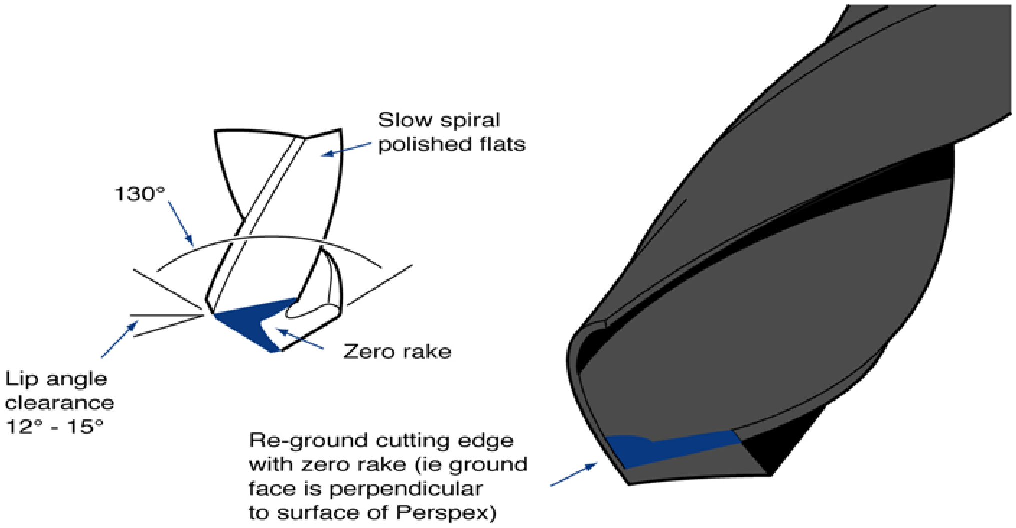


Figure 3.14: Choice of drill bit for drilling Perspex® (Courtesy: Lucite)

3.5 Frame

The stand was constructed using stainless steel and laminated wooden panels (fig. 3.15). Major consideration in the design and construction of the stand was towards the stability, ability to withstand the filled load of the column and convenient layout for accessibility.

The major weight on the stand is due the column when filled with water (assuming water alone at 20°C). It can be calculated as follows:

Diameter, d = 300mm

Length of the column up to which it is filled with water, l = 2.2m

Volume of water contained in the column V $= \pi d^2 l/4$

So, V $= \pi(0.3)^2(2.2)/4$

We get, V = $0.155\text{m}^3 \equiv 155l$

Weight of this volume of water = 155kg

Approximate weight of the Perspex column material = 15kg

Total weight of filled column = 170kg

Taking a factor of safety of 3.5 and considering other mountings, the frame should be able to support a weight of about 700kg.

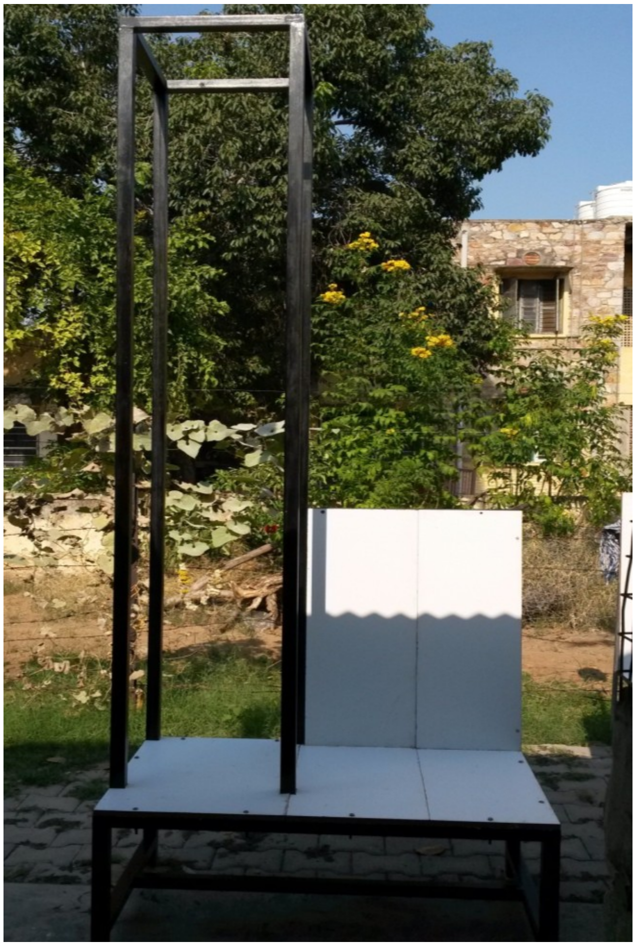


Figure 3.15: Photograph of first make of the stand for the pilot plant under construction at MNIT Jaipur

Since column has a large weight with high centre of gravity so locating it on one side of the skid could make the entire assembly unstable. Considering the moment of the column, and installation of other mountings, the first make of the stand was modified by extending it on both sides and shortening the length of the legs.

3.6 Equipments and accessories

Acrylic Rotameters were used for measurement of flow in the continuous flow pipeline and the pulsed flow pipeline (fig. 3.16). Since they are made with acrylic block and fitted with needle valves, these instruments were found suitable for direct panel mounting because of their accuracy, visibility and ruggedness. Also the measurement characteristics were not affected by high back pressure (Table 3.3).

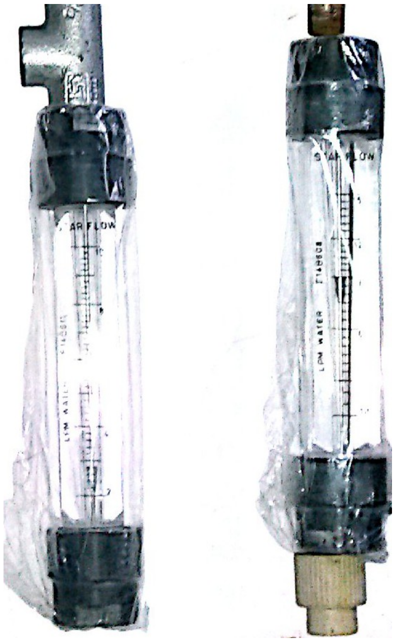


Figure 3.16: Rotameters (of max capacity 10 *l*pm and 15 *l*pm) used in the pilot plant for flow measurement

Table 3.3: Technical specifications of rotameters used in the model

Technical data	Technical Specification
Metering body	Acrylic plastic
Wetted part	SS / Brassi PVC / Teflon
Float	SS / Teflon / PVC / P.P.1/4" NPT / BSP / Screwed rear with valve.
Pipe connections	AND FANGED TOP BOTTOM / REAR
“0” ring	STD : Neoprene / Teflon Viton Silicon
Scale	Engraved on body; 15 lpm and 10 lpm maximum flows
Press ration	To 100 PSIG STD
Rating	0 Pt Higher rating on special application
Temperature	Upto 70 °C
Accuracy	+ .5 TO + 1% at F.S.

As shown in figure 3.17, two tanks of 100*l* capacity each were used for the storage of turbid water and coagulant (at present PAC or alum). Turbidity was imparted synthetically to the water supply by using bentonite powder so that the synthetically generated turbidity is quite close to the natural conditions. Bentonite powder consists mostly of montmorillonite clay and is essentially aluminum phyllosilicate. A solution of bentonite powder in water of strength 100mg/*l* was prepared in the tank and continuously stirred to prevent settling and provide homogeneous dosing for getting the required turbidity levels in the influent water. As shown in figure 3.17, the tank in forefront is used for storage of PAC while the one behind is used for storage of turbidity solution and is provided with a stirring assembly.

Figure 3.17: Two storage tanks of 100*l* capacity each, one of which is provided with a mechanical stirrer

For dosing the coagulant and turbidity, two separate peristaltic pumps were used (fig 3.18). Mechanism of working of peristaltic pump is based on pressing or squeezing of special flexible tubing by rotating rollers, thereby creating a pressurized and metered flow. Unlike other pumps, neither seals and valves are needed, nor priming is required, and therefore they were suitable for dosing against back pressure. The doses were directly injected into the main pipeline by the peristaltic pumps through nozzles to ensure proper mixing.

Figure 3.18: Dosing arrangement by using peristaltic pumps

The most important functions of flocculation and maintenance of a homogeneous sludge blanket are served by pulses of water. These pulses must:

- Have required flow rate
- Be of required duration
- Have programmable cycle to set the on and off time

The two port direct acting normally closed solenoid valve assembly can be called the heart of the system, as it serves the above vital function. This device was found suitable for providing the cycle of pulses because of the following features:

- Bubble tight shut off.
- Applicability in vacuum upto 10 - 6 torr, as well as against high back pressure.
- Vibration resistance upto 9g.
- Ability to be mounted in any position.
- High speed cycling upto 1000 cycles/ min.
- Life of more than 10 million cycles.
- Optional manual override.
- Low power consumption (less than 11W)

The main components of the two port direct acting normally closed solenoid valve assembly are shown in figure 3.19. The actuator valve (fig. 3.19(a)) is installed in a separate pulse flow pipeline and is operated automatically by the solenoid control box (fig. 3.19(b)). The duration of "off time" and "on time" can be controlled by adjusting the control knobs provided in the box. At present a cycle time of 55 seconds with on time of 10s and off time of 45s was used. This was in accordance with that used in Degrémont's research centers for sludge cohesion coefficient testing, however the cycle time should be varied and optimised for different conditions of sludge blanket.

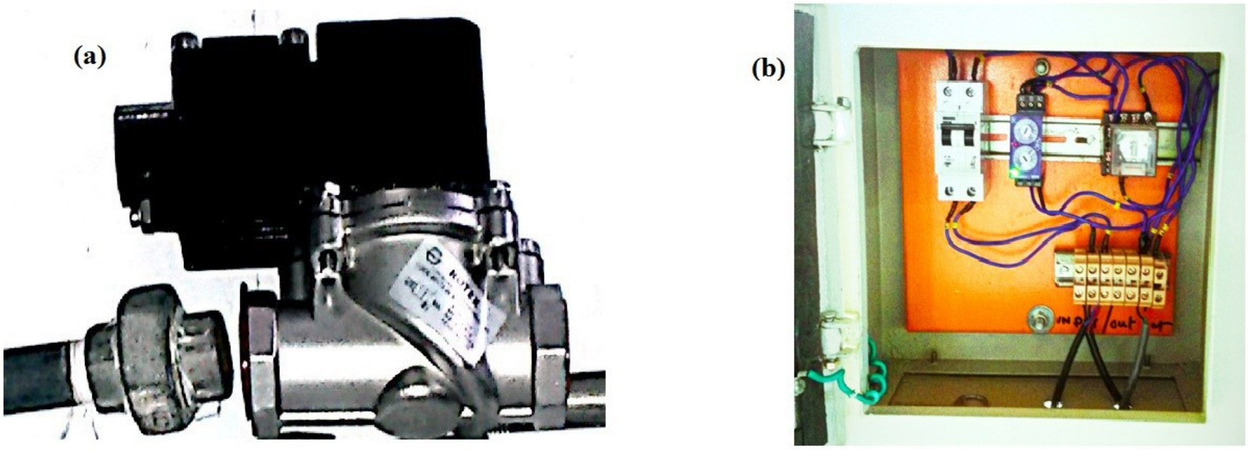


Figure 3.19: (a) Two port direct acting normally closed valve; (b) Solenoid valve control box

The main supply pipeline was of about 5inch diameter, which was reduced finally to 1/2inch as most piping in the panel circuit was chosen to be of ½ inch. Two separate direct lines, one for continuous flow and other for flow of pulse, were connected first to the rotameters of capacity 10 *l*pm and 15 *l*pm respectively, and then to the main column feed line. There was no need for a pump in these two lines as after reduction the pressure was sufficient (after appropriate reductions) and a constant head water supply was obtained from an overhead 10000*l* capacity tank. Part of the line inside the pulsator column was made of PVC and fixed permanently. Thereafter the line was made of galvanised iron for flexibility of the layout and adjustments/repairs. The flows were controlled by adjusting the valves.

All the components were assembled and devices were mounted on the stand panel keeping in mind the layout, visibility and ease of access. Continuous constant head water supply for the pilot plant was given from an overhead tank with 10000*l* capacity. The fully functional pilot plant based on Superpulsator® technology, designed for a capacity of about 8000 liters per day, is presently installed in the Hydraulics lab of Malaviya National Institute of Technology, Jaipur (fig. 3.20). Provisions are given to handle flows that are about four times the designed value. The sludge blanket was maintained at the desired level of depth by removal of concentrated sludge from a conical collector at regular intervals.

Figure 3.20: Pilot plant based on Superpulsator® technology is designed for a capacity of about 8000 liters per day and is installed in the Hydraulics lab of Malaviya National Institute of Technology, Jaipur.

3.7 Working of the pilot plant and study of pulsations

Pulsations are designed to impart the requisite energy for effective floc formation. A crucial function of pulsations is also to prevent channeling in the sludge blanket. The pulsations therefore in addition serve as a means for agitating the sludge blanket, so that there is no short circuiting. This ensures that the entire blanket remains homogeneous and is utilized for treatment of water (fig. 3.21). The pulse also forbids the blanket from settling or collapsing.

Figure 3.21: Development of the sludge blanket in the Superpulsator® pilot plant

The hydraulic energy from the pulse is contained under the flocculation cone, which serves as a tranquilizer plate. This helps create perfect distribution of flocculation energy, without disquieting the blanket above. The arrangement of the inlet pipe and the flocculation cone is shown in figure 3.22(a), when the system is turned off. The pulsed flow and continuous flow together help maintain a homogeneously suspended blanket for continuous supply of treated water. However, it is to be noted that in case of a prolonged power failure, the blanket will collapse or settle down. In such a scenario, the restarting with the normal continuous flow does not produce the desired result. But introduction of the pulse helps re-entrain the flocs to form a blanket. A strong pulse can be used to re-establish the blanket completely and in a relatively much shorter time (fig 3.22(b)). The study of pulsation has been comprehensively described in the video which can be accessed from the CD-ROM attached in Appendix 3.

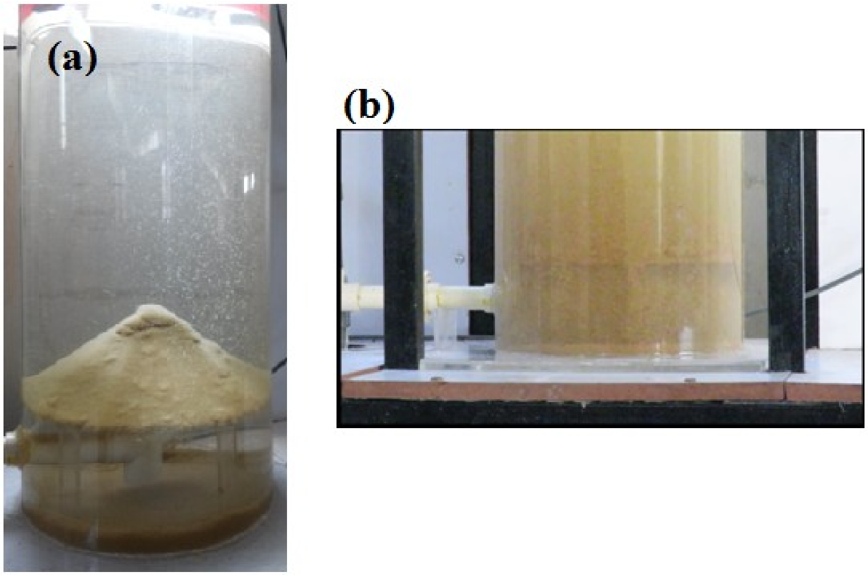


Figure 3.22: (a) Arrangement of the inlet pipe and flocculation cone; (b) flocculation being carried out

The homogeneity of the sludge blanket and fluidity as well as size of the floc particles are dependent on a number of factors. Some factors include, but are not limited to:

- Turbidity of the influent
- Chemical constituents of the water like alkalinity, natural organic matter (NOM), chlorides, phosphates and nitrates
- Choice of coagulant and coagulant aid
- Cycle time of the pulse: off time and on time
- Frequency of the pulse
- Strength of the pulse
- Continuous flow rate

The system is designed to offer complete control over the aforementioned parameters to simulate various practical situations as closely as possible.

With the influx of turbidity, floc particles are formed and are then retained by the contracting and expanding sludge blanket. As the development of the blanket proceeds, the height of the sludge blanket reaches 1.2m from the base. This is the desired sludge depth, and the floc particles are permitted to leave the system. The sludge collection cone allows overflow and subsequent settling of the sludge as quiescent conditions prevail inside the cone (fig. 3.23(a)). The sludge is blown off from time to time.

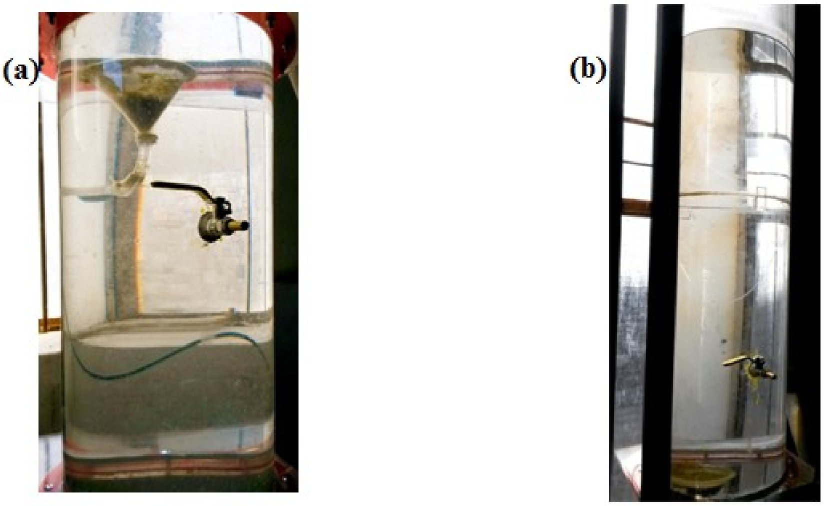


Figure 3.23: (a) Arrangement for sludge withdrawal; (b) Collection of clarified water

The clarified water is finally collected from a height of 2.2m from the base. As shown in figure 3.23(b), this point of extraction of clarified water is 1m above the point of sludge withdrawal.

3.8 Design of Conventional Clariflocculator

A mechanical Rapid mix unit was be provided to uniformly disperse coagulant with raw water and detention time of 30 seconds shall be provided. Diameter and height of basin were kept 14 and 16 cm respectively. Clariflocculator was designed according to CPHEEO manual and had two concentric tanks made of galvanized iron. The inner tank served as flocculation basin and outer tank as clarifier. (fig. 3.24)

Figure 3.24: View of the top of the conventional clariflocculator

Design calculations for horizontal flow clariflocculator:

Design is based for a flow rate of $0.212 m^3/hour$

3.8.1 Rapid Mix unit

Taking Detention time= 30 seconds

Volume = flow × detention time = $0.212 \times \frac{30}{1000} = 1.76 \times 10^{-3} m^3$

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

Volume = $\frac{\pi}{4} \times d^2 \times d$

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

d = $\sqrt[3]{2.24 \times 10^{-3}}$

So, d = 13.36 cm

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

Free board= 2 cm ; height= 16cm

3.8.2 Power requirements

Power spent = $\mu G^2 \times$ Volume

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

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

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

So, P = 0.64 watts

Taking N =120 rpm and ratio of impeller diameter to tank diameter as 0.4:1

Diameter of Impeller= 0.4×14 cm= 5.6 cm

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

P= $^{1}/_{2} \times C_d \times \ell \times A_p \times V_r^3$

A_p= 0.0393m^2

Provide 4 blades of 0.1m×0.1m

3.8.3 Clariflocculator:

Again, flow rate = 0.212m^3/hr

Taking detention time = 20 minutes

G = 40 s^{-1}

and velocity of 1m/sec

$^{\pi}/_{4} \times D_p^{\ 2} = \frac{0.212}{3600}$

D_p = 8.6 mm; so, provide the diameter of the influent pipe D_p as 1cm

Volume of flocculator = $\frac{0.212\times 20}{60}$ = 0.07m^3

Taking depth = 0.25m

plan area= 0.28m^2

$^{\pi}/_{4} \times (D^2 - D_p^{\ 2}) = 0.28m^2$ (where, D = dia of flocculator and D_p = dia of infleunt pipe = 1cm)

So, D = 60cm

Power= μG^2×volume = 0.113 watts

N= 4-5 rpm

P= 1/2 $\times C_d \times \ell \times A_p \times (V-v)^3$

$A_p = 4.6\times 10^{-3}$ m^2

Provide 4 paddles 0.1m height and 0.2m width

Assuming velocity of water below the partition wall = 0.3 cm/minute

Area= $0.212/(0.3\times60) = 0.0117\text{m}^2$

Depth below partition wall= $0.0117/\pi \times 0.06 = 0.0625\text{m} = 6.25\text{cm}$

Depth for sludge storage = 2.5% of height = $2.5\times0.25=0.00625\text{m}$ providing 1 cm

8% slope for bottom

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

3.8.4 Design of clarifier

Taking surface overflow rate (SOR) = $40\text{m}^3/\text{m}^2/\text{day}$

surface area= $0.212\times24/10 = 0.1272\text{m}^2$

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

D_{cf} = 72 cm

Provide diameter of clarifier= 72 cm; flocculation basin= 60 cm; total height = 38cm

Dimensions finally calculated are depicted in figure 3.25(a). Figure 3.25(b) shows the photograph of the actual conventional clariflocculator based on the above design, installed at the hydraulics lab of MNIT Jaipur.

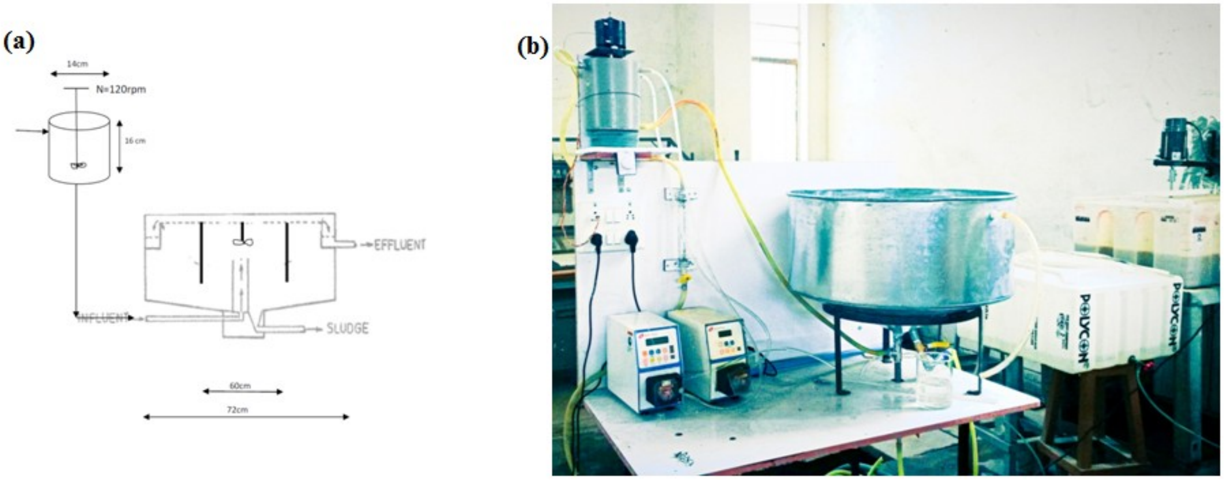


Figure 3.25: (a) Dimensions of conventional clariflocculator; (b) Continous flow conventional clarilocculator at operation in the hydraulics lab of MNIT Jaipur

Chapter 4. Parametric tests and methodology

In this chapter, the procedure adopted for conducting various parametric tests has been discussed, along with the description of the chemicals and equipments used. Calculations behind the simulation have been shown and the basis for comparison of coagulants has been explained. The statistical methods used for the interpretation of the zetapotential and particle size graphs have also been discussed briefly.

4.1 Coagulants

During all the experiments, distilled water was used unless specified otherwise. Borosilicate glassware washed with warm water and dilute HCl (0.1N) was used for all experiments. The specifications of the chemicals used are given below:

4.1.1 Polyaluminium Chloride (PAC)

PAC is an inorganic macromolecule with high Al_{13} units. The Al_{13} units are known as 'Keggin' Al_{13}^{7+} cation $[Al_{13}O_4(OH)]_n^{7+}$. PAC is commercially available in different specifications in both liquid and solid (powder) form. High basicity liquid Arya™ PAC of Vikram® PAC, manufactured by Grasim Industries Ltd., (Chemical Division) is used for water treatment at the Surajpura WTP and the same was used for the experiments as well. The specifications of the PAC are given in Table 4.1.

Table 4.1: Relevant specifications of PAC used

Particulars	Specifications
Commercial name	Arya PAC
Grade	Liquid
Aluminium as Al_2O_3, percent by mass, min	10.2
Chloride as Cl, percent by mass, max	10.5
Specific gravity at 25°C, min	1.20
pH of 5% aqueous solution, w/v	2.5 - 4.5
Basicity, percent by mass, min	64.0
Sulphate as SO_4, percent by mass, max	2.5

4.1.2 *Alum*

Alum powder in the form of aluminum sulfate hexahydrate manufactured by Merck Life Science Private Limited was used as coagulant. The specifications are given (Table 4.2) below-

Table 4.2: Relevant specifications of Alum used

Particulars	Specifications
Molecular Formula	$Al_2(SO_4)_3.16H_2O$
Formula Weight	630.38
Density	2.71 g/mL at 25 °C(lit.)
Color	White

4.2 Jar test

The jar test apparatus used in the project at MNIT Jaipur is a variable speed, multiple station or gang unit with the following configuration:

- number of test stations: 6
- size: 1000 mL
- shape of test jars: round
- method of mixing: paddles

4.2.1 *Objectives*

Jar tests were conducted on synthetic and natural surface water in order to:

1. Determine type of coagulants.
2. Determine dosage of coagulants.
3. Determine sequence of chemical addition.
4. Determine optimum energy and mixing time for rapid and slow mixing.
5. Simulate the parshall flume at Surajpura WTP

4.2.2 *Procedure followed*

The detailed procedure for the setting up, running, and interpreting a jar test as followed for the project is explained in various publications. Synthetic water of required turbidity was prepared by mixing appropriate amount of bentonite clay with tap water. This was used for determining the coagulant dose for the pilot plant and conventional clariflocculator, as the continuous flow based models run on the locally available tap water. Actual surface water samples from Bisalpur

headworks were used for determining water quality parameters, dosage of coagulants, simulation of parshall flume at Surajpura WTP, measurement of zeta-potential and particle size analysis.
Basically, for dosage optimization, samples of water, were poured into a series of jars, and various dosages of the coagulant were fed into the jars. Thereafter coagulants were rapidly mixed at a speed of 60 rpm for a period of 40s then allowed to flocculate at a slow speed of 20rpm for a period of 20 min. The suspension was finally left to settle for 20–45 min under quiescent conditions.

The appearance and size of the floc, the time for floc formation, and the settling characteristics were noted. The supernatant was analyzed for turbidity, zetapotential, particle size and pH.

4.2.3 Simulation of Surajpura plant conditions

Simulation of Surajpura plant conditions at parshall flume was done by Jar tests. Then the samples were tested, along with a sonicated duplicate set. Procedure for simulation is as follows:

During the field visits to Bisalpur headworks and Surajpura WTP, it was observed that the pre-chlorination (with chlorine dosage of 4.25ppm) was done at the inlet of the parshall flume (fig. 4.1(a)). After flow duration of about 5 mins, the PACl dose was given by sprinkling it over the surface of water (fig. 4.1(b)). At present (during the entire duration of the study) a constant dose of 25 ppm was being administered.

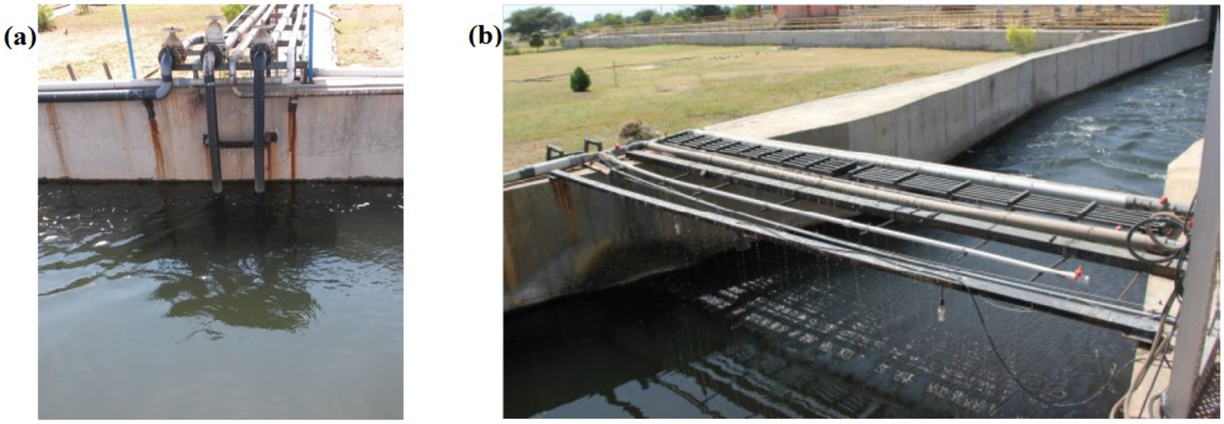


Figure 4.1: (a) Dosing of Chlorine at Parshall flume; (b) Dosing of PAC at the Venturi throat of Parshall flume

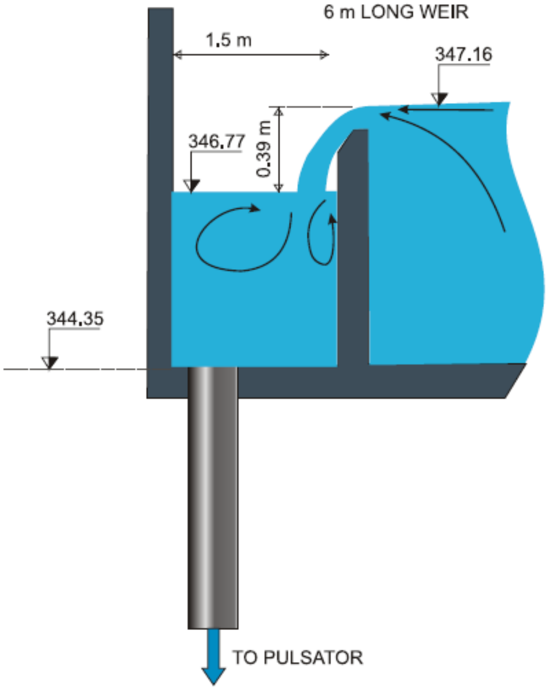


Figure 4.2: Dimensional description of the hydraulic jump

Subsequently the water flows through the parshall flume for another 12 to 14 mins before encountering the hydraulic jump. The pulsator inlet weir has a fall of 0.39m (fig. 4.2) that imparts a hydraulic mixing energy calculated as below:

P (Watts) = Q (m^3/s) × ρ (Kg/m^3) × g (m/s^2) × h (m)

For a flow of 50 MLD per pulsator (Q = 0.578 m^3/s) we get mixing power as :

P = 0.578 × 1000 × 9.81 × 0.39 = **2215 W** (or 2.215 KW)

It is postulated that the hydraulic jump might be causing the flocs to break and thus our interest is in the zone where maximum floc damage takes place. This hydraulic turbulence is generally limited to top 500mm of water as we go down the G values will decrease.

Calculating G values for the top 500mm of the top turbulent water layer (V =1.5 × 6 × 0.5m^3):

G = Sqrt { P (Nm/s) / μ (Ns/m^2) × V (m^3) }

That is $G = \sqrt[2]{P/_{\mu V}}$

So, $G = \sqrt[2]{2215/_{(1.002 \times 10^{-3} \times 4.5)}}$

G = 700.88 or ~ **700 s^{-1}**

The G values for mixing should be around 20-60 s^{-1} for flocculation while for flash mixing, the requirements are in the range of 700-1000 s^{-1}. This also makes it clear that these high G values are responsible for high shear and breakage of the flocs. Nevertheless, all the hydraulic values were simulated faithfully with due consideration of the times of mixing.

The corresponding values time were set in the jar test apparatus by sequentially dosing chlorine and PAC at intervals of time governed by those followed at the actual parshall flume. The G values as calculated above were simulated by reading the tables correlating the RPM required for achieving a given G for the instrument. A chlorine dose of 4.25ppm was given initially to the samples of raw water from inlet of Surajpura WTP and the speed of the paddles was set at 20 RPM for 5mins. Then, the jars were then dosed with 25ppm PACl. The speed of the paddles was set at 40 RPM for 14mins. For simulating the hydraulic jump, the G value was 700s^{-1} for which the speed of the paddles was set at 125 RPM for 90s. This completed the parshall flume simulation, and the samples were rushed for analyses like zetasizing.

4.3 Zetasizing Analysis

Zetasizing was carried out on Malvern® Zetasizer at the MRC lab of MNIT for the samples obtained after simulation. This nanoparticle analyzer was used for two purposes- (i) to measure the zeta potential of the particles and (ii) to measure the sizes of the particles at nanoscale. All the samples were at a temperature of 25°C at the time of test.

The analysis was carried out for samples representing the water at the inlet, flocs formed after addition of chlorine and PAC in the parshall flume, and their fate at the inlet to the Superpulsator®, that is after the hydraulic jump. The values of zeta potential of the colloidal particles at sequential stages would throw light on the effectiveness of the coagulant dosage and also lend an explanation to the turbidity graph.

The results indicated the particle sizes ranging from 3.8 to 8.5 microns but that might be due to measurement limit of nanoparticle analyzer having a range of measurement upto 6microns . We expect higher floc sizes and therefore we would be carrying out PSA on mastersizer as well as hydrometer.

4.3.1 Zeta Potential

The colloidal particles are generally charged, which is the primary reason behind their stability and the net charge of the colloidal particles is represented by their zeta potential (fig. 4.3). Consequently, the higher the value of the zeta potential, the larger is the magnitude of the repulsive power between the particles and hence the more stable is the colloidal system. The principle behind the measurement of the magnitude of the zeta potential is based on the determination of the electrophoretic measurement of particle mobility in an electric field. The zeta potential of a given suspension can therefore be determined by using the Helmholtz–Smoluchowski equation:

$$\zeta = {}^{K\mu v}/_{\varepsilon E}$$

where ζ = zeta potential (mV), K = constant, μ = viscosity, v = measured velocity of colloids (μm/s), ε = dielectric constant, and E = applied electric field gradient (V/cm).

On application of electric field, the charged particles in the suspension move toward an electrode opposite to their surface charge with velocity that is proportional to the amount of charge of the particles. Zeta potential can be estimated by measuring the velocity of the particles. In order to determine the speed of the particles' movement, the particles are irradiated with a laser light and the scattered light emitted from the particles is detected. Since the particles are in motion, frequency of the scattered light is shifted from the incident light. This shift is in proportion to the speed of the particles' movement, and the electrophoretic mobility of the particles can be measured from the frequency shift (Doppler shift) of the scattered light. The instrument directly measures and takes the parameters K, μ, v, ε, E and gives the final reading of the zeta potential.

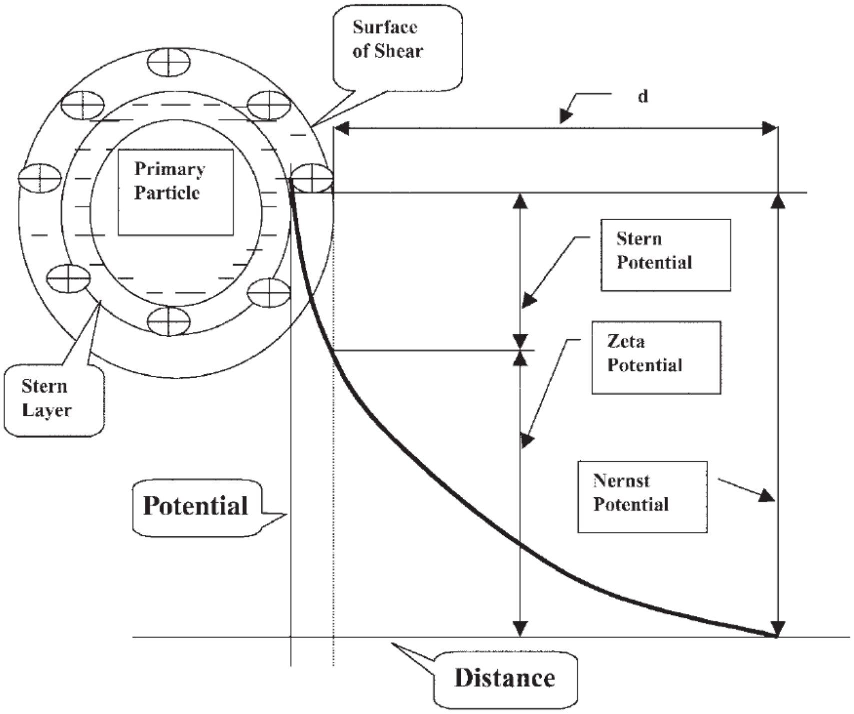


Figure 4.3: The electrical potential of a negatively charged colloidal particle (source: Wang et al., 2005)

4.3.2 Nanosizing

The particle characterization tool of the instrument is based on several principles including laser diffraction, dynamic light scattering and image analysis. The results give an insight on the size of colloidal particles, the size of the flocs and thus the efficiency of the coagulation and the mechanism to follow to bring about effective coagulation. The Malvern® Zetasizer at MRC lab has a least count of 0.1nm with the maximum upper limit of 10,000nm. In general it is typically used to measure sizes upto 6000nm.

Laser diffraction technique is used in nanosizing and the results are reported on a volume basis. The volume mean diameter is generally used to define the central point or the Z-Average and the equation for defining the volume mean diameter is given as-

$$D_{avg} = \frac{\sum_1^n D_{ivi}^4}{\sum_1^n D_{ivi}^3}$$

The histogram table showing the upper and lower limits of n size channels along with the percent within this channel is plotted by the software. The Di value for each channel is the geometric mean, the square root of upper x lower diameters. For the numerator take the geometric Di to the fourth power x the percent in that channel, summed over all channels. For the denominator the geometric Di is raised to the third power x the percent in that channel, summed over all channels. Statistical calculations such as standard deviation and variance are also reported in arithmetic form by the instrument software.

4.4 Mastersizing

The nanosizer had a limited range (upper limit of 1000nm), and thus was not suitable for approximation of larger floc sizes. Malvern's® Mastersizer 2000™, installed in the Department of Metallurgical and Materials Engineering of MNIT (fig. 4.4), is also based on the principle of laser diffraction for the measurement of particle sizes but it has an upper limit of 1000µm with least count of 0.1µm. The instrument was used to measure the size and specific surface area of the flocs and particles in the clarified water from the pilot plant and particle size of bentonite clay suspension in tap water (used for preparing synthetic turbid water). The samples at the time of test were at 25°C.

Interpretation of the particle size distribution calculations is crucial once the analysis is complete as a single number cannot in general describe the distribution of the sample. Therefore the common approach to define the distribution width is to cite three values on the x-axis, the D_{10}, D_{50}, and D_{90} as shown in figure 4.5. The D_{50}, the median, and can be defined as the diameter where half of the population lies below this value. Similarly, 90 percent of the distribution lies below the D_{90}, and 10 percent of the population lies below the D_{10}.

Figure 4.4: Malvern's® Mastersizer 2000™ installed in the Extractive Metallurgy Lab of MNIT Jaipur

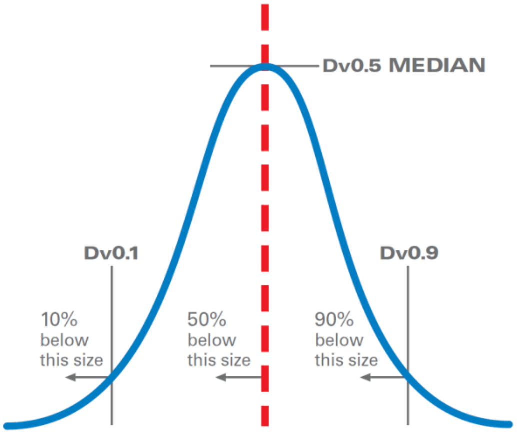


Figure 4.5: Three axis values D_{10}, D_{50} and D_{90} in particle size analysis (source: Horiba Instruments, Inc.)

4.5 Chlorine demand, residual chlorine & break point chlorination

The chlorine demand of a water is the amount of chlorine which is needed to react with organic matter and other substances. It is necessary to add sufficient chlorine to react with all the various substances present and still leave an excess or residual, if microorganisms are to be destroyed. The chlorine demand can therefore be calculated as the difference between the amount of chlorine added and the amount of residual remaining after a given contact time at a given temperature of water.

This residual chlorine may be present in the free-state, having the form of the molecule (Cl_2), hypochlorous acid (HOCl), and hypochlorite ion (OCl^-). It may be combined with ammonia to form less active chloramine; or it may be absorbed by organic matter to form relatively inactive chloro-organic compounds with little or no disinfecting power.

As the chlorine dose added is increased for a given water, the chlorine residual also increases, but at a rate less than that applied (caused by the reaction with ammonia). The chloramine residuals generally reach the maximum when the chlorine to ammonia molar ratio reaches 1:1. As applied chlorine concentration is increased beyond this point, the chloramine residuals decline and reach a minimum at chlorine to ammonia molar ratio of about 1.5:1. This point is called break point. Further addition of chlorine results in formation of free chlorine residuals, which increase linearly with the applied chlorine.

4.5.1 Objectives

The test was conducted in order to

1. Determine the chlorine demand of the intake water at Surajpura WTP.
2. Plot the break point chlorination curve for optimization of the dosage of disinfectant being administered in the form of pre-chlorination (4.25ppm) and post chlorination (1ppm) at Surajpura WTP.
3. Aid in carrying out the simulation of the parshall flume conditions at Surajpura WTP.
4. Removal of algal growth on the inner surface of the Perspex® column of the pilot plant.

According to BIS and the plant design guidelines laid down by American Water Works Association the commonly accepted minimum bacteria residuals of chlorine for potable water supplies are: 0.2 mg/L as free residual at pH values of about 9.2 or less increasing to about 0.3 mg/L at pH 9.5 and 0.5 at pH 10. The minimum combined residuals are 2 mg/L at pH levels below about 7 and rising logarithmically to 2.5 at pH 8, 2.8 at pH 9, and 3.0 at pH 10.

4.5.2 Conventional procedure followed

Detailed procedure is available in the manual of standard laboratory methods. Residual chlorine with concentration less than 2 ppm was measured with the help of color comparator using orthotolidine reagent.

For concentrations above 2 ppm, residual chlorine was measured by titrimetric method. Firstly chlorine solution was prepared for chlorination of the samples, with the help of bleaching powder and then the solution was standardized for the available chlorine content. Sodium thiosulphate was taken in the burette and added to the given sample until the yellow colour of the liberated iodine was almost discharged. After this, starch indicator was added and the titration was continued till colourless end-point was reached. The tests were carried out at the lab in Surajpura WTP (fig. 4.6) as well as PHE lab of MNIT Jaipur.

Figure 4.6: (a) Test on the turbidity meter at Surajpura WTP lab; (b) Test on colorimeter at Surajpura WTP lab

4.5.3 HANNA® free chlorine

The ion specific multi-parameter photometer of Hanna® instruments, based on method adaptation of the *EPA DPD method 330.5* was used for testing free and total chlorine in conjunction with conventional titrimetric methods because of the advantage of portability as well requisite range and resolution (fig. 4.7). Careful attention was paid to avoid any interference.

Basically, the content of one packet which is provided for testing of chlorine (HI 93701 DPD reagent) was added to the sample taken in the cuvet. The cap was replaced and the mixture was shaken gently for 20 seconds. The reaction between free chlorine and the DPD reagent causes a pink tint in the sample. After giving a minute to allow the undissolved reagent to precipitate, the cuvet was reinserted into the instrument to directly read the concentration in mg/L of free chlorine.

Figure 4.7: Portable HANNA® spectrophotmeter kit for testing chlorine in use on field

4.6 Test for Aluminium

Analysis of residual aluminiumin was done for clarified water samples from conventional clariflocculator model and superpulsator pilot plant by employing Eriochrome Cyanine R Spectrophotometric method. The testing was carried out on Shimadzu UV 1800® spectrophotometer installed in the PHE lab of MNIT Jaipur at a wavelength of 535nm (fig. 4.8). The working range of the instrument for this protocol for aluminium was 1–65µg/L. Stock aluminium solution was prepared by dissolving 8.791g aluminium potassium sulphate, $AlK(SO_4)_2.12H_2O$, (Merck) in water and diluting it to 1L. Standard Al solutions in the multiples of 5µg/L, upto 65µg/L concentration were prepared by freshly diluting 10ml of the standard reference (stock) solution to 1000ml with distilled water, so that 1ml of standard Al solution was equivalent to 5µg of Al. The detailed procedure followed for the testing can be obtained from the manual of standard analytical procedures for water analysis (Test ID: 1.30, Version: 2).

Significant amount of Al may be present in the form of solid precipitates. Therefore, procedure was followed for solubilization of the precipitated forms of Al. The digestion was done by lowering sample pH to 1 with the help of trace metal grade concentrated nitric acid and keeping it for 2 h before measurement.

Figure 4.8: Testing for residual aluminium on Shimadzu UV 1800 spectrophotometer installed at the PHE lab

4.7 Basis for comparison

In this section, the basisfor comparison of effect of coagulant on the performance of Superpulsator® pilot plant and Conventional clariflocculator has been discussed. For the purpose of the comparison, the amount of elemental aluminium influx into the influent stream was taken as the basis. Calculation for the amount of elemental aluminium for a set dose of coagulant requires a thorough inspection of the grade and specification of the coagulant, given the sheer variety in which manufacturers present them commercially.

4.7.1 Calculation of Aluminum content in PAC:

Specifications for the grade of PAC used are given in Table 4.1.

Aluminium as Al_2O_3, percent by mass, min = 10.2

Molar mass of $Al_2O_3 = 2 \times [Al] + 3 \times [O]$

$$= 2 \times 27 + 3 \times 16$$

$$= 102$$

Percentage of Al in Al_2O_3, by mass = $\frac{2\times[Al]}{2\times[Al]+3\times[O]} \times 100$

$$= \frac{2\times27}{2\times27+3\times16} \times 100$$

$$= \frac{54}{102} \times 100$$

$$= 52.94\%$$

Therefore, Al content in PAC, percent by mass, min = $10.2 \times 52.9\%$

$$= 5.396\%$$

Specific gravity of PAC = 1.2g/mL

If calculations are done for a dose of 25ppm PAC then,

for a dose of 25ppm, 25mg of PAC by mass is added per liter of water.

Volume of PAC (undiluted) required per liter of water for 25ppm dose = $\frac{25}{1.2}$

$$= 20.83 mL/L$$

Influx of elemental Al for a dose of 25ppm = $25 \times 5.396\%$

= 1.349mg

4.7.2 Calculation of Aluminum content in Alum:

Specifications for the grade of Alum used are given in Table 4.2.

Alum is never produced as pure $Al_2(SO_4)_3$ but always contains waters of crystallization. Molecular formula of the grade of alum used (Merck) is given by $Al_2(SO_4)_3.16H_2O$.

Formula weight = 630.38

Percentage of Al in alum, by mass = $\frac{54}{630.38} \times 100$

$= 8.566\%$

Percentage of Al in alum, by mass, min = $8.566 \times 98\%$

$= 8.227\%$

Now, keeping the influx of elemental Al as calculated earlier for PAC = 1.349mg

Amount of alum required for providing 1.349mg of elemental Al = $\frac{1.349}{8.227} \times 100$

$= 16.397mg \approx 16.4mg$

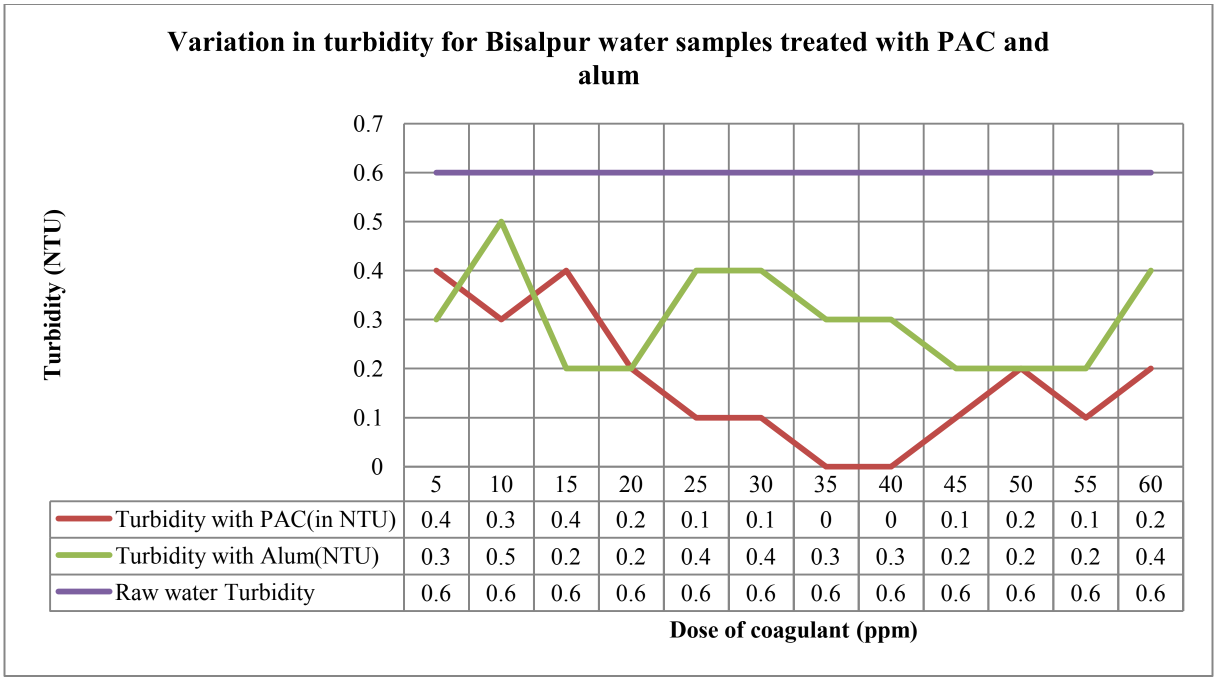
Therefore, for the same influx of elemental Al as for the dose of 25ppm of PAC, the required dose of alum = 16.4ppm

Chapter 5. Results and discussions

The results of the actual experiments and tests carried out in the labs of Surajpura WTP and MNIT Jaipur have been discussed in this chapter. These include the experiments carried out at first on the water samples from Surajpura WTP, to estimate the characteristics of water and its treatment efficiency. After the development, fabrication and installation of the pilot plant and conventional clariflocculator was completed, tests were run on them with synthetic turbid water. The later part of this chapter is dedicated to the comparative analysis with conventional clariflocculator when polyaluminium chloride and alum are used as coagulants (separately).

5.1 Jar tests on raw water samples from Bisalpur

Dosage of PAC and Alum was increased from 5ppm to 60ppm with increments of 5ppm. Procedure for the jar test has already been elaborated in previous chapter. The Bisalpur raw water had a turbidity of 0.6NTU. It can be noticed from figure 5.1, that in the jar tests low turbidity in supernatant was obtained when coagulant used was PAC. The PAC dose of 25ppm gave the turbidity reading of 0.1NTU, while it declined to nil for a dose of 35ppm.



	5	10	15	20	25	30	35	40	45	50	55	60
🟥 Turbidity with PAC(in NTU)	0.4	0.3	0.4	0.2	0.1	0.1	0	0	0.1	0.2	0.1	0.2
🟩 Turbidity with Alum(NTU)	0.3	0.5	0.2	0.2	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.4
🟪 Raw water Turbidity	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Figure 5.1: Variation in turbidity for Bisalpur water samples after treatment with PAC and alum as coagulants in the jar test

It can be seen from figure 5.2, lower residual aluminium levels were obtained for PAC at low doses in general. However, for doses in excess of 30ppm, lower residual Al was obtained in the supernatant for alum. It should be noted that a dose of 25ppm PAC is being administered at the Surajpura WTP, and the plant is based on the Superpusator® technology. Since the jar tests are suited to depict the conventional rapid mix and flocculation, perhaps for conventional water treatment plants, the residual Al levels would have been around 0.02ppm and turbidity of the treated water about 0.1NTU.

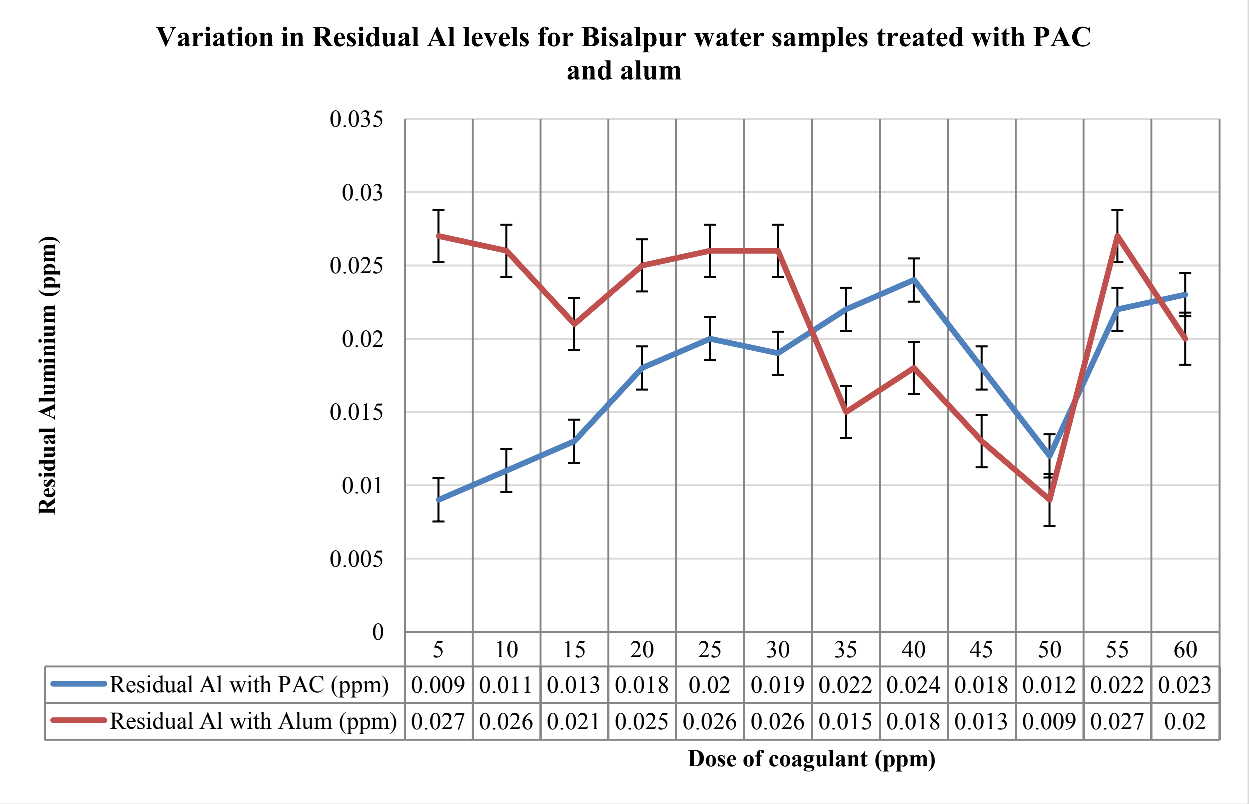


Figure 5.2: Variation in residual aluminium levels for Bisalpur water samples after treatment with PAC and alum as coagulants in the jar test

The effect of the dose of coagulant on pH and alkalinity of the raw water samples from Bisalpur after jar test is shown in figure 5.3 and figure 5.4 respectively. There is a definite trend of reduction in pH with increase in dose for both the coagulants, however there is a greater dip in pH for alum. This may be due to the fact that the grade of PAC used in the experiments, which is of the same specifications as the one used in Surajpura WTP, is of high basicity (64%). This is further evinced in the graph for alkalinity (fig. 5.4) where a greater destruction of alkalinity occurs in case of alum.

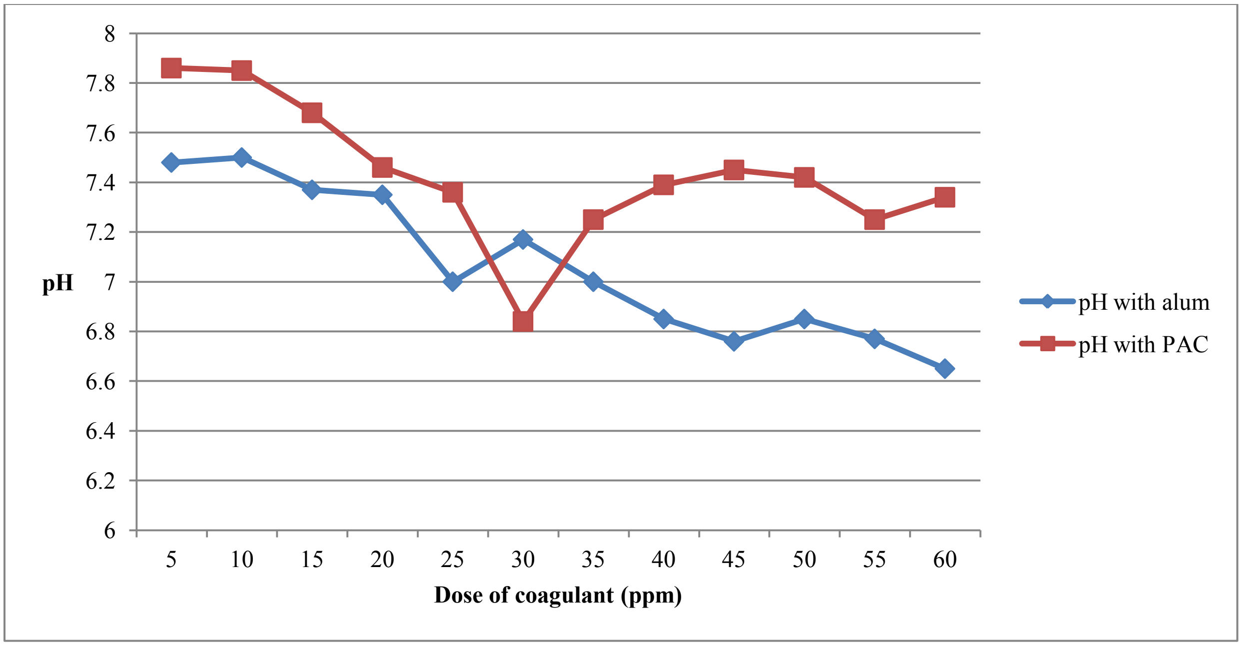


Figure 5.3: Variation in pH for Bisalpur water samples after treatment with PAC and alum as coagulants in the jar test

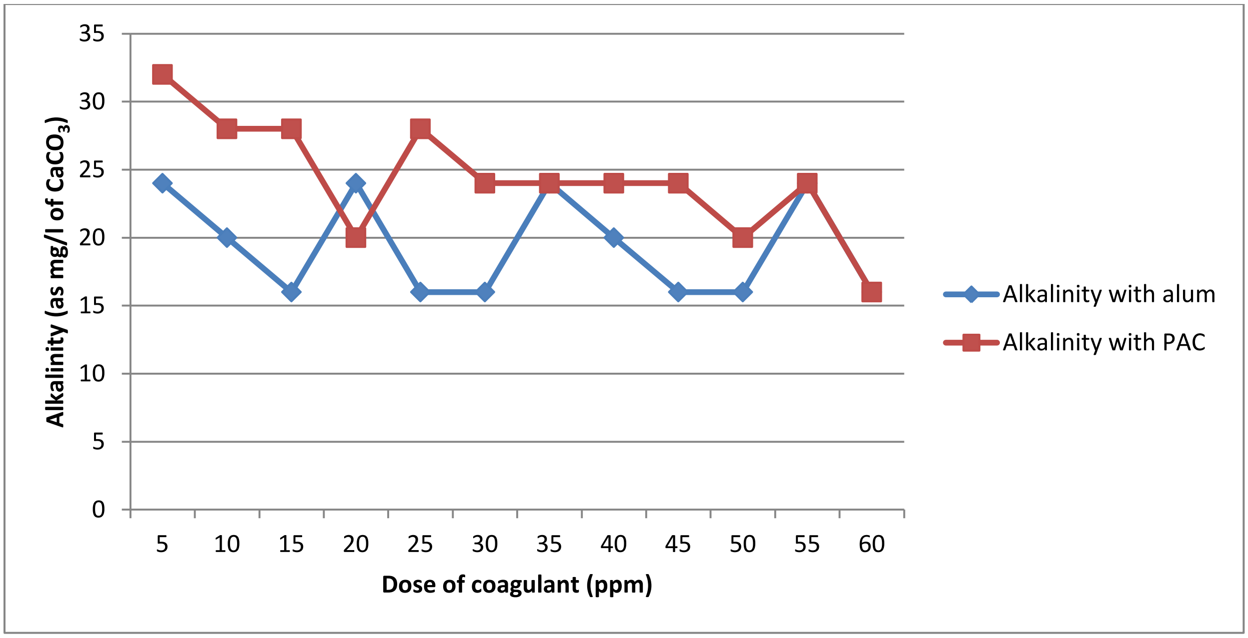


Figure 5.4: Variation in alkalinity for Bisalpur water samples after treatment with PAC and alum as coagulants in the jar test

5.2 Tests for chlorine

During the visits to Bisalpur dam and Surajpura WTP, the portable Hanna® spectrophotometer was carried to test the free chlorine levels at various sampling points. The results summarized in table show that the treated and filtered water has 0.70ppm residual free chlorine.

Interestingly, the raw water showed a presence of 0.21ppm free chlorine (Table 5.1). Possible reason for this anomalous result might be that there is some interference with this test reagent. Therefore test for free chlorine for raw water was repeated twice (on the same date and after about a month) with colorimeter (orthotolidine method), however similar levels of free chlorine were again detected. Thus a possible explanation could be that since the extraction point for sample of raw water though upstream, was still quite close to the point of chlorination, some free chlorine might have permeated into the samples.

Table 5.1: Readings of free chlorine by Hanna® spectrophotometer at various sampling points on actual field location

Sampling pts	Free chlorine in ppm
Raw	0.21
After chlorination	3.20
Before Pulsator	2.14
After Pulsator	0.95
After Filter	0.70

Test for chlorine residual was done n the raw water admitted to the Surajpura WTP and break point chlorination curve was plotted to optimize/verify the chlorine dosage for the plant. Figure 5.5 gives the breakpoint chlorination curve interposed on the corresponding turbidity of the supernatant obtained after the test.

The graph confirms the presence of ammoniacal compounds in the raw water. Further, the breakpoint occurs at about 5.5ppm after which the curve rises. Therefore, the current practice of pre-chlorination of 4.25ppm to 4.5ppm and ppost-chlorination of 1ppm at Surajpura is optimsed for chlorine dosage.

Also there is a sharp increase in the turbidity for chlorine dose between 4ppm to 5ppm. It might be due to experimental random error where a floc might have been sucked into the pipette. Though all efforts were made to carefully conduct the experiment and the supernatant was drawn from the surface. A more plausible explanation might be that after about a mole of chlorine has been added for ammonia, which might have occurred for the dose of 3.5ppm, further increase of chlorine results in the formation of trichloramines and oxidation of part of ammonia to N_2 or NO_3. Some of these trichloramine species impart a milky appearance to water.

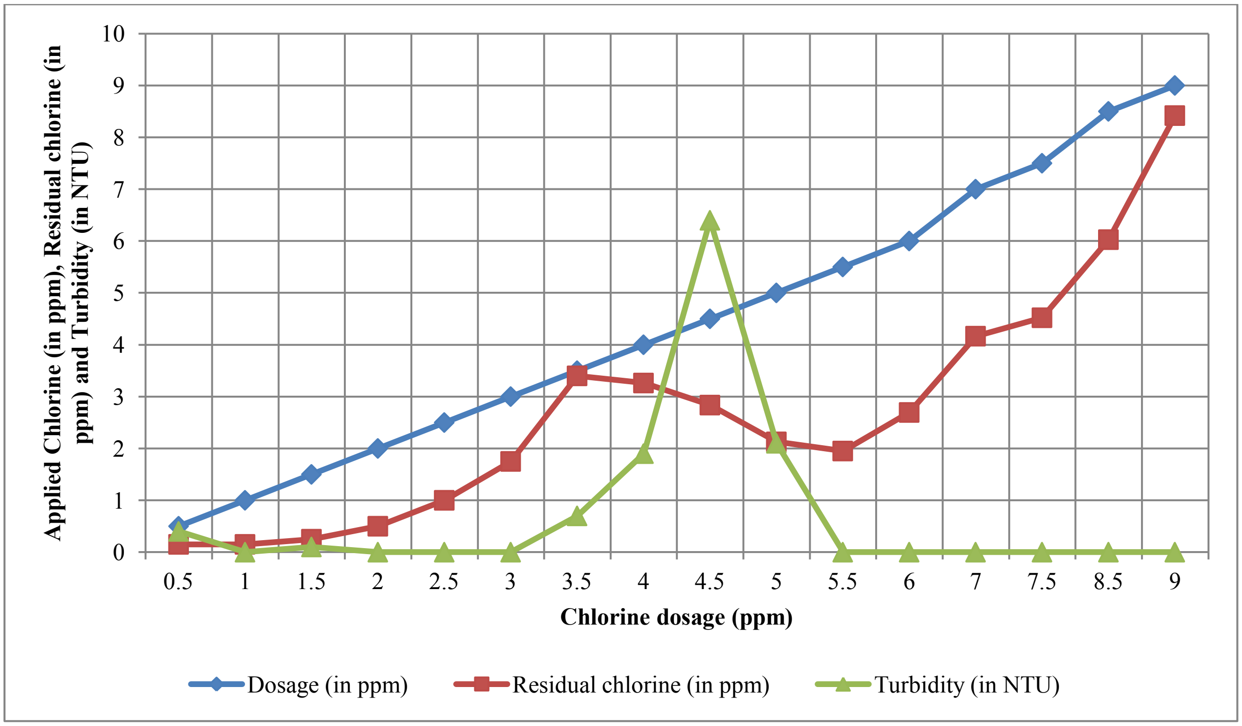


Figure 5.5: Breakpoint chlorination curve and corresponding turbidity of supernatant

After the installation of the pilot plant and its running for a couple of months, problem of algal bloom inside the column occurred. Actually, the column of the Superpulsator® pilot plant is made of Perspex® cylinders to allow observance for a number of advantageous reasons cited earlier. However, the model was placed close to a window through which sunlight filtered into the column. In the presence of sunlight, water and nutrients, growth of algae occurred attached to the inner surface o the Perspex® column. This resulted in increased turbidity and colour in the clarified water.

For cleaning the algae, first of all the column was emptied and then a constant dose of 5ppm chlorine was applied to the ingoing stream of tap water. The free chlorine in the water from the outlet of te column was measured by using Hanna® spectrophotometer. The dosage of chlorine was continued till the free chlorine in the outlet was close to 5ppm. The process was carried out for two days, and the result of the measurements of free chlorine in the outlet water is given in figure 5.6 and figure 5.7.

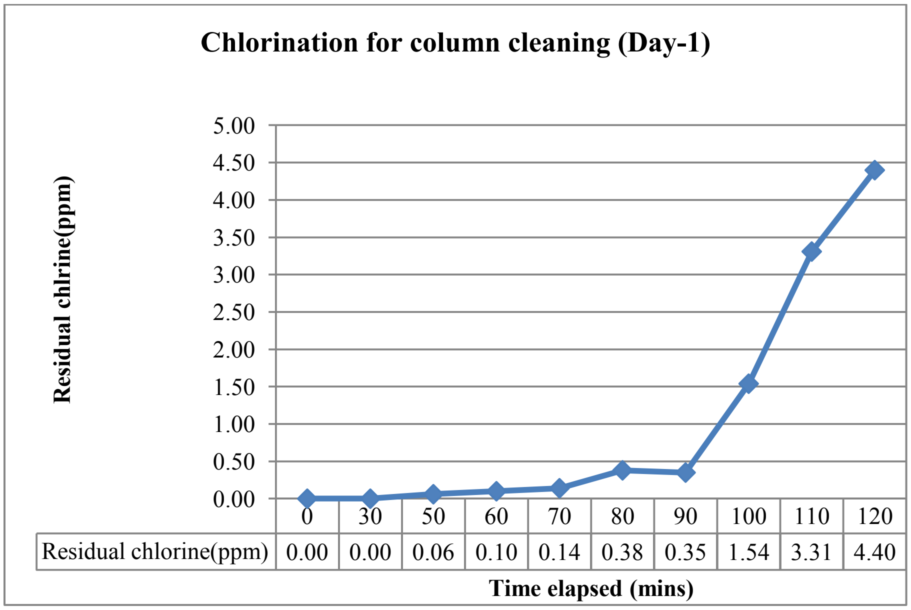


Figure 5.6: Residual free chlorine in the outlet during the first day of cleaning of the pilot plant column

The column was left overnight after this (day 1 chlorination), but the algae removal was not complete although there was marked reduction (fig. 5.8(b)). The process was repeated for the second day and the readings of the free chlorine are shown in figure 5.7.

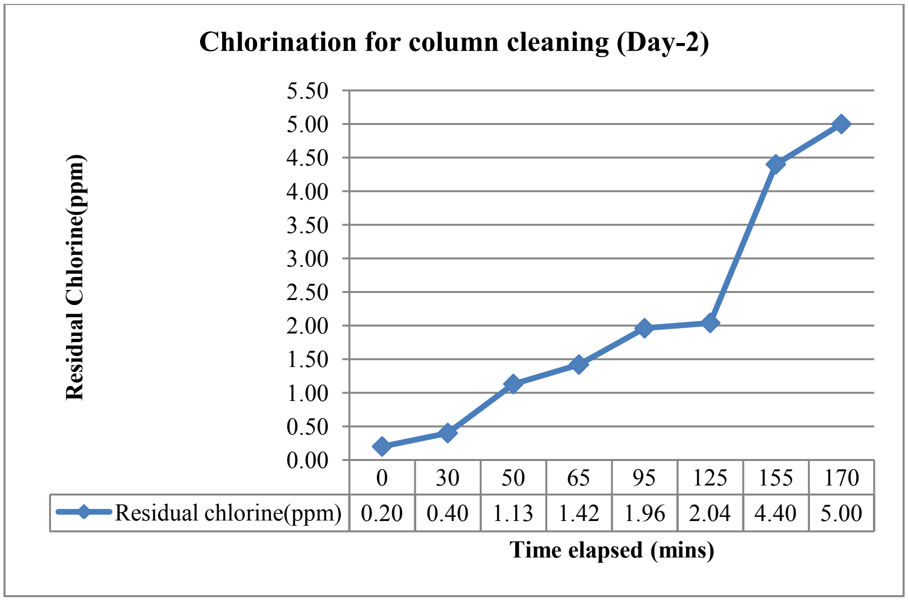


Figure 5.7: Residual free chlorine in the outlet during the second day of cleaning of the pilot plant column

After this, the column was manually scraped to remove the algae attached to the column walls. Various stages of cleaning of algal growth in the column are shown in figure 5.8 (a) to (d).

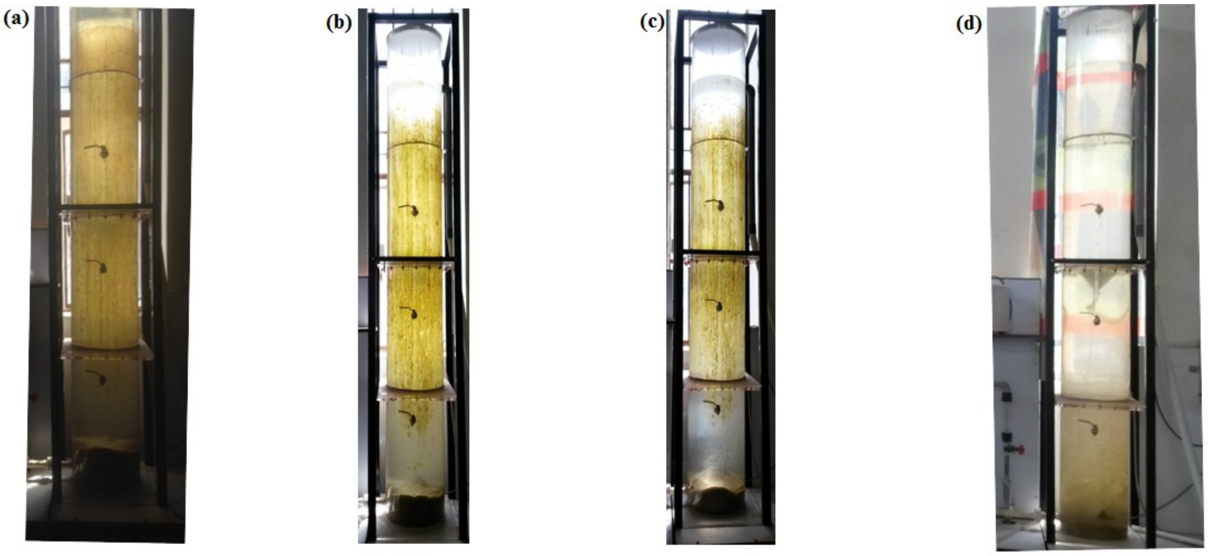
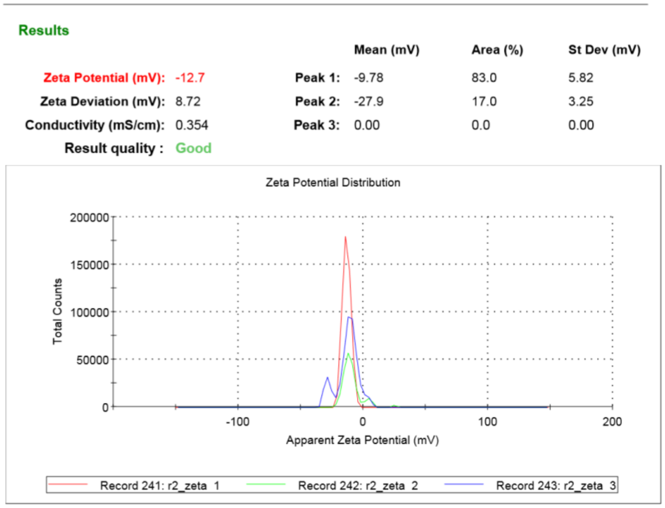


Figure 5.8: (a) Algal growth inside the transparent Perspex® column of the pilot plant due to infiltration of sunlight through the window; (b) reduction in the algal population after first day of chlorination; (c) further reduction of the algal population after second day of chlorination; (d) column after it was scraped clean of the attached algae and covered from behind

5.3 Zetasizing analysis of samples representing extraction points of the parshall flume at Surajpura WTP as simulated in the jar tests

The procedure and calculations for simulation of the parshall flume conditions at Surajpura WTP have been discussed in detail in the previous chapter. The analysis on Malvern® Zetasizer at the MRC lab of MNIT was carried out for samples representing the water at the inlet, flocs formed after addition of chlorine and PAC in the parshall flume, and their fate at the inlet to the Superpulsator®, that is after the hydraulic jump. All the tests were carried out at a temperature of 25°C.

The results of zetapotential analysis of raw water at the inlet of the parshall flume of Surajpura WTP are shown in figure 5.9. Apparently the colloidal particles have a significant net negative charge of -12.7mV.



Results

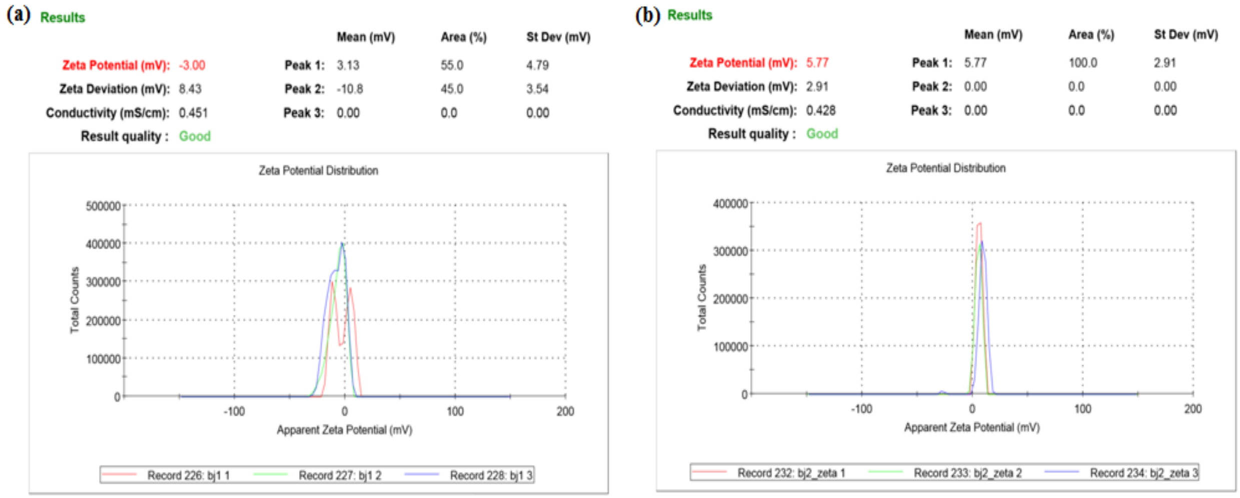
Zeta Potential (mV): -12.7
Zeta Deviation (mV): 8.72
Conductivity (mS/cm): 0.354
Result quality : Good

	Mean (mV)	Area (%)	St Dev (mV)
Peak 1:	-9.78	83.0	5.82
Peak 2:	-27.9	17.0	3.25
Peak 3:	0.00	0.0	0.00

Figure 5.9: Bisalpur raw water zeta potential

Coagulation and flocculation are dynamic processes and time plays an important role. Therefore, a duplicate set of samples was prepared and sonicated in the MRC lab just before the test. This was done because there was some time lag of a few minutes between extraction of samples and testing them at MRC lab. Purpose of sonication was to impart just the sufficient amount energy to bring the system back to the condition at the time of extraction.

The zetapotential of the sonicated and unsonicated samples before the hydraulic jump was found to be -3.00mV and 5.77mV respectively (fig. 5.10).


(a) Results

Zeta Potential (mV): -3.00
Zeta Deviation (mV): 8.43
Conductivity (mS/cm): 0.451
Result quality : Good

	Mean (mV)	Area (%)	St Dev (mV)
Peak 1:	3.13	55.0	4.79
Peak 2:	-10.8	45.0	3.54
Peak 3:	0.00	0.0	0.00

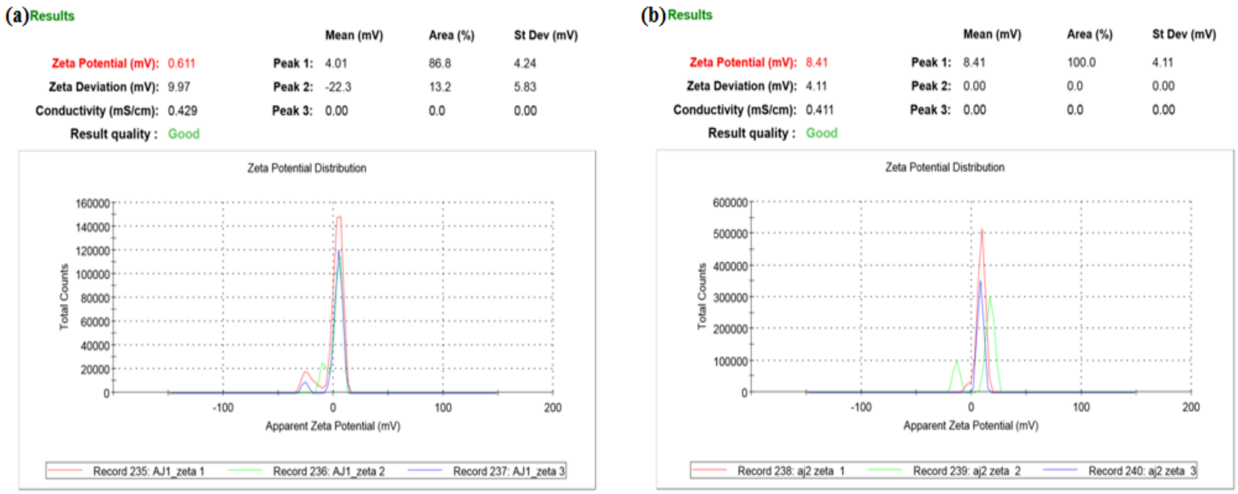
(b) Results

Zeta Potential (mV): 5.77
Zeta Deviation (mV): 2.91
Conductivity (mS/cm): 0.428
Result quality : Good

	Mean (mV)	Area (%)	St Dev (mV)
Peak 1:	5.77	100.0	2.91
Peak 2:	0.00	0.0	0.00
Peak 3:	0.00	0.0	0.00

Figure 5.10: (a) Zeta potential of pre-chlorinated and coagulated Bisalpur water before hydraulic jump as simulated along with sonication; (b) Zeta potential of pre-chlorinated and coagulated Bisalpur water before hydraulic jump as simulated and without sonication

With a G value of about 700s-1, the hydraulic jump imparts a large amount of mixing energy. Zetapotential of the particles can throw some light on the effect of this mixing on the electrophoretic mobility of the particles. The zetapotential of the sonicated and unsonicated samples after the hydraulic jump was found to be 0.611mV and 8.41mV respectively (fig. 5.11).


(a) Results

Zeta Potential (mV): 0.611
Zeta Deviation (mV): 9.97
Conductivity (mS/cm): 0.429
Result quality : Good

	Mean (mV)	Area (%)	St Dev (mV)
Peak 1:	4.01	86.8	4.24
Peak 2:	-22.3	13.2	5.83
Peak 3:	0.00	0.0	0.00

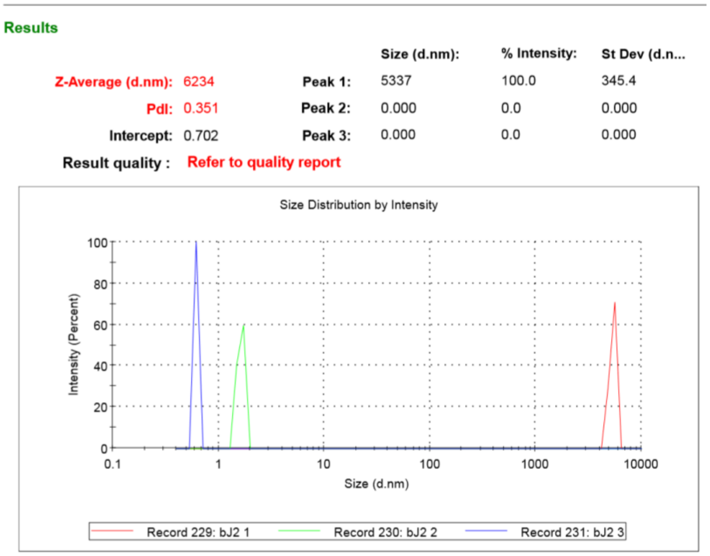
(b) Results

Zeta Potential (mV): 8.41
Zeta Deviation (mV): 4.11
Conductivity (mS/cm): 0.411
Result quality : Good

	Mean (mV)	Area (%)	St Dev (mV)
Peak 1:	8.41	100.0	4.11
Peak 2:	0.00	0.0	0.00
Peak 3:	0.00	0.0	0.00

Figure 5.11: (a) Zeta potential of pre-chlorinated and coagulated Bisalpur water after hydraulic jump as simulated along with sonication; (b) Zeta potential of pre-chlorinated and coagulated Bisalpur water after hydraulic jump as simulated and without sonication

Similarly by simulation, assessment of the particle size was made for the flocs formed after addition of chlorine and PAC in the parshall flume, and their fate at the inlet to the Superpulsator®, that is after the hydraulic jump. The calculation of the average value of diameter has been discussed in the previous chapter. As shown in figure 5.12, the particle size of flocs reaches a Z_{avg} value of 6234nm before hydraulic jump.



Results

Z-Average (d.nm): 6234

PdI: 0.351

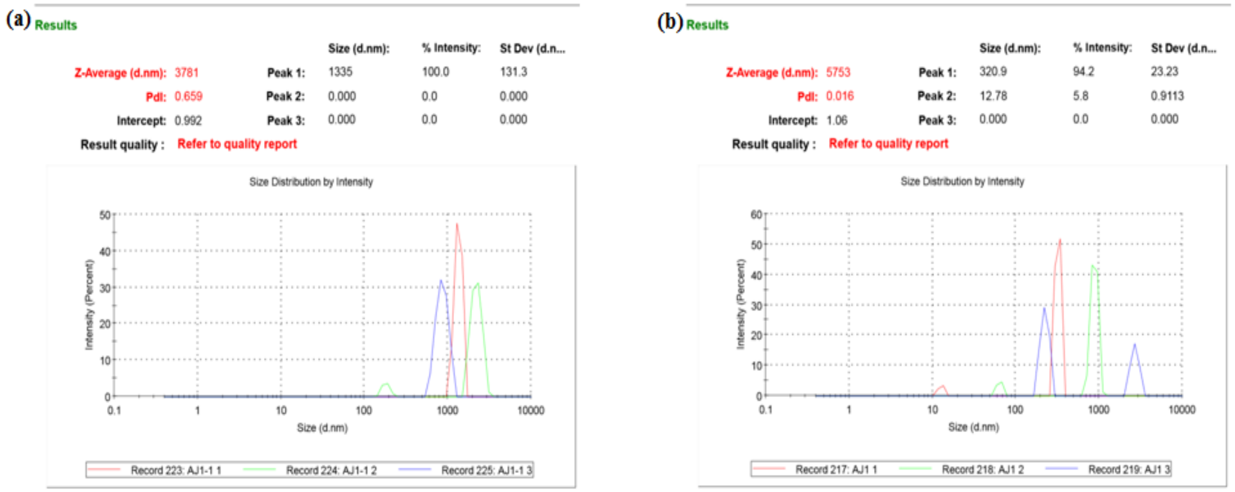
Intercept: 0.702

Result quality : Refer to quality report

	Size (d.nm):	% Intensity:	St Dev (d.n...
Peak 1:	5337	100.0	345.4
Peak 2:	0.000	0.0	0.000
Peak 3:	0.000	0.0	0.000

Figure 5.12: Particle size analysis of pre-chlorinated and coagulated Bisalpur water (unsonicated) before hydraulic jump as simulated on Malvern® Zetasizer

It is evident from figure 5.13, that a reduction in the floc sizes occurs after the hydraulic jump, as the results give Z_{avg} values of 3781nm and 5753nm for sonicated and unsonicated samples respectively. This is perhaps due to the fact that the large mixing energy imparted by the fall of 0.38m (giving G value of $700s^{-1}$) is causing the breakage of the fragile flocs.


(a) **Results**

Z-Average (d.nm): 3781

PdI: 0.659

Intercept: 0.992

Result quality : Refer to quality report

	Size (d.nm):	% Intensity:	St Dev (d.n...
Peak 1:	1335	100.0	131.3
Peak 2:	0.000	0.0	0.000
Peak 3:	0.000	0.0	0.000

(b) **Results**

Z-Average (d.nm): 5753

PdI: 0.016

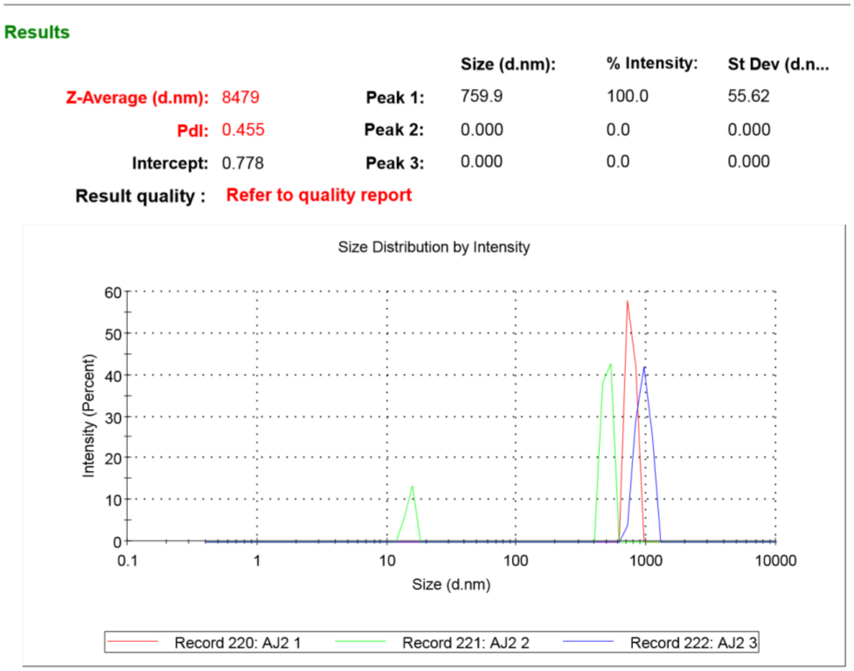
Intercept: 1.06

Result quality : Refer to quality report

	Size (d.nm):	% Intensity:	St Dev (d.n...
Peak 1:	320.9	94.2	23.23
Peak 2:	12.78	5.8	0.9113
Peak 3:	0.000	0.0	0.000

Figure 5.13: (a) Particle size analysis of pre-chlorinated and coagulated Bisalpur water after hydraulic jump as simulated along with sonication on Malvern® Zetasizer; (b) Particle size analysis of pre-chlorinated and coagulated Bisalpur water after hydraulic jump as simulated and without sonication on Malvern® Zetasizer

The coagulation process is however effective as was shown from the zetapotential results. If sufficient detention time is given, we observe an increase in the size of the floc again (fig. 5.14).


Results

Z-Average (d.nm): 8479

PdI: 0.455

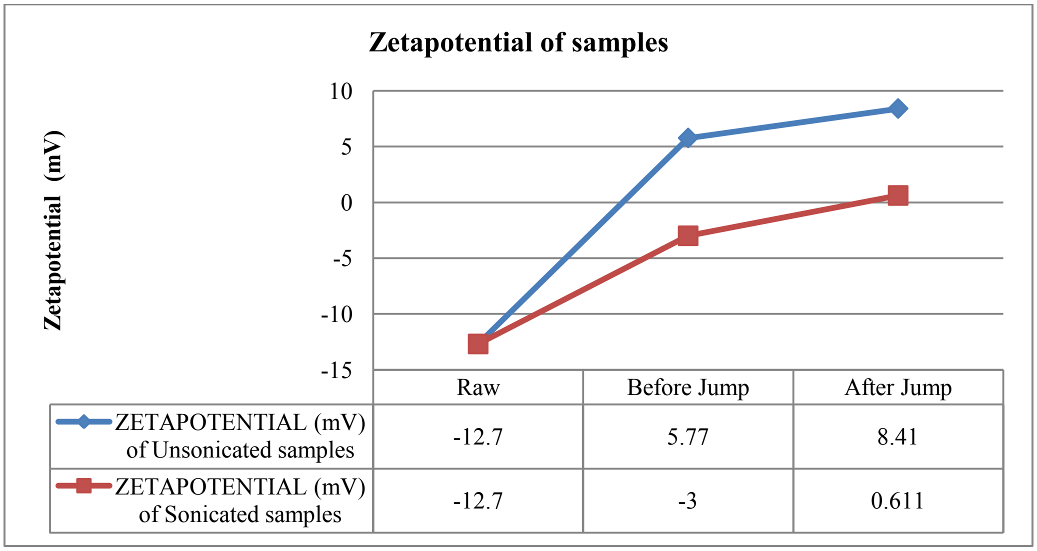
Intercept: 0.778

Result quality : Refer to quality report

	Size (d.nm):	% Intensity:	St Dev (d.n...
Peak 1:	759.9	100.0	55.62
Peak 2:	0.000	0.0	0.000
Peak 3:	0.000	0.0	0.000

Figure 5.14: Particle size analysis of pre-chlorinated and coagulated Bisalpur water (unsonicated) with about 4 minute detention time after hydraulic jump as simulated

The results of zetapotential analyses have been summarized in figure 5.15. A zetapotential within the range -5mV to 5mV indicates effective coagulation. It can however be seen from figure 5.15 that the zetapotential of the unsonicated before jump sample just exceeds + 5mV and the value for unsonicated after jump sample is even higher (8.41mV). Clearly a charge reversal occurs and this indicates that the delivered coagulant dose of 25ppm PAC might be in excess. The corresponding values for unsonicated samples are lower and fall within -5mV to 1mV range. Since the purpose of sonication was to impart just the sufficient amount energy to bring the system back to the condition at the time of extraction, the results indicate just the perfect coagulation conditions. However we must be wary of this interpretation of the results of the sonicated samples because the sonication was somewhat uncontrolled as the precise energy to be imparted for bringing back the earlier conditions was not known.



	Raw	Before Jump	After Jump
ZETAPOTENTIAL (mV) of Unsonicated samples	-12.7	5.77	8.41
ZETAPOTENTIAL (mV) of Sonicated samples	-12.7	-3	0.611

Figure 5.15: Zetapotential of samples representing extraction points parshall flume of Surajpura WTP as simulated in the jar tests

Nanosizing results have been summarized by plotting the Z_{avg} values of the samples on a scale of range 9000nm in figure 5.16. The limit of the nanosizer equipment was 10000nm and therefore it was unsuitable for analysizing flocs of larger sizes. There is a clear indication of breakage of flocs due to hydraulic jump but with higher detention time floc sizes increase again.

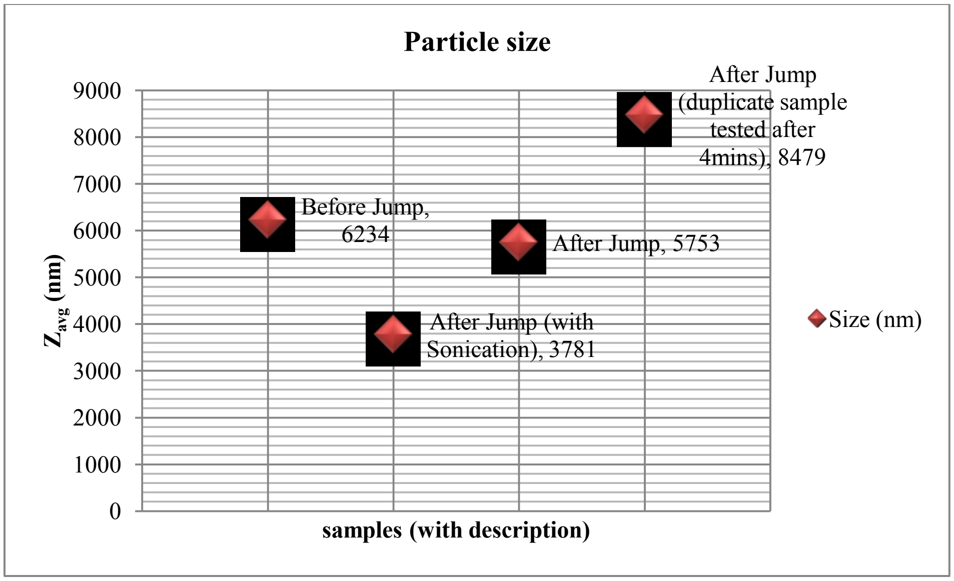


Figure 5.16: Particle size of flocs in the samples representing extraction points parshall flume of Surajpura WTP as simulated in the jar tests

5.4 Runs on Superpulsator® pilot plant and conventional clariflocculator

Both the models are continuous flow based and thus turbidity was imparted synthetically to the tap water supply by using bentonite powder so that the synthetically generated turbidity is quite close to the natural conditions. Bentonite powder consists mostly of montmorillonite clay and is essentially aluminum phyllosilicate. A solution of bentonite powder in water of strength 100mg/*l* was prepared in the tank and continuously stirred to prevent settling and provide homogeneous dosing for getting the required turbidity levels in the influent water. This solution was mixed in the turbulent stream of tap water in the main pipeline of the pulsator pilot plant via peristaltic pump. In case of conventional clariflocculator model, this solution was admitted to the rapid mix chamber via peristaltic pump.

In both the cases, a known strength of bentonite solution was mixed thoroughly at a set rate with a known flow rate of tap water. Now in order to estimate the turbidity of the final influent water, a graph was plotted (fig. 5.17) for relating the strength of bentonite in tap water in ppm and the turbidity of the prepared solution in NTU. An excellent regression correlation was obtained with the R^2 value of 0.9915.

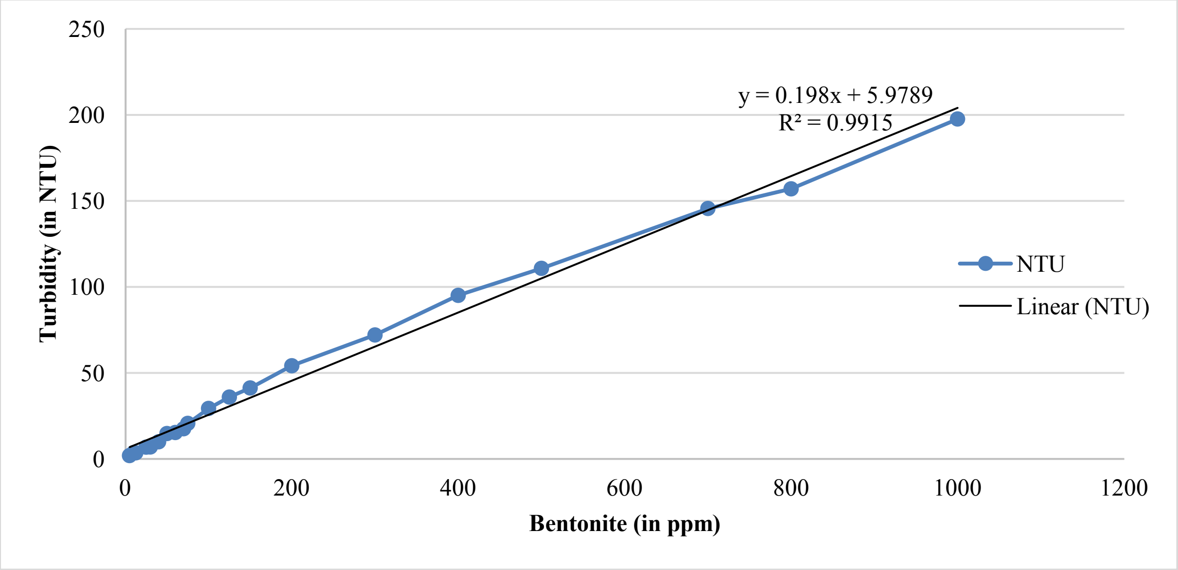


Figure 5.17: Regression analysis for correlation between strength of bentonite solution in ppm and turbidity of the solution in NTU

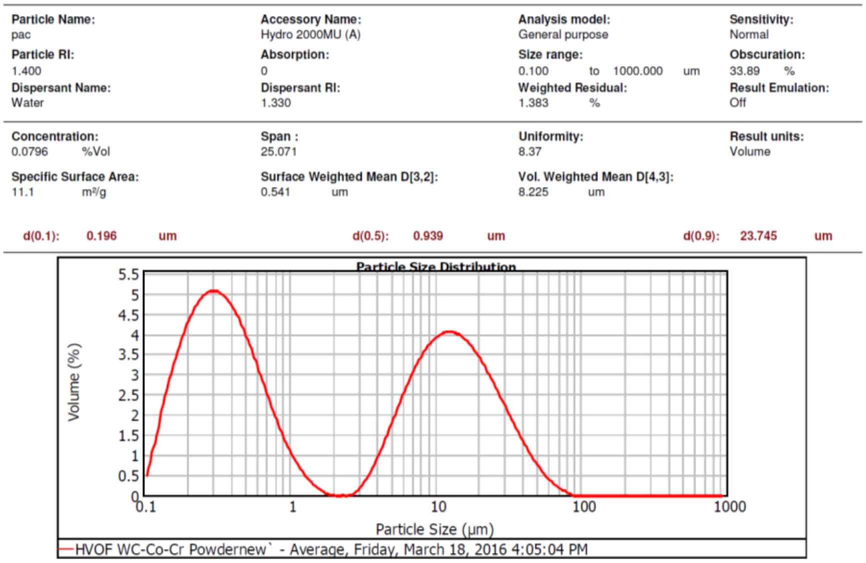
5.4.1 Mastersizing

Particle size analysis was carried out on Malvern® Mastersizer 2000™, which has an upper limit of 1000µm with least count of 0.1µm, to measure the size and specific surface area of the bentonite clay suspension in tap water (used for preparing synthetic turbid water) and flocs in the clarified water from the pilot plant. All the samples at the time of test were at 25°C. Interpretation of the statistical numbers expressed in the graphs has been discussed in previous chapter.

The bentonite clay powder may have the particle sizes in a narrow range, but the particle size of the suspension in water may vary. Therefore several tests were conducted with different strengths of the clay suspension in order to estimate the average size of clay particles. The volume mean diameter can be calculated by using the equation

$$D[4,3] = \frac{\sum_1^n D_{ivi}^4}{\sum_1^n D_{ivi}^3}$$

It can be inferred from figures 5.18, 5.19 and 5.20 that the volume weighed means of the clay suspension samples are 8.225µm, 36.408µm and 59.781µm respectively.

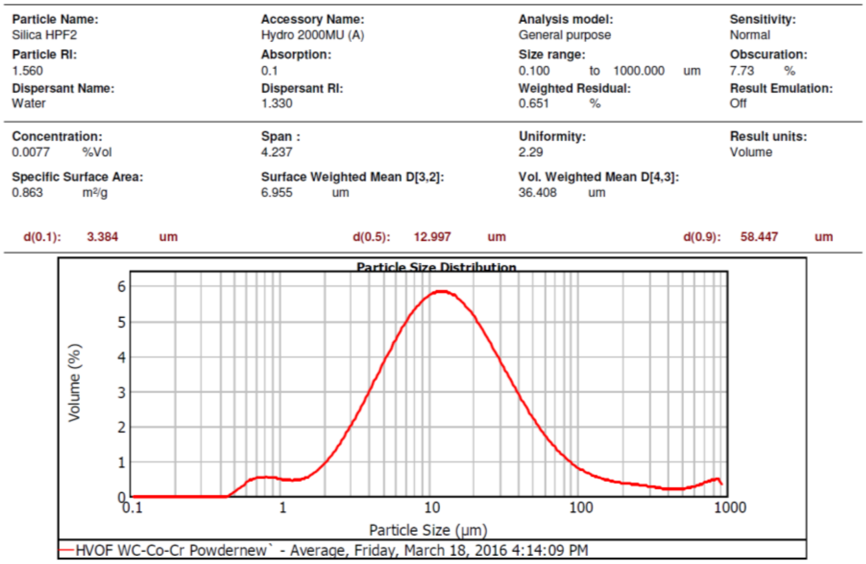

Particle Name: pac
Accessory Name: Hydro 2000MU (A)
Analysis model: General purpose
Sensitivity: Normal
Particle RI: 1.400
Absorption: 0
Size range: 0.100 to 1000.000 um
Obscuration: 33.89 %
Dispersant Name: Water
Dispersant RI: 1.330
Weighted Residual: 1.383 %
Result Emulation: Off

Concentration: 0.0796 %Vol
Span : 25.071
Uniformity: 8.37
Result units: Volume
Specific Surface Area: 11.1 m²/g
Surface Weighted Mean D[3,2]: 0.541 um
Vol. Weighted Mean D[4,3]: 8.225 um

d(0.1): 0.196 um
d(0.5): 0.939 um
d(0.9): 23.745 um

*

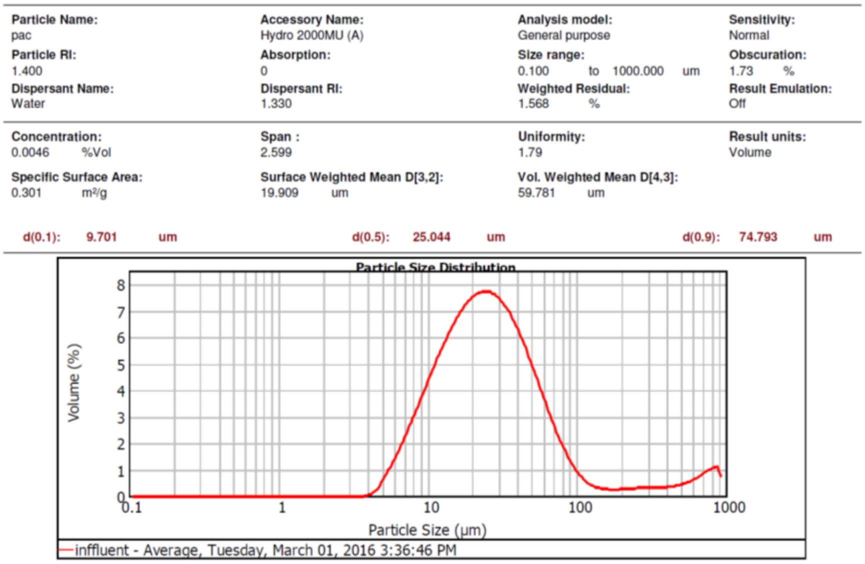
Figure 5.18: Particle size analysis of clay in the turbid water admitted to the pilot plant carried out on Malvern® Mastersizer 2000™ for clay suspension of concentration 0.0796 %Vol


Particle Name: Silica HPF2
Accessory Name: Hydro 2000MU (A)
Analysis model: General purpose
Sensitivity: Normal
Particle RI: 1.560
Absorption: 0.1
Size range: 0.100 to 1000.000 um
Obscuration: 7.73 %
Dispersant Name: Water
Dispersant RI: 1.330
Weighted Residual: 0.651 %
Result Emulation: Off

Concentration: 0.0077 %Vol
Span : 4.237
Uniformity: 2.29
Result units: Volume
Specific Surface Area: 0.863 m²/g
Surface Weighted Mean D[3,2]: 6.955 um
Vol. Weighted Mean D[4,3]: 36.408 um

d(0.1): 3.384 um
d(0.5): 12.997 um
d(0.9): 58.447 um

Figure 5.19: Particle size analysis of clay in the turbid water admitted to the pilot plant carried out on Malvern® Mastersizer 2000™ for clay suspension of concentration 0.0077 %Vol



Particle Name: pac
Accessory Name: Hydro 2000MU (A)
Analysis model: General purpose
Sensitivity: Normal
Particle RI: 1.400
Absorption: 0
Size range: 0.100 to 1000.000 um
Obscuration: 1.73 %
Dispersant Name: Water
Dispersant RI: 1.330
Weighted Residual: 1.568 %
Result Emulation: Off

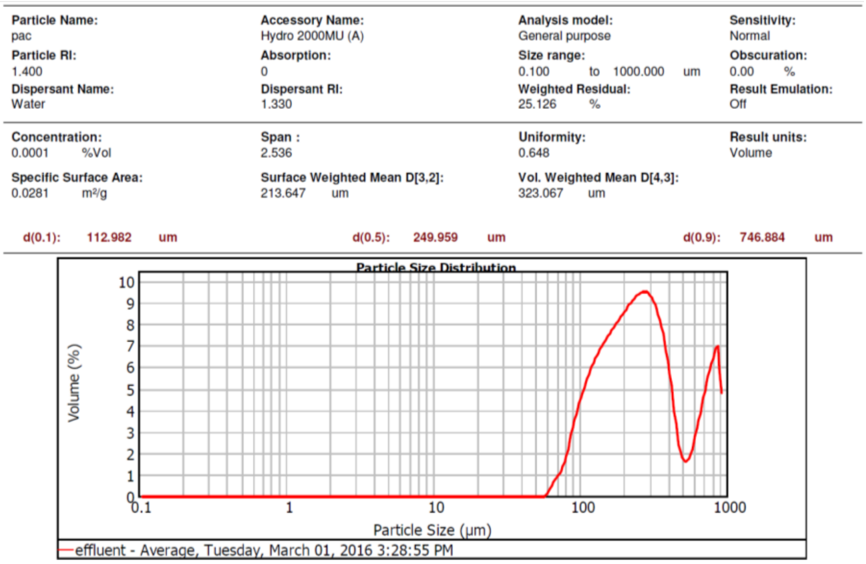
Concentration: 0.0046 %Vol
Span : 2.599
Uniformity: 1.79
Result units: Volume
Specific Surface Area: 0.301 m²/g
Surface Weighted Mean D[3,2]: 19.909 um
Vol. Weighted Mean D[4,3]: 59.781 um

d(0.1): 9.701 um
d(0.5): 25.044 um
d(0.9): 74.793 um

Figure 5.20: Particle size analysis of clay in the turbid water admitted to the pilot plant carried out on Malvern® Mastersizer 2000™ for clay suspension of concentration 0.0046 %Vol

An important part of the mastersizing analysis was to get a better estimate of the size of the flocs formed in the Superpulsator® pilot plant because of the greater range of the equipment. This would throw light on the efficiency of the process leading to proper blanket formation and as a result causing effective solids contact for water treatment.

For the day when the influent turbidity was maintained at 20NTU and PAC dose of 15ppm was given, significantly large floc sizes were obtained. As shown in figure 5.21, the D_{10}, D_{50} and D_{90} values were 112.982µm, 249.959µm and 746.884µm respectively. The specific surface area of the flocs was 0.0281m^2/g.

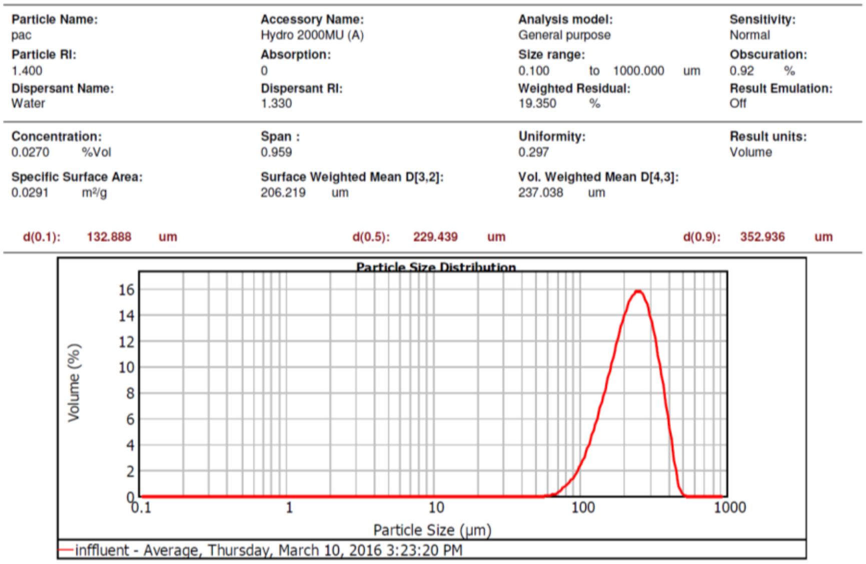


Particle Name: pac	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.400	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 0.00 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 25.126 %	**Result Emulation:** Off
Concentration: 0.0001 %Vol	**Span :** 2.536	**Uniformity:** 0.648	**Result units:** Volume
Specific Surface Area: 0.0281 m²/g	**Surface Weighted Mean D[3,2]:** 213.647 um	**Vol. Weighted Mean D[4,3]:** 323.067 um	

d(0.1): 112.982 um **d(0.5):** 249.959 um **d(0.9):** 746.884 um

Figure 5.21: Particle size analysis of flocs in the clarified water from pilot plant carried out on Malvern® Mastersizer 2000™ for influent turbidity of 20NTU and PAC dose of 15ppm

As shown in figure 5.22, for the day when the influent turbidity was maintained at 10NTU and PAC dose of 21ppm was given the D_{10}, D_{50} and D_{90} values were 132.888µm, 229.439µm and 352.936µm respectively. The specific surface area of the flocs was 0.0291m^2/g.

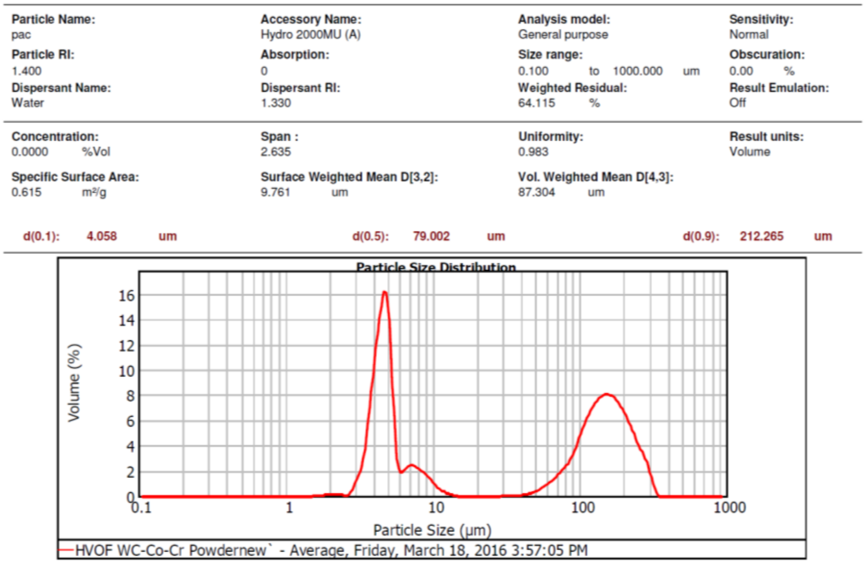


Particle Name: pac	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.400	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 0.92 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 19.350 %	**Result Emulation:** Off
Concentration: 0.0270 %Vol	**Span :** 0.959	**Uniformity:** 0.297	**Result units:** Volume
Specific Surface Area: 0.0291 m²/g	**Surface Weighted Mean D[3,2]:** 206.219 um	**Vol. Weighted Mean D[4,3]:** 237.038 um	

d(0.1): 132.888 um **d(0.5):** 229.439 um **d(0.9):** 352.936 um

Figure 5.22: Particle size analysis of flocs in the clarified water from pilot plant carried out on Malvern® Mastersizer 2000™ for influent turbidity of 10NTU and PAC dose of 21ppm

For the day when the influent turbidity was maintained at 8NTU and PAC dose of 25ppm was given the D_{10}, D_{50} and D_{90} values were 4.058µm, 79.002µm and 212.265µm respectively. The specific surface area of the flocs was $0.615 m^2/g$ (fig. 5.23).

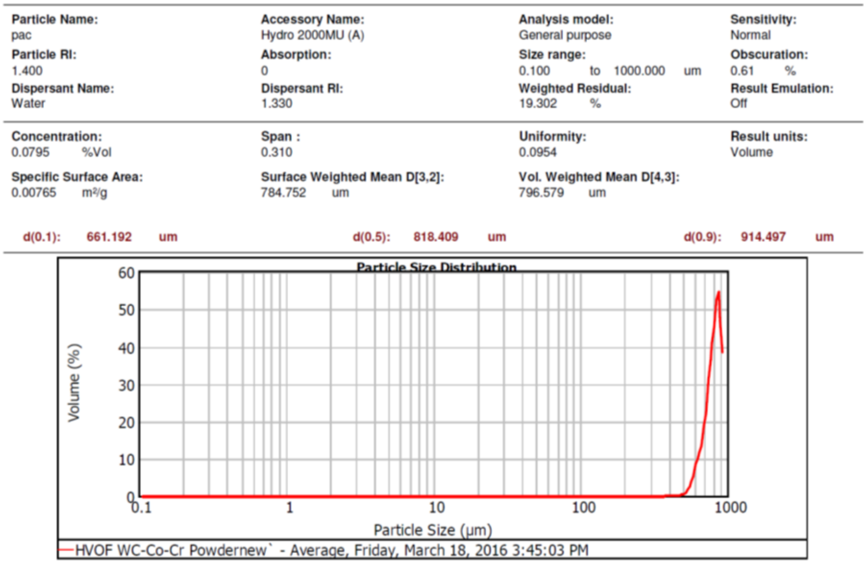


Particle Name: pac	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.400	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 0.00 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 64.115 %	**Result Emulation:** Off
Concentration: 0.0000 %Vol	**Span :** 2.635	**Uniformity:** 0.983	**Result units:** Volume
Specific Surface Area: 0.615 m²/g	**Surface Weighted Mean D[3,2]:** 9.761 um	**Vol. Weighted Mean D[4,3]:** 87.304 um	

d(0.1): 4.058 um **d(0.5):** 79.002 um **d(0.9):** 212.265 um

Figure 5.23: Particle size analysis of flocs in the clarified water from pilot plant carried out on Malvern® Mastersizer 2000™ for influent turbidity of 8NTU and PAC dose of 25ppm

Also for the day when the influent turbidity was again maintained at 8NTU and PAC dose of 25ppm was given (but the sample was different) the D_{10}, D_{50} and D_{90} values were 661.192µm, 818.409µm and 914.497µm respectively. The specific surface area of the flocs was 0.00765m^2/g (fig. 5.24).



Particle Name: pac	**Accessory Name:** Hydro 2000MU (A)	**Analysis model:** General purpose	**Sensitivity:** Normal
Particle RI: 1.400	**Absorption:** 0	**Size range:** 0.100 to 1000.000 um	**Obscuration:** 0.61 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 19.302 %	**Result Emulation:** Off
Concentration: 0.0795 %Vol	**Span :** 0.310	**Uniformity:** 0.0954	**Result units:** Volume
Specific Surface Area: 0.00765 m²/g	**Surface Weighted Mean D[3,2]:** 784.752 um	**Vol. Weighted Mean D[4,3]:** 796.579 um	

d(0.1): 661.192 um d(0.5): 818.409 um d(0.9): 914.497 um

Figure 5.24: Particle size analysis of flocs in the clarified water from pilot plant carried out on Malvern® Mastersizer 2000™ for influent turbidity of 8NTU and PAC dose of 25ppm

The D_{90} values of the results of particle size analyses on the mastersizer have been plotted on the graph for comparison (fig. 5.25). It is evident that coagulation and flocculation occur properly which result in sufficiently large floc sizes. It is to be noted that the Hydro 2000™ accessory of Malvern® Mastersizer causes a whirlpool in the sample and thus damage the fragile flocs. The results of mastersizing analysis therefore give a lower estimate and the actual floc sizes may be even greater.

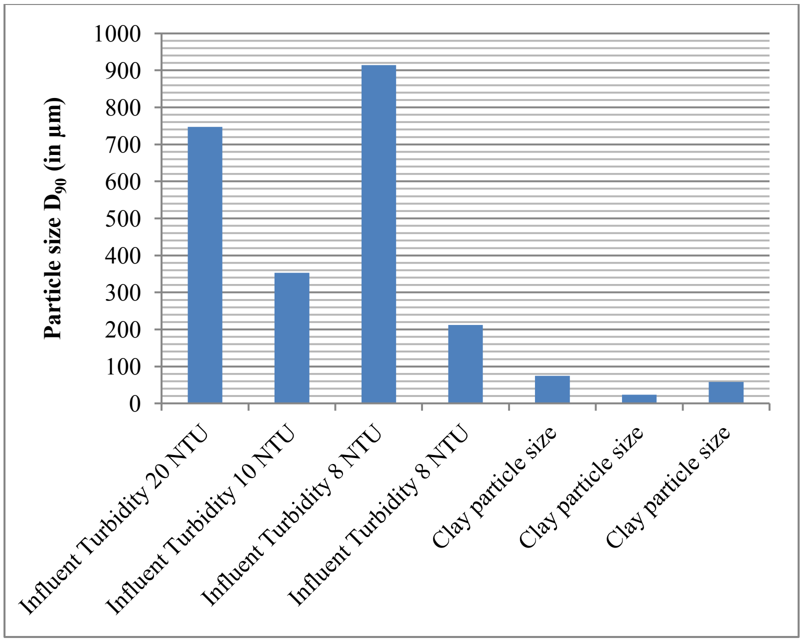


Figure 5.25: Particle size D_{90} for bentonite clay suspension and flocs

5.4.2 Effect of coagulant on the performance of Superpulsator® pilot plant

In this section, comparison of performance of Superpulsator® pilot plant is done when PAC and alum are used as coagulants.

In figure 5.26, turbidity levels in the clarified water from the pilot plant for different influent turbidities are compared for the two coagulants. The turbidity levels in the clarified water are similar for the two series, except for the case of when influent turbidity is 30NTU. Generalization cannot however be drawn as the effluent quality of the Superpulsator® pilot plant depends on the sludge blanket dynamics, depth of the blanket, stabilization time and a number of other factors.

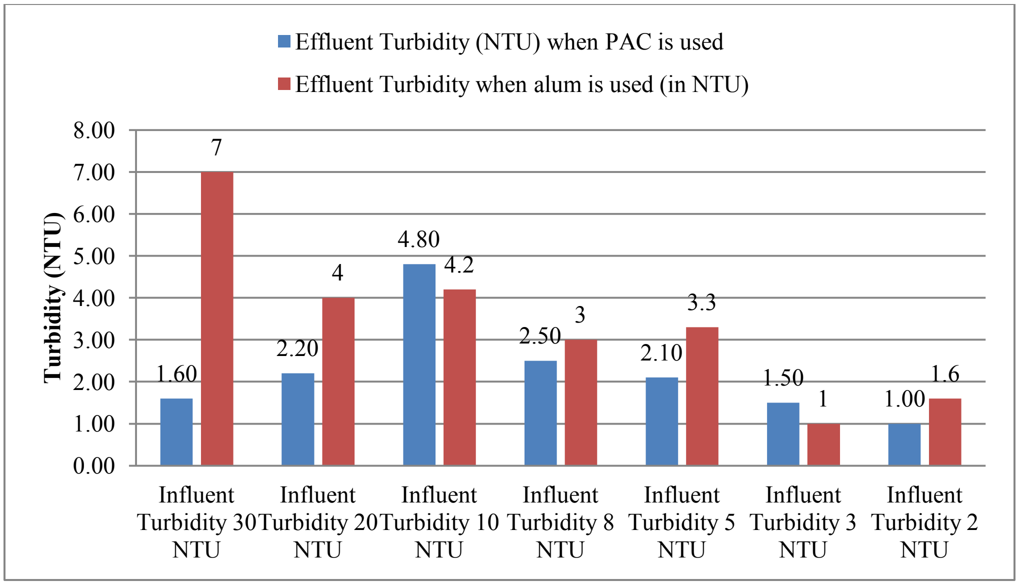


Figure 5.26: Comparison of turbidity levels of clarified water from pilot plant

Figure 5.27 expresses the results in terms of percentage removal of turbidity. Although there is a decline in the percentage removal for both the series with lowers turbidity in influent water, but the value of turbidity in clarified water is low.

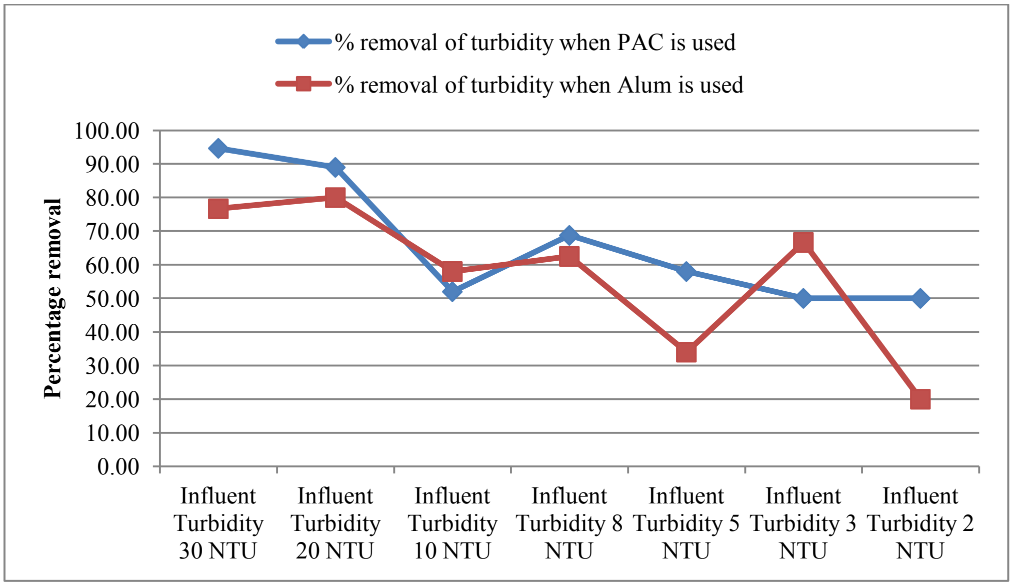
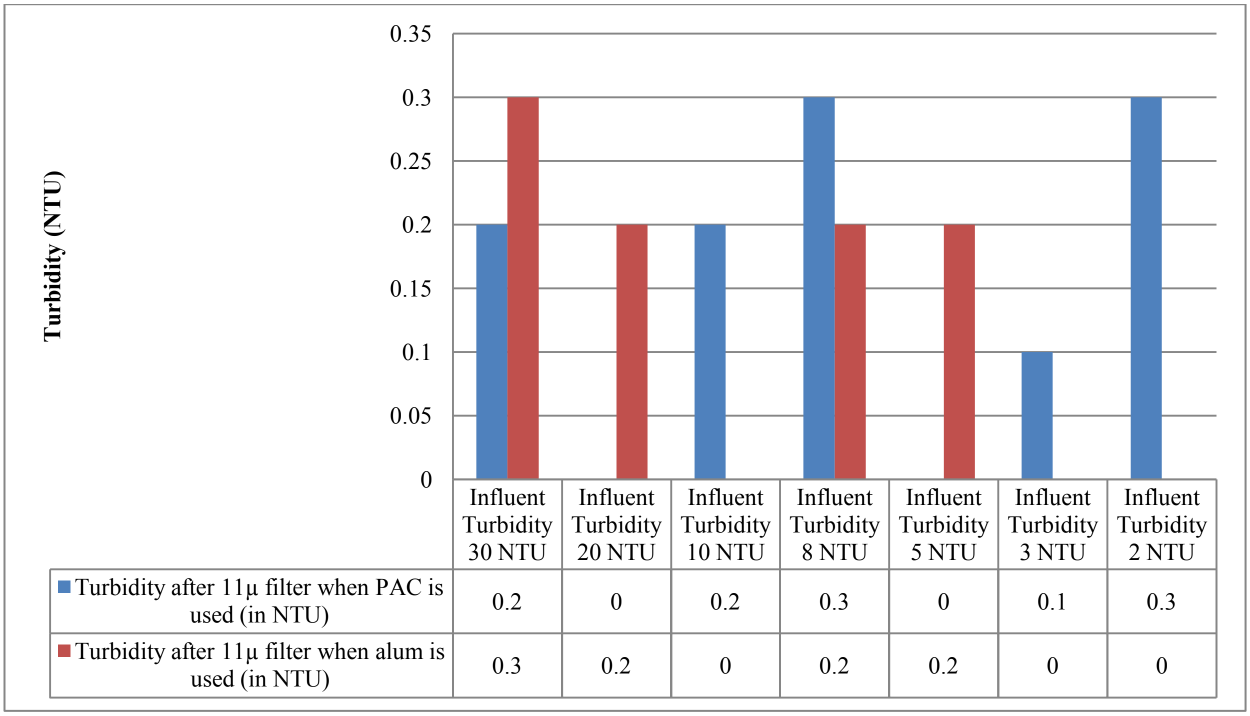


Figure 5.27: Comparison of percentage removal of turbidity by pilot plant

It should be noted that the turbidity level in the clarified water does not give the complete assessment about the performance of the plant. After clarification, the water passes through the filters, and depending upon the type of filter, particles above a range of size are trapped in the pores of the filter. After a good flocculation, some flocs may pass on to the clarified water but these will be removed easily if the floc size is large. Therefore particle size analysis was done on the mastersizer. To throw more light on the subject, comparison of turbidity levels after passing the clarified water through filters of pore-size11µ and 20µ is done.

It is evident from figure 5.28, that after passing through 11µ filter, water contains almost negligible turbidity (<0.35NTU) for all conditions. This also indicates superior performance of the Superpulsator® pilot plant due to its high rate solids contact resulting in large floc sizes.

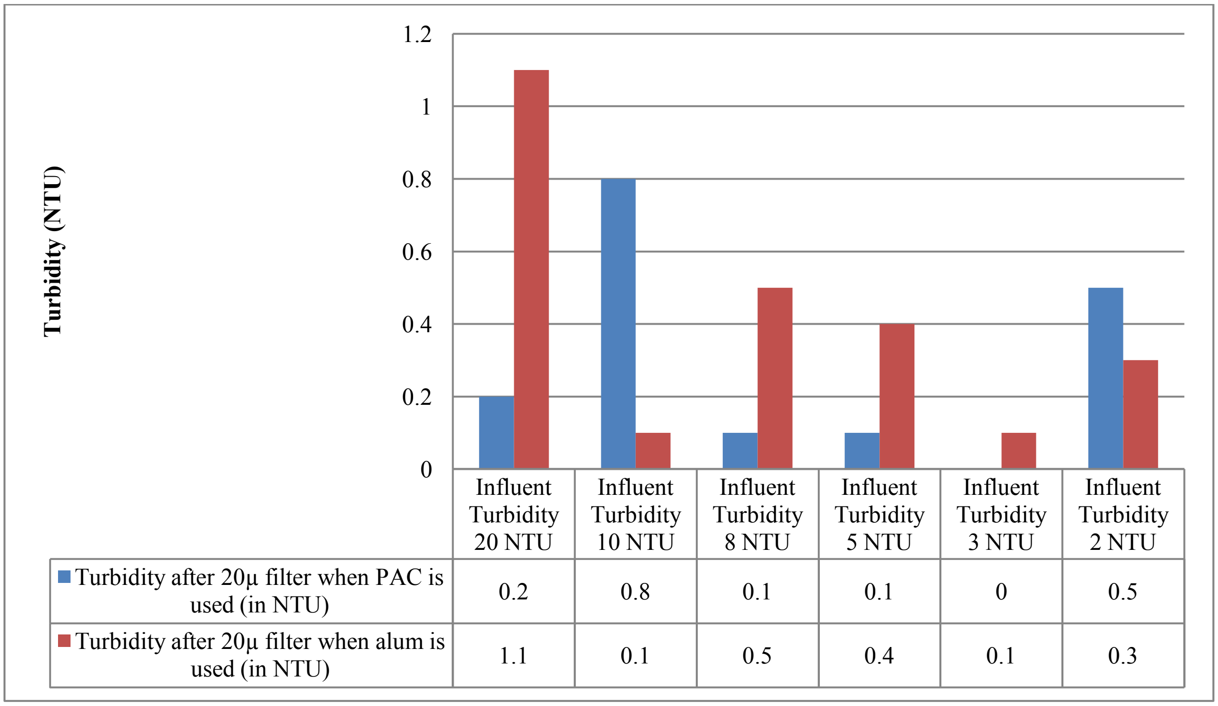


	Influent Turbidity 30 NTU	Influent Turbidity 20 NTU	Influent Turbidity 10 NTU	Influent Turbidity 8 NTU	Influent Turbidity 5 NTU	Influent Turbidity 3 NTU	Influent Turbidity 2 NTU
🟦 Turbidity after 11µ filter when PAC is used (in NTU)	0.2	0	0.2	0.3	0	0.1	0.3
🟥 Turbidity after 11µ filter when alum is used (in NTU)	0.3	0.2	0	0.2	0.2	0	0

Figure 5.28: Comparison of turbidity levels after filtration (pore size 11µ) for pilot plant

Aquazure - V® filters are used at Surajpura WTP, which are basically twin bed, constant rate rapid sand filters. Literature review was done to find the average pore size of these filters, but only grain sizes of the media were available, not the pore size. This may be because the filters are dynamic systems and the pore size may vary with the duration of operation, rate of filtration, frequency of backwashing and other operational factors. However it was found that, in general, *cryptosporidium parvum* passes through the rapid sand filters but not through slow sand filters. Since the average size of a fully developed *cryptosporidium parvum* is 20µ, therefore to estimate the efficiency of the rapid sand filter, filter papers of 20µ pore size were used.

Comparison of the turbidity levels in the filtered water obtained after passing the clarified water through filter paper of 20µ pore size is done in figure 5.29. Turbidity levels are below 1.2NTU for all cases. For influent turbidities of 8NTU, 5NTU and 3NTU, turbidity levels in filtered water are almost negligible at 0.1NTU, 0.1NTU and 0NTU respectively.



	Influent Turbidity 20 NTU	Influent Turbidity 10 NTU	Influent Turbidity 8 NTU	Influent Turbidity 5 NTU	Influent Turbidity 3 NTU	Influent Turbidity 2 NTU
🟦 Turbidity after 20µ filter when PAC is used (in NTU)	0.2	0.8	0.1	0.1	0	0.5
🟥 Turbidity after 20µ filter when alum is used (in NTU)	1.1	0.1	0.5	0.4	0.1	0.3

Figure 5.29: Comparison of turbidity levels after filtration (pore size 20µ) for pilot plant

The other most important part of the analysis was to analyse the residual aluminium levels in the water treated by the Superpulsator® pilot plant. The comparison of the reduction in the level of residual aluminium from the influx of the elemental aluminium when PAC and Alum are used as coagulants was done. Except for one anomalous point (influent turbidity is 20NTU), it is apparent from the figure 5.30, that much greater reduction in residual aluminium levels occurs when alum is used as coagulant as compared to PAC.

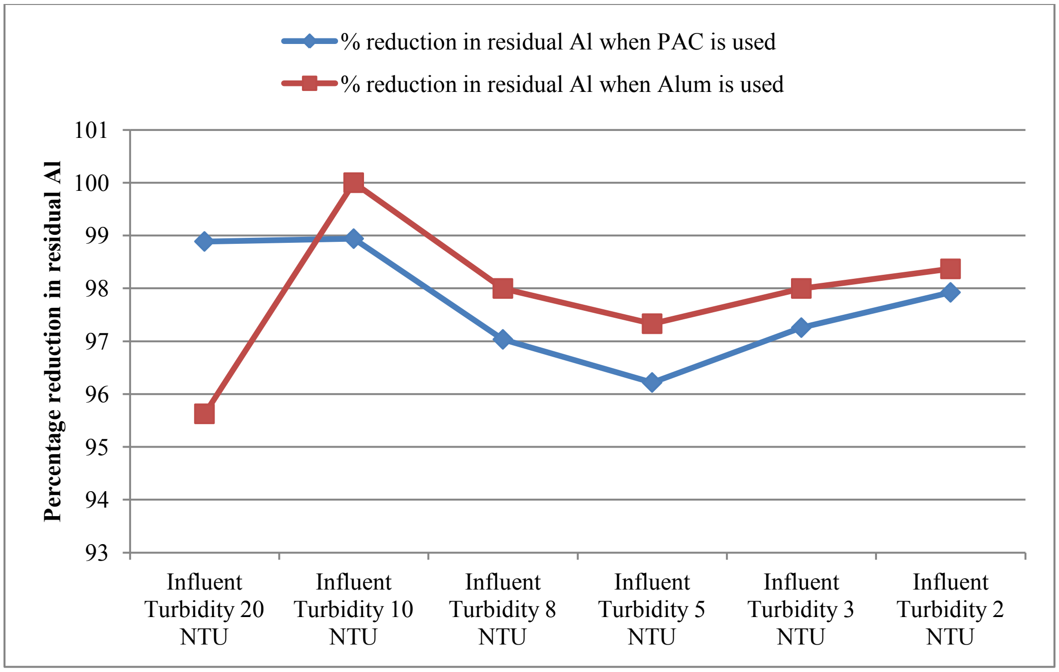
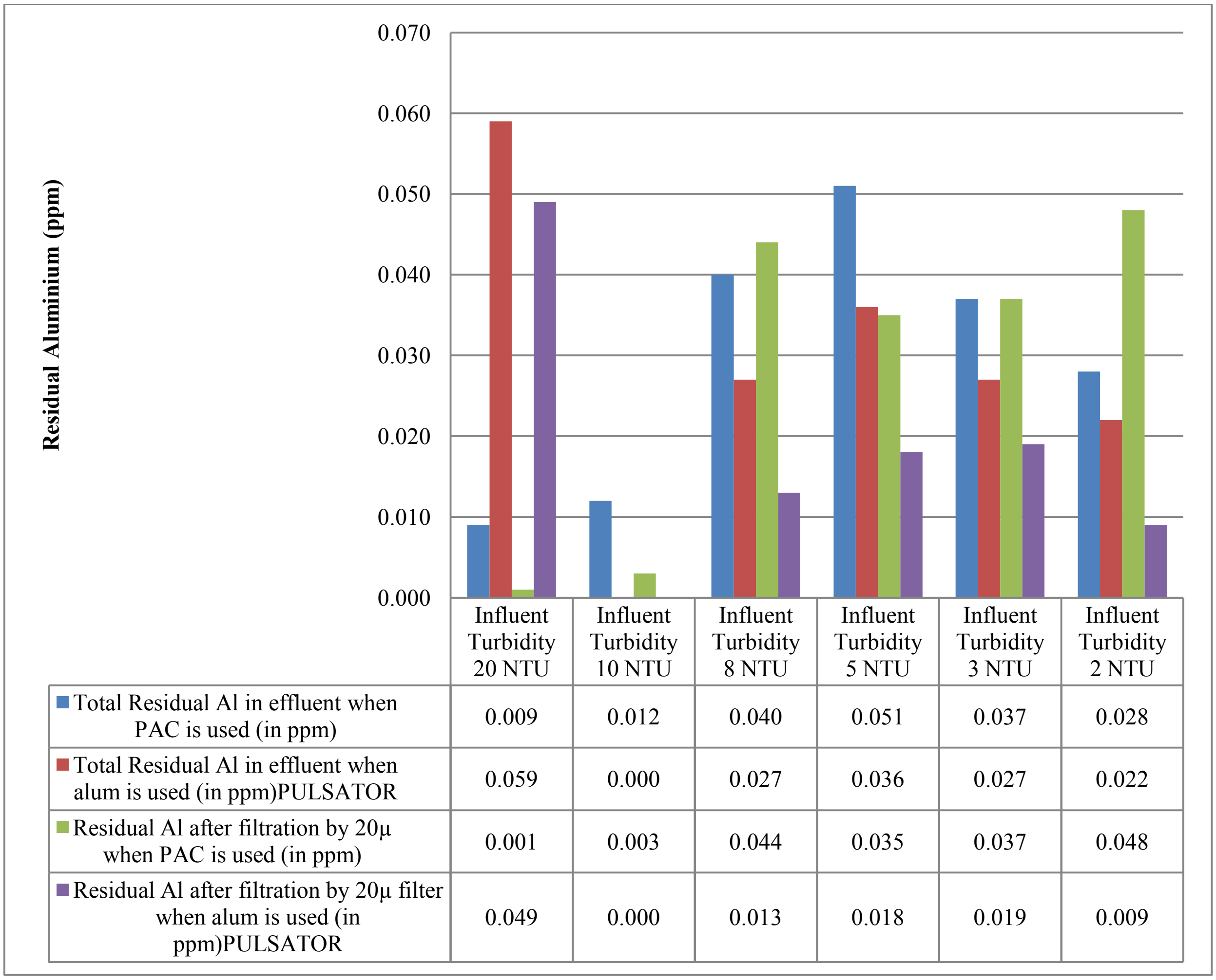


Figure 5.30: Comparison of percentage reduction in residual aluminium in clarified water from the influx for pilot plant

Comparison of residual aluminium levels in clarified water and filtered water (through 20µ pore size) when PAC and alum are used is shown in figure 5.31. Noticeable reduction in the level of residual aluminium occurs after filtration in both the cases. As discussed in previous chapter, there is no prescribed limit for residual Al, although from the WHO study, it is evident that residual Al levels below 100µg/L (0.1ppm) pose low risk for human health. Residual Al levels in clarified water as well filtered water from Superpulsator® pilot plant was below 60µg/L in all cases.

The dose of alum, maintained at 16.4ppm was perhaps optimum for minimizing the residual Al in case of pulsator pilot plant when influent turbidity is 10NTU since residual Al was absent in both clarified water and filtered water. Again the trend shows that lower residual Al levels are obtained in both clarified water and filtered water for alum compared to PAC except for high turbidity of 20NTU when negligible (only 0.001ppm) residual Al is read in the filtered water.



	Influent Turbidity 20 NTU	Influent Turbidity 10 NTU	Influent Turbidity 8 NTU	Influent Turbidity 5 NTU	Influent Turbidity 3 NTU	Influent Turbidity 2 NTU
🟦 Total Residual Al in effluent when PAC is used (in ppm)	0.009	0.012	0.040	0.051	0.037	0.028
🟥 Total Residual Al in effluent when alum is used (in ppm)PULSATOR	0.059	0.000	0.027	0.036	0.027	0.022
🟩 Residual Al after filtration by 20µ when PAC is used (in ppm)	0.001	0.003	0.044	0.035	0.037	0.048
🟪 Residual Al after filtration by 20µ filter when alum is used (in ppm)PULSATOR	0.049	0.000	0.013	0.018	0.019	0.009

Figure 5.31: Residual aluminium levels in clarified water and filtered water (through 20µ pore size) for pilot plant

Besides, a significant amount of Al may be present in the form of solid precipitates. The digestion of the sample for dissolving the precipitated forms of Al was done by lowering sample pH to 1 with the help of trace metal grade concentrated nitric acid and keeping it for 2 h before measurement. The residual Al concentration of digested clarified water for certain samples was done to estimate the precipitated Al content (fig. 5.32).

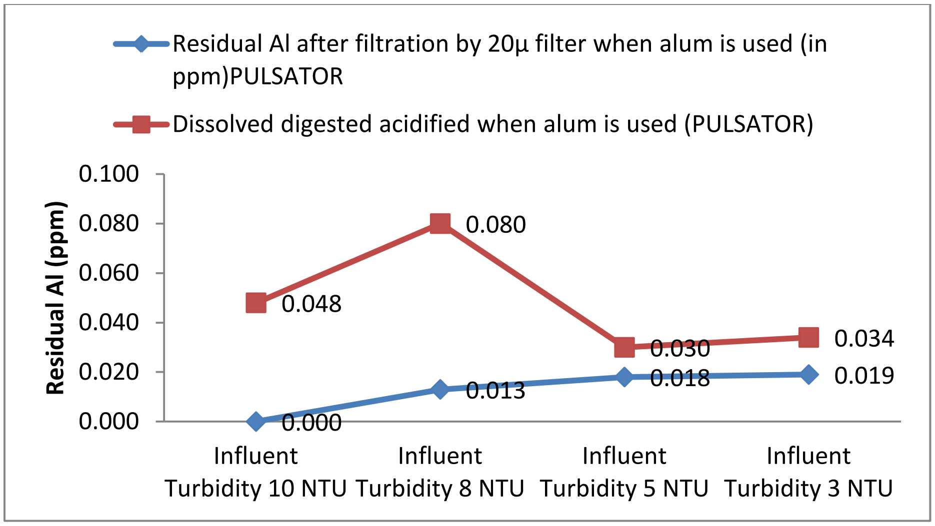


Figure 5.32: Residual aluminium levels in digested clarified water and filtered water (through 20µ pore size) when alum is used for pilot plant

5.4.3 Effect of coagulant on the performance of Conventional Clariflocculator

In this section, comparison of performance of conventional clariflocculator model is done when PAC and alum are used as coagulants. It should however be noted that at present the conventional clariflocculator did not have the circumferential weir and a piped circular exit was used as the outlet for clarified water. Therefore, the weir load was greatly increased and the flocs were sucked in as a result. Due to this the turbidity and hence the the residual aluminium as well are supposedly higher than actual.

First of all, turbidity levels in the clarified water from the conventional clariflocculator for different influent turbidities are compared for the two coagulants. From figure 5.33, it can be inferred that alum gives a better result when influent turbidity levels are below 10NTU. For influent turbidity 10NTU and 20NTU, PAC gives a better result compared to alum.

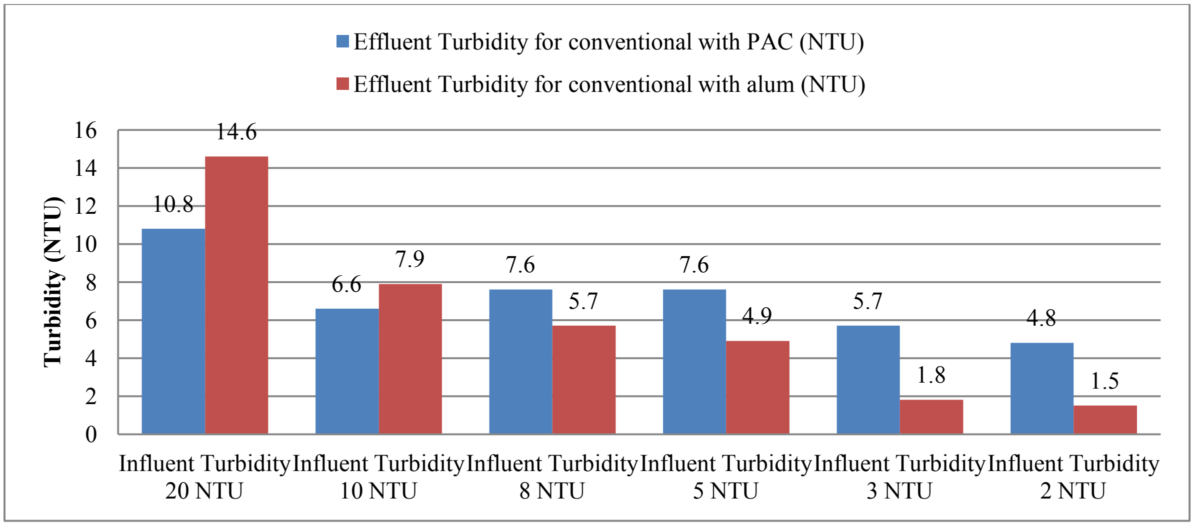
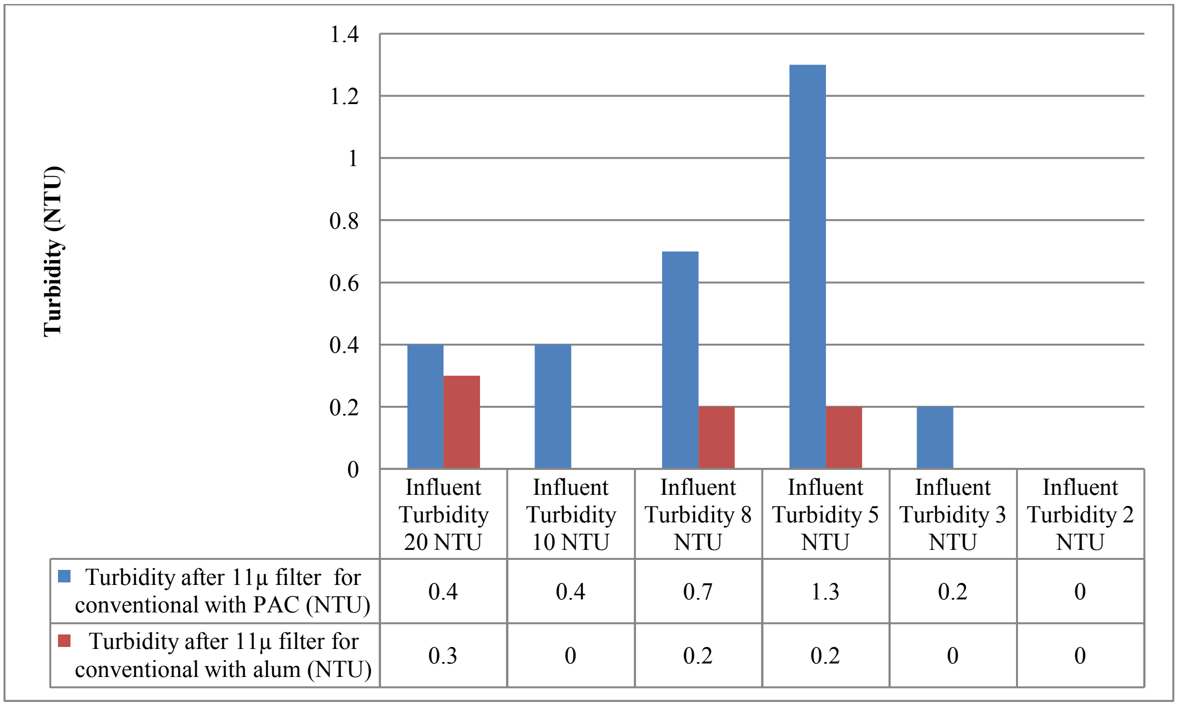


Figure 5.33: Comparison of turbidity levels of clarified water from conventional clariflocculator

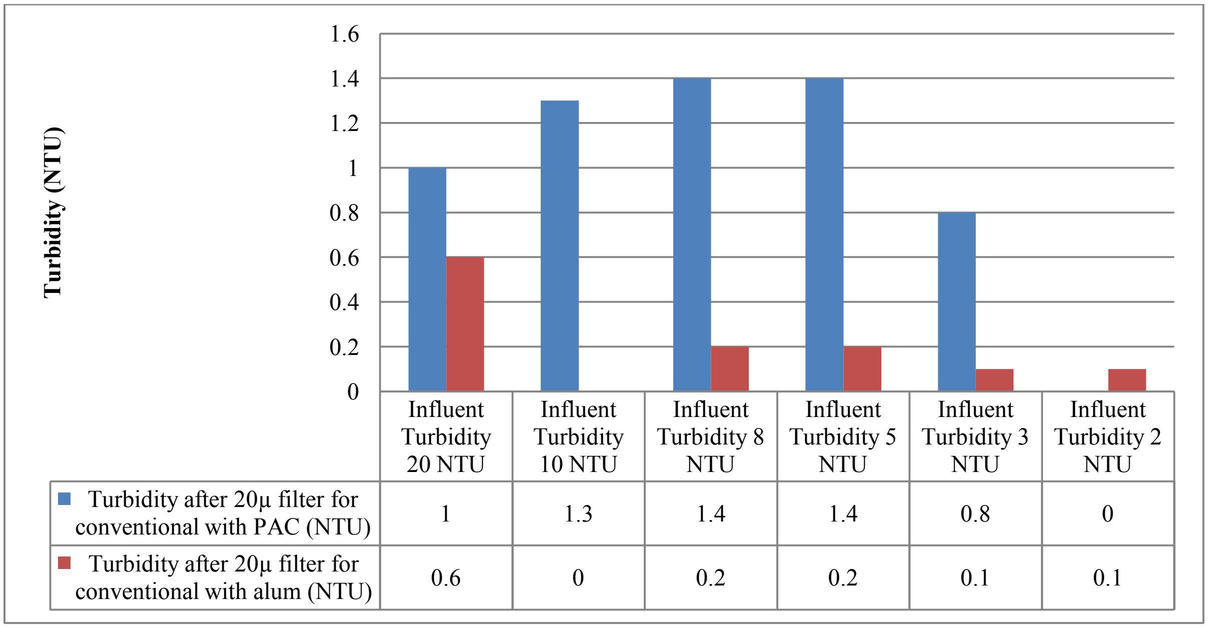
After clarification, water passes through filters. Comparative analysis of the turbidity of clarified water after passing through a filter of pore size 11µ is depicted in figure 5.34. It is apparent that alum performs better than PAC, since turbidity levels in the water filtered with a 11µ pore size filter paper are much lower in all cases with alum.



	Influent Turbidity 20 NTU	Influent Turbidity 10 NTU	Influent Turbidity 8 NTU	Influent Turbidity 5 NTU	Influent Turbidity 3 NTU	Influent Turbidity 2 NTU
🟦 Turbidity after 11µ filter for conventional with PAC (NTU)	0.4	0.4	0.7	1.3	0.2	0
🟥 Turbidity after 11µ filter for conventional with alum (NTU)	0.3	0	0.2	0.2	0	0

Figure 5.34: Comparison of turbidity levels after filtration (pore size 11µ) for conventional clariflocculator

Similarly, assessment of the turbidity levels was made after filtering the clarified water with 20µ filter paper. The above inference is once again validated from figure 5.35, where it can be observed that turbidity levels in the water passed through 20µ pore size filter paper are lower to a great extent in all cases when alum is used as coagulant as compared to PAC. Therefore, it can be safely assumed that better floc sizes are obtained in a conventional clariflocculator when alum is used as a coagulant.



	Influent Turbidity 20 NTU	Influent Turbidity 10 NTU	Influent Turbidity 8 NTU	Influent Turbidity 5 NTU	Influent Turbidity 3 NTU	Influent Turbidity 2 NTU
🟦 Turbidity after 20µ filter for conventional with PAC (NTU)	1	1.3	1.4	1.4	0.8	0
🟥 Turbidity after 20µ filter for conventional with alum (NTU)	0.6	0	0.2	0.2	0.1	0.1

Figure 5.35: Comparison of turbidity levels after filtration (pore size 20µ) for conventional clariflocculator

Comparison of the percentage reduction in the level of residual aluminium from the influx of the elemental aluminium when PAC and Alum are used as coagulants is shown in figure 5.36. Significant reduction (more than 95%) in the level of residual Al occurs with conventional clariflocculator for both coagulants, but clearly higher reduction is observed when PAC is used.

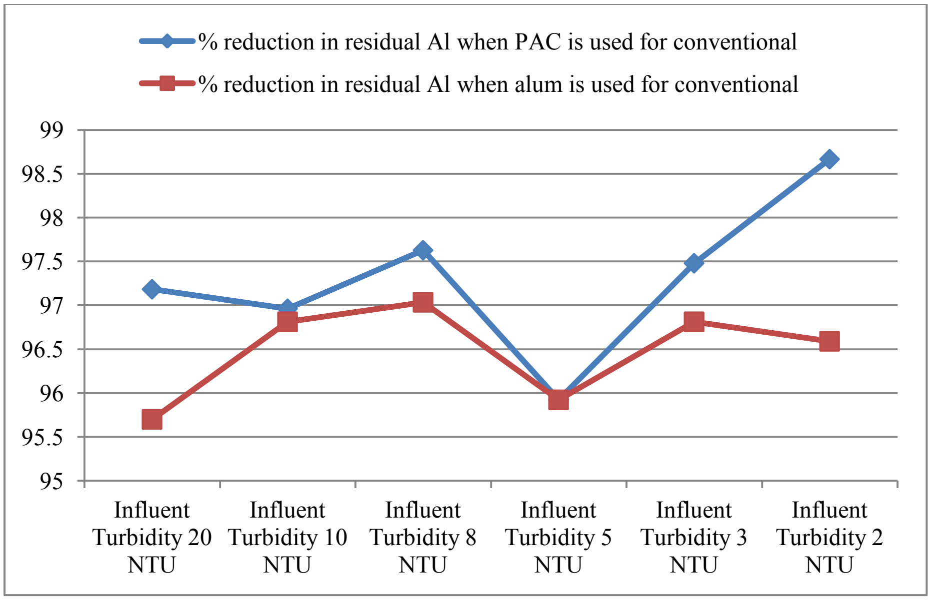
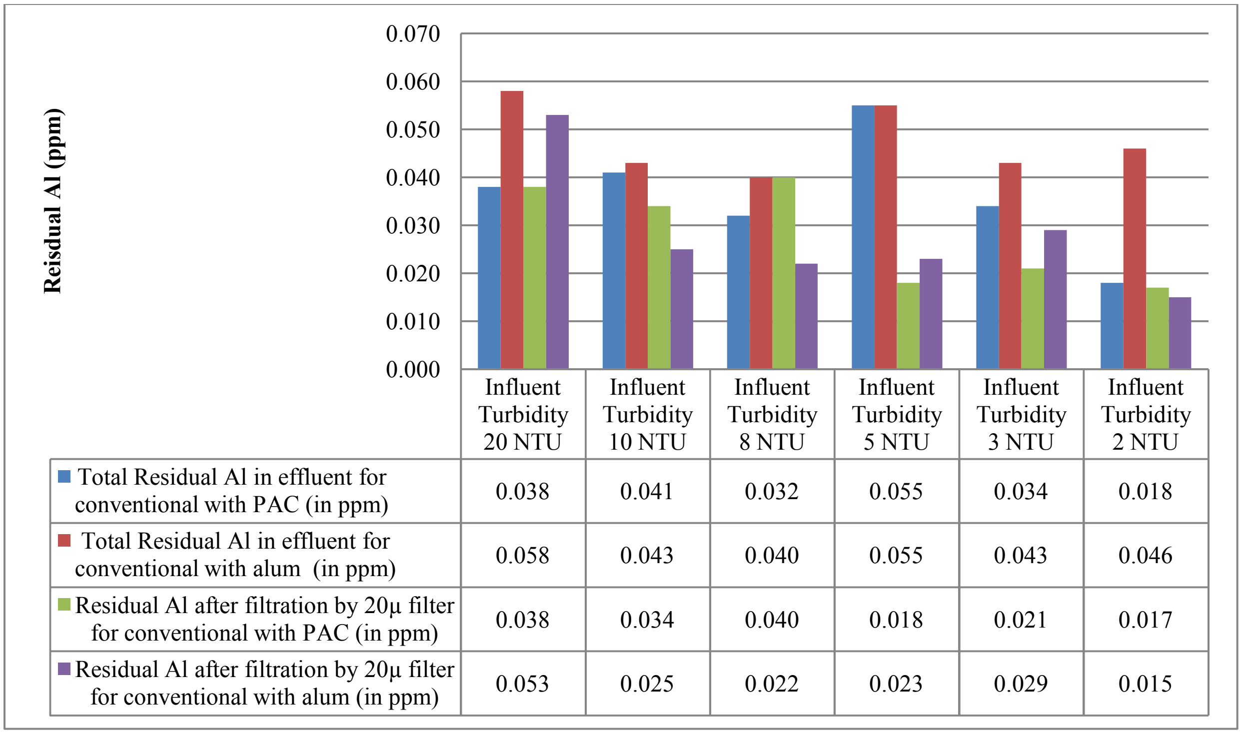


Figure 5.36: Comparison of percentage reduction in residual aluminium in clarified water from the influx for conventional clariflocculator

Comparison of residual aluminium levels in clarified water and filtered water (through 20µ pore size) when PAC and alum are used is shown in figure 5.37. In general, there is a reduction in the level of residual aluminium occurs after filtration in both the cases. In the case of conventional clariflocculator also, the levels of residual aluminium are lower than 0.060ppm, which is well below 100µg/L.

It is evident from the graph that lower aluminium levels are obtained in clarified water and filtered water when PAC is used as coagulant as compared to alum. Another important point which can be noticed is that although there is significant reduction, but still some amount of Al does remain as residual in case of conventional clariflocculator, while in case of pulsator pilot absence and near absence of residual Al was observed.



	Influent Turbidity 20 NTU	Influent Turbidity 10 NTU	Influent Turbidity 8 NTU	Influent Turbidity 5 NTU	Influent Turbidity 3 NTU	Influent Turbidity 2 NTU
🟦 Total Residual Al in effluent for conventional with PAC (in ppm)	0.038	0.041	0.032	0.055	0.034	0.018
🟥 Total Residual Al in effluent for conventional with alum (in ppm)	0.058	0.043	0.040	0.055	0.043	0.046
🟩 Residual Al after filtration by 20μ filter for conventional with PAC (in ppm)	0.038	0.034	0.040	0.018	0.021	0.017
🟪 Residual Al after filtration by 20μ filter for conventional with alum (in ppm)	0.053	0.025	0.022	0.023	0.029	0.015

Figure 5.37: Residual aluminium levels in clarified water and filtered water (through 20μ pore size) for conventional clariflocculator

The digestion of samples of clarified water was done for dissolving the solid precipitated forms of Al, and the corresponding residual Al content was measured (fig. 5.38). It may be inferred that as residual Al level in filtered water increases, the content in digested water decreases and vice-versa.

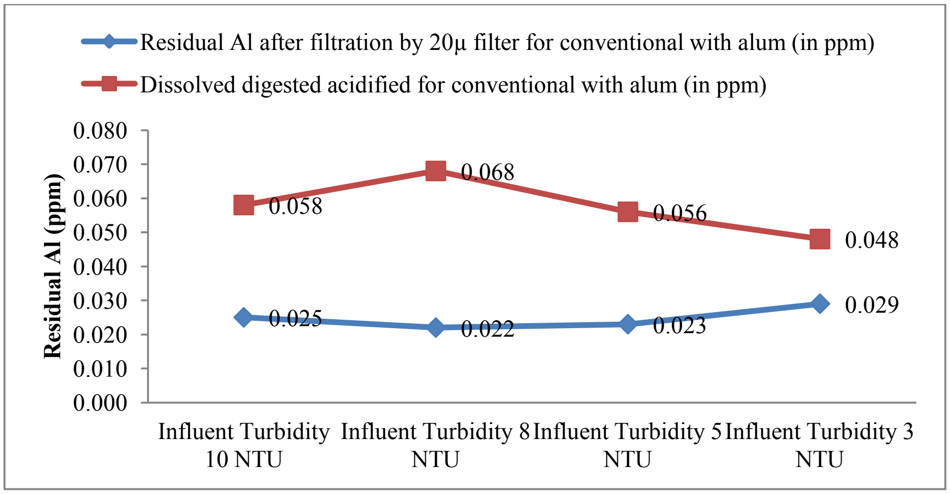


Figure 5.38: Residual aluminium levels in digested clarified water and filtered water (through 20μ pore size) when alum is used for conventional clariflocculator

Chapter 6. Conclusions and future scope

Effort was devoted toward conceptualization and design of the pilot plant based on Superpulsator® clarifier. Fabrication, assembly and installation of both pilot plant and conventional clariflocculator was done meticulously to ensure continuous treatment of about 8000L each of water per day. Performance of the two models was evaluated and compared when PAC and alum are used as coagulants. Various tests were also conducted on the actual water samples from Bisalpur for assessing the conditions of Surajpura WTP.

6.1 Conclusions

Following conclusions can be drawn from the study:

- From the jar tests on raw water of Bisalpur, it was observed that low turbidity in supernatant was obtained for PAC dose of 25ppm (turbidity reading of 0.1NTU) while it declined to nil for a dose of 35ppm. In case of residual aluminium, lower levels were obtained for PAC at low doses in general, while for doses (in excess of 30ppm), lower residual Al was obtained in the supernatant for alum. A trend of reduction in pH with increase in dose for both the coagulants was observed, however the dip in pH was greater for alum. The trend in pH was explained and verified by the graph of alkalinity.
- Break point chlorination curve confirms the presence of ammoniacal compounds in the raw water. Further, the breakpoint occurs at about 5.5ppm after which the curve rises. Therefore, the current practice of pre-chlorination of 4.25ppm to 4.5ppm and post-chlorination of 1ppm at Surajpura is optimised for chlorine dosage.
- The results of zetapotential analysis of raw water at the inlet of the parshall flume of Surajpura WTP show that the colloidal particles have a significant net negative charge of -12.7mV. Simulation of Surajpura plant conditions at parshall flume was done by Jar tests and then the samples were tested, along with a sonicated duplicate set. Zetapotential of the unsonicated before jump sample just exceeds +5mV and the value for unsonicated after jump sample is even higher (8.41mV). Clearly a charge reversal occurs and this indicates that the delivered coagulant dose of 25ppm PAC might be slightly in excess.

Whereas, the corresponding values for unsonicated samples are lower and fall within -5mV to 1mV range, which is just right.

- Similarly by simulation, assessment of the particle size was made for the flocs formed after addition of chlorine and PAC in the parshall flume, and their fate at the inlet to the Superpulsator®, that is after the hydraulic jump. Adequate floc development had taken place, as indicated by the sizes. There was a clear indication of breakage of flocs due to hydraulic jump but with higher detention time floc sizes increase again.
- Particle size analysis was carried out on Malvern® Mastersizer 2000™, which has an upper limit of 1000µm and least count of 0.1µm, for water samples clarified by the pilot plant. The D_{90} value for particle size of flocs, as large as 914.497µm was obtained. It is evident that coagulation and flocculation occur properly which result in sufficiently large floc sizes and thus adequate formation of sludge blanket for high solids contact.
- From comparison of the pilot plant's performance for coagulants PAC and alum, it can be inferred that turbidity removal levels by clarification are high and somewhat similar for the two coagulants. Moreover, generalization is difficult as the effluent quality of the Superpulsator® pilot plant depends on the sludge blanket dynamics, depth of the blanket, stabilization time and a number of other factors. The turbidity levels in the filtered water obtained after passing the clarified water through filter papers of 11µ and 20µ pore size are below 0.35NTU and1.2NTU respectively for both coagulants. Turbidity in filtered water is even absent in some cases with PAC as well as alum, which also indicates high performance of the Superpulsator® pilot plant due to its high rate solids contact resulting in large floc sizes.
- The comparison of the reduction in the level of residual aluminium from the influx of the elemental aluminium when PAC and Alum are used as coagulants in the pulsator pilot plant shows that much greater reduction in residual aluminium levels occurs when alum is used as compared to PAC.
- Comparison of turbidity levels in the clarified water from the conventional clariflocculator for different influent turbidities indicates that alum gives a better result when influent turbidity levels are below 10NTU. For influent turbidity 10NTU and 20NTU, PAC gives a greater turbidity removal as compared to alum. Further assessment of the turbidity levels was made after filtering the clarified water with 11µ and 20µ filter

paper, and it was observed that turbidity levels in the filtered water are lower to a great extent in all cases when alum is used as coagulant as compared to PAC. Therefore, it can be safely assumed that better floc sizes are obtained in a conventional clariflocculator when alum is used as a coagulant.

- Significant reduction (more than 95%) in the level of residual Al occurs with conventional clariflocculator for both coagulants. Comparison of the percentage reduction in the level of residual aluminium from the influx of the elemental aluminium when PAC and alum are used as coagulants clearly indicates higher reduction when PAC is used. In the filtered water (clarified water passed through 20µ filter paper) also lower aluminium levels were obtained for most points when PAC was used as coagulant as compared to alum.
- Residual Al levels in clarified water and filtered water from Superpulsator® pilot plant as well as conventional clariflocculator was below 60µg/L for both alum and PAC in all cases. It was noticed that although significant reduction occurs, but still some amount of Al does remain as residual in case of conventional clariflocculator, whereas in case of Superpulsator® pilot plant, near and complete absence of residual Al was observed in many cases.
- PAC contains a high cation (aluminium) to anion (chloride or sulphate) ratio, and thus it produces significantly less sludge than would alum. In other words, alum produces more sludge and thus would give a better formation of sludge blanket in Superpulsator® pilot plant, even more so because high solids contact zone exists at the bottom of the column. This was validated by much lower residual aluminium levels when alum was used as compared to PAC in pilot plant.

6.2 Future scope

The study can be further extended on the lines of some of the following suggestions-

1. Detailed comparative analysis of Superpulsator® pilot plant vis-à-vis conventional clariflocculator or other technologies can be done on the reduction of residual aluminium with special consideration towards Al speciation.

2. Use of polyamine or polyDADMAC type polyelectrolytes in conjunction with alum (lower cation to anion ratio produces more sludge) in the Superpulsator® pilot plant, since the high detention time may perhaps lead to better properties of sludge blanket. Investigation of other coagulants, blends and doses for effect on the performance may also be studied.
3. The solenoid valve actuated pulse can be varied in terms of 'on' duration and 'off' duration for frequency and pipeline valves can be adjusted to vary the strength, in order to obtain homogeneous sludge blanket for different influent conditions and this will be crucial for the optimization of the operation of the Superpulsator® pilot plant.
4. The Superpulsator® pilot plant can be studied to develop customized integrated systems for processes like defluoridation.
5. Computational fluid dynamics can be employed for modelling the working of Superpulsators® to explain the rationales behind the behavior and functioning of these units.

References

- Bureau of Indian Standards (BIS), 2009. Drinking water – specification (second revision of IS 10500), Section: Drinking Water (FAD 25), Food and Agriculture Division, Bureau of Indian Standards (BIS), 2009. Link: http://bis.org.in/sf/fad/FAD25(2047)C.pdf
- Carlson, K. H., Champlin, T. L., Hendricks, D. W., Sullivan, L. P., Walters, R. W. and Zibell, T. G., 1993. Treatment train modeling for aqueous contaminants, Vol. I Summary Report, Environmental Engineering Technical Report No. 53-2415-93-1, Department of Civil Engineering, Colorado State University, Fort Collins, Dec. 1993
- Central Pollution and Control Board (CPCB), 2010. Status of water treatment plants in India, Ministry Of Environment And Forests.
- Chowdhury Z. K., Amy G. L. and Bales R. C., 1991. Coagulation of submicron colloids in water treatment by incorporation into aluminium hydroxide flocs. Environ. Sci. Technol. 25, 1766-1773
- Clayton D. B., 1989. Water pollution at Lowermoore North Cornwall: Report of the Lowermoore incident health advisory committee. Truro, Cornwall District Health Authority, 22 pp.
- Colomina M. T. et al., 1994. Lack of maternal and developmental toxicity in mice given high doses of aluminium hydroxide and ascorbic acid during gestation. Pharmacology and toxicology, 74:236-239.
- Connor D. J., Jope R. S. and Harrell L. E., 1988. Chronic, oral aluminum administration to rats: cognition and cholinergic parameters. Pharmacology, biochemistry, and behaviour, 31:467-474.
- Domingo J. L. et al., 1987. Nutritional and toxicological effects of short-term ingestion of aluminum by the rat. Research communications in chemical pathology and pharmacology, 56:409-419.
- Edzwald, J. K., Haff, J. D. and Boak, J. W., 1977. Polymer coagulation of humic acid water, J. Environ. Eng. Div., American Society of Civil Engineers, 103(EE6):989-1000.
- Exall, K. N. and Vanloon, G. W., 2000. Using coagulants to remove organic matter, J. Am. Water Works Assoc., 92(12):93-102
- Flaten T. P., 1990. Geographical associations between aluminium in drinking water and death rates with dementia (including Alzheimer's disease), Parkinson's disease and

amyotrophic lateral sclerosis in Norway. Environmental geochemistry and health, 12:152-167.

- Fox, K. R. and Lytle, D. A., 1996. Zeta potential and particle counting for optimizing pathogen removal, Proceedings, AWWA National Conference at Toronto, American Water Works Association, Denver, June, 1996
- George, S., Pandit, P. and Gupta, A.B., 2010. Residual aluminium in water defluoridated using activated alumina adsorption – Modeling and simulation studies, Water Research, Volume 44, Issue 10, May 2010, Pages 3055-3064, doi:10.1016/j.watres.2010.02.028
- Gomez M. et al., 1990. Evaluation of the maternal and developmental toxicity of aluminum from high doses of aluminum hydroxide in rats. Veterinary and human toxicology, 32:545-548.
- Gregor J. E., Nokes C. J. and Fenton E., 1997. Optimising natural organic matter removal from low turbidity waters by controlled pH adjustment of aluminium coagulation. Wat. Res. Vol. 31, No. 12, pp. 2949-2958
- Kathpalia G. N. and Kapoor R., 2002. Water Policy and Action Plan for India 2020: An Alternative, Planning Commission, Government of India.
- Kawamura S., 1973. Coagulation considerations. J. AWWA 65, 417-423
- Khezri S. M., Dadvar E. and Shekarabi H. H., 2012. A study of the Suction Height Effect on Turbidity Removal Efficiency of Water in Pulsator, Global Journal of Researches in Engineering, General Engineering, Vol. 12, Issue 2, (May 2012), ISSN: 2249-4956
- Langelier, W. F. and Ludwig, H. F., 1949. Mechanism of flocculation in the clarification of turbid waters, J. Am. Water Works Assoc., 41(2):163-181
- Leckie, J. O. and James, R. O., 1974. Control mechanism for trace metals in natural waters, in Aqueous Environmental Chemistry of Metals, Rubin, A. J., Ed., Ann Arbor Science Publishers, Ann Arbor, MI
- Neri L. C. and Hewitt D., 1991. Aluminium, Alzheimer's disease, and drinking water. Lancet, 338:390.
- Ongerth, J., 1996. Electrophoteric mobility of Cryptospoidium oocysts and Giardia cysts, J. Env. Eng. Div., ASCE, 122(3):228-231
- Packham, R. F., 1962. The coagulation process II; Effect of pH on the precipitation of aluminium hydroxide, J. Appl. Chem., 12:564-568.

- Pernitsky, D. J. and Edzwald, J. K., 2000. Polyaluminium chloride – chemistry and selection, Proceedings of 2000 Annual Conference at Denver (CDROM), American Water Works Association, Denver.
- Su, S.T., Wu, R.M. and Lee, D.J., 2004. Blanket dynamics in upflow suspended bed, Water Research, Volume 38, Issue 1, January 2004, Pages 89-96, doi:10.1016/j.watres.2003.09.002
- Weber, W. J., Hopkins, C. B. and Bloom, R., Jr., 1970. Physiological treatment of wastewater. J. Water Pollution Control Fed., 42(1):83-99
- World Health Organization (WHO), 1998. Aluminium in Drinking-water; Guidelines for drinking-water quality, 2nd ed. Addendum to Vol. 2. Health criteria and other supporting information. World Health Organization, Geneva.
- Wu X., Ge X., Wang D. and Tang H., 2007. Distinct coagulation mechanism and model between alum and high Al13-PACl. Colloids and Surfaces A; Physicochem. Eng. Aspects 305, 89-96
- Yen-Koo H. C., The effect of aluminum on conditioned avoidance response (CAR) in mice. Toxicology and industrial health, 8:1-7. (1992)

Appendix 1

Schematic plan and dimensions of the designed Superpulsator® pilot plant and vertical flow conventional clariflocculator are given below-

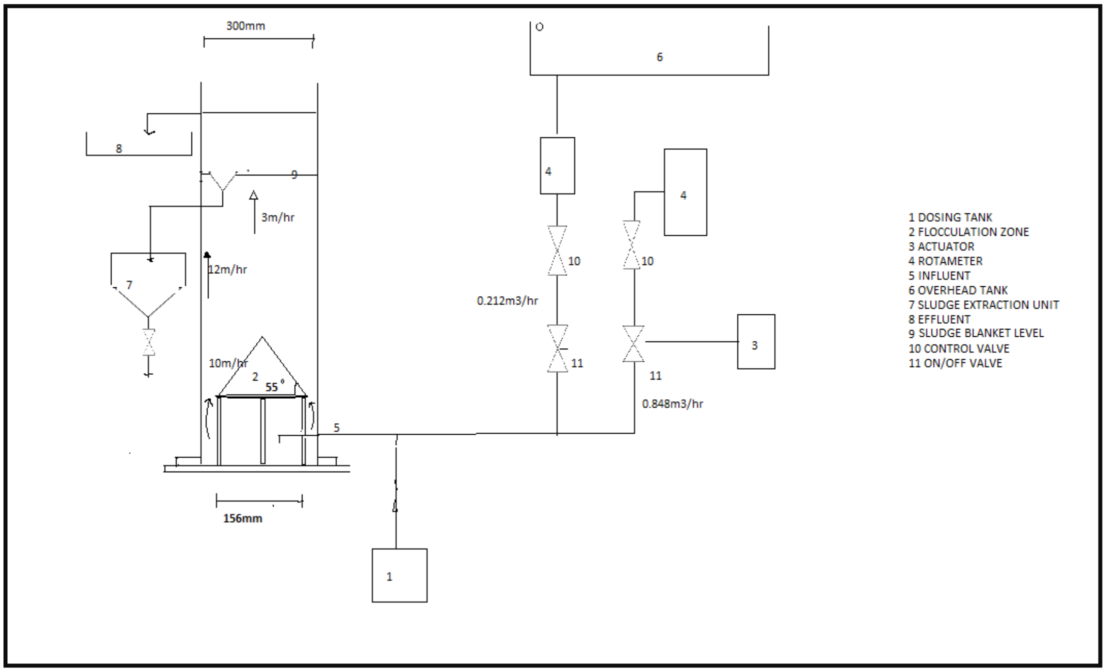


Figure: Schematic diagram of Pulsator pilot model

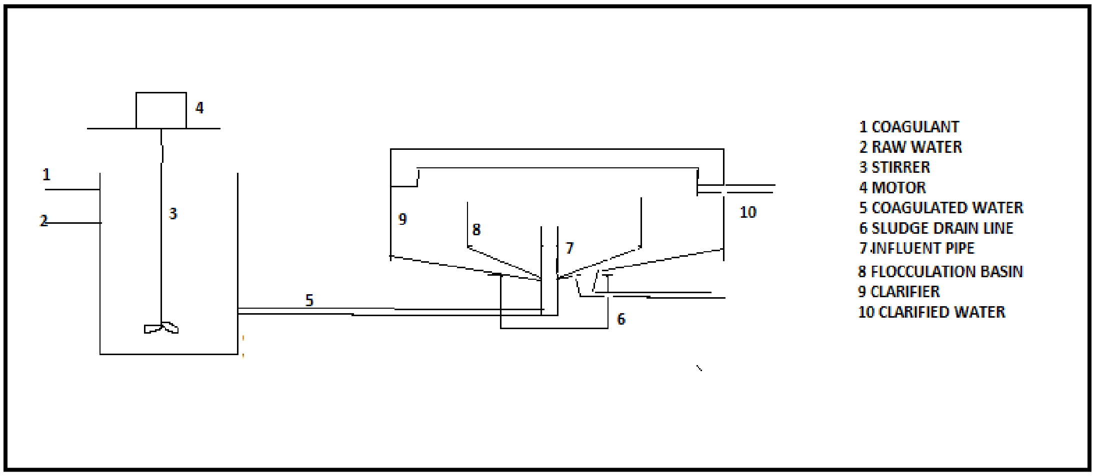


Figure: Schematic diagram of Conventional clariflocculator

Appendix 2

Test for Aluminium (Al)
Method: Eriochrome Cyanine R Spectrophotometric
ID:1.30 Version:2

Apparatus

a. Spectrophotometer: For use at 535ηm with light path of 1 cm or longer. (fig. 0.1)

b. Glassware: Treat all glassware with 1 + 1 warm HCl and rinse with aluminium free distilled water.

Reagents

a. Stock aluminium solution: Dissolve 8.791 g aluminium potassium sulphate, AlK(SO4)2.12H2O, in water and dilute to 1 L.

b. Standard aluminium solution: Dilute 10 mL stock aluminium solution to 1000 mL with distilled water; 1.00 mL = 5.00 µg Al. Prepare daily.

c. Sulphuric acid, H2SO4, 0.02 *N* and 6 *N*.

d. Ascorbic acid solution: Dissolve 0.1 g ascorbic acid in water and make up to 100 mL in a volumetric flask. Prepare fresh daily.

e. Buffer reagent: Dissolve 136 g sodium acetate, NaC2H3O2.3H2O, in water, add 40 mL 1*N* acetic acid and dilute to 1 L.

f. Stock dye solution: Stock solutions can be kept for about one year. Use any of the following products:

− Solochrome cyanine R-200 (Arnold Hoffman & Co., Providence, R.I.) or Eriochrome cyanine (K & K Laboratories, K & K lab. Div., Life Sciences Group, Plainview, N. Y.) Dissolve 100 mg in water and dilute to 100 mL in a volumetric flask. This solution should have a pH of about 2.9.

− Eriochrome cyanine R (Pfaltz & Bauer, Inc., Stamford, Conn.) Dissolve 300 mg dye in about 50 mL water. Adjust pH from about 9 to about 2.9 with 1 + 1 acetic acid (approximately 3 mL will be required). Dilute with water to 100 mL.

− Eriochrome cyanine R (EM Science, Gibbstown, N.J.) Dissolve 150 mg dye in about 50 mL water. Adjust pH from about 9 to about 2.9 with 1 + 1 acetic acid (approximately 2 mL will be required). Dilute with water to 100 mL.

g. Working dye solution: Dilute 10.0 mL of stock dye solution to 100 mL in a volumetric flask with water. Stable for at least 6 months.

h. Bromcresol green indicator, pH 4.5, solution: Dissolve 100 mg bromcresol green, sodium salt, in 100 mL distilled water.

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

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

Procedure

a. Prepare standards between 0 to 7 µg by taking 0,1.0, 3.0, 5.0 and 7.0 mL standard aluminium solution in 50 mL volumetric flasks and adding water to a total volume of 25 mL

b. Add 1 mL 0.02 *N* H_2SO_4 to each standard and mix. Add 1mL ascorbic acid solution and mix. Add 10 mL buffer solution and mix. With a volumetric pipette add 5.00 mL working dye reagent and mix. Immediately make up to 50 mL with distilled water, mix and let stand for 5 to 10 minutes.

c. Read absorbance at 535 nm within 15 min of addition of dye, adjusting instrument to zero absorbance with the standard containing no aluminium. Plot the calibration curve between absorbance and aluminium concentration.

d. Place 25 mL sample, or an aliquot diluted to 25 mL, in a flask, add a few drops of bromcresol green and titrate with 0.02 N H_2SO_4 to yellowish end point. Record reading and discard sample.

e. To two similar samples add the same amount of acid used in the titration and add 1 mL in excess.

f. To one sample add 1 mL EDTA to complex any aluminium present. This will serve as blank. To both samples add 1 mL ascorbic acid, 10 mL buffer reagent, 5 mL working dye reagent, make up to 50 mL and read absorbance as in *c* above. (fig. 0.2)

Calculation

Read aluminium concentration in the sample against its absorbance value from the calibration curve.

Note

An underestimation of the aluminium concentration between 10 and 50% occurs when this method is applied on samples that contain fluoride in the range of 0.4 and 1.5 mg/L.

Appendix 3

CD-ROM contains

1. Results of zetapotential analysis on Malvern® Zetasizer
2. Results of particle size analysis on Malvern® Zetasizer
3. Results of particle size analysis on Malvern's® Mastersizer 2000™
4. Video showing the working of Superpulsator® pilot plant.

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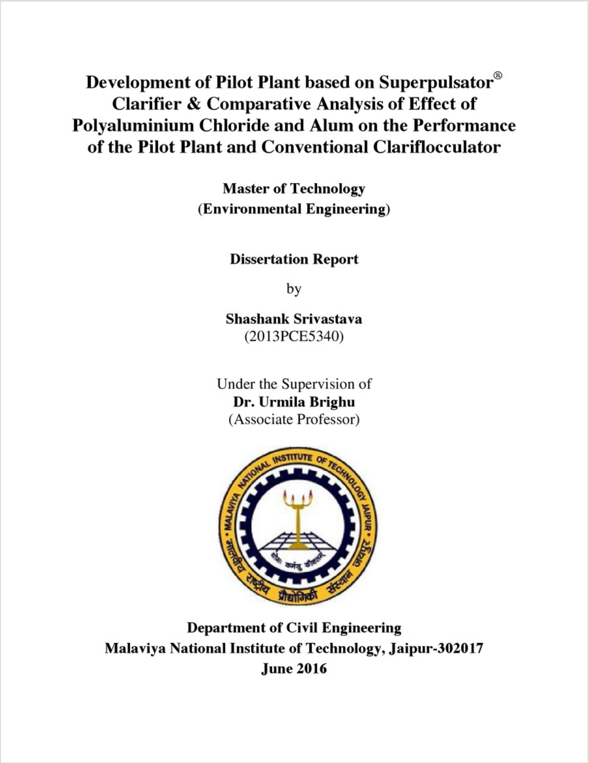

Development of Pilot Plant based on Superpulsator® Clarifier & Comparative Analysis of Effect of Polyaluminium Chloride and Alum on the Performance of the Pilot Plant and Conventional Clariflocculator

Master of Technology
(Environmental Engineering)

Dissertation Report

by

Shashank Srivastava
(2013PCE5340)

Under the Supervision of
Dr. Urmila Brighu
(Associate Professor)

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Malaviya National Institute of Technology, Jaipur-302017
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