Performance Analysis of Surajpura Water Treatment Plant of Bisalpur Jaipur Water Supply Project and Cost Optimization Study using a Pulsator Clarifier Pilot Plant

A

Dissertation Report

Submitted by

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(2014PCE5268)

(in the partial fulfillment of the requirements for the award of the degree of)

Master of Technology
(Environmental Engineering)

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

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CERTIFICATE

I hereby certify that the work which is being presented in the dissertation report entitled "**Performance Analysis of Surajpura Water Traetment Plant of Bisalpur Jaipur Water Supply Project and Cost Optimization Study using a Pulsator Clarifier Pilot Plant"** in the partial fulfillment of the requirements for the award of the **Degree of M. Tech. (Environmental Engineering)** and submitted in the **Department of Civil Engineering** of the 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 have not been submitted for the award of any other degree of this or any other institute. It is further certified that this thesis has been evaluated using **Turnitin Originality Check** system and based on **Turnitin** report it is certified that the references in the thesis are in accordance with good scientific practice.

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Date: June, 2016

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LIST OF ABBREVIATIONS

1. WTP: Water Treatment Plant
2. BJWSP: Bisalpur Jaipur Water Supply Project
3. RUIDP: Rajasthan Urban Infrastructure Development Project
4. PHED: Public Health Engineering Department
5. O&M: Operation & Maintenance
6. L&T: Larsen & Toubro Ltd.
7. PAC: Poly Aluminium Chloride
8. MLD: Million Litres per Day
9. BCM: Billion Cubic Meters
10. TDS: Total Dissolved Solids
11. CPCB: Central Pollution Control Board
12. Lab: Laboratory
13. mL: Millilitres
14. mm: Millimetres
15. MNIT: Malaviya National Institute of Technology
16. MRC: Material Research Centre, MNIT, Jaipur

ABSTRACT

Potable water is a precious commodity and its production with least possible cost is of paramount significance. Thus, there is a need to study the operational status of water treatment plants for ensuring their performance and cost optimization. With this objective, the largest WTP of Rajasthan at Surajpura of 600 MLD capacity to be expanded to 1020 MLD over next few years and presently catering to Bisalpur-Jaipur Water Supply Project (BJWSP) was studied. This WTP is a state-of-the-art plant, only one in Rajasthan, and among the select few in India, based on the relatively lesser known and little unconventional (in Indian perspective) Pulsed sludge blanket technology. Successful fabrication and operation of a Pulsator Clarifier Pilot Plant in Perspex sheet designed in consultation with Degremont Limited for a capacity of about 8000 liters per day and based on the Infilco Degrémont's Superpulsator® technology was also carried out at the Malaviya National Institute of Technology, Jaipur in order to better understand the process of sludge blanket formation through visual display and to carry out experiments on the fabricated model to find out the economic dosage of chemicals for cost minimization.

The water quality parameters at different stages of water treatment were analysed during the plant visits as well as over three seasons that included post-monsoon period (October 2015), winters (January 2016) and summers (April 2016) for a substantial period of five days in a row, every season. The analysis indicated that the Surajpura WTP is performing well and all the water quality parameters are well within the specified limits. The plant visits of Surajpura WTP and analysis of data obtained from the plant laboratory for three seasons along with the experimental data of the pulsator clarifier model resulted into the recommendations that there exists a strong opportunity to reduce the chemical dosage i.e. the pre-chlorination dosage may be reduced up to or below 3.00 ppm from the presently administered dosage of 4.25 – 5.00 ppm and also the PAC dosage may be reduced to the range of 5 -10 ppm in steps from the presently administered dosage of 25 – 40 ppm when the raw water turbidity levels are below 10 NTU. The rare opportunity to visually observe the process of sludge blanket formation helped in acquiring the knowledge to keep the blanket in suspension, to stabilize it by the intermittent but regular sludge extraction and also to regulate its height by adjusting the regular and the pulsed flow.

1. INTRODUCTION

Water is a precious commodity. Most of the earth water is sea water. About 2.5% of the water is fresh water that does not contain significant levels of dissolved minerals or salt and two third of that is frozen in ice caps and glaciers. In total, only 0.01% of the total water of the planet is accessible for consumption. Clean drinking water is a basic human need. Unfortunately, more than one in six people still lack reliable access to this precious resource in the developing world (Baroniya *et al.*, 2012).

India accounts for 2.45% of land area and 4% of water resources of the world but represents 16% of the world population. With the present population growth-rate (1.9 percent per year), the population is expected to cross the 1.5 billion mark by 2050. The Planning Commission, Government of India has estimated the water demand increase from 710 BCM (Billion Cubic Meters) in 2010 to almost 1180 BCM in 2050 with domestic and industrial water consumption expected to increase almost 2.5 times (CPCB report, 2006). The trend of urbanization in India is exerting stress on civic authorities to provide basic requirement such as safe drinking water. The rapid growth of population has exerted the pressure on potable water demand, which requires exploration of raw water sources, developing treatment and distribution systems.

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. The backwash water and sludge generation from water treatment plants are of environment concern in terms of disposal. Therefore, optimization of chemical dosing and filter runs carries importance to reduce the rejects from the water treatment plants. Also, there is a need to study the water treatment plants for their operational status and to explore the best feasible mechanism to ensure proper drinking water production with least possible rejects and its management. With this backdrop, this small effort has been made to evaluate the performance of the largest WTP of Rajasthan based on a relatively lesser known and little unconventional (in Indian perspective) pulsed sludge blanket technology.

1.1 Bisalpur-Jaipur Water Supply Project (BJWSP):

Bisalpur-Jaipur Water Supply Project (BJWSP) is the lifeline of Jaipur City catering water to more than three million population of Jaipur City and presently supplying about 540 MLD water to Jaipur City. The Bisalpur-Jaipur Water Supply Project (BJWSP) has been designed to deliver water from the existing Bisalpur Dam headworks (situated on river Banas in Tonk District) 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 (RUIDP report, 2011). The conceptual planning for the BJWSP is to utilize the Bisalpur Dam water in a phased manner in order to meet the ever increasing water demands of Jaipur City and reduce the groundwater abstraction to sustainable limits. Phase I of the BJWSP with water treatment plant (WTP) designed to supply a total of 400 MLD with a provision of 360 MLD for Jaipur city and 40 MLD for rural area was commissioned in 2009 and the Phase II expansion with the provision of enhancing the capacity of the WTP with another 200 MLD has been recently completed and thus providing a total of 600 MLD of treated water out of which 540 MLD to Jaipur City and 60 MLD to the rural areas. The planning and preparation of DPR to facilitate the construction of Stage II of the Project to achieve a total capacity of 1020 MLD clear water production is presently underway.

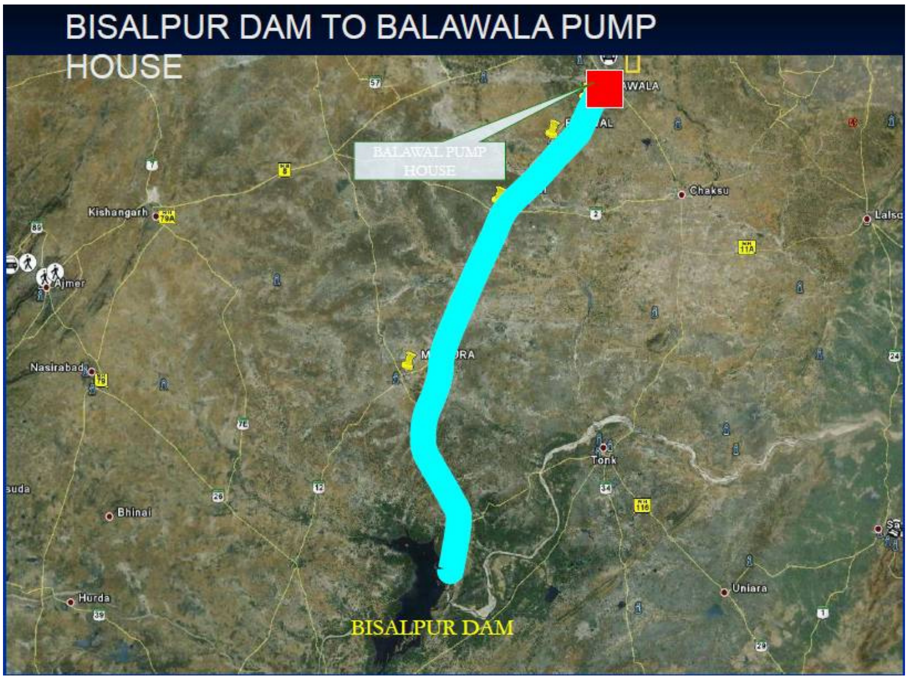


Figure 1.1: Depiction of Water Transfer from Bisalpur Dam (Tonk) to Balawala Pump House (Jaipur) of BJWSP

1.2 Pulsed Sludge Blanket Technology:

The Bisalpur-Jaipur Water Supply Project (BJWSP) 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. In a pulsator clarifier, the water flows upward through the sludge blanket in a cycling or pulsating flow. During surging flow, the bed expands uniformly. During subsiding flow, the bed settles uniformly as it would in a liquid at rest. As a result of pulsating flow, the blanket remains homogeneous throughout, with no stratification, facilitating continuous, effective contact between water and sludge (Ballard P T, 1992).

If the water is having low turbidity and low alkalinity which is normally the case 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 PAC as the coagulant (Pernitsky D J and Edzwald J K, 2000) or/and improved clarification by employing a zone of high solids contact to achieve a better quality effluent. 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.

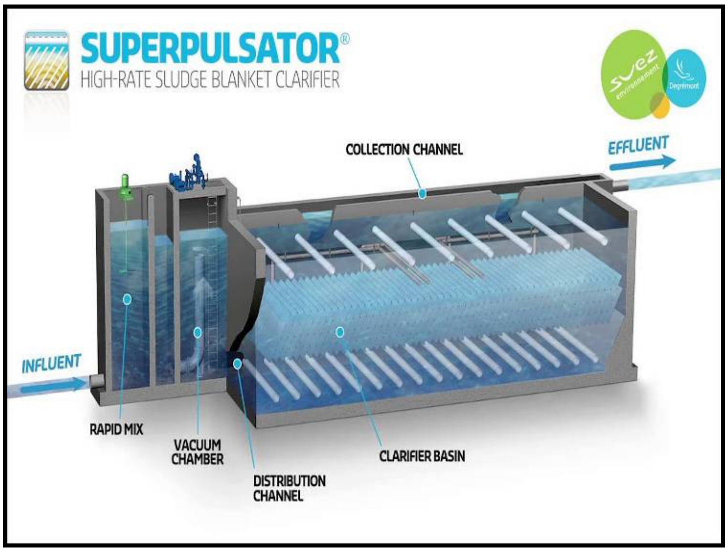


Figure 1.2: Pulsator Clarifier design by Degremont Technologies at BJWSP

‘Pulsator,' a proprietary technology for flocculation, is generally designed and sized by manufacturer’s recommendations. Rationales that explain the behaviour of the proprietary technologies like pulsator, with the exception of solids contact clarifier, are not available, albeit in the terms of qualitative descriptions. Few pieces of research have been done, and many realms haven’t even been touched upon for this promising technology, namely effect of variation in coagulants, removal of fluoride, residual aluminium etc.

1.3 Significance and Need of the Study:

The normal raw water intake turbidity from Bisalpur Dam is reported to be consistently ranged between 2.5-3.5, while pH ranges from 7 to 8 but at times the raw water quality at the dam varies seasonally and induces problems like colour and odour in treated water. This has led to the increased dosage of chemicals in the treatment process. It is a well-known fact that the Chlorine and Aluminium compounds are known to have adverse impacts on human health and the environment and therefore, any increase in the dosage of these chemicals is undesirable besides being expensive and adding to O&M cost. At present Polyaluminium Chloride is used as coagulant at the Surajpura WTP @ 25-40 ppm, leading to a daily cost in excess of 0.1 million INR. Also, the operational expenditure on Chlorine is in excess of 15,000 INR daily. Thus the daily cost of chemicals is significantly high vis-à-vis the raw water quality. and thus leaves enough scope to research and optimize operational cost of chemicals.

Further, there has been a change in the regime of O&M administration at the plant in May 2015 as till May 2015 the L&T was operating the plant in partnership with the Degremont Ltd. as Design and Operation Consultants since its commissioning in December 2009 as per the contract executed at the time of award of the work of construction & five years O&M of Surajpura WTP but since June 2015, M/s L&T limited was appointed as the sole O&M contractor by PHED Rajasthan for another five years during the bidding held in the first quarter of 2015. This change in regime surfaced some operational issues in the maintenance of plant. Thus, a performance analysis intending to ensure the proper operation of plant as per the designed and contract conditions over a period of one year and accounting for seasonal variations backed by the experimental data was thought of to be carried out.

Also, the pulsed sludge blanket technology has not gained momentum in India as well as in Rajasthan as there are very few plants working on this technology in India despite established advantages like integrated treatment functions that combines flocculation, clarification and sludge collection into one compact system with lower operating costs, as water supply professionals and engineers are at times sceptical on the efficient working of this technology in the absence of any visual display of the process of blanket formation at all. Thus, the study of pulsations and blanket formation where the process can be visualized to establish the technology deep into the hearts of water professional was also desired.

1.4 Objectives:

1. Performance Evaluation of the Surajpura WTP of Bisalpur-Jaipur Water Supply Project (BJWSP) in view of the designed and contract conditions vis-a-vis operational parameters taking into account the seasonal variations.
2. Design and fabrication of a lab scale model of Pulsator clarifier in order to carry out the study of pulsations and visual display of the process of blanket formation.
3. Carrying out experiments on the fabricated Pulsator clarifier model to find out the economic dosage of chemicals for cost minimization
4. Recommend practices for O&M for efficient functioning of Surajpura WTP using the performance evaluation study, experimental data and literature survey

1.5 Project Pulsator Group:

The present study has been carried out by a group of four students of MNIT, Jaipur. The complete study work consisting of (i) field visits and analysis, (ii) design and fabrication of pilot plants and (iii) experimental work on pilot plants was done as a team and individual studies are then taken up by each student for detailed investigation. The work was divided into following four theses:

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

2. REVIEW OF LITERATURE

Literature regarding water treatment systems and processes particularly the concept of pulsed sludge blanket technology along with the Superpulsator® technology of Inflico Degremont Inc. has been discussed at length in this chapter. Review of specific experimental processes taken up in the study as well as overview of Surajpura Treatment Plant of Bisalpur Jaipur Water Supply Project has also been discussed.

2.1 Water Treatment System:

Production of biologically and chemically safe water is the primary goal in the design of water treatment system; anything less is unacceptable. A properly designed plant is not only a requirement to guarantee safe drinking water, but also skillful and alert plant operation and attention to the sanitary requirements of the source of supply and the distribution system are equally important. The second basic objective of water treatment is the production of water that is appealing to the consumer. Ideally, appealing water is one that is clear and colorless, pleasant to the taste, odorless, and cool. It is none staining, neither corrosive nor scale forming, and reasonably soft.

Another most important objective of water treatment is that water treatment may be accomplished using facilities with reasonable capital and operating costs. Various alternatives in plant design should be evaluated for production of cost effective quality water. Alternative plant designs developed should be based upon sound engineering principles and flexible to future conditions, emergency situations, operating personnel capabilities and future expansion.

2.2 Water Treatment Processes:

Water treatment involves physical, chemical and biological processes that transform raw water into drinking water. Clarification is one of these processes, which includes the removal of excessive color or turbidity of raw water to produce clear uncolored water. Generally, clarification of turbid water includes coagulation, flocculation and settling processes (Schulz C S and Okun D A., 1992). Coagulation, flocculation, and settling processes have received extensive attention as the theoretical and experimental studies of these processes became increasingly important because of their widespread applications in industry.

Coagulation and Flocculation may be broadly described as the chemical / physical process of blending or mixing a coagulating chemical into a stream and then gently stirring the blended mixture. The overall purpose is to improve the particulate size and colloid reduction efficiency of the subsequent settling and or filtration processes.

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 microorganisms such as bacteria, plankton, algae, viruses etc.

Coagulation is the process of destabilization of the charge (predominantly negative) on suspended particulates and colloids. The purpose of destabilization is to lessen the repelling character of the particles and allow them to become attached to other particles so that they may be removed in subsequent processes. The particulates in raw water (which contribute to color and turbidity) are mainly clays, silts, viruses, bacteria, minerals and organic particulates. At pH levels above 4, such particles or molecules are generally negatively charged.

Coagulant chemicals are hydrolyzing electrolytes such as metal salts and/or synthetic organic polymers that, when added to water at an optimum dose (normally in the range of 1 to 100 mg/l), will cause destabilization. Most coagulants are cationic in water. The common coagulants are alum, ferric sulfate, lime, poly aluminium chloride (PAC) and cationic organic polymers.

Flocculation is the agglomeration of destabilized particles and colloids toward settleable (or filterable) particles (flocs). 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. Flocculation begins immediately after destabilization in the zone of decaying mixing energy (downstream from the mixer) or as a result of the turbulence of transporting flow. Such incidental flocculation may be an adequate flocculation process in some instances. Normally flocculation involves an intentional and defined process of gentle stirring to enhance contact of destabilized particles and to build floc particles of optimum size, density, and strength to be subsequently removed by settling or filtration.

Coagulation and precipitation processes both require the addition of chemicals to the water stream. The success of these processes depends on rapid and thorough dispersion of the chemicals. The process of dispersing chemicals is known as rapid mix or flash mix.

The third step in clarification process is the sedimentation of flocs formed in the second step. **Sedimentation** is one of the two principal liquid-solid separation processes used in water treatment, the other being filtration. In most conventional water treatments plants, the majority of the solids removal is accomplished by sedimentation as a means of reducing the load applied to the filters. Sedimentation process is achieved in settling basins. These settling basins can be classified according to the direction of flow through the basin into three main types; horizontal flow basins, upward flow basins and spiral flow basins (Smethurst G, 1997). In the upward flow basins the sedimentation is replaced by **fluidization** process.

Filtration is the most relied water treatment process to remove particulate material from water. Coagulation, flocculation, and settling are used to assist the filtration process to function more effectively. The coagulation and settling processes have become so effective that sometimes filtration may not be necessary. However, where filtration has been avoided, severe losses in water main carrying capacity have occurred as the result of slime formation in the mains and thus filtration is still essential.

2.3 Pre Chlorination vis-a-vis Break Point Chlorination:

Pre-chlorination is the addition of chlorine to the raw water prior to treatment to produce residual chlorine after meeting chlorine demand. The residual chlorine is useful in several stages of the treatment process – aiding in coagulation, controlling algae problems in sedimentation basins, reducing odour problems, and controlling mud-ball formation in filters. In addition, the chlorine has a much longer contact time when added at the beginning of the treatment process, so pre-chlorination increases safety in disinfecting heavily contaminated water. Pre-chlorination is generally applied to the water before coagulation. It improves the coagulation and reduces load on filters. It also reduces taste, colour, odour, algae and other organisms.

Breakpoint chlorination involves the addition of sufficient chlorine to result in the generation of free chlorine residuals. Conceptually, four steps are involved as shown in figure 2.1:

I. Easily oxidized substances such as nitrites, ferrous ions, hydrogen sulfide, and certain types of organics react with chlorine and reduce it to chloride giving little or no increase in chlorine residual.

II. Chloramines and chloroorganic compounds are produced as the hypochlorite ion reacts with ammonia.

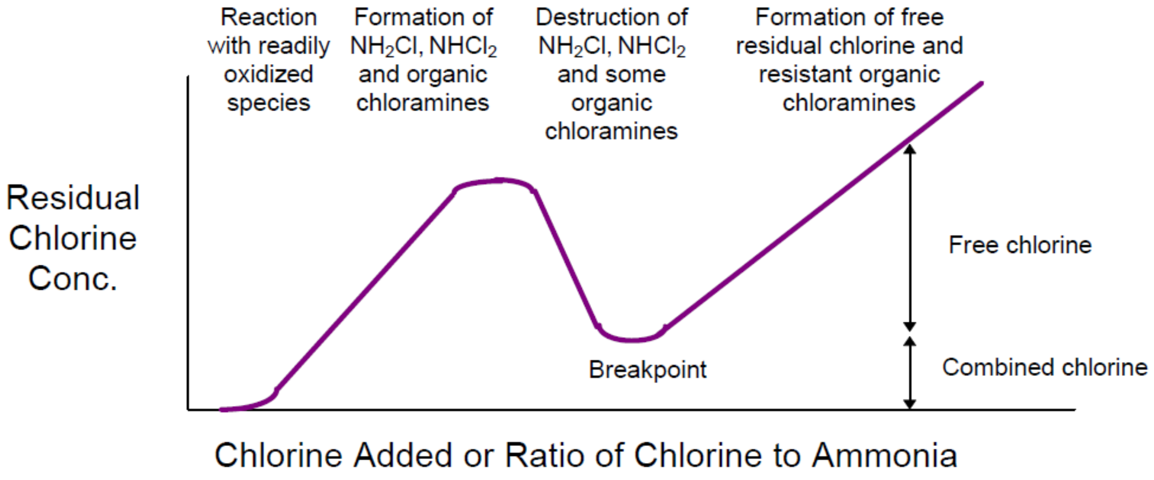


Figure 2.1: Schematic representation of the breakpoint chlorination curve.

III. Oxidation of chloramines and chloroorganic compounds, with the production of N2O, chloride, N2 and nitrogen trichloride results in a reduction in chlorine residuals. At the breakpoint, virtually all of the chloramines and a significant fraction of the chloroorganics have been oxidized.

IV. Further addition of chlorine results in a free residual of hypochlorous acid and hypochlorite ion.

The residual of free chlorine, appearing after break point, is not usually removed except by sun light and therefore, it takes care of the future recontamination of water. The breakpoint chlorination is the most common form of chlorination, in which enough chlorine is added to the water to bring it past the breakpoint and to create some free chlorine residual.

2.4 Pulsator Clarifier:

Pulsator clarifier is a simple type of upward flow tank whose effectiveness depends on a sludge blanket. It is one of the most widely used clarifier in the world as it is highly reliable and flexible. In pulsator clarifier, the water flows upward through the sludge blanket in a cycling or pulsating flow. During surging flow, the bed expands uniformly. During subsiding flow, the bed settles uniformly, as it would behave in a liquid state at rest. As a result of pulsating flow, the blanket remains homogeneous throughout, with no stratification, facilitating continuous, effective contact between water and sludge (Al-Dawery S K *et. al.*, 2007).

In a typical Degremont Pulsator®, the vacuum caused by a pump is interrupted by a water-level-controlled valve at preset time intervals, causing the water in the central compartment to discharge through the perforated pipe system at high rates in order to attain uniform flow distribution and to agitate the sludge blanket.

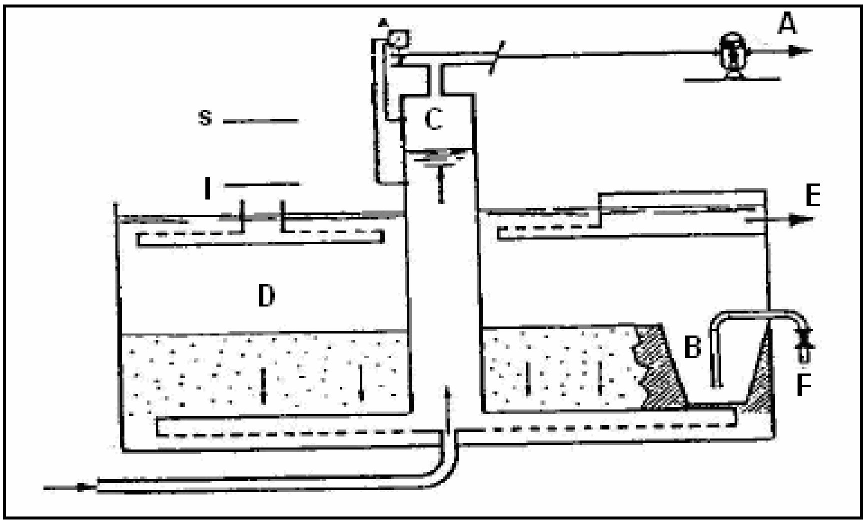


Figure 2.2 : Depiction of First Half Cycle in a Pulsator Clarifier (CPCB Report, 2006)

Pulsator Reactor First Half Cycle (figure 2.2): Air valve A is closed. The Water rises in the vacuum chamber C. The water in the Clarifier D is at rest. The sludge settles.

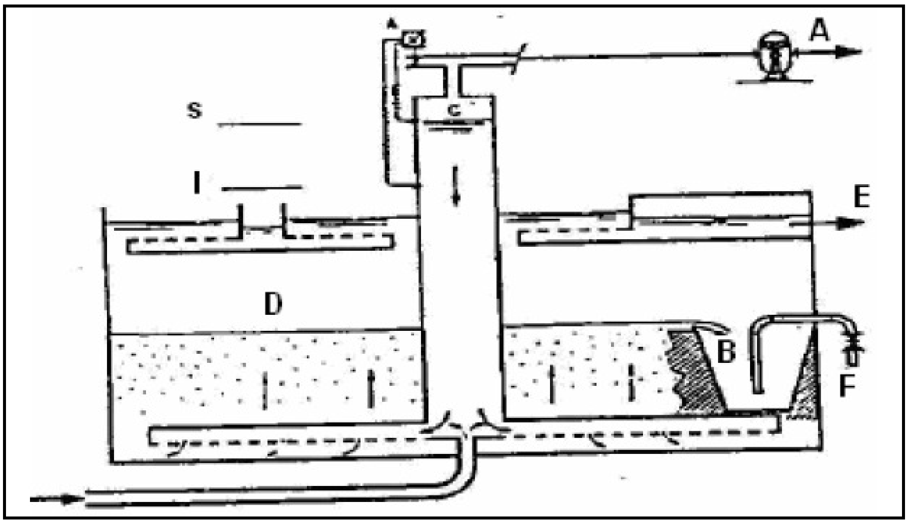


Figure 2.3: Depiction of Second Half Cycle in a Pulsator Clarifier (CPCB Report, 2006)

Pulsator Reactor Second Half Cycle (figure 2.3): The water in the Vacuum chamber C enters the clarifier D. The sludge in the clarifier rises with the water. The excess sludge enters concentrator B. The clarified water flows off at E. When the water falls to the level I in vacuum chamber C, valve A closes. The compacted sludge in concentration B is evacuated via automatic valve F.

Sludge removal in sludge-blanket units is usually by means of a concentrating chamber into which the sludge at the top of the sludge blanket overflows. Sludge draw-off is regulated by a timer-controlled valve.

2.5 Degremont Superpulsator® Clarifier:

The Superpulsator® Clarifier design by Degremont Technologies (Dyson J D, Inflico Degremont Inc.) is based on the following principles:

1. Plug flow.
2. Combined flocculation/clarification in one vessel.
3. Pulsed flow through the vessel.
4. Internal sludge concentration and automatic sludge removal.
5. No submerged moving parts.
6. Lamellar clarification.
7. Simple treatment chemistry and effective usage of chemicals.

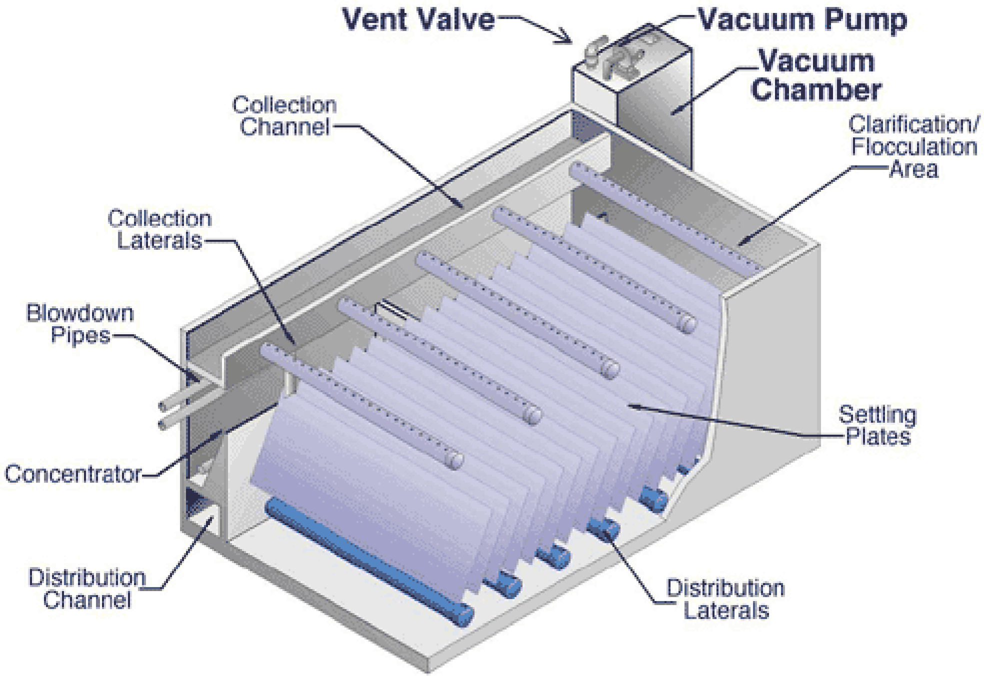


Figure 2.4: Degremont Superpulsator® Clarifier

The Superpulsator® Clarifier consists of five main components (See figure 2.4):

1. Raw water distribution.
2. Lamellar Plates and/or Tubes.
3. Effluent collection.
4. Sludge collection, concentration and discharge.
5. Vacuum chamber equipment.

Before entering the Superpulsator® Clarifier, the raw water and chemicals are added and mixed via inline mixer or rapid mix. The coagulated water is then split between the individual treatment units via flow splitter boxes, which then transfer the water to the vacuum chamber via a transfer pipe. The vacuum system creates low pressure within the chamber, causing the water to rise to a predetermined level. The vacuum time is adjustable by the control system which allows height and frequency of the rise (water level) to be adjustable. The amount of vacuum in the chamber is controlled by an air bleed valve on the vacuum line. This also helps fine-tune the height and pulsing action within the Superpulsator® Clarifier.

When the water reaches a maximum adjustable level (equal to the vacuum time) in the vacuum chamber, the vent valve opens releasing the vacuum on the chamber. The hydraulic head within the chamber causes a surge of water into the bottom distribution system. Orifices in the distribution pipes create uniform distribution across the entire clarifier tank displaying a plug flow characteristic.

The coagulated water, as it is distributed across the bottom of the flocculation/clarification zone, creates the pulsing energy. This energy is converted into gently stirring turbulence. The gently stirring turbulence helps flocculate the coagulated water into a settable floc. Within the flocculation/clarification zone, newly flocculated floc is mixed with previously flocculated sludge. The contacting of the newly formed floc with previously formed floc helps create larger and more settleable floc.

When the hydraulic head water level in the vacuum chamber reaches a low level (equal to vent time) and the energy has been dissipated, the surge of flow slows and the sludge blanket begins to settle. At the low water level, the vent valve closes and the vacuum is applied again to the vacuum chamber. The incoming raw water rises in the vacuum chamber and repeats the cycle described above. A complete pulsation cycle is usually 40 to 60 seconds. This action helps create a uniform sludge blanket.

As water enters the sludge blanket and passes upward through it, the sludge blanket performs a double task. First it agglomerates newly formed floc, then it helps the suspended matter and colloidal particles adhere to the floc. The sludge blanket acts as a "flocculation-filter" in which these tasks are accomplished.

The advantages of Superpulsator® Clarifier over the conventional systems as claimed by the Inflico Degremont Inc. may be listed as:

- **Integrated**: Flocculation and clarification functions are combined in one basin, eliminating the need for a separate flocculation chamber. This result into a smaller footprint that significantly reduces the land required for construction as well as overall construction and operating costs.
- **Optimum flocculation and chemical usage:** Nearly all other solids contact clarifiers compromise flow distribution in order to gain efficient solids contact. Superpulsator distributes and collects flow over the entire area of the clarifier, utilizing the clarifier volume and sludge blanket in an efficient separation process.
- **Low maintenance:** Most solids contact processes require mechanical or flow impeding devices such as mixers, pumps, or baffles to keep the sludge homogeneous. Superpulsator accomplishes this through pulsations powered by a vacuum system. There are no moving parts or parts susceptible to clogging — under water.
- **Operator friendly:** The vacuum pump, vent valve arrangement, and sludge waste valves are Superpulsator’s only mechanical parts. Automated and easily accessible, they require minimal operator attention.
- **Energy efficient:** Compared to other clarification processes, Superpulsator has very low energy requirements. It consumes approximately one horsepower unit per mgd vs. four to five horsepower units for competitive systems.

2.6 Operational Characteristics of Pulsator Clarifier:

Flocculation rate is one of the most important characteristics in the operation of pulsator clarifier. This rate is influenced by a number of physical parameters and operating conditions. Sludge blanket height, upflow velocity of coagulated water, volume concentration of sludge blanket and physical properties of flocs. All these factors are highly interactive and control the pulsator clarifier performance. Numerous investigation shows that flocculation criteria G*C*t (The product of shear rate, volume concentration of sludge blanket and residence time) gives an indication for the best flocculation conditions in sludge blanket clarifier (Coma

J *et. al.*, 1990). Also, the flocculation criteria is a basic factor in the design of any sludge blanket clarifiers type (Svarovsky L, 1981).

Steady fluidization is one of the most important characteristics of Pulsator clarifier, which represent the balance between the varying upward flow velocity of the coagulated water and the hindered settling velocity of the fluidized bed. Many authors suggested an empirical correlation that relates the upward velocity with the individual settling velocity and volume concentration of flocs (Foscolo P U, 1987).

Despite the wide use of pulsator clarifier worldwide in many water treatment stations, no theoretical and experimental analysis has been reported yet in the literature to describe the operation of pulsator clarifier. Numerous investigators describe experimentally and theoretically the operation in horizontal flow and spiral flow clarifier (Bridoux G A *et. al.,* 1998). Most of the experimental and theoretical investigations that have been reported on flocculation process in upward flow clarifiers were for hopper-bottomed sludge blanket clarifier and accelerator type solid contact clarifier (Head R *et. al.*, 1997). However, the information about the factors that affect the operation of pulsator clarifier is not adequate. Therefore, in order to obtain a general predictive model for the performance of a pulsator clarifier, there is a need for better understanding of the role of the physical, design and operating parameters. Thus, one of the aims of the present study is to study the pulsations and blanket formation using different operating parameters.

2.7 Description of Surajpura Water Treatment Plant of BJWSP:

The total capacity of the Surajpura water treatment Plant is envisaged with the following stages.

Table 2.1: Stage Wise Capacity of WTP

Stage	Year	Total Capacity in MLD
Stage I - Phase I	2011	400 (Existing)
Stage I - Phase II	2015	200 (Existing)
Stage II	2021	420 (Future)
	Total	**1020**

The total land available for the WTP at Surajpura is of 500m x 500 m. The entire WTP premises have been planned considering the requirement up to Stage-II including all process and allied structures with other ancillary works. The existing treatment unit includes inlet chamber, distribution chamber, clarifier, filter units, thickeners and sludge drying beds. The inlet chamber, main distribution chamber and connecting channel has been designed and constructed for Stage-II requirement. The campus also comprises of 25 ML Clear Water Reservoir, Clear Water Pump House, 33 KV Sub Station, Staff Quarters, Offices and other ancillary structures.

The major WTP units along with their design capacities are summarized in the following table.

Table 2.2: Design Capacity of WTP Units

S. No	Unit	Quantity in Nos.	Total Capacity in MLD
1	Receiving Chamber cum Distribution Chamber	1 No.	1060 (Stage – I 624 MLD, Stage – II 436 MLD)
2	Raw Water Measuring Channel and Flume	1 No.	624 MLD
3	Clarifier Distribution Chamber	1 No.	624 MLD
4	Clarifier	13 (12 W+1 S)	624 MLD
5	Filtration with Backwash arrangement	26 (24 W+2 S)	624 MLD
6	Clear Water Reservoir	2 No.	25 ML each
7	Alum Dosing System		Max dosing 60 mg/l & average dosing 30 mg/l at 624 MLD
A	Alum Dosing Tank	3 nos.	70m3
B	Alum Dosing Pump	3 nos (2W+1S)	
7	Chlorination		
A	Pre Chlorination	4 (3W+2S)	50 kg/hr @ 5 mg/l
B	Post Chlorination	3 (2W+1S)	40 kg/hr@ 3 mg/l
8	Lime Dosing System		20 mg/l at 600 MLD
A	Lime Dosing Tank	3 nos	45 m3
9	Poly Dosing System		2 kg/ton of dry solid
A	Poly Doing tank	2 Nos. (1W+1S)	

S. No	Unit	Quantity in Nos.	Total Capacity in MLD
B	Poly Dosing Pumps	2 Nos.	
11	Sludge Thickener	2	18 m dia x 3.5 m SWD
12	Sludge Drying Beds	60 nos	30 m x 10 m

The schematic arrangements of water treatment process at the Surajpura WTP are shown in figure 2.5. Coagulant (PAC) and chlorine are dosed on upstream and downstream of the Parshall flume channel. After chlorination the Clarified Water is sent to Clear Water Reservoir within WTP campus at Surajpura and from Surajpura reservoir the water is further pumped to Balawala CWR and for Rural supply.

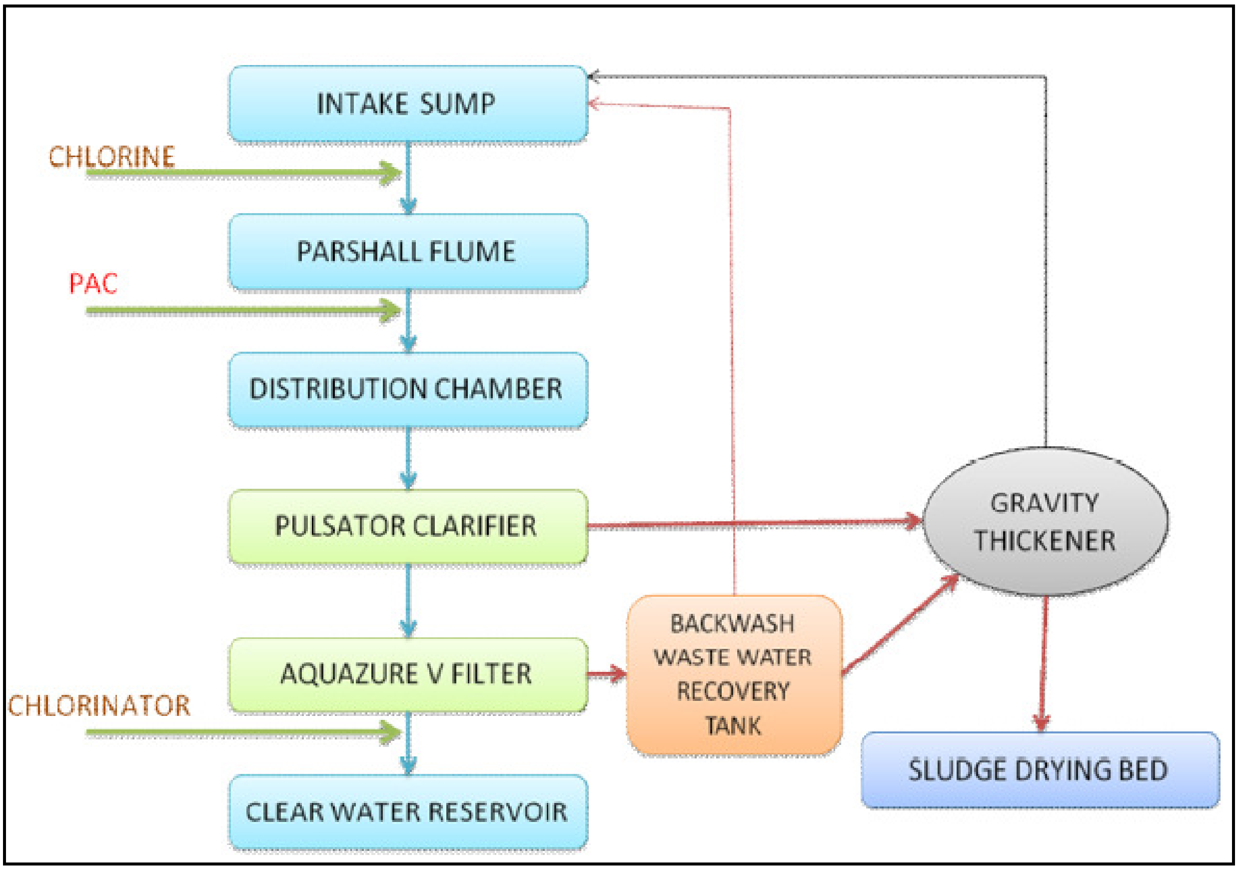
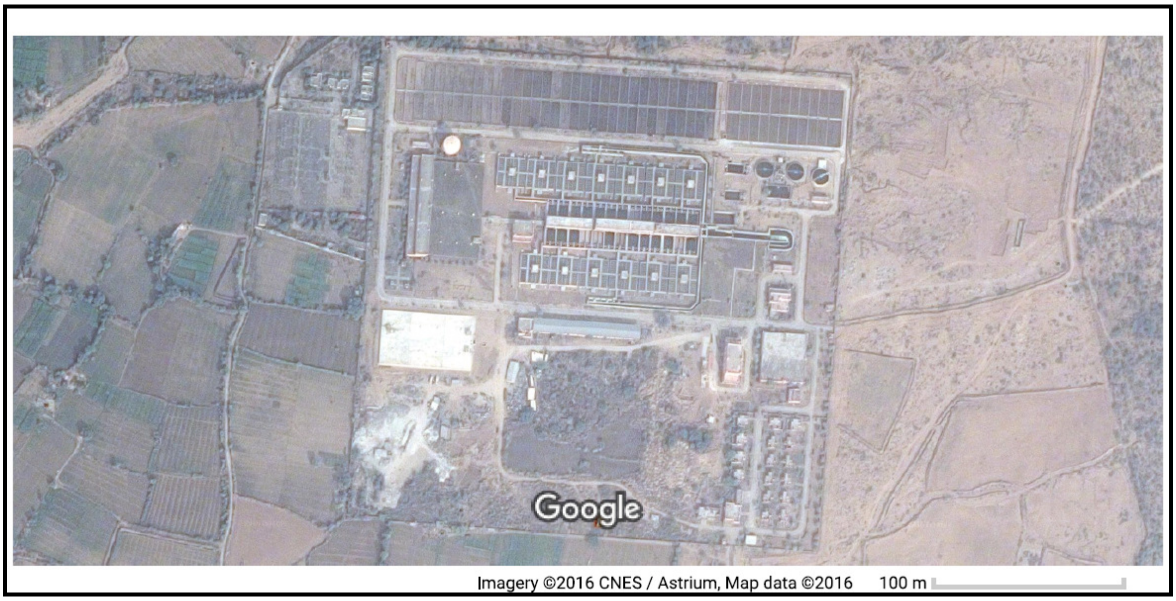


Figure 2.5: Schematic arrangements of Surajpura WTP

Figure 2.6 is showing the plan of WTP for phase I of stage I (400 MLD) as depicted in the modal of phase I whereas figure 2.7 is depicting the plan of phase I & phase II of stage I (400 + 200 = 600 MLD) as taken from Google maps. The number of pulsator clarifiers for phase I can be seen as 9 (8 Working + 1 standby) from the modal image whereas the total no. of pulsator clarifiers for combined phase I & II can be seen as 13 (12 working + 1 standby) from the Google imagery.

Figure 2.6: Plan of the Surajpura WTP (as depicted in Modal for Phase I of Stage I)



Imagery ©2016 CNES / Astrium, Map data ©2016

Figure 2.7: Google Map depicting the plan of the plant (Phase I & II of the Stage I)

2.8 Raw and Treated Water Quality at Surajpura WTP:

The source of raw water for Surajpura WTP is the Bisalpur dam. The average turbidity of the raw water is quite low at 2.5 NTU and a pH of 7.8. Despite low turbidity, the raw water contains colour due to algae. Though the turbidity of raw water is low but the plant has been designed to clarify water even at a very high turbidity. The raw water parameters for which the plant has been designed are given in table 2.3.

Table 2.3: Raw Water Parameters for which the WTP has been designed

S. No	Parameter	Unit	Value
1	Turbidity	NTU	5 - 500
2	pH	---	7 - 8
3	Colour	Hazen	0 - 45

The guaranteed outlet parameters for the water treatment plant as per the present O&M contract of PHED with the L&T are given in table 2.4.

Table 2.4: Outlet Water Parameters (as per the O&M contract)

S. No	Parameter	Unit	Value
1	Turbidity	NTU	< 0.5
2	pH	---	7.0 – 8.5
3	Colour	Pt-Co Scale	0 - 5.00
4	Faecal Coliforms	Number/100 ml	0
5	Coliform Organisam	Number/100 ml	0
6	Iron, Fe	mg/l	<0.1
7	Residual Aluminium, Al	mg/l	<0.1

3. MATERIALS AND METHODS

The major objective of this study involved performance evaluation of the Surajpura water treatment plant of BJWSP taking into account the seasonal variations for which multiple plant visits for evaluating physical and operational conditions of the various plant units, sample collections for analysing various parameters at the PHE/Environmental engineering laboratory of MNIT as well as secondary data collection from the plant laboratory and PHED were the most important tasks. Also, in order to carry out the visual display of the process of blanket formation and the study of pulsations along with the experimental analysis of the water treatment process for optimizing the dosage of chemicals, design and fabrication of a lab scale model of Pulsator clarifier using the transparent Perspex sheet/pipe was carried out. Following paragraphs discusses the elaborative methodology adopted to carry out the study:

3.1 Site Visit and Data Collection:

Multiple plant visits of daylong durations were planned in order to develop an understanding of the water treatment operations at the plant and to specifically carry out the following:

(i) Physical review of plant structures and equipment
(ii) Identification of the sampling locations at the treatment plant for analysing water quality parameters onsite, in the plant laboratory and in the PHE/Environmental engineering laboratory of MNIT Jaipur
(iii) Collection of the technical data and relevant documents as available with the plant personnel and PHED records
(iv) Onsite operational problems assessment with plant operator

3.2 Sampling and Testing:

During the first visit of the plant made in early September 2015, six sampling locations were identified as indicated in figure 3.1 and may be listed as-

1) Raw water at Inlet
2) Immediately after Pre-chlorination and PAC dosing
3) Before Hydraulic Jump
4) After Hydraulic Jump and before Pulsator
5) Pulsator outlet before Filter
6) Filter Outlet

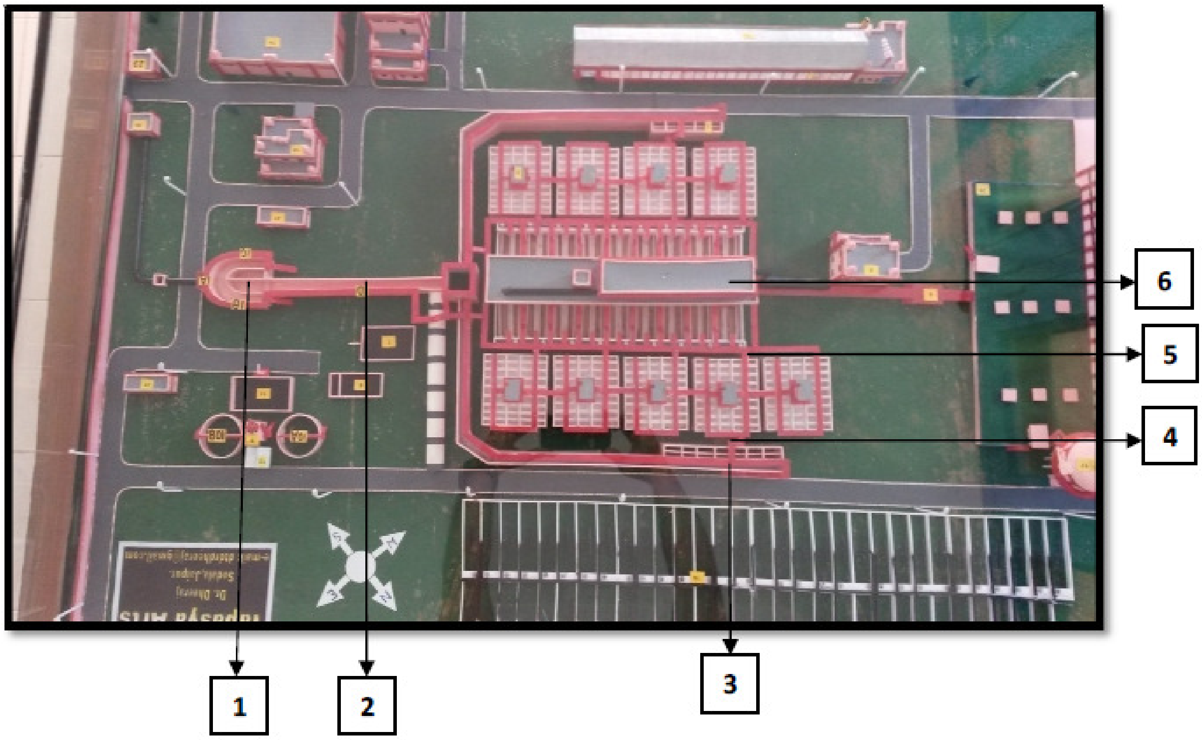


Figure 3.1: Sampling points at Surajpura water treatment plant

It was decided to take samples from the six sampling points as specified above for testing of various parameters at different sampling points along with a sampling module (as given in the table 5) specifying that which tests are to be carried out onsite/plant laboratory and at the PHE/Environmental engineering laboratory of MNIT Jaipur.

It was further decided that during the plant visits by the students of Project Pulsator Group, the onsite test as specified in the table 3.1 would be carried out by the students either using the portable instruments carried from the Environmental engineering laboratory of MNIT or at the plant laboratory (with due permission from the plant administration). But due to requirement of a larger data size to carry out the performance analysis of the water treatment plant and also to account for seasonal variations, it was decided to obtain the secondary data from the plant laboratory for five days in a row during a season i.e. sampling and testing was to be done during Post Monsoon (September/ October), Winters (December/ January) and Summers (April/ May). Thus, sampling was to be done for 15 days and a total of 90 samples were to be analysed for various chemical parameters related to water treatment and quality analysis. A format for obtaining the daily testing data as per the requirement was provided to the plant laboratory as indicated in table 3.2.

Table 3.1: Module for testing of various chemical parameters of water

S.No.	Sampling Point	Required Tests	Tests to be carried out onsite or at the Lab of the Plant	Tests to be carried out at MNIT Lab
1	2	3	4	5
1.	Raw Water at inlet	(i) Turbidity, (ii) pH, (iii) TDS and (iv) Alkalinity	All as per column 3	-
2.	Immediately after Pre-chlorination and PAC dosing	(i) pH, (ii) Residual Chlorine, and (iii) Residual Aluminium	All as per column 3	-
3.	Before Hydraulic Jump	(i) Particle Size Analysis (PSA) and (ii) Residual Chlorine	Residual Chlorine	PSA
4.	After Hydraulic Jump before Pulsator	(i) PSA, (ii) Residual Chlorine and (iii) Alkalinity	Residual Chlorine & Alkalinity	PSA
5.	Pulsater Outlet before Filter	(i) Turbidity, (ii) pH, (iii) Residual Chlorine, (iv) Residual Aluminium and (v) PSA	All as per column 3 except PSA	PSA
6.	Filter Outlet	(i) Turbidity, (ii) pH, (iii) TDS, (iv) Residual Chlorine and (v) Residual Aluminium	All as per column 3	-

Table 3.2: Format for Daily Report of Testing carried out at the Plant Laboratory

S.No.	Sampling Point	Tests Results					
		Turbidity (NTU)	pH	TDS (mg/l)	Residual Chlorine (mg/l)	Residual Aluminium (mg/l)	Alkalinity (as mg/l of $CaCO_3$)
1	2	3	4	5	6	7	8
1.	Raw Water at inlet				NR	NR	
2.	Immediately after Pre-chlorination and PAC dosing	NR		NR			NR
3.	Before Hydraulic Jump	NR	NR	NR		NR	NR
4.	After Hydraulic Jump before Pulsator	NR	NR	NR		NR	
5.	Pulsater Outlet before Filter			NR			NR
6.	Filter Outlet						NR

NR: Not Required

3.3 **Laboratory Analysis:**

Various experiments and laboratory analysis of the samples of the raw water from Bisalpur dam collected from the inlet channel of the plant for examining turbidity, pH, alkalinity, free chlorine, residual aluminium, chlorine demand through breakpoint chlorination analysis, particle size analysis (PSA) etc. were carried out by the students of the Project Pulsator Group at the Environmental engineering laboratory of MNIT besides the onsite & plant laboratory analysis of the samples.

3.3.1 Chlorine Demand of Raw Water:

Chlorine, when added to water, reacts with organic matter and other substances which destroy its disinfecting power. Therefore, it is necessary to add sufficient chlorine to react with all the various substances present and still leave an excess or residual if bacteria are to be destroyed.

This residual chlorine may be present in the free state, which has a very rapid disinfecting power; 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 concentration is increased for a given water, the free available chlorine increases, but at a rate less than that applied (caused by the reaction with ammonia). As applied chlorine concentration continues to increase, the free available chlorine residual declines to near zero, which is the break point. After that, the free chlorine increases linearly with the applied chlorine. Thus, the chlorine concentration added to reach to breakpoint is deemed as chlorine demand of water.

Sixteen samples of raw water from Bisalpur dam each of about 300 ml were taken in glass bottles and chlorine were added to these bottles ranging from 0.5 mg/l to 8.0 mg/l with an increment of 0.5 mg/l i.e. samples were prepared with chlorine dosing as 0.5, 1.0, 1.5....8.0 mg/l. The appropriate chlorine dose was calculated using the bleaching powder solution whose chlorine content were checked first just before the experiment by starch-iodide titration method.

After the 15 minutes reaction time, the free residual chlorine up to 2 ppm (2 mg/l) dose was measured by Colour comparator (Lovibond) as depicted in figure 3.2 and for samples above 2 ppm, residual chlorine was measured by titration with sodium thiosulphate. Sodium thiosulphate was added until the brown colour of the liberated iodine turned to pale yellow as if almost disappeared. After that, the starch indicator was added yielding purple colour, and the titration was continued till colourless endpoint was reached (as shown in figure 3.3).

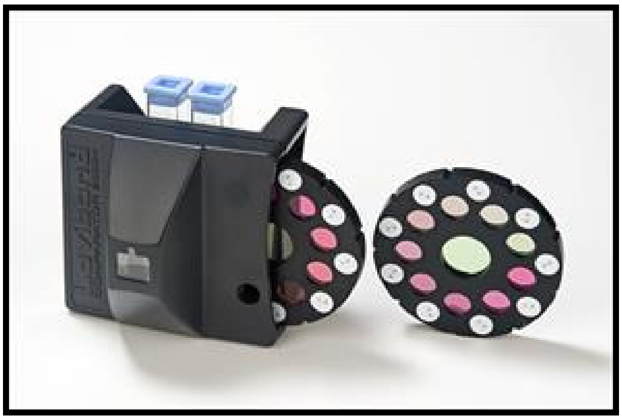


Figure 3.2: Lovibond Colour Comparator for measuring free chlorine

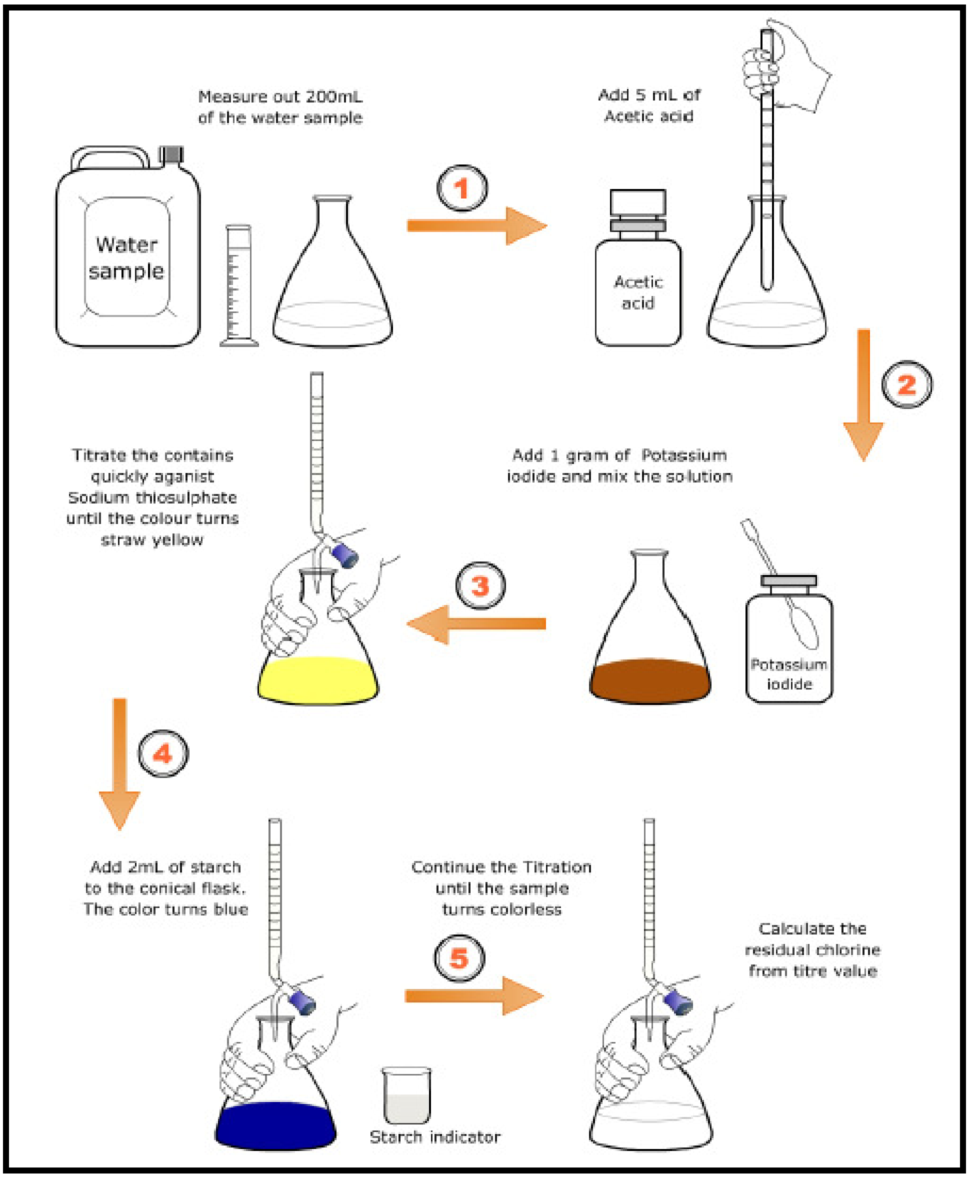


Figure 3.3: Illustration of starch-iodide titration method for measuring free chlorine

The complete experiment (testing of sixteen samples) was carried out in 3-4 rounds of experimentation as in one round only 4-5 samples can be tested by four team members of Project Pulsator group otherwise, the chlorine contact time may increase for remaining samples and may yield erroneous results.

3.3.2 Particle Size Analysis:

The PAC/Coagulant dosing point at Surajpura WTP is immediately after the raw water inlet channel and just before the parshal flume as depicted in figure 10 (between point no. 1 and 2). It is understood that dosing point has been kept at this location just to utilize the flow energy for mixing as the parshal flume here is of submerged hydraulic jump type (figure 3.4) but the mixing here appears to be uneven and uncontrolled. It was observed that the raw water after PAC dosing takes 10-12 minutes in reaching to the hydraulic jump type pulsator inlet distribution weir (figure 3.5) flowing through raw water channel and clarifier feed channels. During this period of 10-12 minutes, there is substantial flocculation, but it appears that these flocs breaks at the hydraulic jump just before the pulsator inlet and causes loss of flocculation efficiency. This subsequently results into the increased dosage of coagulant for achieving the desired clarification.

Figure 3.4: Surajpura WTP Pictures showing the (i) PAC dosing just before the Parshal Flume and (ii) Long Clarifier Feeding Channel

Figure 3.5: Picture showing Hydraulic Jump at the Clarifier Distributor Channel

To establish this apparent phenomenon, it was decided to simulate the mixing and flocculation conditions after PAC dosing and then upto hydraulic jump of the Surajpura plant at the laboratory of MNIT using jar test apparatus. The slow mixing in the raw water channel and clarifier feed channels for about 10-12 minutes (after PAC dosing and then just before the hydraulic jump) was simulated by running the jar test apparatus for 10 minutes at 20 rpm and then the flash mixing condition at the hydraulic jump of the plant was simulated by running the jar test apparatus for 20 seconds at 100 rpm as the *G* (velocity gradient g bar) values calculated earlier for the hydraulic jump was about 500/sec and that is equivalent to the mixing energy imparted in a jar test apparatus for about 20 seconds at 100 rpm.

Thus, the effectiveness of the coagulant dosage on the flocculation characteristics in the raw water/clarifier feed channel as well as the impact of the hydraulic jump on flocculation can be studied by analysing the zeta potential and particle sizes of the colloidal particles and flocs formed at the (i) raw water stage, (ii) water just before and (iii) after the hydraulic jump. This analysis was carried out using the Jar test apparatus available in the environmental engineering laboratory of MNIT (figure 3.6) and the Zeta Potential & Nano Particle Analyzer (Malvern) available at the Material Research Centre (MRC) of MNIT (figure 3.7).

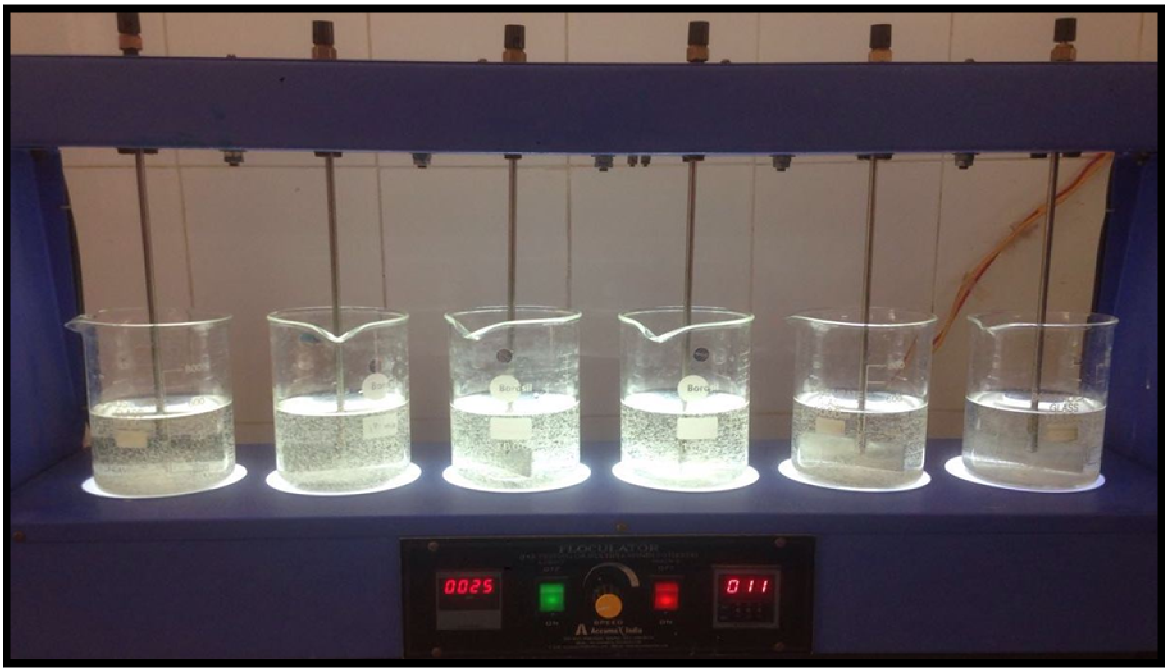


Figure 3.6: Jar Test apparatus at PHE lab, MNIT Jaipur

Figure 3.7: Zeta Potential & Nano Particle Analyzer (Malvern) at MRC of MNIT Jaipur

3.3.3 Laboratory Instruments:

Besides the chlorine water demand and the particle size analysis the other parameters such as turbidity, pH, alkalinity, free chlorine, residual aluminium, etc. were analysed routinely for various raw and treated water samples in the environmental engineering laboratory of MNIT using standard methods and protocols and the following instruments (pictures are shown in figure 3.8 & 3.9)-

Table 3.3: List of Instruments used at PHE Lab of MNIT Jaipur

S.No.	Parameter	Instrument	Company	Model
1.	pH	pH Meter	Labtronics	LT-11
2.	Turbidity	Nephelometer	Electronics India	Model 341
3.	Free chlorine	Photometer	Hanna	HI 96711
4	-	Weighing Balance	CAS	CAUW220D

Figure 3.8: Pictures of Digital pH meter & Weighing Balance

Figure 3.9: Pictures of Digital Nephelometer & Hanna Photometer

3.4 Design and Fabrication of a Lab Scale Pulsator Clarifier:

There is no standard or typical method for design of a pulsator clarifier as ‘Pulsator®’, a proprietary technology for flocculation, is generally designed and sized by manufacturer’s recommendations. Rationales that explain the behavior of the proprietary technologies like pulsator are not available, albeit in the terms of qualitative descriptions. The pilot plant of pulsator was designed in consultation with Degrémont Limited, the design consultants for the pulsator clarifiers at the Surajpura WTP. In the design of pulsator clarifier, the flow velocity is the critical parameter and shouldn’t be allowed to exceed limits that may cause the sludge blanket to destabilize and collapse. Hence, the rise rate of water in the vertical upflow clarifier was taken as the design parameter for the pilot plant. A rise rate of 3m/hr was selected during normal flow and the design flows were selected on the basis that the pulsed flow should be four times the regular flow. Moreover, the state-of-the-art water treatment plant of PHED at Surajpura of 600 MLD capacity was surveyed and studied for sizing the pilot plant in order to depict the functioning as closely as possible. Therefore, a pilot plant based on the Superpulsator® technology was designed for a clarifying capacity of about 8000 liters per day.

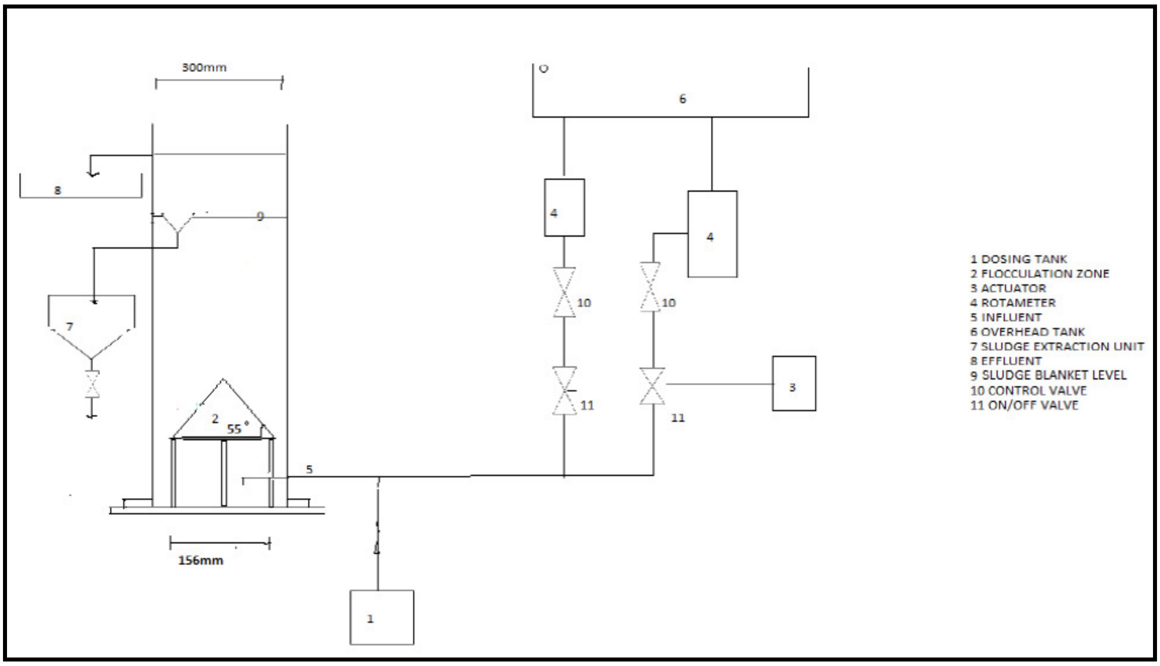


Figure 3.10: Schematic Diagram of pulsator model

The fabrication of the lab scale model was done at MNIT, Jaipur campus. It consisted of the pulsator column, actuator assembly, rotameters, peristaltic pumps, dosing tanks, stirrers, necessary pipes & pipe fittings including valves etc. and the systemic arrangements to make it a continuous flow system. The pulsator column was made of Perspex sheet in order to provide a clear picture and understanding of the concept of sludge blanket formation. Four commercially available 300 mm outer diameter Perspex cylinders with 5 mm thickness and 2 feet length each were joined to form a column of 8 feet height wherein, at one place these pipes were joined rigidly and at another two places square Perspex flanges of 16 inch having 12 mm thickness with suitable gaskets were used (as shown in figure 20). Also, the bottom of this 8 feet high pipe was covered with a 16-inch flange and placed on & joined with a table top thus a total of five Perspex flanges were used. An iron frame was used to support the height of the pulsator column and the entire model is fitted on a wooden stand to provide structural stability.

Figure 3.11: Construction of pulsator column and stand at MNIT, Jaipur

To prevent the sludge blanket from collapsing an intermittent pulse system is provided. The pulse is generated by using an actuator assembly (figure 3.14) and a solenoid valve with an electronic timer. As depicted in the schematic diagram (figure 3.10), the system is so designed that the clarifier column is fed through two pipes one for the regular flow and the other one for the pulsed flow. The two flows were merging before the inlet. The solenoid valve causes the flow to remain shut off for specific time intervals as controlled by an electronic timer to cause the heavy flow for small durations giving the effect of a periodic pulse. The pulse cycle, which consists of pulse duration and idle time, can be adjusted manually by the operator. The sludge blanket in the bottom part of the Pulsator is subjected to alternating vertical motions. It expands during the pulse when the water rushes in and then shrinks (packs) during the regular flow (idle time of pulsation cycle).

An inverted cone of Perspex sheet is placed at the bottom of the column (as depicted in figure 3.12), just after the inlet. The purpose of the cone is to facilitate adequate mixing of the coagulant with the raw water by reduction in cross section area of flow, thus providing increased velocity for mixing. Additionally, the cone should be so designed that the particles do not settle on it, instead slide from the annular space between the cone and the pulsator column back into the flocculation zone. To meet this requirement, the cone angle was selected as 55 degrees. The model was designed to run at a regular flow rate of 0.212 m^3/hr and pulse flow rate of 0.848 m^3/hr. A rotameter of 10 lpm was used for the regular flow and a second rotameter of 20 lpm was used to measure and control the pulsed flow (figure 3.12 is showing the rotameters arrangement).

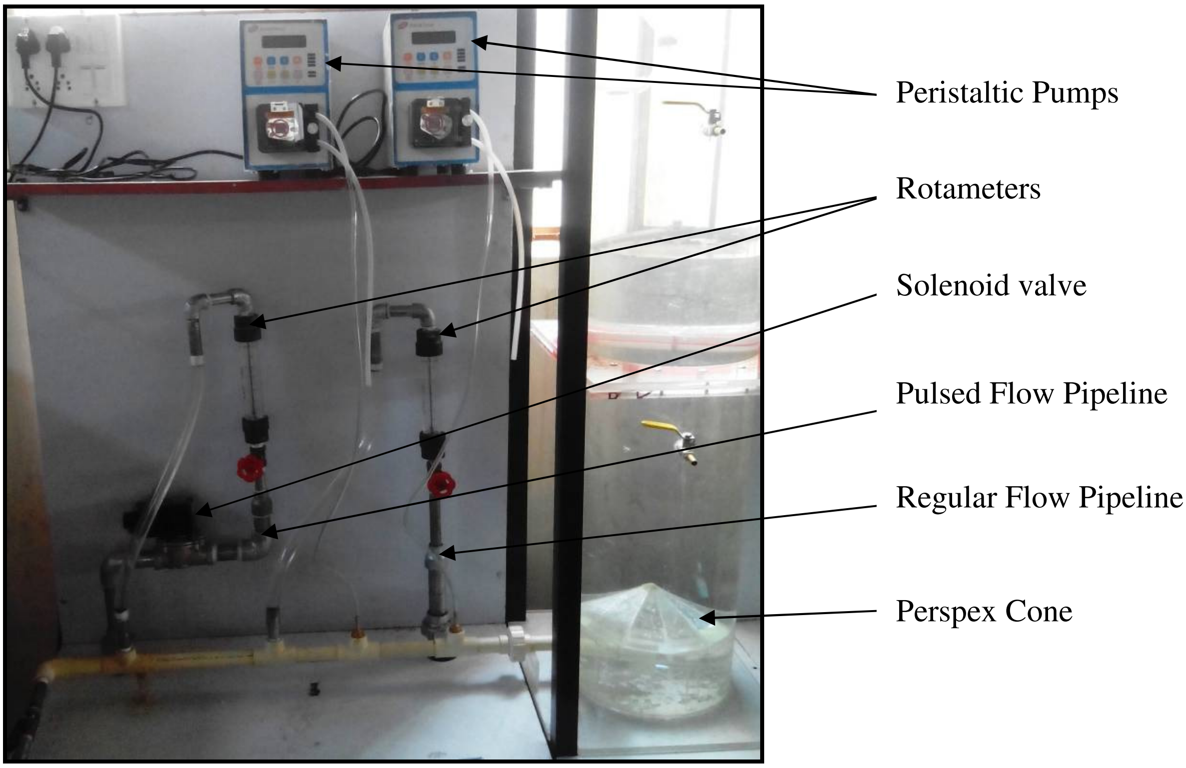


Figure 3.12: Picture showing detailed arrangement of peristaltic pumps, rotameters, flow pipelines, valves and Perspex Cone

A sludge extraction unit at a height of 1.2 m above the bottom of the tank in the form of a hopper with an outlet out of the clarifier tank was provided to remove the excess sludge (figure 3.13). The system was designed in such a manner that the excess sludge would flow into the hopper provided in one section of the clarifier and got concentrated there. Sludge is drawn off periodically through the sludge removal pipes. The effluent or clarified water is collected through a hose pipe positioned at a height of 2.2 m above the bottom of the tank. The location is so selected that enough detention time is available for the flocs to settle.

Figure 3.13: Pictures showing Sludge Extraction (Hopper) and Stirrer arrangements

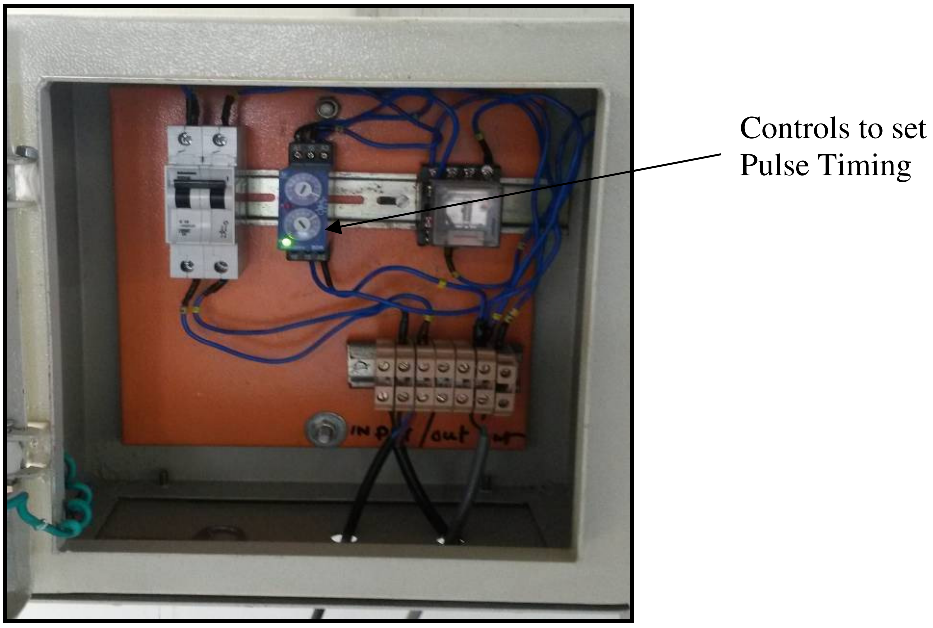


Figure 3.14: Picture showing Actuator Assembly with Electronic Timer

Two dosing tanks of PVC, each of 100 liters capacity were provided to introduce turbidity and the coagulant. A heavy duty stirrer arrangement using a 0.3 KW motor with a speed regulator (as depicted in figure 3.13) was made for the turbidity dosing tank in order to ensure that the turbidity introduction into the tap water used for feeding the pilot plant is uniform and thus synthesizing the raw water with the desired turbidity levels. Two peristaltic pumps each with a maximum flow rate of 450 ml/minute and an rpm range of 0-160 with a speed control level of up to 0.1 rpm (as depicted in figure 3.12) were installed to feed the bentonite solution (turbidity) and coagulant from the dosing tanks into the influent pipe carrying the raw water at a precisely controlled rate. An empirical relationship was established between the flow rate and rpm of the peristaltic pumps. The pump was operated at different rpm and the corresponding flow rate was measured. It was found that the pump flow rate in ml/minute is three times the pump rpm. This relationship was used for the input of chemicals to the systems. The influent pipe delivers the raw water at the geometric centre of the pulsator column. The complete setup of the pulsator clarifier pilot plant is depicted in figure 3.15.

Figure 3.15: Photograph of the complete setup of the pulsator clarifier pilot plant

3.5 Installation of Pulsator Clarifier Pilot Plant Setup:

The experimental setup of the pulsator clarifier pilot plant was installed at the Hydraulics Lab of MNIT, Jaipur due to the sufficient availability of required water quantity (approximately @ 8000 litres per day) at a minimum head of 8.0 meter from the overhead water tank exclusively supplying water to the instruments and prototypes in the hydraulics lab. The pilot plant was provided water through a separate one inch PVC pipe connection taken directly from a 4 inches MS pipe supplying water from the overhead tank to instruments in the hydraulics lab, using a reducer and gate valve arrangement. Thus, the water without any significant head loss was made available to run the pilot plant as this was a necessary prerequisite to induce high-pressure pulse if needed for sludge blanket formation in the pilot plant. The hydraulics lab also has ample drainage and water recirculation facility as per the need. The pilot plant was designed for the continuous operations round the clock, but the experiments were carried out during the daytime and work was carried out from February to April 2016.

3.6. Selection of Parameters for carrying out Experimental Analysis:

In order to carry out the experiments on the fabricated Pulsator clarifier model to find out the economic dosage of chemicals for cost minimization, few parameters like inlet turbidity levels and coagulant dosage were selected through the analysis of the weekly reports of the Surajpura water treatment plant. 35 weeks data from June 2015 to January 2016 was analyzed. A total of seven turbidity values, i.e., 2,3,5,8,10,20,30 NTU were selected to be run on the pilot plant. The inlet turbidity at the Surajpura water treatment plant varied from 2- 14 NTU for the 35 week period and it was found that 99% of inlet turbidities were less than 13.9 NTU. Hence, five out of seven turbidities were selected below 13.9 NTU, viz, 2,3,5,8 and 10 NTU. Two turbidity values were selected above 13.9 NTU, viz, 20 and 30 NTU for research purpose.

A PAC dose of 25 ppm is been currently used at the plant under normal conditions. The dose is increased to 30 or 35 ppm in case colour in raw water is reported. Weekly analysis of coagulant dose show that 70% times a dose of 25 ppm was used at the plant. Hence, a PAC dose of 25 ppm and the alum dose having equivalent aluminium content were selected for the pulsator pilot plant.

Table 3.4: Inlet Turbidity and Coagulant dosage

Inlet Turbidity runs (Total -7)	**2,3,5,8,10,20,30 NTU**
Coagulant Dosage	**25 ppm PAC & Alum dose containing equivalent aluminium**

4. RESULTS & DISCUSSION

This chapter presents the overall results of the study. The data has been analyzed to bring out trends and inferences from the study.

4.1 Outcomes of the Surajapura WTP Field Visits:

Two daylong visits of Surajpura WTP were carried out by the Students and Faculty of Project Pulsator Group, one in early September and the other one in early October 2015. During the first visit, the sampling points were identified, and samples were collected at six points (as specified at para 3.2). The pre-chlorination and coagulant (PAC) dosage administered that day was 4.5 and 25 ppm respectively. In order to further examine the appropriateness of pre-chlorination dose, free chlorine was measured at various points using the Hanna Photometer being carried from the PHE Laboratory of MNIT Jaipur and the results are given in table 4.1.

Table 4.1: Free Chlorine at various points

S.No	Sampling Points	Free Chlorine in PPM
1	Raw Water	0.21
2	After Pre-chlorination before Parshal Flume	3.20
3	Before Pulsator	2.14
4	After Pulsator	0.95
5	After Filter	0.70

Free chlorine of 0.21 ppm in raw water was quite unexpected and was attributed to some experimental interference or limitation. Free chlorine of 3.20 ppm immediately after pre-chlorination dose of 4.5 ppm, indicated a loss of more than 1 ppm chlorine in moments and was a matter of concern. Though, the chlorine was supplied apparently deep into raw water (as shown in figure 4.1) but it appears that present arrangement is not suffice to prevent loss of chlorine and some alternate arrangements for better mixing of chlorine need to be made such as the pipe should go deeper into water with a little more length (may be by providing extra bend in pipe) and perforations should be there on pipe for better mixing of chlorine through these perforated outlets deep in water.

Figure 4.1: Pre-chlorination arrangement in raw water at Surajpura WTP

During the second visit, the water quality parameters at different stages i.e. raw water, clarified water (at pulsator outlet before filter) and treated water (after filter outlet) were measured using the instruments carried from the PHE laboratory of MNIT and also at the Plant laboratory by the students of the Project Pulsator Group at their own. The data (as given in table 4.2) was compared with the quality parameters as specified in the O&M contract and it was found that all the parameters were well within the specified limits and thus meeting the contract requirement fully.

The format for daily reports of the laboratory analysis to be carried out for five days in a row at the plant laboratory for three seasons were also discussed with the plant lab personnel. The ways and methods for sampling and lab analysis were also discussed in detail. It was brought to our notice that besides the standard methods and instruments used for measuring pH, turbidity, TDS and alkalinity, the lab personnel were using Lovibond colour comparator for measuring free chlorine and residual aluminium (using specific but undisclosed reagent by the supplier) having least counts as 0.25 mg/l and .05 mg/l as the least counts respectively.

Table 4.2: Onsite Test Results of Surajpura WTP

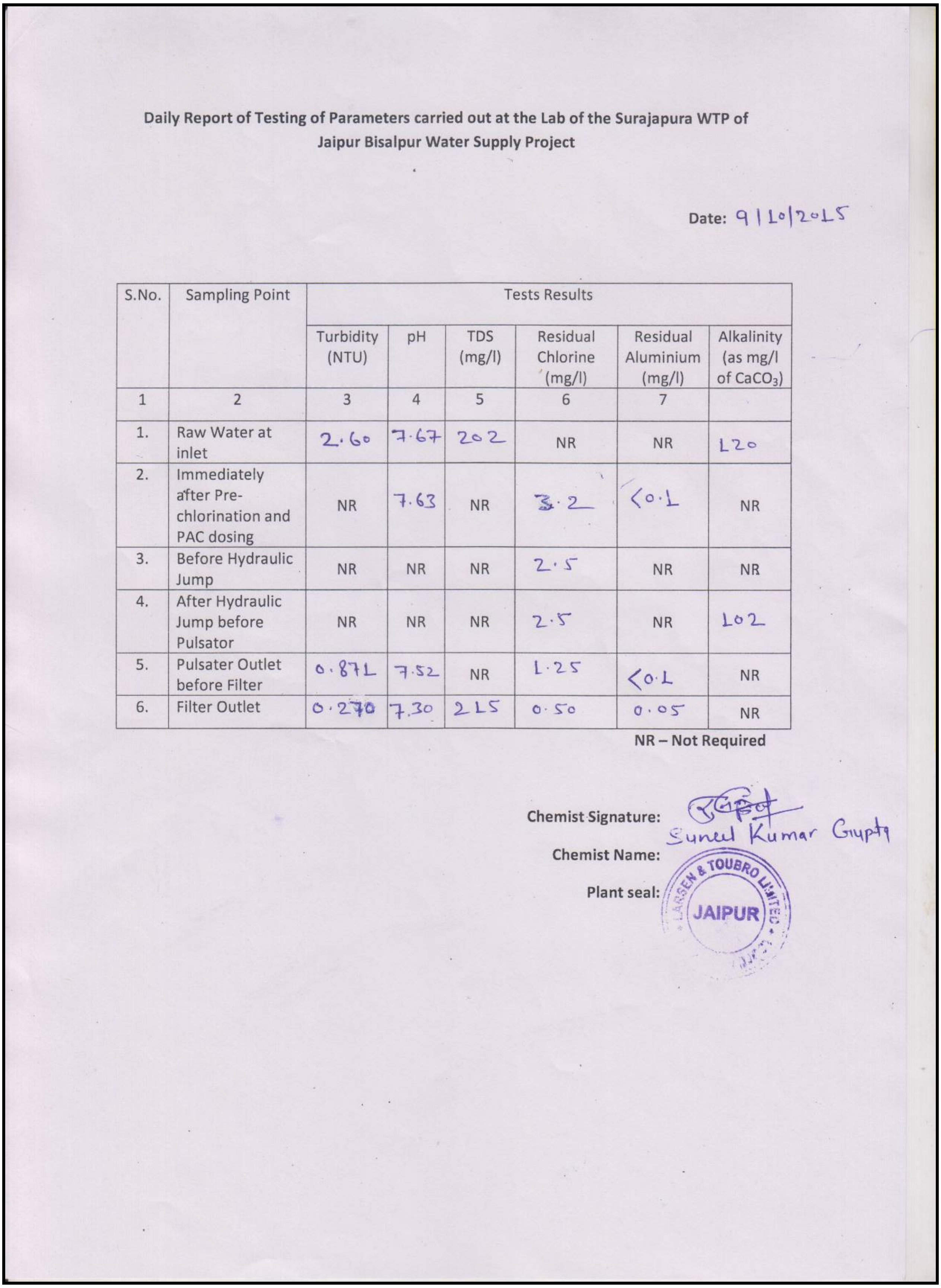
Particulars	Test results	As per contract
Raw water quality		
pH	7.68	7-8.5
Turbidity (NTU)	2.49	5-500
Colour (Hzn)	15	
Clarified water quality		
Turbidity (NTU)	0.913	<7
Suspended solids (mg/l)	1.79	<5
Treated water quality		
pH	7.28	7-8.5
Turbidity (NTU)	0.23	<0.5
Colour (Hzn)	1	<2
Iron (mg/l)	0.04	<0.1
R/Al as Aluminum (mg/l)	0.05	<0.1

4.2 Analysis of Five Day Results Over Three Seasons:

In order to carry out the performance analysis of the water treatment plant and also to account for seasonal variations, detailed laboratory analysis of quality parameters of water at different stages of treatment were carried out (as discussed in para 3.2) for five days in a row over three seasons that includes Post Monsoon (9-13 October 2015), Winters (19-23 January 2016) and Summers (18-22 April 2016). The data provided by the Plant laboratory in the typical format as discussed in para 3.2 is shown in figure 4.2. The quantity of data to be analysed every season was quite substantial and therefore it has been tried to present the data in four graphs that may indicate the daily variations vis-a-vis during the five-day period in the comparable values of various parameters (i.e. those parameters that can be presented on one scale has been taken in one graph).

4.2.1 Post Monsoon Data Analysis:

Figure 4.3 is showing analysis for turbidity values at three stages of water treatment namely (i) raw water at inlet, (ii) pulsator outlet and (iii) filter outlet over five days in Post Monsoon period whereas figure 4.4 is indicating pH values at the same locations as for figure 4.3.



Daily Report of Testing of Parameters carried out at the Lab of the Surajapura WTP of Jaipur Bisalpur Water Supply Project

Date: 9/10/2015

S.No.	Sampling Point	Tests Results					
		Turbidity (NTU)	pH	TDS (mg/l)	Residual Chlorine (mg/l)	Residual Aluminium (mg/l)	Alkalinity (as mg/l of $CaCO_3$)
1	2	3	4	5	6	7	
1.	Raw Water at inlet	2.60	7.67	202	NR	NR	120
2.	Immediately after Pre-chlorination and PAC dosing	NR	7.63	NR	3.2	<0.1	NR
3.	Before Hydraulic Jump	NR	NR	NR	2.5	NR	NR
4.	After Hydraulic Jump before Pulsator	NR	NR	NR	2.5	NR	102
5.	Pulsater Outlet before Filter	0.871	7.52	NR	1.25	<0.1	NR
6.	Filter Outlet	0.270	7.30	215	0.50	0.05	NR

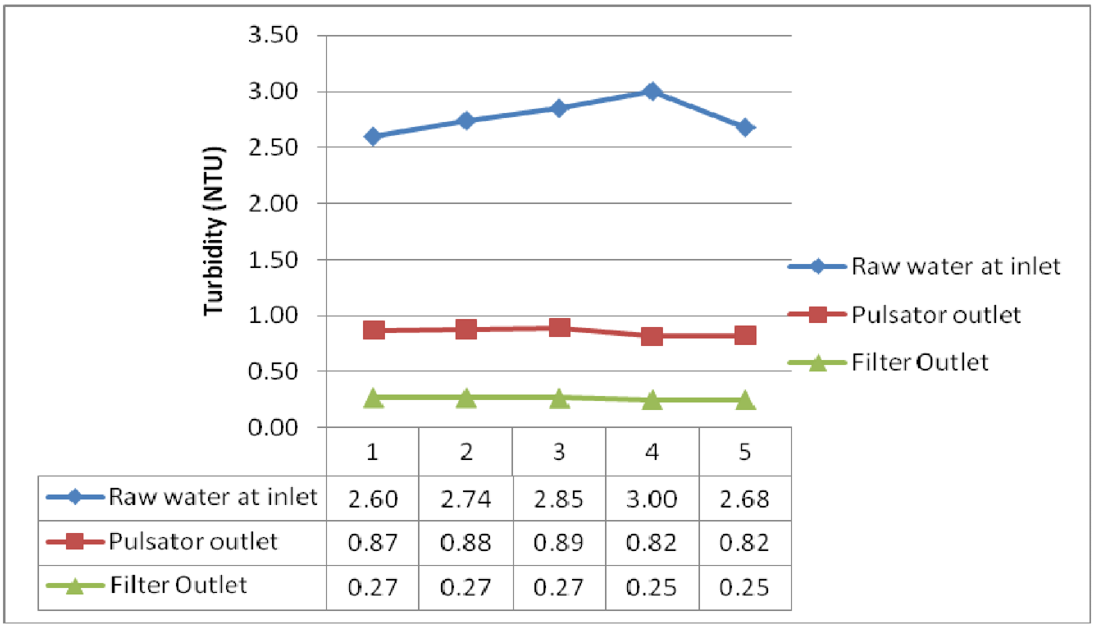
NR – Not Required

Chemist Signature:

Chemist Name: Suneel Kumar Gupta

Plant seal: LARSEN & TOUBRO LIMITED JAIPUR

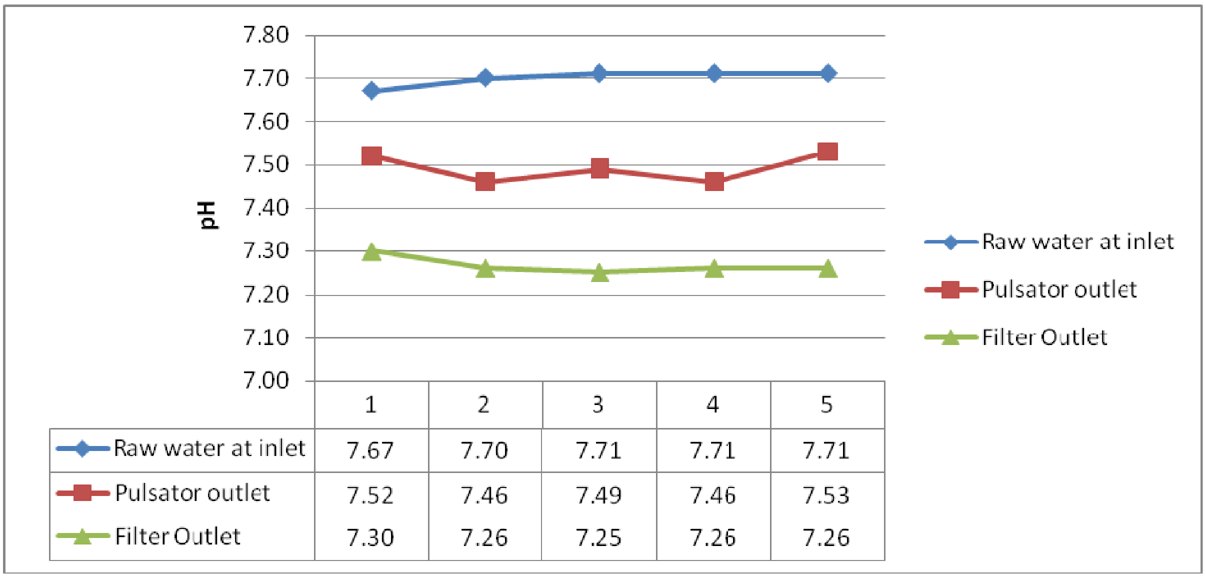
Figure 4.2: Picture of typical daily report obtained from Surajpura WTP



	1	2	3	4	5
Raw water at inlet	2.60	2.74	2.85	3.00	2.68
Pulsator outlet	0.87	0.88	0.89	0.82	0.82
Filter Outlet	0.27	0.27	0.27	0.25	0.25

Figure 4.3: Turbidity values Post Monsoon over five days (9-13 Oct. 2015)

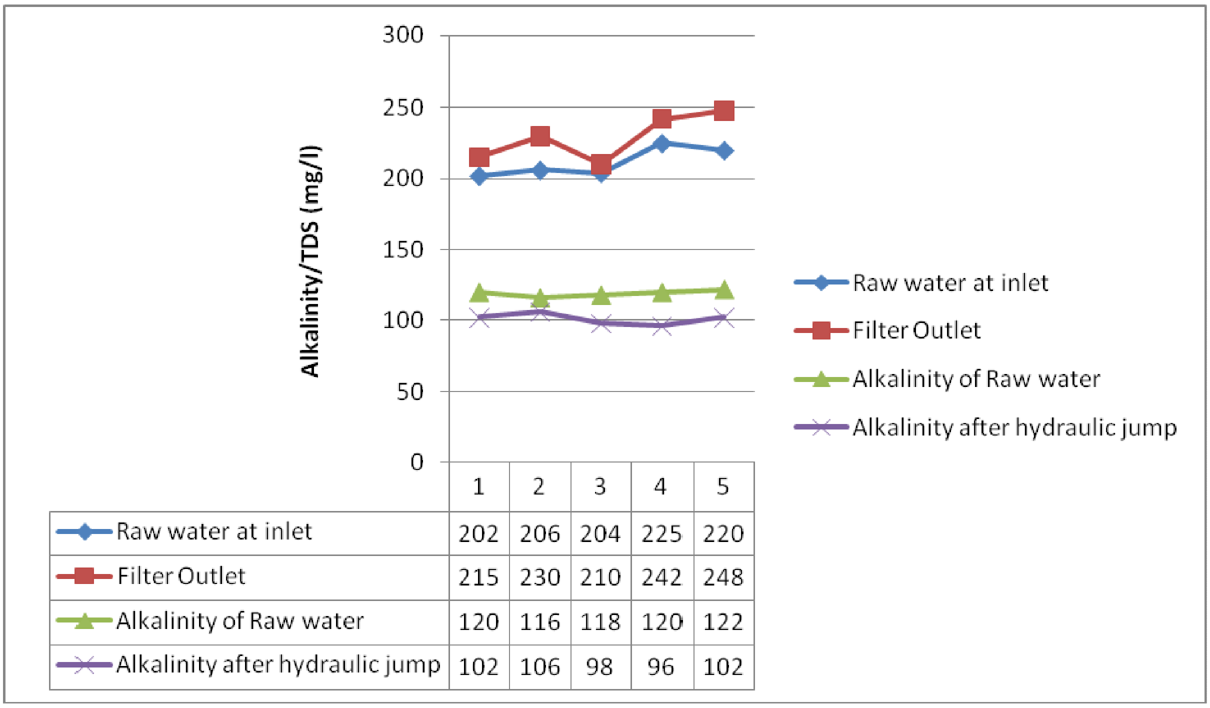
The data in figure 4.3 is indicating that raw water turbidity was unexpectedly quite low (being the post monsoon period) ranging from 2.6 – 3.0 only and removal up to pulsator was about 70 % and finally turbidity removal post filtration was more than 90 % and well within the treated water requirement (as per contract) of less than 0.5 NTU. Also, the pH at these locations as indicated in figure 4.4 was well within the specified range of 7.0 – 8.5.



	1	2	3	4	5
Raw water at inlet	7.67	7.70	7.71	7.71	7.71
Pulsator outlet	7.52	7.46	7.49	7.46	7.53
Filter Outlet	7.30	7.26	7.25	7.26	7.26

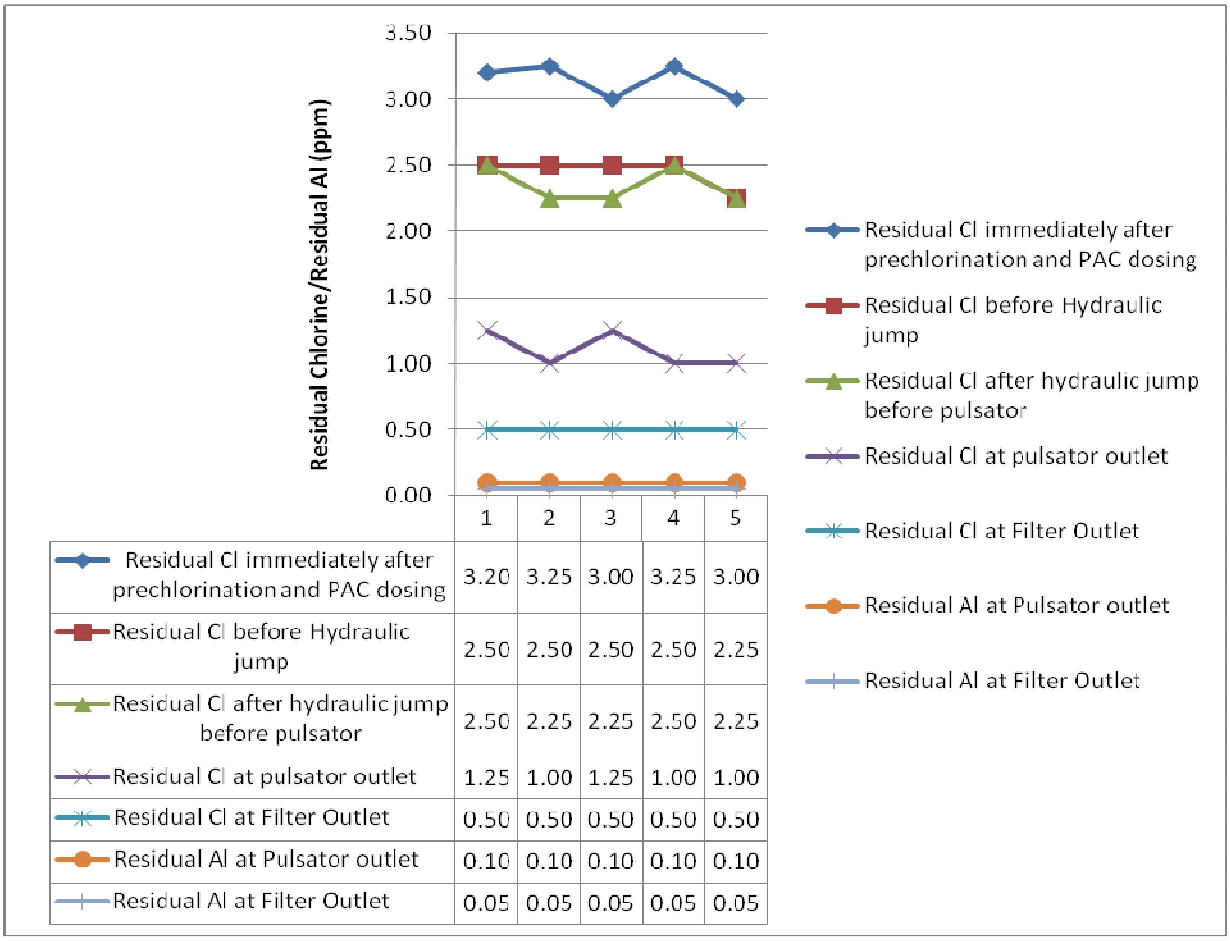
Figure 4.4: pH values Post Monsoon (9-13 Oct. 2015)

The values of TDS for the raw water at inlet and the filter outlet i.e. treated water and also the Alkalinity values of the raw water and at the point where coagulant is supposedly mixed completely i.e. just before pulsator (after hydraulic jump) are indicated in figure 4.5.



	1	2	3	4	5
Raw water at inlet	202	206	204	225	220
Filter Outlet	215	230	210	242	248
Alkalinity of Raw water	120	116	118	120	122
Alkalinity after hydraulic jump	102	106	98	96	102

Figure 4.5: TDS and Alkalinity values Post Monsoon (9-13 Oct. 2015)



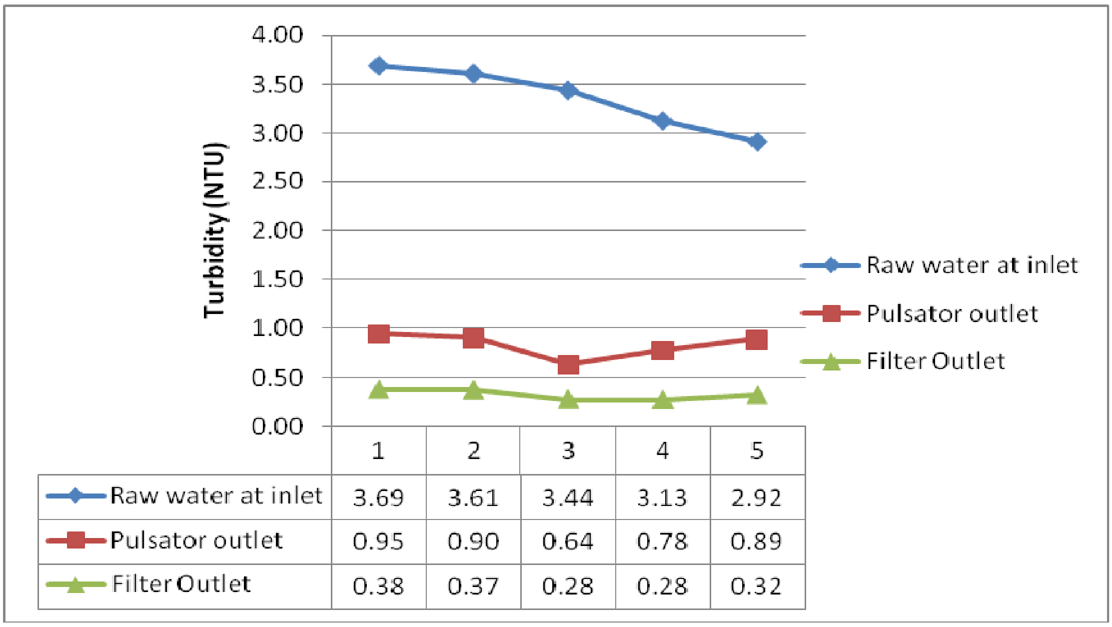
	1	2	3	4	5
Residual Cl immediately after prechlorination and PAC dosing	3.20	3.25	3.00	3.25	3.00
Residual Cl before Hydraulic jump	2.50	2.50	2.50	2.50	2.25
Residual Cl after hydraulic jump before pulsator	2.50	2.25	2.25	2.50	2.25
Residual Cl at pulsator outlet	1.25	1.00	1.25	1.00	1.00
Residual Cl at Filter Outlet	0.50	0.50	0.50	0.50	0.50
Residual Al at Pulsator outlet	0.10	0.10	0.10	0.10	0.10
Residual Al at Filter Outlet	0.05	0.05	0.05	0.05	0.05

Figure 4.6: Free Chlorine and Residual Al values Post Monsoon (9-13 Oct. 2015)

The TDS was increasing marginally during the treatment process due to addition of coagulant but no significant drop in alkalinity due to addition of coagulants was observed as indicated in figure 4.5. Figure 4.6 is showing the maximum data among the four graphs and indicating the values of free chlorine at five points namely (i) after pre-chlorination and PAC dosing, (ii) just before hydraulic jump, (iii) after hydraulic jump before pulsator, (iv) pulsator outlet and (v) filter outlet and the values of residual aluminium at two points namely (i) pulsator outlet and (ii) filter outlet are indicated. The free chlorine values at various points were in line with the earlier findings during the plant visit. The chlorine consumption in the clarifier feed channel as well as in the pulsator is about 1.00 ppm and in the filter it is about 0.5 ppm. However, there is a loss of more than 1.00 ppm immediately after pre-chlorination (as the pre-chlorination dose was 4.5 ppm) which is a matter of concern and needs rectification. Further, the aluminium at the filter outlet is reported as 0.05 ppm (as the least count of measuring instrument is 0.05 ppm) which is well within the contract limit of 0.1 ppm but doesn’t meet the latest water standards requirement of 0.03 ppm as per IS 10500 and thus a matter of concern. Further evaluation of residual aluminium is required.

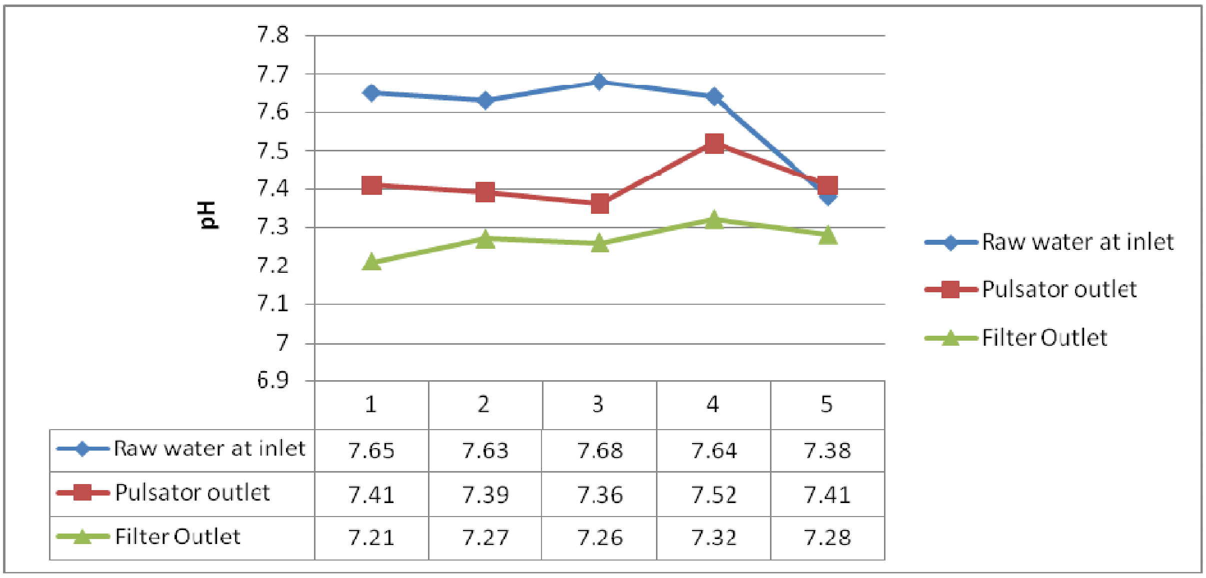
4.2.2 Winter Season Data Analysis:

During winters the raw water turbidity was again low and ranged from 2.9 to 3.7 as depicted in figure 4.7. The turbidity removal pattern was similar to post monsoon data and removal up to pulsator was about 70 % and finally turbidity removal post filtration was more than 90 %. Again, the pH as indicated in figure 4.8 was well within the specified range of 7.0 – 8.5.



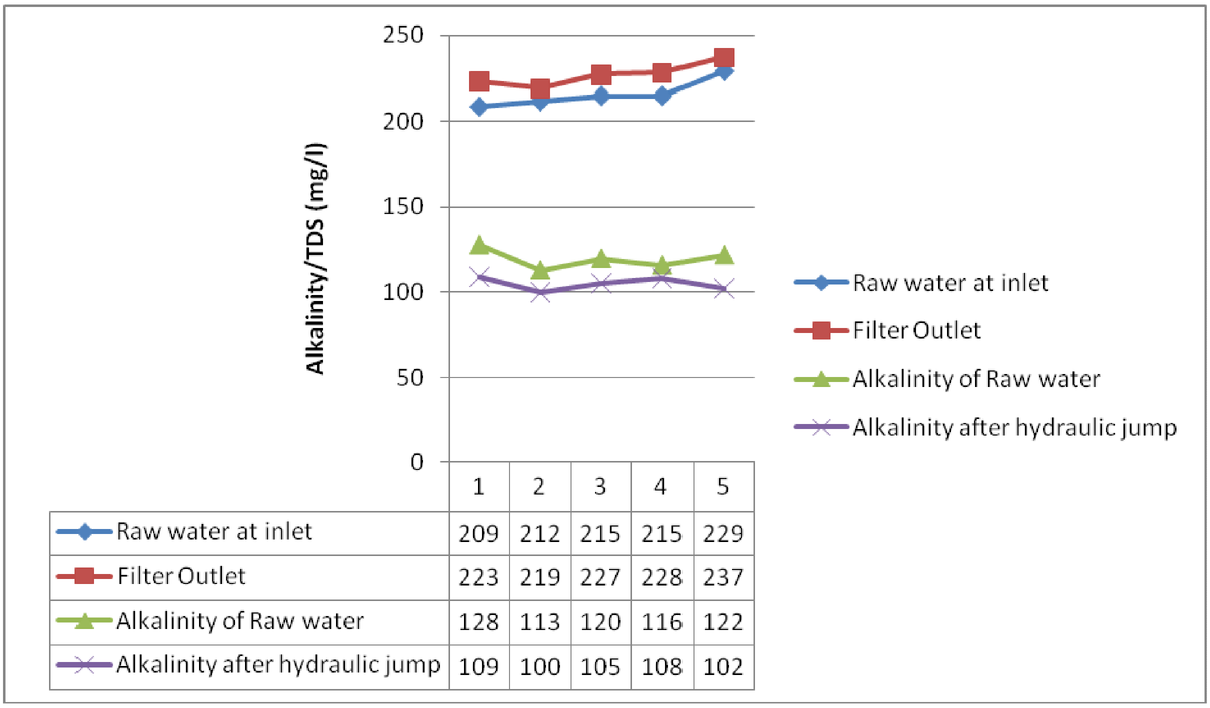
	1	2	3	4	5
Raw water at inlet	3.69	3.61	3.44	3.13	2.92
Pulsator outlet	0.95	0.90	0.64	0.78	0.89
Filter Outlet	0.38	0.37	0.28	0.28	0.32

Figure 4.7: Turbidity values in Winter Season over five days (19-23 Jan. 2016)



	1	2	3	4	5
Raw water at inlet	7.65	7.63	7.68	7.64	7.38
Pulsator outlet	7.41	7.39	7.36	7.52	7.41
Filter Outlet	7.21	7.27	7.26	7.32	7.28

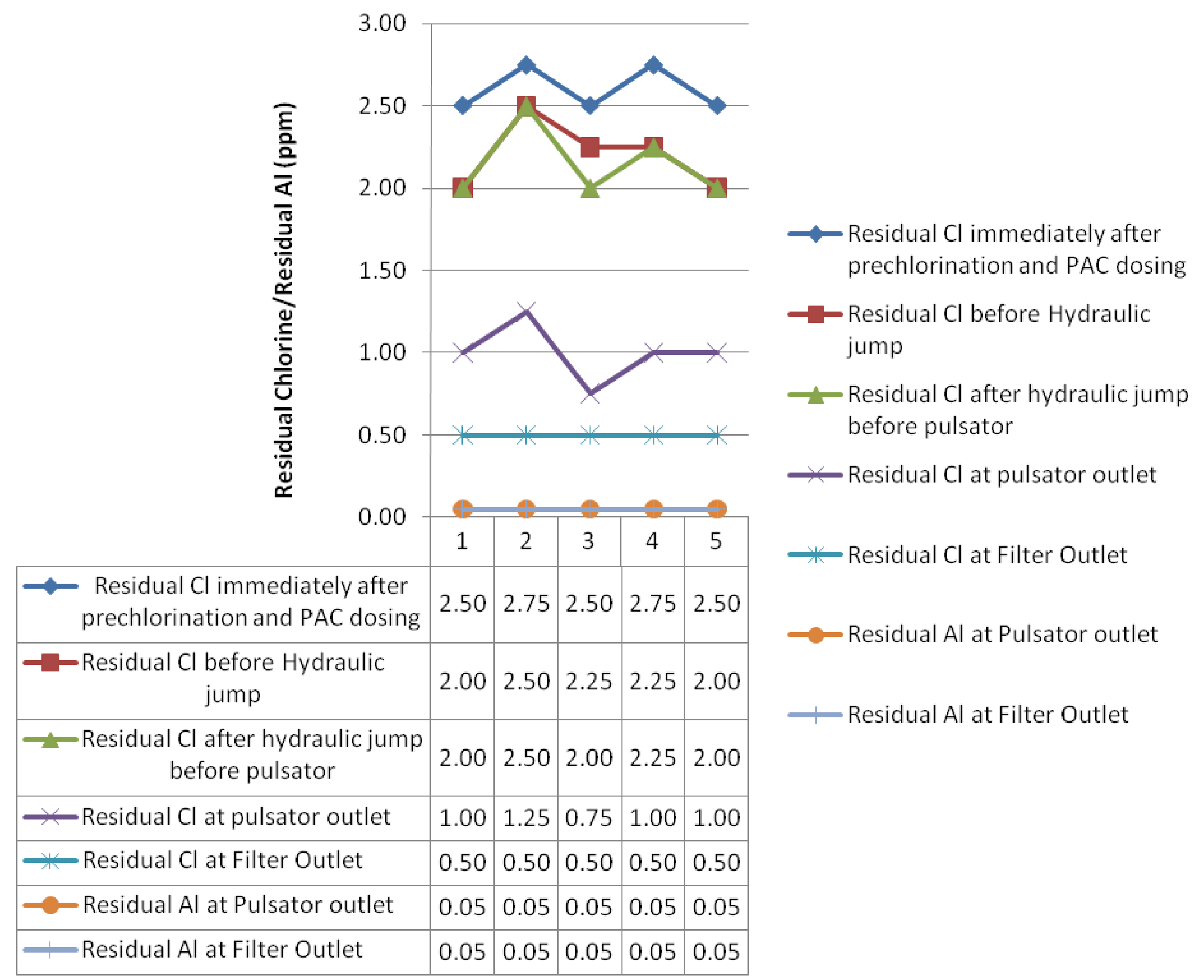
Figure 4.8: pH values in Winter Season (19-23 Jan. 2016)



	1	2	3	4	5
Raw water at inlet	209	212	215	215	229
Filter Outlet	223	219	227	228	237
Alkalinity of Raw water	128	113	120	116	122
Alkalinity after hydraulic jump	109	100	105	108	102

Figure 4.9: TDS and Alkalinity values in Winter Season (19-23 Jan. 2016)

The TDS and alkalinity values as depicted in figure 4.9 are having similar pattern as for the post-monsoon period and no significant changes were noticed. Figure 4.10 is showing results for free chlorine and residual aluminium for five days during winters. The pre-chlorination dose was 4.0 ppm thus again there is a loss of more than 1.00 ppm immediately after pre-chlorination. The consumption in clarifier feed channel is about 0.5 ppm which is a significant change from the post-monsoon period. However, consumption in pulsator and filter is similar to the post-monsoon period.

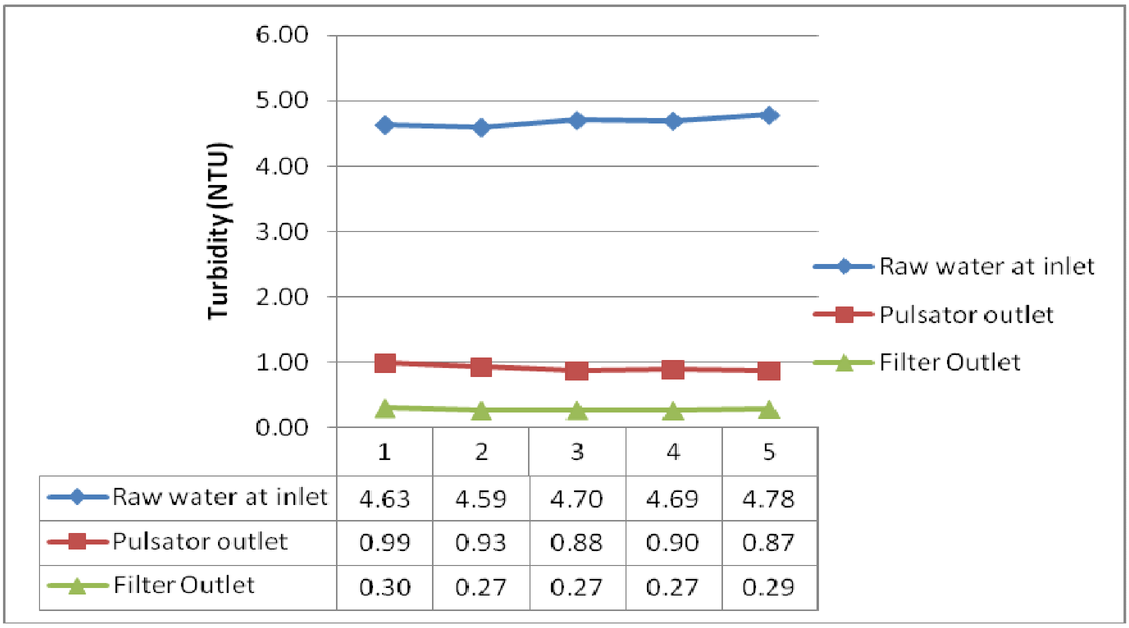


	1	2	3	4	5
Residual Cl immediately after prechlorination and PAC dosing	2.50	2.75	2.50	2.75	2.50
Residual Cl before Hydraulic jump	2.00	2.50	2.25	2.25	2.00
Residual Cl after hydraulic jump before pulsator	2.00	2.50	2.00	2.25	2.00
Residual Cl at pulsator outlet	1.00	1.25	0.75	1.00	1.00
Residual Cl at Filter Outlet	0.50	0.50	0.50	0.50	0.50
Residual Al at Pulsator outlet	0.05	0.05	0.05	0.05	0.05
Residual Al at Filter Outlet	0.05	0.05	0.05	0.05	0.05

Figure 4.10: Free Chlorine and Residual Al values in Winter Season (19-23 Jan. 2016)

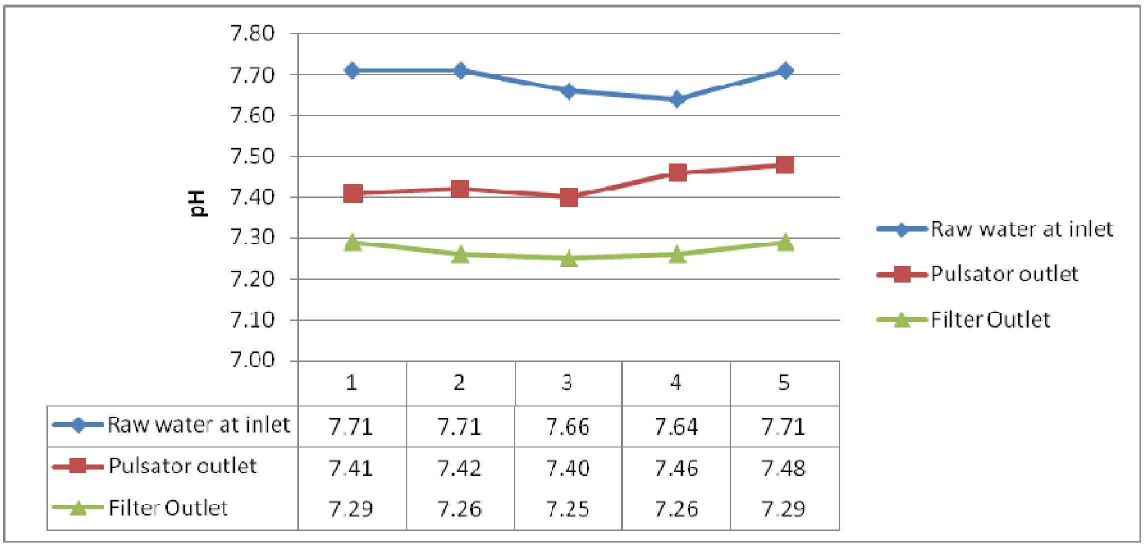
4.2.3 Summer Season Data Analysis:

During summers, the raw water turbidity was low and ranged from 4.6 to 4.8 as depicted in figure 4.11 but among the three seasons for which the data was analyzed, these turbidity levels were highest. The turbidity removal in pulsator clarifier is a little higher up to 80 % and post filtration turbidity removal is up to 95 % as the outlet turbidity is almost similar to the data for the other two seasons. Thus, this indicates that the removal efficiency in pulsator clarifier increases with the increased turbidity levels in raw water. Also, the pH as indicated in figure 4.12 was well within the specified range of 7.0 – 8.5 at different treatment stages of raw water.



	1	2	3	4	5
Raw water at inlet	4.63	4.59	4.70	4.69	4.78
Pulsator outlet	0.99	0.93	0.88	0.90	0.87
Filter Outlet	0.30	0.27	0.27	0.27	0.29

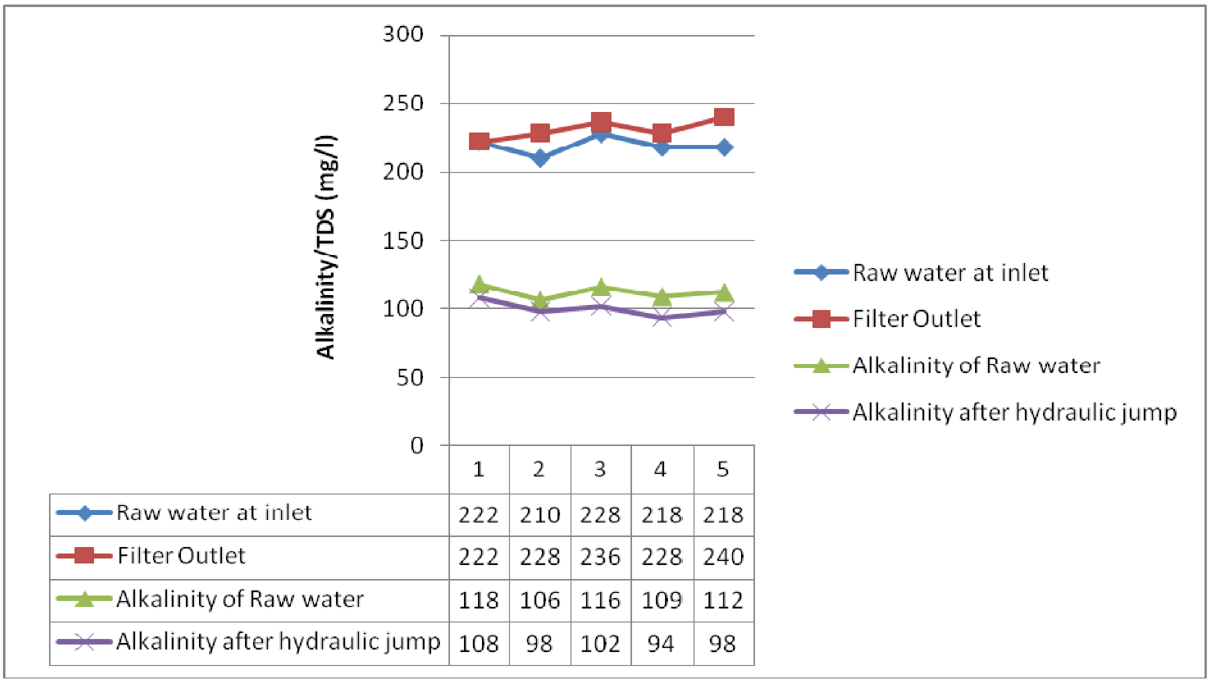
Figure 4.11: Turbidity values in Summer Season over five days (18-22 April 2016)



	1	2	3	4	5
Raw water at inlet	7.71	7.71	7.66	7.64	7.71
Pulsator outlet	7.41	7.42	7.40	7.46	7.48
Filter Outlet	7.29	7.26	7.25	7.26	7.29

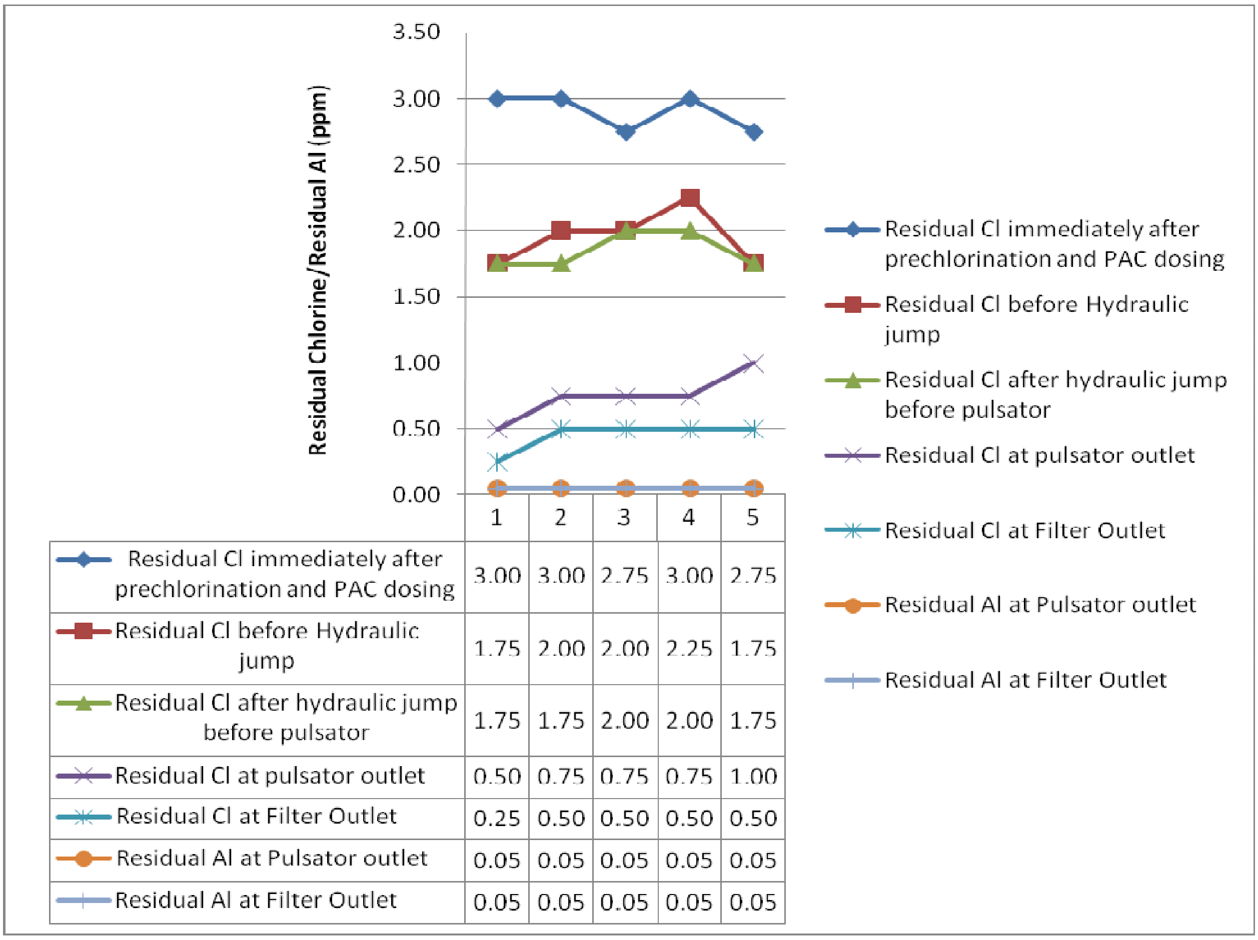
Figure 4.12: pH values in Summer Season (18-22 April 2016)

The TDS and alkalinity values for summer season as depicted in figure 4.13 are having similar pattern as for the other two seasons and no significant changes were noticed. The figure 4.14 is showing results for free chlorine and residual aluminium for five days during summers. The pre-chlorination dose was 4.25 ppm thus the chlorine loss of about 1.00 ppm immediately after pre-chlorination is similar to other two seasons data. The consumption in clarifier feed channel increased again to about 1.0 ppm from 0.5 ppm in winters but the consumption in filtration decreased to about 0.25 ppm which is a significant change from the winter season.



	1	2	3	4	5
Raw water at inlet	222	210	228	218	218
Filter Outlet	222	228	236	228	240
Alkalinity of Raw water	118	106	116	109	112
Alkalinity after hydraulic jump	108	98	102	94	98

Figure 4.13: TDS and Alkalinity values in Summer Season (18-22 April 2016)



	1	2	3	4	5
Residual Cl immediately after prechlorination and PAC dosing	3.00	3.00	2.75	3.00	2.75
Residual Cl before Hydraulic jump	1.75	2.00	2.00	2.25	1.75
Residual Cl after hydraulic jump before pulsator	1.75	1.75	2.00	2.00	1.75
Residual Cl at pulsator outlet	0.50	0.75	0.75	0.75	1.00
Residual Cl at Filter Outlet	0.25	0.50	0.50	0.50	0.50
Residual Al at Pulsator outlet	0.05	0.05	0.05	0.05	0.05
Residual Al at Filter Outlet	0.05	0.05	0.05	0.05	0.05

Figure 4.14: Free Chlorine and Residual Al values in Summers (18-22 April 2016)

4.3 Determination of Chlorine Demand of Bisalpur Raw Water:

The chlorine demand of the Bisalpur raw water in the month of October (post monsoon period) was determined at PHE lab of MNIT by analyzing the breakpoint as given in Chapter 3 of this thesis at para 3.3.1. The breakpoint chlorination curve was drawn as shown in figure 4.15. The chlorine demand of the raw water is about 5.25 - 5.50 ppm.

Table 4.3: Breakpoint Chlorination data of Bisalpur raw water

Chlorine Dosage (in ppm)	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	7.00	7.50	8.50
Residual chlorine (in ppm)	0.15	0.15	0.25	0.50	1.00	1.75	3.40	3.26	2.84	2.13	1.95	2.69	4.17	4.52	6.03

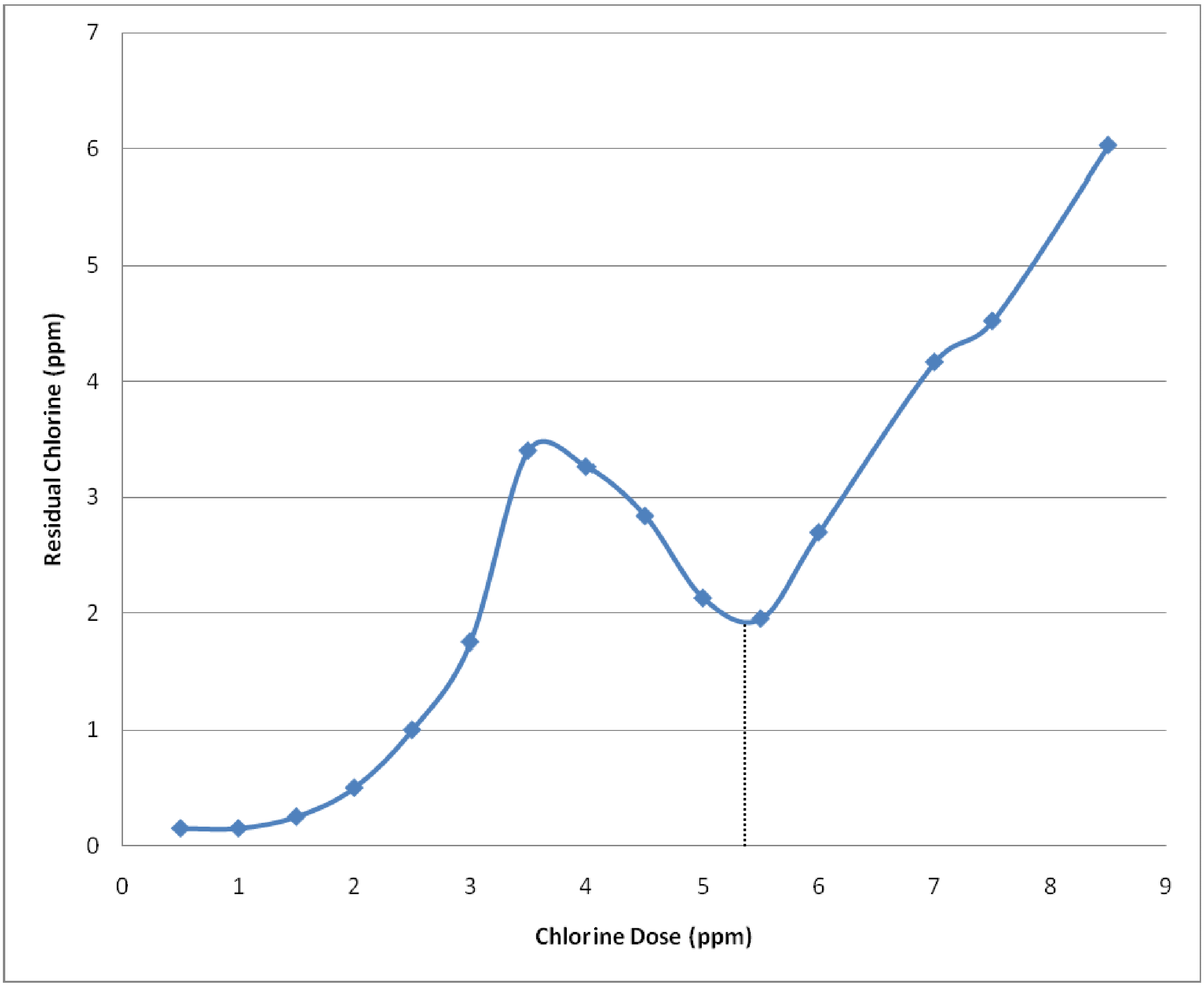


Figure 4.15: Determination of Chlorine Demand of Bisalpur Raw Water

Thus against the chlorine demand of 5.25 - 5.50 ppm, the presently administered chlorine dosage of about 4.25 – 5.0 ppm at the Surajpura WTP is on higher side as if this dose is utilized effectively (as presently it has been found that there is a likely loss of chlorine of up to 1.00 ppm at the pre-chlorination dosing point), this may cause complete oxidation of organics and leaves very little for clarification process. Thus, there is scope of reducing pre-chlorination dosage up to 3.00 ppm with better pre-chlorination dosing and mixing provisions.

4.4 Particle Size Analysis for Impact Assessment of Hydraulic Jump:

To establish the phenomenon that at the Surajpura WTP, the flocs formed during 10-12 minutes (after PAC dosing) in raw water channel and clarifier feed channels, breaks at the hydraulic jump just before the pulsator inlet and causes loss of clarification efficiency, the slow mixing in the raw water channel and clarifier feed channels was simulated as detailed in chapter 3 at para 3.3.1. The zeta potential and particle sizing results are presented in figure 4.16 and 4.18 respectively. The typical result as made available by the Nano Particle Analyzer (Malvern) at the MRC of MNIT Jaipur is also shown in figure 4.17.

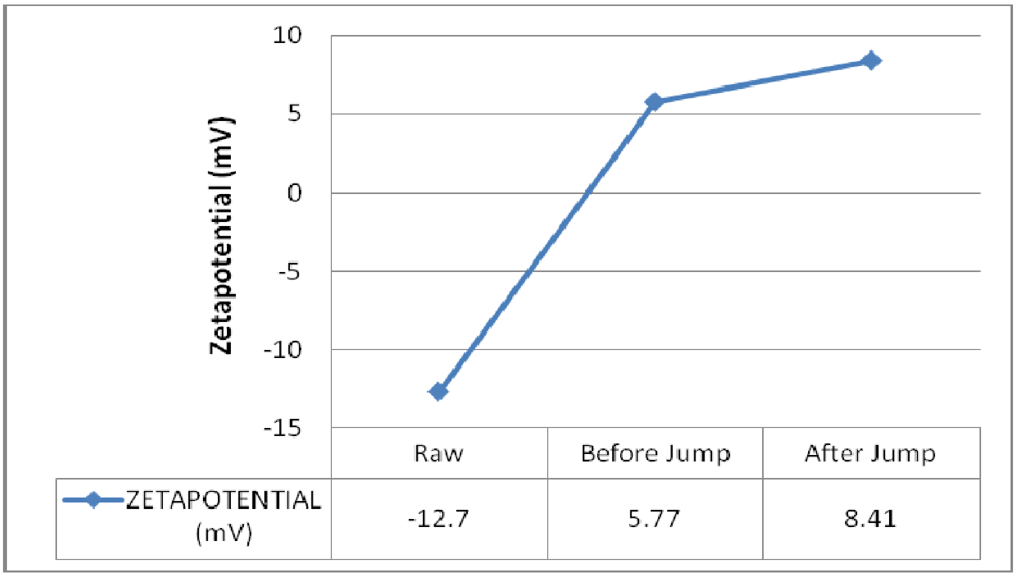
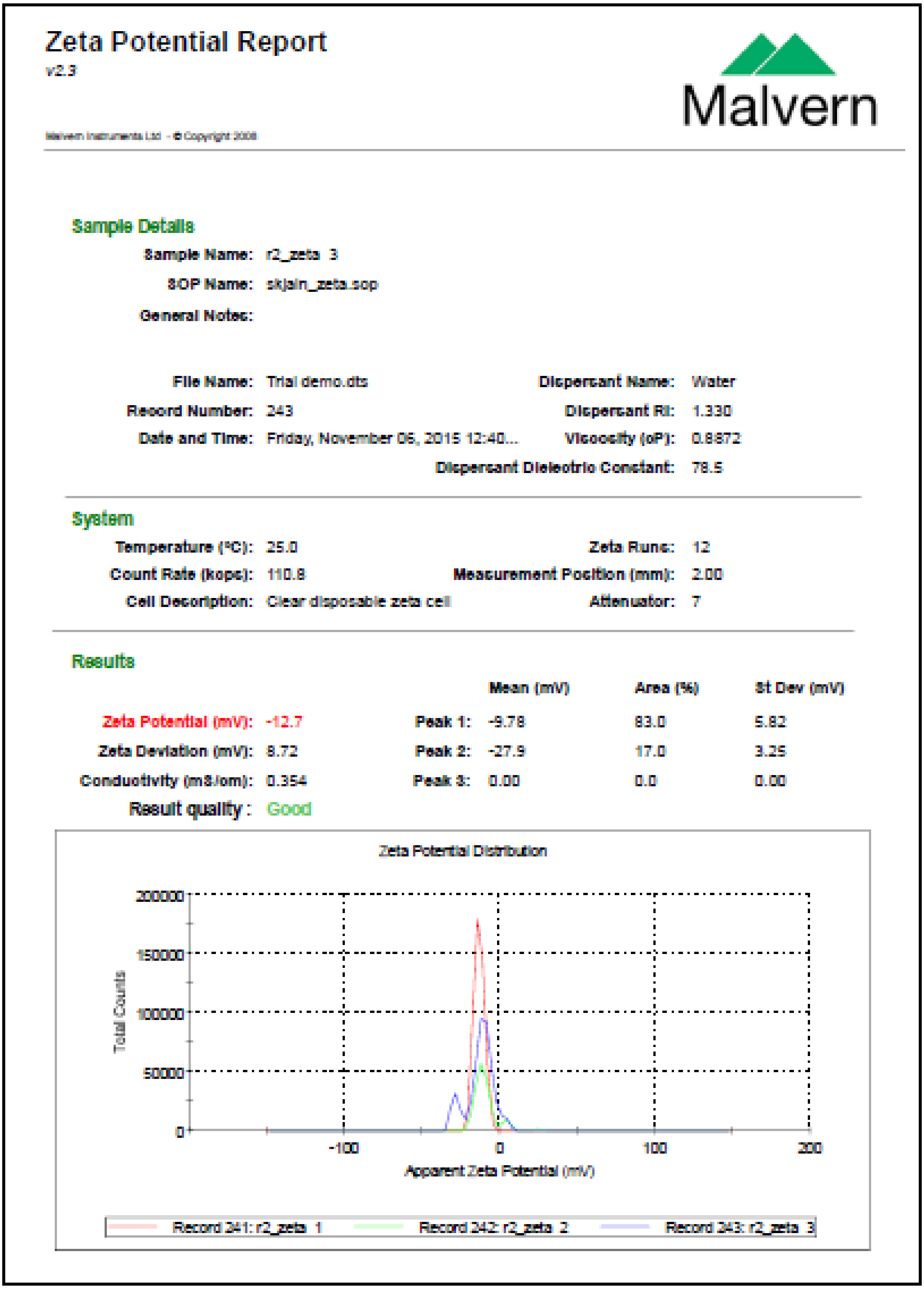


Figure 4.16: Results of Zeta Potential Analysis by the Nano Particle Analyzer

Figure 4.16 clearly depicts that the stabilized colloids and particles in raw water with a zeta potential of -12.7 mV got destabilized with a zeta potential of 5.77 mV (closer to the zeta potential range of destabilized colloids i.e. 0 to ± 5 mV) just before the hydraulic jump and thus also indicating the coagulation efficiency but after hydraulic jump these colloids and particles restabilizes as their zeta potential increases to 8.41 mV.



Zeta Potential Report

v2.3

Malvern Instruments Ltd - © Copyright 2008

Malvern

Sample Details

Sample Name: r2_zeta 3

SOP Name: skjain_zeta.sop

General Notes:

File Name: Trial demo.dts

Record Number: 243

Date and Time: Friday, November 06, 2015 12:40...

Dispersant Name: Water

Dispersant RI: 1.330

Viscosity (cP): 0.8872

Dispersant Dielectric Constant: 78.5

System

Temperature (°C): 25.0

Count Rate (kcps): 110.8

Cell Description: Clear disposable zeta cell

Zeta Runs: 12

Measurement Position (mm): 2.00

Attenuator: 7

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 4.17: Picture of typical zeta potential report from the Nano Particle Analyzer (Malvern) at the MRC of MNIT, Jaipur

Further, the particle sizing results as depicted in figure 4.18 also indicates this phenomenon as the particle sizing reduces after the hydraulic jump.

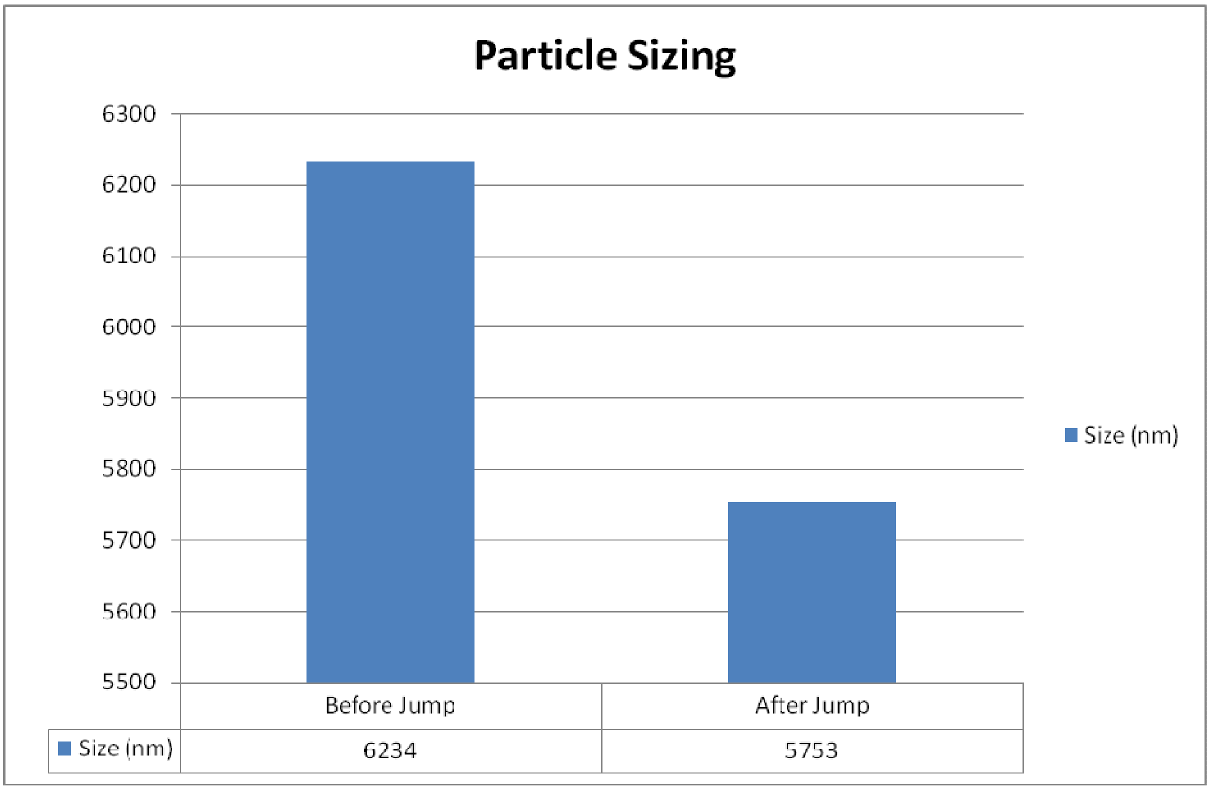


Figure 4.18: Results of Particle Size Analysis by the Nano Particle Analyzer (Malvern)

The results also indicated that 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 up to 6 microns only. We expected a higher floc sizes and therefore these results were considered as indicative only rather than confirmatory but the zeta potential results may be considered as confirmatory results.

4.5 Pulsator Clarifier Operation and Sludge Blanket Formation:

In a pulsator clarifier, sludge blanket not only helps in agglomerating newly formed floc but also helps the suspended and colloidal matter to adhere to the floc. Thus, blanket depth, homogeneity, and its physical properties play an important role in the flocculation process. One of the major objectives of this work was to carry out the study of pulsations and visual display of the process of sludge blanket formation. To achieve this, flow parameters i.e. pulsed flow and regular flow as well as the pulsation cycle i.e. the time duration of the pulse and the idle time before next pulse are of huge importance.

For our study, it was decided to establish a sludge blanket of height 1.2 m. The blanket was developed by seeding the sludge initially by feeding a very high dose of turbidity in the form of Bentonite. A 500 ppm dose of bentonite and a 100 ppm dose of PAC were fed into the system for four hours for two days. The sludge blanket gradually increased in volume due to entrapping of the impurities contained in the feed water. The blanket was kept in suspension by adjusting the regular and the pulse flow. An increase in pulse flow pushes the particles upwards and keeps them in suspension. A decrease in pulse flow gives the flocs time to settle under gravity. After few trials, the pulse cycle was set to 55 seconds where the pulse duration was 10 seconds and the idle time was 45 seconds. The height of the blanket is maintained at desired level by continuously extracting the sludge through the hopper (as per the detailed arrangements given in chapter 3 at para 3.4). Figure 4.19 is depicting the pictures of initiation of sludge blanket formation in the pilot plant.

Figure 4.19: Photograph of blanket formation in Pulsator pilot plant

Numerous combinations of pulsed and regular flow were run on the pulsator model so that the sludge blanket remains stable in suspension and of desired height, i.e 1.2 m above the bottom. Based on this, a regular flow of 2.2 lpm and a pulsed flow of 8.8 lpm were worked out after several trials for conducting the experimentation further. Thus, the system was operated at an overall flow of 3.745 liters/ minute and a capacity of 5393 liters/day. The operating pulse flow also worked out to be four times the regular flow as per the design criteria. The pictures of stable sludge blanket in its full height of 1.2 m from different angles are depicted in figure 4.20.

Figure 4.20: Pictures of Stable Sludge Blanket in its Full Experimental Height

Though the pilot plant was designed and installed for continuous round the clock operation but during its operations it was figured out that it takes 60 to 90 minutes in full development of sludge blanket from the start and also since the actual calculated rise rate of the system with the stabilised flow conditions at 3.745 lpm was about 2.75 m/hr as against the designed rise rate of 3 m/hr, the rise time from inlet to outlet was worked out as approximately 40 minutes. Thus, the system stabilizes as a continuous system within a maximum period of about 2.5 hrs for carrying out experiments with different set of coagulant and turbidity dosage and accordingly daylong operations of the pilot plant were carried out for the desired experimental analysis.

4.6 Experimental Analysis on Pulsator Clarifier Pilot Plant:

Experiments on the fabricated Pulsator clarifier model were carried out in order to optimize the pulsator clarification efficiency vis-à-vis economic dosage of coagulant. As detailed in chapter 3 at para 3.6, a total of seven turbidity values, i.e., 2,3,5,8,10,20,30 NTU were run in the pulsator with a PAC dose of 25 ppm and the alum dose having equivalent aluminium content that was about 16.4 ppm for the alum used at the PHE lab, MNIT Jaipur.

4.6.1 Turbidity Removal Analysis with PAC as Coagulant:

Figure 4.21 is showing results of turbidity removal in the pulsator and then in filtration with 20 micron and 11 micron filters with 25 ppm dose of PAC as coagulant for all the seven turbidity levels. Figure 4.22 is showing the percentage removal and thus indicating the clarification and filtration efficiencies.

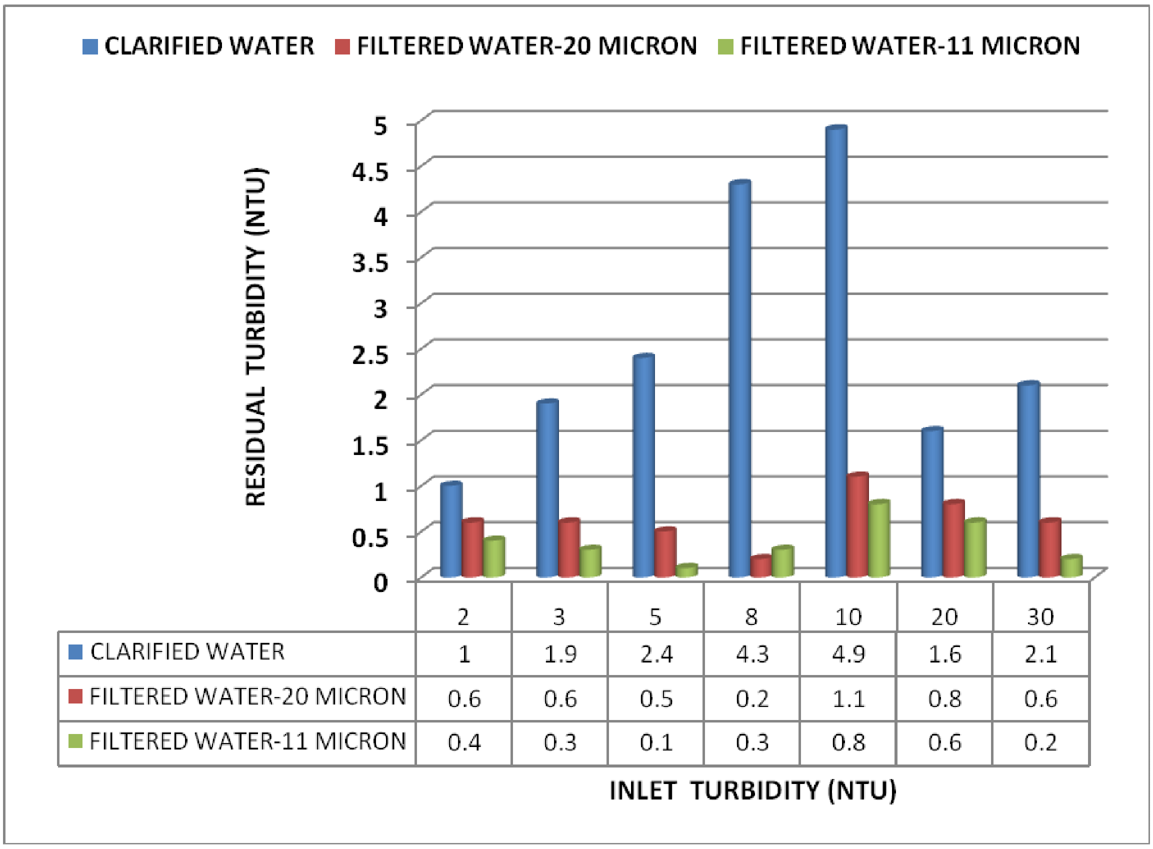
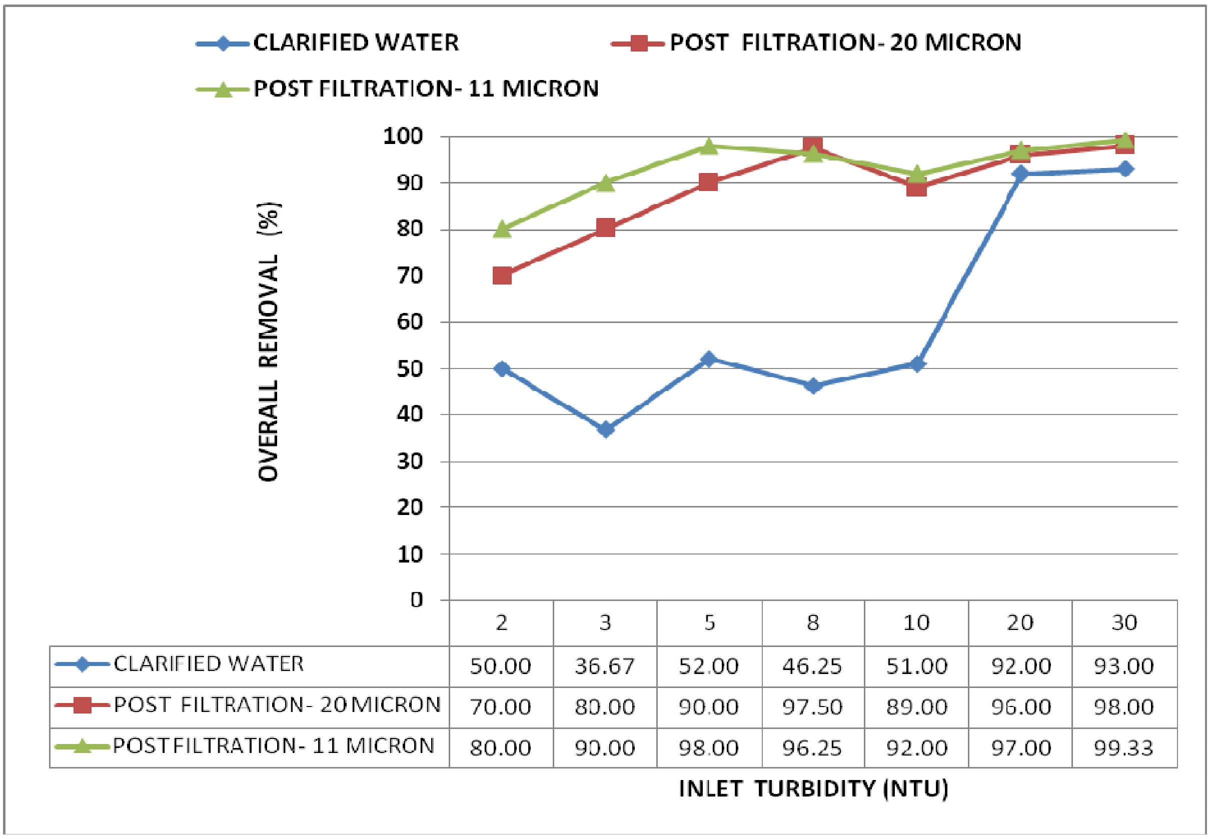


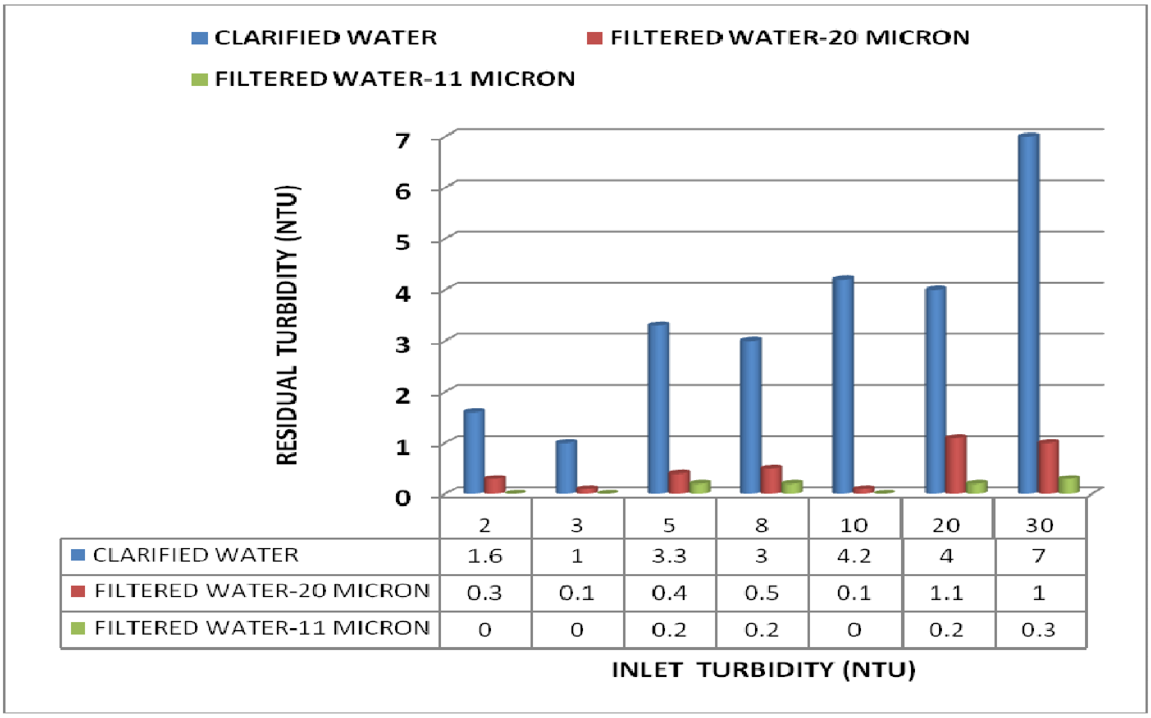
Figure 4.21: Turbidity Removal with PAC in Pulsator vis-a-vis Filtration



	2	3	5	8	10	20	30
CLARIFIED WATER	50.00	36.67	52.00	46.25	51.00	92.00	93.00
POST FILTRATION- 20 MICRON	70.00	80.00	90.00	97.50	89.00	96.00	98.00
POST FILTRATION- 11 MICRON	80.00	90.00	98.00	96.25	92.00	97.00	99.33

Figure 4.22: Percentage Turbidity Removal in Pulsator vis-a-vis Filtration (PAC)

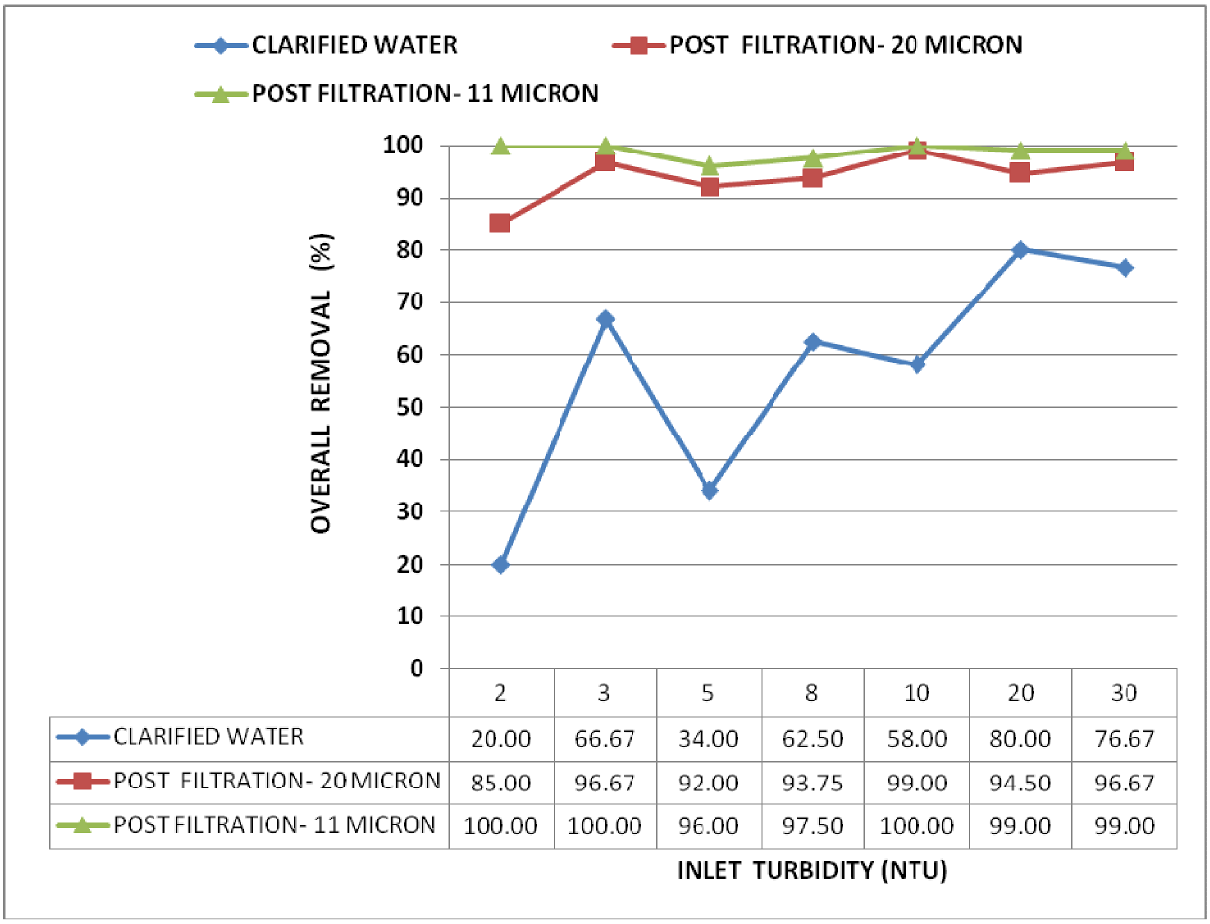
4.6.2 Turbidity Removal Analysis with Alum as Coagulant:



	2	3	5	8	10	20	30
CLARIFIED WATER	1.6	1	3.3	3	4.2	4	7
FILTERED WATER-20 MICRON	0.3	0.1	0.4	0.5	0.1	1.1	1
FILTERED WATER-11 MICRON	0	0	0.2	0.2	0	0.2	0.3

Figure 4.23: Turbidity Removal with Alum in Pulsator vis-a-vis Filtration

Figure 4.23 is showing results of turbidity removal in the pulsator and then in filtration with 16.4 ppm dose of alum as coagulant for all the seven turbidity levels. Figure 4.24 is showing the overall percentage turbidity removal.



	2	3	5	8	10	20	30
CLARIFIED WATER	20.00	66.67	34.00	62.50	58.00	80.00	76.67
POST FILTRATION- 20 MICRON	85.00	96.67	92.00	93.75	99.00	94.50	96.67
POST FILTRATION- 11 MICRON	100.00	100.00	96.00	97.50	100.00	99.00	99.00

Figure 4.24: Percentage Turbidity Removal in Pulsator vis-a-vis Filtration (Alum)

From the figure 4.22 & 4.24, it can be clearly inferred that the pulsator efficiency increases with the increase in the raw water turbidity. The pulsator efficiency with the raw water turbidity of 20 and 30 NTU is above 90% with PAC and about 80% with alum whereas when the inlet turbidity levels are less than 10 NTU, it is about 50% for PAC and 60% for alum. This inference that the pulsator efficiency increases with the increase in the raw water turbidity is in line with the pulsator behaviour at the Surajpura WTP as when the raw water turbidity (4.5 – 4.8 NTU) was higher in the summer season (April 2016), the pulsator efficiency was about 80% as against the pulsator efficiency of 70% during the low turbidity levels (2.6-3.0 NTU) in post monsoon period (October 2015).

Also, the residual turbidity levels after pulsator even for low inlet turbidity levels which are at par with the Bisalpur raw water turbidity levels, is on higher side than the Surajpura WTP pulsator clarifier for both the PAC and Alum as coagulants but post filtration turbidity levels of pulsator pilot plant are at par with Surajpura WTP levels, even when the inlet turbidity is much higher i.e. up to 30 NTU. Thus, this clearly signifies the importance of filtration in maintaining the outlet turbidity levels low for the treated water.

Thus in view of above arguments, it can be stated that the high dosage of PAC (25 – 40 ppm) at the Surajpura WTP for raw water turbidity levels below 10 NTU are of little use and there exists a strong opportunity to reduce the PAC dosage to the range of 5 -10 ppm in steps. This may cause a little increase in load on filters but as per the plant analysis corroborated by experimental analysis, it can be stated that the filters can very easily take this little increase in loading.

5. CONCLUSIONS AND RECOMMENDATIONS

1. The output water quality parameters data as analysed during the plant visits as well as analysed over three seasons that includes post monsoon period (October 2015), winters (January 2016) and summers (April 2016) for a substantial period of five days every season, clearly indicates that the Surajpura WTP is performing well and all the parameters are well within the specified limits and thus meeting the contract (O&M contract) requirement fully. Also, the residual aluminium at the filter outlet is reported as 0.05 ppm (as the least count of measuring instrument is 0.05 ppm) which is well within the contract limit of 0.1 ppm but doesn't meet the latest water standards requirement of 0.03 ppm as per IS 10500 and thus a matter of concern. Further evaluation of residual aluminium is required.

2. The chlorine demand of Bisalpur dam raw water is about 5.25 - 5.50 ppm against this the presently administered chlorine dosage of about 4.25 – 5.0 ppm at the Surajpura WTP is on higher side as if this dose is utilized effectively (as presently it has been found that there is a likely loss of chlorine of up to 1.00 ppm at the pre-chlorination dosing point), this may cause complete oxidation of organics and leaves very little for clarification process. Thus, there is scope of reducing pre-chlorination dosage up to or below 3.00 ppm with better pre-chlorination dosing and mixing provisions such as the pipe should go more deeper into water with a little extra length (may be by providing extra bend in pipe) and perforations should be there on pipe for better mixing of chlorine through these perforated outlets deep in water.

3. The particle size analysis results obtained by simulating the slow mixing in the raw water channel and clarifier feed channels of the Surajpura WTP, established that the flocs formed during 10-12 minutes (after PAC dosing) in raw water channel and clarifier feed channels, break at the hydraulic jump just before the pulsator inlet causing loss of clarification efficiency. However, overall results indicate that despite the flocs breaking at the pulsator inlet distribution weir, the sludge blanket was effective in capturing the suspended solids substantially. It is recommended that relocating the PAC dosing point to inlet distribution weir will help reducing chemical consumption and thus may lead to process optimization.

4. Successful fabrication and operation of Pulsator Clarifier Pilot Plant in Perspex sheet provided the rare opportunity to visualize and thus better understand the process of sludge blanket formation. The visual display of sludge blanket helped in acquiring knowledge about the parameters governing stability of the blanket in suspension especially through intermittent but regular sludge extraction and also to control its thickness by adjusting the regular and the pulsed flow, which is one of the most significant achievements of this study.

5. Analysis of the data of pulsator behaviour over three seasons indicated that the turbidity removal efficiency in pulsator clarifier increases with the increased turbidity levels in the raw water. This inference was further corroborated by the experimental analysis carried out with the pulsator pilot plant using both PAC and alum as coagulants.

6. Surajpura WTP plant data as well as the experimental data of pulsator pilot plant indicated that the filtration has a very significant role in maintaining the outlet turbidity levels low for the treated water specifically in ensuring the outlet turbidity is below the contract level of 0.5 NTU even when the inlet or raw water turbidity levels are high up to 30 NTU.

7. Thus, in view of the arguments placed at point 5 & 6, it is recommended that there exists a strong opportunity to reduce the PAC dosage to the range of 5 -10 ppm in steps from the presently administered dosage of 25 – 40 ppm at Surajpura WTP particularly when the raw water turbidity levels are below 10 NTU. This may cause a little increase in load on filters but as discussed earlier the filters can very easily take this increase in loading as presently they are highly underutilized.

6. FUTURE RESEARCH

After the successful operation of Pulsator Clarifier Pilot Plant and the knowledge acquired in sludge blanket formation and its regulation, there appears to be a no. of practical research ideas that can be executed. Few of these are:

1. Suggestion of a better and economical coagulant, as against 100% Polyaluminium Chloride being currently administered at the Surajpura WTP of Bisalpur-Jaipur Water Supply Project (BJWSP). The ability of the pulsator clarifier to handle low solids concentration water and chemistry of the water supplied from the bisalpur dam, *prima facie* warrant a deeper investigation of the coagulation mechanism and the coagulant used. Combinations of alum, Polyaluminium Chloride and other chemicals can be simulated to come up with an improved coagulant for the Surajpura WTP.

2. Primary aim of the present experiments was to asses and quantizes the turbidity removal and effectiveness in minimizing the residual aluminium which has been carried out to some extent but a lot is still to be done by using varying coagulants and their dosage as well as combinations of these coagulants.

3. The present study can be extended to examine the direct removal of many other contaminants that can be adsorbed by colloids. These contaminants include metals such as arsenic, toxic organic matter, viruses, emerging pathogens such as Cryptosporidium and Giardia, and humic materials.

4. The potential of pulsed sludge blanket technology in fluoride removal may also be examined. Particularly, this technology may be examined for replacing the settler and membrane combination in the ‘Nalgonda’ process equipment for the de-fluoridation of water. It is also expected that the new design employing this technology would result in much reduced residual aluminium levels.

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