# Experiments On Tube Settler For The Treatment Of Fbw And Optimization Of Plant Operation For Residual Reduction

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## ABSTRACT

Conventional water treatment plant generates two types of process wastes, filter back wash water and sludge. Characteristic studies of these wastes reveals that it contains high solids content, metals and bacteriological concentration, which are generally more than permissible disposable standards. Direct disposal of these wastes in to natural stream pollutes the receiving streams, affects human health on downstream users and violation of disposal standards. These wastes constitute considerable amount of water and direct disposal of filter back wash water causes wastage of these scare resources. Thus direct disposal of water treatment plant waste will affect the natural ecosystem. This study intends to develop a residual reduction and reuse plant for filter back wash water in conventional water treatment plant. The main objective of the present study is to reduce the amount of filter back wash water generated, by modifying the operational conditions of filter back wash and to know the potentiality of tube settler on the removal of FBW sludge. This study also encompasses the reuse of FBW sludge as a raw material for brick manufacturing. Optimization studies on filtration as well as back wash processes were conducted at Chavasseryparamba water treatment plant, Kerala and operational modifications mainly focused on the reduction of residual generated during back wash. Characterization of filter back wash water and sludge were carried out to assess the pollutant loading, degree of treatment and possible reuse options. Laboratory scale tube settler experiments were conducted to study the settling character of filter back wash water. FBW sludge has been characterized and the result of which reveals that, it contains metal oxides such as $SiO_2Al2O_3$, CaO, $Fe_2O_3$ and MgO.FWB sludge has mixed with brick earth for different proportions, molded to the standard brick dimensions and sun dried over a period of seven days. Results of optimization studies on the operation of rapid sand filter and its back wash shows that the optimum filter loading rate and filter run volume are found to be 8m/hr, and $560m^3/m^2$ respectively. With the above mentioned optimum operating conditions the filter back wash volume reduce up to 18%, Results of characteristic study of FBW reveals that filter back wash water contains high solid content and bacterial density of 53 NTU and 3286 MPN/ 100ml, respectively. Experimental studies on tube settler show that both theory of discreet particle settling and flocculent settling are applicable for the treatment of filter back wash water. From the tube settler studies, it is observed that optimum settling velocity of $6.40x10^{-4}$m/s is found to be more suitable for tube settler treatment of FBW water with recycle in conventio0nal WTP (effluent turbidity < 30 NTU).How ever if we need to treat the FBW water without passing through conventional treatment, i.e., directly passing the FBW water through tube settler along with disinfection process, then the ideal settling velocity through tube settler found to be $3.27 \times 10^{-4}$m/s. At this velocity the effluent turbidity of the tube settler is found to be less than 10 NTU.

Characteristics of FBW sludge reveals that it contains higher organic material (26.50%) and metallic oxides. Mineralogical studies reveals that sludge contain higher percentage of clay and silt(57%). Presence of metallic oxides and fine clay and silt particles make WTP sludge favorable for the usage in brick making, however, the presence of higher organic content limits the usage. The optimum sludge usage in brick making was found to be 25percent by volume. The compressive strength of brick made with WTP sludge are found to be on par with BIS requirements. Brick made with 25 % sludge have compressive strength of 111.65 kg/ $cm^2$which comes under class10 of IS 1077(1992) which can be used for all type of construction.

**KEYWORD:** Experiment, Tube Settler, Treatment Of Fbw, Optimization, Plant Operation, Residual Reduction

## 1. INTRODUCTION

### 1.1 GENERAL

Water treatment is the main process which satisfies the basic need of potable water to public. Separation–based unit operations are the major processes of drinking water production, with the objectives of removal of physical, chemical and biological contaminants present in the raw water. This process results in generation of waste streams, due to system cleaning procedure to ensure treatment performance and in some unit operations, part of source water is get converted as residuals. Raw water quality and unit operations define the character and volume of residuals streams generated in water treatment process. Generally in conventional water treatment plants, major unit operations such as coagulation, flocculation, sedimentation, filtration and disinfection are being practiced, in which solids removal is achieved by sedimentation and filtration process.

In coagulation process chemicals (coagulants) have been used to destabilize colloidal particle and bring them together to form flocks. Flocculation is the process of agglomeration of flocks with or without using coagulant aid. Sedimentation is the settling process under quiescent conditions. The semi solid residuals generated from sedimentation process are known as sludge. The quantity of sludge generated from clarification process is depending on the total suspended solids concentration of raw water, removal efficiency of the process and chemical dosage. Conventionally in coagulation process the coagulant used is aluminum sulphate (Alum- $Al_2 (SO_4)_3 18H_2O$) and the typical contaminant are suspended solids, organics, inorganic, and metals. The residual produced from this operation is coagulant sludge, contain high percentage of gelatinous hydroxide precipitates ($Al_2 (OH)_3$). When alum is added to water containing colloidal suspended solids, it reacts with the alkalinity present (or provided) according to the following reaction.

$Al_2(SO_4)_3.18H_2O + 3\ Ca(HCO_3)_2 = 2\ Al\ (OH)_3 + 3\ CaSO_4 + 6\ CO_2 + 18\ H_2O$ (1.1)

Stoichiometrically the above reaction indicates that 1 mg of $Al^{3+}$ reacting with 5.5 mg of alkalinity as $CaCO_3$, form 2.89 mg aluminum hydroxide flocks. Now the clarifier liquid containing sludge is allowed to settle, the supernatant is discharged to natural streams and settled sludge is send for land filling.

Solids removal efficiency of various unit operations depend on the size of particulates and concentration, plain sedimentation is efficient in removing particulates up to 100μm, sweep flocculation up to 0.50 μm and micro flocculation up to 0.01μm, but the removal depends on the charge of solids and ionic strength of water. Water contains solids in the form of silt, clay, algae, bacteria and virus, which is unable to remove by sedimentation, hence filtration, is the final treatment of solids removal in conventional water treatment process. The main methods of filtration are screening and granular filtration also known as depth filtration. In conventional treatment process granular filtration is adopted. The earliest recoded reference to the use of filters in water treatment occurred about 3000 years ago in India. The first patent for the filter was granted in Paris, France 1746.The earliest use of filters for a domestic water supplies occurred in Scotland 1804, followed there after by the installation of sand filters in England 1829.

Filters are capable of removing a wide range of particulate material both organic and inorganic, the size of particulate material ranges from 0.001 to 1000 μm. In filtration process water passes through a filter medium and particles are collected through its depth. The principal particle removal mechanisms in a gravity filters are straining, sedimentation, impaction, adhesion, and flocculation. Due to the deposition of suspended particle within in the granular bed, reduces the rate of filtration, and increases the effluent turbidity accompanied by the increase in head loss.

When the quality reaches the highest point of acceptable water quality (limiting effluent quality), it is known as Breakthrough. When this stage is reached the filter is subjected to back wash. Back wash is the process in which media is subjected high pressure reverse flow to remove the settled particle, this process results in filter back wash water which contains accumulated particle in the media including pathogens. The requirement of water for back wash is in the range between 2 to 8% of plant capacity

Direct discharge of clarifier supernatant, sludge and filter back wash water causes organic and inorganic pollution to the receiving water body. The aluminum hydroxide in the course of its travel reacts with mineral acidity and release aluminum, which inhibits biological activity in the receiving water body. Higher aluminum concentration in water is believed to be cause Alshimmers and mental retardation in children. As the water contains high solids content, which settles at the bottom of the stream prevents the purification by micro-organisms and destroys hydro geologic property of the stream. In summer when the flow is lean, the large volume of sludge, could exert BOD and deplete DO. Sludge and back wash water contain high bacterial load like *cryptosprodium* and *Giardia* pose potential threat to the down- stream users. Besides above a considerable quantity of water is wasted, as the country experiencing scarcity of water, it is necessary to conserve this valuable resource. Further various countries have their own stringent regulations on the discharge of filter back wash water to the natural water bodies, water supply agencies no longer able continue with present disposal methods, and hence the disposal and reuse plan for these residuals is an alternative.Regulatory compliance in the context of water treatment waste includes two criteria, for direct disposal of FBW and sludge the characteristic parameters should not exceeds the discharge standards and recycle stream should satisfy the characteristic requirement for the source water. There are no specific discharge standards for the WTP residuals; this will come under the general standards for the disposal in to inland surface water.

Under central pollution control board standards for the discharge in to inland surface water, the maximum allowable solids content and metallic (Fe) concentrations are 100 mg/l and 3 mg/l, respectively. Previous studies showed that solids content in FBW is in the range of 120 to 150 mg/l and iron concentration in the range of 10 to 15 mg/l. Hence direct disposal of FBW and sludge is violation of existing regulations. For recycle of FBW, the recycle stream should satisfy the requirement under source water quality for designated best use as per IS: 2290-1983, the source water for conventional treatment is classed as “C”, for which the maximum allowable turbidity is 30 NTU. The average filter back wash turbidity is in the range of 150 to 200 NTU; hence treatment is necessary for filter back wash reuse.

### 1.2 SELECTION OF DISPOSAL / REUSE OPTIONS

The disposal/reuse plan for a treatment plant should be based on various factors, including the production volume, effluent character, regulatory requirements and economic factors. Based on these factors, a residual management plan is selected.

### 1.3 SCOPE AND PERSPECTIVE OF STUDY

Conventional water treatment process generates two types of waste, filter back wash water and sludge. This wastes contains organic and inorganic constituents, direct disposal of this waste pollutes soil, water and effects human health. Along with these wastes considerable volume of water and process chemicals are also disposed, which cause wastage of this scare resources. Studies showed that characteristic values of FBW exceeds the discharge standards, hence direct disposal of FBW is violation of regulatory requirement. Beneficial use of FBW and chemical sludge is the feasible solution to the above problems. Thus scope of this work is to develop a residual treatment and reuse plan which satisfy the goals of pollution abetment, resource utilization and regulatory compliance Chavsseryparamaba treatment plant of Kannur water supply scheme, 30 mld capacity, using 75 kg alum and 70 kg of lime per day, generates 1.22 mld of filter back wash and 325 kg of sludge. Filter back wash water constitutes 4.30 % of plant production. The optimum FBW volume reported in literature are 2 to 3 percent hence there is a scope for operational modification to reduce the FBW volume. The filter back wash contains high solids concentration, sedimentation is the suitable treatment option but for the treatment of FBW by conventional sedimentation require large storage and considerable time. Hence high rate sedimentation by tube settler is one of the feasible treatment option. The characteristic study of WTP sludge showed that it is suitable for use as construction material. Use of WTP sludge as a construction material assures cent percent use. Hence perspective of this study is to conduct laboratory experiments on tube settler for the treatment of FBW, optimize the plant operations for residual reduction and on usage of WTP sludge for the manufacture of bricks.

### 1.4 OBJECTIVES

The main objective of the present study is to conserve the back- wash water by optimising and reusing the back wash water as well as to study the potentiality of the reuse of combined sludge as a building material.The specific objectives are

- To characterize of filter back wash water and combined sludge obtained from a water treatment plant.
- Optimisation of treatment plant operation for volume residual reduction.
- To conduct laboratory bench scale tube settler studies for the treatment of filter back wash water.
- To check the possibility of using combined filter back wash sludge as construction material (brick).

## 2. MATERIALS AND METHODOLOGY

### 2.1. GENERAL

Based on the objectives laboratory experimental and actual field process studies were conducted. The study includes characterization and quantification of FBW water and sludge, optimization for filtration and back washing, laboratory bench scale tube settler studies for the treatment of filter back wash water along with settling characteristic studies of flocculent particles. The present study also includes: determination of optimum ratio of WTP sludge with clay and sand in the manufacture of brick and to compare the properties of WTP sludge bricks with standard bricks.

### 2.2. MATERIALS

The materials used in the present study are simulated filter back wash water and combined sludge. Bench scale tube settler module was used to the study settling characteristics of filter back wash water.

#### 2.2.1 Sludge

Sludge used in the present study was combined sludge obtained both from clarifier and from filter back wash. In Chavasseryparamba WTP, Kerala state, sludge from clarifier and filter back wash water conveyed by a common leading channel to a natural settling tank and allowed to settle is shown in plate 3.1. Three samples of combined sludge 5 liters were collected at three different locations in the settling tank at a depth of 0.50 m during winter season and analyzed for Physico-Chemical characteristics.

#### 2.2.2 Filter back wash water analysis

A representative twenty liters filter back wash water sample was collected from the outlet of filter unit during back wash. Two liters FBW samples were collected at one minute interval over a period of ten minutes (back wash duration). Samples were collected and mixed together to get a composite sample. Turbidity measurements were made for individual and composite samples. Composite turbid sample were collected and used in laboratory scale tube settler studies. Raw water and treated water were collected from aerator and clear water sump of treatment plant and analyzed for various drinking water quality parameters.

### 2.2.3 Tube settler

The continuous flow laboratory bench scale tube settler treatment unit was fabricated and used. It consists of three parts, storage tanks (2 Nos) with stirrer arrangement, peristaltic pump for controlling the flow rate and tube settler module. The tube settler unit is made of Persplex glass of 6 mm thick, fabricated to the required dimensions. Tube settler unit comprises of three components; inlet chamber, inclined tubes and out let chamber. In let chamber dimensioning 15 cm x 15 cm x 10 cm, attached with an inlet valve and scour valve. Baffle wall is provided to have a laminar flow condition. Three numbers of tubes, 4 cm internal diameter and 40 cm long, fitted at required angles ($30^0$, $35^0$, $40^0$, $55^0$ and $60^0$ for each setup) with the horizontal. The tubes are connected between two horizontal plates provided at top and bottom of the inlet and out let chamber. Five modules with tube angle of inclinations of $30^0$, $35^0$, $40^0$, $55^0$, and $60^0$ with the horizontal are fabricated. The outlet chamber is measuring 15 cm x 15 cm x 5 cm provided with an out let valve to collect the treated water. The experimental set up is shown in Figure.1.

**FIGURE.1 EXPERIMENTAL SETUP OF TUBE SETTLER**

## 2.3 METHODS

The present study mainly focused on the reuse of FBW water generated in the water treatment plant.The study encompasses both fields as well as laboratory bench scale experimental studies. Field work includes the characterization and quantification of FBW water and sludge. Filters as well as back wash optimization studies have been conducted at Chavasseryparamba water treatment plant, Kerala. The laboratory study includes tube settler studies for the removal of turbidity from the FBW water at various tube settler inclinations.

### 2.3.1 Quantification and characterization of FBW water and back wash sludge

The quantification of filter back wash water was determined by observing water level in back wash water reservoir, for various raw water turbidity. Composite samples of raw, treated and filter back wash water were collected from the water treatment plant and analyzed for various drinking water quality parameters at Quality control laboratory of Kerala Water Authority, Kannur. The major water quality parameters monitored are turbidity, pH, electrical conductivity, total solids, Ca, Mg, Cl, Fe, acidity and bacterial contamination. Sodium and potassium concentrations were also measured using Flame photo meter. Water samples were analyzed as per Standard Methods for the examination of water and waste water (IS: 3025-1983). All the reagents used for the analysis were of analytical grade.

### 2.3.2 Turbidity measurement

Turbidity in the water samples were measured for each flow rate during continuous flow as well as under batch process (Figure.2.). Turbidity in the water samples was measured by using Spectrophotometer.

**FIGURE.2 TUBE SETTLER UNIT ALONG WITH TREATED WATER COLLECTED IN THE TANK.**

### 2.3.3 Sludge analysis

FBW sludge collected from the Chavasseryparamba water treatment plant has been used for the tube settler study. Before characterization of FBW sludge, it is oven dried at $105^0$ C for 24 hours. The sludge was analyzed for particulate organic matter (POM) content using $H_2O_2$ digesting liquid. In order to know the particle size distribution Sieve analysis of the sludge has been conducted. The metallic oxide content of the sludge, such as $SiO_2$, CaO, $Fe_2O_3$ and MgO have been analyzed using Inductively Coupled Plasma Electro Spectrometer (ICP-ES) by digesting the sludge with $HNO_3$ and $H_2O_2$ (EPA acid digestion method,3050B).

## 2.4 EXPERIMENTAL PROGRAM

Experimental programs in this study include; optimization study of filtration and back wash, tube settler performance studies, design of filter back wash unit and sludge based brick specimen casting and testing.

### 2.4.1 Filtration and back washing optimization studies

Filter optimization studies were carried out using a filter unit (unit No.3) of Chavasseryparamba water treatment plant, Kerala. Filter is run at various filter loading rates i.e., 4, 8, 12 and 16 $m^3/m^2/h$ over a range of filter run duration of 10 to 120 hours. Filter back wash water volume for the above mentioned filter run were determined by measuring the reservoir levels and the quantity of leakage through valves, which have been considered while evaluating the volume of FBW water.

Back wash optimization studies were conducted as per USEPA filter back wash guidance rule. Existing back wash process of Chavasseryparamba WTP has been analyzed and various filter back wash optimization options have been studied. The optimization methods employed are: in the first method surface wash has been carried out during back wash i.e., during last phase of water wash the surface of the filter was kept agitated using water jets. This process has been carried-out by using PVC pipes of 40 mm diameter, and the flow rate maintained was 110lpm. In the second method the duration of back wash has been reduced by 3minutes. This can be achieved by increasing the rate of air wash with reduced scour time. Finally, alum was added just before the commencement of back wash at the rate ranging between 25 mg/l to 50 mg/l depending upon the amount of turbidity in the back wash.

### 2.4.2 Design of FBWW treatment unit for Chavasseryparamba WTP

Design of back wash treatment unit has been carried out for average filter back wash flow. The unit includes equalization tank, inlet chamber, and tube settler module and outlet chamber. Provision for sludge pumping has been included in the design. The design of tube settler treatment unit is based on the experimental results obtained from bench scale study. Tube settler treatment unit is designed in such a way that storage volume should be available in the sludge pit.

### 2.4.3 Tube settler studies

Filter back wash water sample were collected from the Chavasseryparamaba WTP and used in the laboratory experiments. To begin with FBW water was fed to the first tank and it was continuously pumped using peristaltic pump to the second tank at desired rate (Table.1). The water level in the second tank was kept constant. Continuous stirring of FBW water was done in first tank to prevent settling or to get uniform turbid water. Raw and treated water was taken simultaneously and turbidity was measured. For each inclination, turbidity was measured for flow rates ranging from 0.013 to 0.75 lpm. Particle settling lengths in tubes for each flow rate were also measured and are shown in Figure.3. Tube settler experiments were conducted with modules having tube inclinations $30^0$, $35^0$, $40^0$, $55^0$ and $60^0$ with the horizontal.

**TABLE.1 COMPOSITION OF BRICK SPECIMENS ADOPTED IN THE PRESENT STUDY**

| Sample No | WTP sludge (% by wt.) | Brick clay (% by wt.) | Sand (% by wt.) |
|---|---|---|---|
| 1 | 50 | 0 | 50 |
| 2 | 35 | 30 | 35 |
| 3 | 25 | 0 | 75 |
| 4 | 100 | 0 | 0 |
| 5 | 50 | 50 | 0 |

### 2.4.4 Preparation of specimen and testing

The settled WTP sludge was collected from sludge pit; air dried for about 7 days, and was mixed with different proportions with sand and clay, and used in the manufacturing of bricks. The ratios of WTP sludge, brick clay and sand adopted in the present study are being presented in Table.1. Brick specimens are made by hand moulding (Fgure. 4 & 5). The moulded brick specimens are burned to a temperature of $950^0$ C. Five preliminary brick specimens are tested for water absorption, hardness, color and structure as per IS-3495 (1992). Based on the results from preliminary specimens two secondary specimens are made with 25 % and 35 % WTP sludge. These specimens were tested for all the parameters including compressive strength.

**FIGURE.3 TRANSITION LENGTH (19.50 CMS) CORRESPONDING TO A FLOW OF 0.16 LPM**

**FIGURE.4 PREPARATION OF BRICK SPECIMEN USING WTP SLUDGE**

**FIGURE.5 BRICK SPECIMEN WITH WTP SLUDGE AND BRICK EARTH**

## 3.RESULTS AND DISCUSSIONS

### 3.1 General

Based on the experimental program as discussed in chapter 3, the results obtained from the laboratory experiments have been discussed in this chapter. Characterization studies are conducted to analyze the characteristics of filter back wash water and chemical sludge, various operating parameter affecting the effluent quality and treatment process were analyzed. Quantification of filter back wash water has been done to determine the treatment volume; to quantify the combined sludge, which was estimated by analytical methods as well as by settable studies. Process optimization studies are conducted at Chavasseryparamba water treatment plant for filtration and back washing. The operational modifications include: filter loading rate, back wash interval and back wash duration. Laboratory scale study on tube settler is carried out to determine the optimum flow through velocity, surface overloading rate and inclinations, for the treatment of filter back wash water. These parameters are determined for treatment and recycle and direct reuse of filter back wash water. In order to determine optimum operating conditions, tube settler experiments were conducted with various inclinations and flow through velocities. Sludge analysis is carried out to determine the Physico-Chemical characteristics of sludge which will helps to know the potentiality of sludge generated in the treatment plant as an admixture in the manufacture of building bricks. Brick specimen characterization studies are conducted to verify the requirements as per Bureau of Indian Standards (IS: 1077-1992). The results have been discussed in the following sections.

### 3.2 CHARACTERIZATION OF WATER TREATMENT PLANT SLUDGE

The chemical characteristics of water treatment plant sludge were carried out are presented in Table.2. From this table it is observed that silica, alumina and iron oxides are the major components present in the sludge. Sludge also

**TABLE.2 AVERAGE METALLIC OXIDES CONTENT IN THE WATER TREATMENT PLANT SLUDGE OF KANNUR WATER SUPPLY SCHEME**

| Metallic oxides | Content (%) | Methods of analysis |
|---|---|---|
| $SiO_2$ (Silica) | 38.58 | Direct Weighing |
| $Al_2O_3$ (Alumina) | 13.43 | ICP-ES |
| CaO | 6.74 | Calculation |
| $Fe_2O_3$ | 9.29 | ICP-ES |
| MgO | 2.96 | ICP-ES |
| Others (Ti,Mn,Na,$K_2$ and $P_2$) | 2.50 | Average value |
| Lost for calcinations | 26.50 | $H_2O_2$ digestion |

contains higher percentage of organic content (26.10 %), which limits the usage in bricks as it affects the density of brick. However, the presence of silica, alumina and iron will improve the properties of brick (color and compressive strength) and hence it is recommended to use the water treatment plant sludge as an admixture in brick manufacturing. The results of particle size analysis (Table.2) shows that sludge contain higher percentage of clay and silt, which improve the plasticity of the soil and makes suitable for brick manufacturing. Mohammed et al. (2008) have analyzed sludge obtained from Giza water treatment plant, Cairo, Egypt. The results revels that the sludge contains $SiO_2$ and $Al_2O_3$ of 43.12 % and 15.97 %, respectively. Zamora et al (2008) have conducted studies on the reuse of sludge from Loss Berros water treatment plant, Mexico city found that the main constituents of sludge are $SiO_2$ and $Al_2O_3$ of 33.23 % and 31.98 %, respectively.

### 3.3 VOLUME AND RATE OF FILTER BACK WASH WATER

The quantity of filter back wash water generated depends on the raw water turbidity and solids removal efficiency of the treatment process, Table.3 shows the volume of filter back wash water generated at Chavasseryparamba water treatment plant for various raw water turbidity. A plot of filter back wash volume versus raw water turbidity has been made and is depicted in Figure.6. From Table 4.3, the average raw water turbidity observed in the plant is 12 NTU and the average FBW generation is about 1.22 mld. The average rate of flow rate through the filter was measured and found to be 216.05 $m^3/m^2$/day. The rate of filter back wash maintained was 11.26 $m^3/m^2$ of filter area, and the average filter back wash volume of 1.22 mld constitutes 4.30 % of the plant production (28 mld). USEPA filter back wash guidance manual reported that, under normal operating conditions filter back wash accounts for 2.50 % of plant production. The existing back wash requirement is 4.30 % which is on a higher side. Hence, there is a scope for reduction in filter back wash generation by back wash process optimization.

**TABLE.3 MINERALOGY OF WTP SLUDGE**

| Component | Particle content (%) |
|---|---|
| Sand | 42.87 |
| Silt | 26.14 |
| Clay | 30.99 |
| Total | 100 |

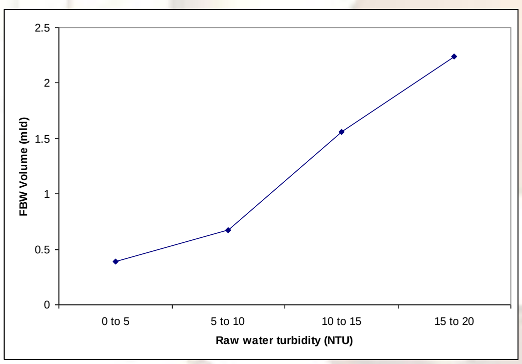


**FIGURE.6 FILTER BACK WASH VOLUME FOR VARIOUS RAW WATER TURBIDITY**

Swaminathan et al. (2007) have reported that 3.40 % of plant production is used for back washing in Kalliseri water treatment plant in kerala. Lokesh et al. (1993) have reported that the quantity of back wash water generated in Hongalli water works in Mysore is 8.80 % of the plant production.

## 3.4 CHARACTERISTICS OF FILTER BACK WASH WATER

Raw, treated and filter back wash water have been characterized for various Physico-Chemical parameters From this table it is observed that turbidity and bacterial load in the filter back wash found to be higher and all the other parameters are found to be well within the raw water standards as per Bureau of Indian Standards (IS: 2290-1983). Turbidity of composite sample of filter back wash water is 53 NTU and the turbidity varies from 7 to 210 NTU. The variation in turbidity during back wash is presented in Figure.7. Kawamura et al. (2000) have reported that turbidity of FBW from conventional treatment plant varies from 150 to 250 NTU. Cornwell et al. (1993) have showed that turbidity during back wash varies from 0.57 and 97 NTU. Similarly Bourgeois et al. (2004) have reported that the turbidity of combined back wash water from Lake major WTP and Victoria Park WTP, Canada are 27 and 125 NTU, respectively. Analysis is carried out in presence of metallic cations to asses the treatment options. Bourgeous et al. (2004) have shown that sedimentation and dissolved air flotation are feasible if monovalent and divalent cation ratios are 0.33:1 to 1:1, respectively. From the above, it is concluded that, the ratio of Monovalent to divalent cation ratio is 0.238: 1, which is closer to ratio of 0.33:1 as obtained by Bourgeois et al. (2004). Hence it is proposed sedimentation treatment for FBW, rather than the dissolved air flotation. It is also proposed to add 7.65 mg/l of $NaCO_3$ to obtain optimum cation ratio in the sedimentation tank.

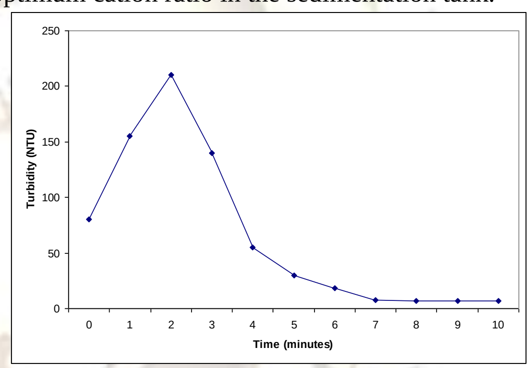


**FIGURE.7 VARIATION IN FILTER BACK WASH TURBIDITY DURING BACK WASH**

## 3.5 OPTIMIZATION OF FILTRATION

Optimization of filtration in context with back wash water reduction includes: running the filter at optimum unit filter run volume (UFRV) which generates minimum filter back wash. Filter optimization study involves determination of filtered water production efficiency, i.e., the ratio of net filtered volume of water to total filtered volume water, at various filter loading rates and unit filter run volume. In the present study filter No.3 of of Chavasseryparamba water treatment plant, were run at filter loading rates of 4, 8, 12 and 16 $m^3/m^2$/h and the corresponding production efficiency of filter loading rates were measured are presented in Table 4.7. A plot of unit filter run volume versus filtered water production efficiency has been plotted and is presented in Fig 4.3. From this figure it is observed that optimum unit filter run volume and filter loading rate are 560 $m^3/m^2$ and of 8 $m^3/m^2/h$, respectively. The filter production efficiency at optimum condition found to be 96.70 % at 70 hours of filter run. The plant existing filter loading rate and unit filter volume are 9.00 $m^3/m^2$ and 648 $m^3/m^2$ for a filter run of 72 hours, which is being a maximum allowable filter run as specified by CPHEEO of 72 hours. Simon et al. (2006) have shown that filter loading rate of 6 to 9 $m^3/m^2$ and unit filter run volume of 300 to 500 $m^3/m^2$. Bhaman et al. (1999) have stated that the optimum filter loading rate and unit filter volume are 12.20 $m^3/m^2$ and 161.62 $m^3/m^2$, respectively.

### 3.6 OPTIMIZATION OF BACK WASH

Back wash optimization process involve modifying back wash process to reduce the filter back wash volume. The operational modification should be considered very carefully as it effects filtered water quality. USEPA filter back wash guidance manual suggests three methods; in each of these methods effluent turbidity is monitored and should be with in 5 NTU. In the method of surface agitation the surface of the filter will be kept agitated using water jets to prevent resettling of solids during scour. By employing this method, the scour time was reduced by two minutes and there will be increase in turbidity in the FBW water.

Also in this method 16 percent reduction in filter back wash volume is achieved. In the second method also there will be reduction in scour time and this reduction in scour time is based on the turbidity profile of filter back wash water. In the present study the back wash duration has been reduced by 3 minutes, with an end filter back wash turbidity of 12 NTU and filter is being kept back on line to avoid spikes in effluent turbidity. This method saves filter back wash volume by 11 percent. Mayers et al. (2000) have shown that 20 % reduction in back wash volume can be achieved by back washing the filter over a period by two minutes. The third method employed in which alum is being added just before the start of back wash at the rate of 50 mg/l. The present study shows that alum addition prevents the resettling of solids and hence the duration of scour is reduced by 2 to 3 minutes. This method gives 18 percent saving in filter back wash volume. Further the filter is kept back on line for 24 hours before loading to avoid spikes in effluent turbidity. Comparison of the three methods of optimized filter back wash values with the existing values observed in the Chavasseryparamaba water treatment plant are given in Table 4. From this table it is observed that alum addition with reduced duration is the best method for optimizing the filter back wash.

### 3.7 STUDIES ON TUBE SETTLER

Experimental studies were conducted to evaluate the feasibility of tube settler at various inclinations for the treatment of filter back wash water, and the results are calculated. Settling or removal of colloids in tube settler is governed by three factors; settling velocity of colloids which depends on particle size, flow through velocity and system configuration i.e., relative length and angle of inclination of the tubes. In the present investigation, experimental studies in relate to the tube settlers are being conducted and the results have been discussed in the following sections.

**TABLE. 4. OPTIMIZATION OF FILTER BACK WASH FOR A RAW WATER TURBIDITY OF 6 NTU**

| FBW optimization Methods | Duration of Back wash (minutes) | End back wash Water turbidity (NTU) | Volume of FBW (L.L) | % Reduction in FBW volume | Remarks |
|---|---|---|---|---|---|
| Existing values | 10 | 7 | 2.25 | | |
| Surface Agitation by water | 8 | 12 | 1.90 | 16 | Chances of bed loss |
| Reduced duration | 7 | 15 | 2.00 | 11 | Filter ripening |
| Alum dosing 25 mg/l | 7 | 10 | 1.85 | 18 | Improved filter efficiency |
| Increased filter run | Not tested | | | | |

#### 3.7.1 Settling of flocculent colloids in tube settler

For settling of particle in tube settlers the necessary condition is that the residence time available to the particle should be more than or equal to the settling time required by the particle to settle at the bottom of the tube. In other words the configuration (relative length and angle of inclination) and flow through velocity should be such that, it should produce a velocity component in the direction of settling, which is less than or equal to the particle settling velocity. Hence for colloids of given particle size distribution, the optimizing parameters are the flow through velocity, relative length and the angle of inclination. The flow through velocity ($V_0$) defines the settling velocity available for the particle removal and flow region in which the settling takes place. It also defines the size and capital and operating cost involved in the treatment. In the present study, the results tube settler reveals that at lower flow through velocity (0.42 to1.15 x$10^{-4}$ m/s, at transition flow) the effect of inclination on turbidity removal is less. At this velocity the average turbidity removal rate was more than 85 % (Fig 4.4) and the effluent turbidity observed to be less than 3NTU. Corresponding settling velocity was ranging between 0.06 and 0.17 $x10^{-4}$ m/s. At this flow the dominant settling mechanism believed to be random thermal motion or micro flocculation (perikinetic flocculation). Even though there is no lateral mixing for particle aggregation, higher turbidity removal may be due to the micro flocculation and detention time available to the micro flocks to settle. The flow rate maintained is efficient on the removal of colloids of size up to 0.001µm and hence this velocity is more efficient even for the removal of bacteria. However, the flow rate is not suitable for filter back wash recycle, as it increases the number of pipes, area and capital and operating costs. Therefore the flow rates adopted is suitable for small water treatment plants as well as for direct reuse of filter back wash water. Aschroft et al. (1997) have reported that 90 % turbidity reduction is achieved in the treatment of FBW using tube settler with a settling velocity of $1.50x10^{-4}$ m/s, by the addition of 0.70 mg/l of anionic polymer. They also reported that the particles up to 2 µm are being settled.

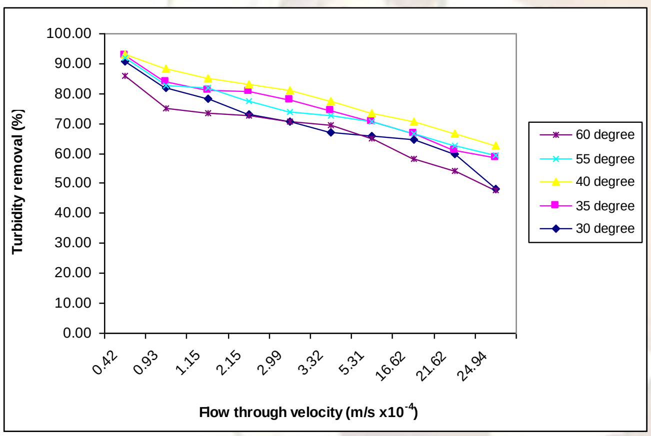


**FIGURE.8 TURBIDITY REMOVAL OF TUBE SETTLER FOR VARIOUS FLOW THROUGH VELOCITY**

In the present study it is observed that, for the flow through velocity of 2.15 to 5.31 x $10^{-4}$ m/sec, 70 to 80% of turbidity removal was observed, corresponding settling velocity was found to be 0.32 to $0.86x10^{-4}$ m/s, and the effluent turbidity was ranging from 4 to 5 NTU. With the above ranging operating parameters the variation on the turbidity removal efficiency due to tube settler inclinations is noticeable. When flow is turbulent, the removal rate is believed due to the velocity gradient (orthokinetic flocculation) and the system is inefficient to remove colloids less than 1 µm size. However this flow rate is acceptable for medium and large scale treatment as it is feasible in terms of volume of water treated and size of the treatment unit. The effect of inclination on turbidity removal efficiency is due to GT (gradient transition) value and gravity on heavier flocks. Cornwell et al. (2001) have reported that effluent turbidity of 2.4 NTU is achieved by the tube settler treatment of filter back wash water with a settling velocity of 2.78 x $10^{-4}$ m/s.

For the flow through velocity ranging between 16.62 and 24.94 $x10^{-4}$ m/sec (Figure.8), it is seen that there will be considerable reduction on the removal rate is observed, and settling length follows Langhaar equation, which shows that no flocculation takes place and the settling may be due to theoretical discrete particle settling (Newton-stokes equation). It is also evident that as the flow is more turbulent which breaks the colloidal flocks and the settling is purely discrete which obeys conventional tube settler theory.

A plot of settling velocity versus turbidity removal has been made and presented in Figure.9. From this figure it is possible to classify the particles based on the size of particles. In this study it is observed that 20 % of the settled sludge contains fine (clay) particles, 25 % represent silt particles and rest of which is representing sand particles. The average settling velocity of alum flocks observed was $3.53x10^{-4}$ m/s (21 mm/m) at $35^0$C. Eshwar et al. (1981) have reported that average settling velocity of alum flocks is 50 mm/min at $10^0$ C. Roderick et al. (1978) have reported that settling velocity of alum flocks observed in their study was ranging between 0.75 and 1.0 inch/min.

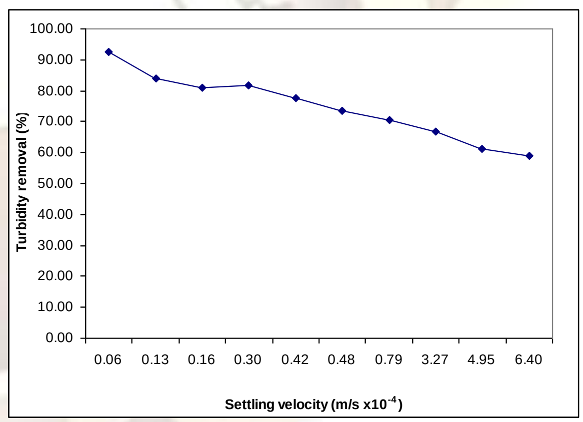


**FIGURE.9 TURBIDITY REMOVAL EFFICIENCY OF TUBE SETTLER FOR VARIOUS SETTLING VELOCITY AT 35DEGREE INCLINATION**

The system efficiency of tube settler is the ratio of flow through velocity to settling velocity, indicating the settling performance for the given flow through velocity. Figure.10 shows that the effect of increase in system efficiency ($V_0/V_s$) on turbidity removal. From this figure it is observed that there is a marginal removal of turbidity when the optimum system efficiency of 7.15. Andreas et al. (1980)

have reported that 45 degree inclination gives the maximum system efficiency. Figure.11 shows a plot of power consumption versus various tube settler inclinations. From this figure it is observed that power consumption increases substantially as the inclination increases from 40 degree onwards. Hence from the point of consumption of power 40 degree is the optimm inclination for tube settler. Pernendu et al. (1988) have stated that operating cost shows constant increase from inclination 30 to 60 degree.

A plot of tube settler inclinations versus turbidity removal has been made, shown in Figure.12. In the present study, the flow through velocity maintained was $5.31x10^{-4}$ m/s. Further, the tube settler studies were conducted at $40^0$ and $55^0$ inclinations during which the turbidity removal efficiency was found to be 73.68 % and 70.58 %, respectively. The optimum settling velocity for FBWW treatment with recycle was found to be $1.13x10^{-4}$ m/s and corresponding surface over loading rate was 9.76 $m^3/m^2$/day. Optimum flow through velocity observed was $5.31x10^{-4}$ m/s. Comparisons of various operating parameters adopted in the present study with the other researchers work on tube settler studies has been made. Roderick et al. (1980) have conducted studies on sliding rate of sludges and showed that $60^0$ degree inclination gives a sliding rate of 3.3 in/min. A plot of turbidity rermoval efficiency against Reynolds number is shown in Figure.13. From this figure it is observed that the turbidity removal efficiency of 70 to 80 percentage is obtained at Reynolds number 8600 to 212400. Hence an average Reynolds number value of 15000 may be acceptable for large scale treatment of flocculant colloids. Roderick et al. (1980) have suggested Reynolds number less than 2000 holds true for discreete particle settling in tube settlers.

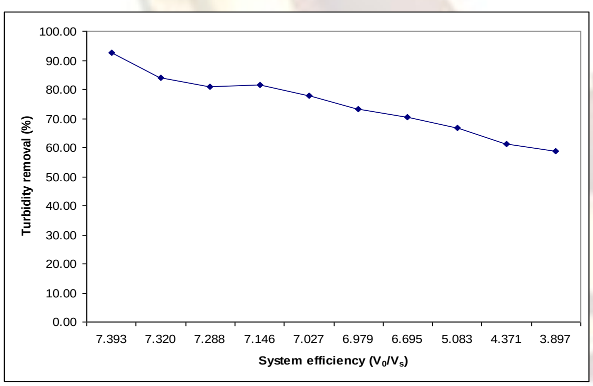


**FIGURE.10 TURBIDITY REMOVAL FOR VARIOUS SYSTEM EFFICIENCY**

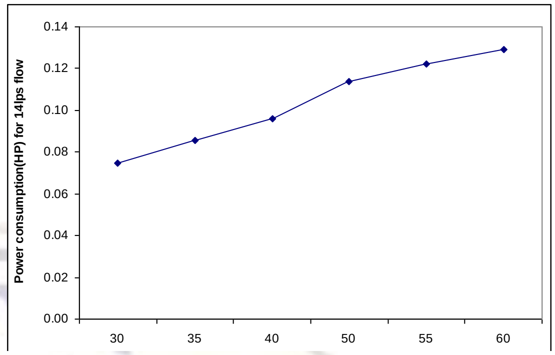


**FIGURE.11 POWER CONSUMPTION FOR VARIOUS TUBE INCLINATIONS**

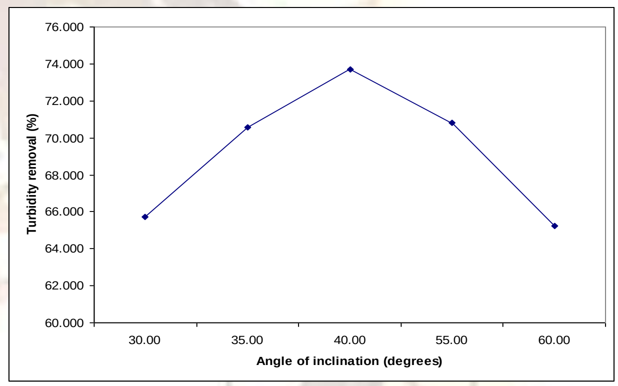


**FIGURE.12 TURBIDITY REMOVAL VERSUS VARIOUS TUBE INCLINATIONS FOR A FLOW THROUGH VELOCITY OF 5.31 $X10^{-4}$ M/S**

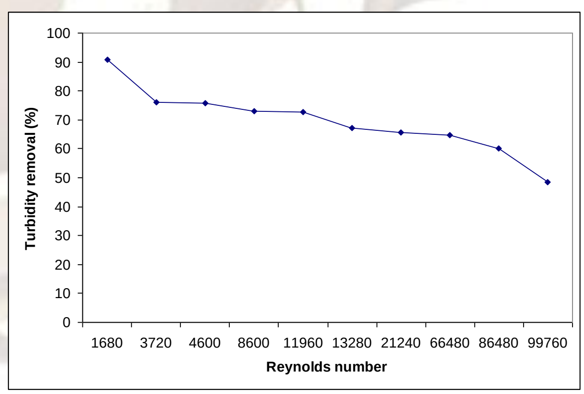


**FIGURE.13 A PLOT OF TURBIDITY REMOVAL VERSUS REYNOLDS NUMBER AT 35 DEGREE INCLINATION**

From the laboratory experimental studies, it has been observed that, the $40^0$ and $55^0$ degrees of inclinations of tube settler gives maximum turbidity removal efficiency of 73.68 and 70.83, respectively. At $55^0$ of tube settler inclination higher flock sliding was observed, which enhances the self cleaning and hence $55^0$ inclination is being recommended.

### 3.8 DESIGN OF FILTER BACK WASH TREATMENT UNIT

Tube settler treatment unit for filter back wash recycle has been designed for the Chavassery treatment plant, Kerala. Based on the experimental studies, the tube settler treatment unit has been designed with $55^0$ inclination. In the present study, tube settler system has been designed in such a way that the treated back wash water should meet the raw water quality standards. The turbidity of combined filter back wash water was found to be 53 NTU. In order to achieve the raw water turbidity level i.e., below 30 NTU, the tube settler system has been designed for 43.40 % of turbidity removal for which the flow through velocity and settling velocity maintained was $24.94\ x10^{-4}$ m/s and $9.14x10^{-4}$ m/sec, respectively. Under the above mentioned operating conditions the turbidity removal in the tube settler found to be 59.20 %. However, by inducting the equalisation basin in to the water treatment plant the back wash water turbidity removal may further be improved. The detailed design and drawings of tube settler filter back wash treamnet unit for Chavasseryparamba water treatment plant have been appended in Appendix- A.

Further, filter back wash water was treated with tube settler for the removal of turbidity. Tube settler experiments were conducted by maintaining settling velocity of $0.46x10^{-4}$ m/s, with tube settler inclinaton of $40^0$, under this condition the turbidity removal efficiency was found to be 81 %, at which the turbidity value in the effluent was found to be 3 NTU ( which is less than 10 NTU, as per CPHEEO standards for drinking water). Hence it is suggested to use tube settler under the above mentioned operating conditions for the treatment of highly turbid filter back wash water.

### 3.9 TREATMENT PLANT SLUDGE

The sludge generated from Chavasseryparamba water treatment plant has been collected and analyzed for various chemical parameters. Tests are carried out to determine the chemical composition and particle size analysis. The quantification of sludge has been carried out by using previous operating records and empirical equations (Cornwell et al., 1987). Preliminary and secondary specimens are made to arrive acceptable percentage of sludge in brick manufacturing.

### 3.10 QUANTIFICATION OF WATER TREATMENT PLANT SLUDGE

The quantity of sludge generated from the water treatment plant can be estimated using the equation developed by Cornwell et al., (1987). In the present study the quantity of sludge generated from the water treatment plant was calculated. The plant generates 325 kg of sludge per day and annual sludge production is about 1,18,625 kg which represents 65.90 $m^3$ with dry density of 1800 $kg/m^3$. The sludge production of 1,18,625 kg/year is enough to produce 1,43,000 bricks using 30 % sludge mixed with brick earth. About 700 $m^3$ of sludge stored in the sludge pit is enough to run a small scale brick industry, which produces 1000 bricks per day, over a period of five years. Plant generates average 1.26 mld FBWW and 16 $m^3$ clarifier wash water per week. Settleable solids in the water treatment plant effluent were calculated.. From this table it is observed that the quantity of sludge generated in the water treatment plant is about 297.25 kg/day. A sludge analysis has been carried out to determine the metallic oxides contents presnt in the WTP sludge. From this table it is observed that Silicon, Aluminum and iron oxides are the major components. There is high percentage of organic content (26.10 %), which limits the usage in brick as it affects the density of brick. Sludge contains silica, alumina and iron, which improve the properties of brick. This shows that sludge can be used as an admixture in brick manufacturing to improve color and strength. Particle analysis results using sieve and pipette method shows there is higher clay and silt, which gives plasticity and making suitable for brick manufacturing. Mohammed et al. (2008) analyzed sludge obtained from Giza water treatment plant, Cairo, Egypt; they found that $SiO_2$ and $Al_2O_3$ content was 43.12 and 15.97 %, respectively. Zamora et al. (2008) have conducted studies in relate to the reuse of sludge from Loss Berros water treatment plant, Mexico City. They found that the main constituents present in the sludge are $SiO_2$ and $Al_2O_3$ with 33.23 % and 31.98 % respectively.

### 3.11 POTENTIALITY OF WTP SLUDGE AS ADMIXTURE IN BRICK MANUFACTURING

The present study also focused on the application of sludge as admixtures in the manufacturing of brick. Based on the mineralogy of sludge as well as type of brick earth available, two types of brick specimens are casted and tested for water absorption, structure, color and hardness. These tests have been conducted as per IS 3495 part I to Part III (1992) and the test results are calculated. The brick test results of the present study has been compared with the standard brick test results as per IS: 1077(1992). Brick specimens were casted by mixing 25 % and 35 % of water treatment plant sludge with the brick earth and subjected to water absorption, structure, color and compressive strength tests. The test results indicate that, the brick manufactured with 25 % of water treatment plant sludge will satisfy the requirement of BIS class 11 for bricks which can be used for all types of building constructions.

### 3.12 EVALUATION OF BRICK CHARACTERISTICS

As discussed the bricks were moulded to standard dimensions for various sludge-brick earth ratios and tested for water absorption. Characteristic studies of bricks made with various proportion of WTP sludge-brick earth mix are conducted. The values obtained from the study. From the table it is evident that increase in WTP sludge increases the water absorption The bricks will come under class 10 and 5 as per IS: 1077-1992, which can be used in construction industry.

From the above it is seen that WTP sludge can be used as colorant and clay substitute in brick manufacturing.

Mohammed et al. (2008) have conducted tests brick specimen studies using water treatment plant sludge obtained from Giza water treatment plant, Cairo, Egypt. Brick with 50 % WTP sludge shows 18 % absorption at a firing temperature of $950^0$ C yields a compressive strength of 75 kg/cm$^2$. Compressive strength of 120 kg/cm$^2$ is reported with 60% water treatment plant sludge. Here the higher strength may be due to the usage of oven dried sludge in brick casting. Mahzuz et al. (2009) have conducted brick specimen studies for making ornamental bricks with water treatment plant sludge, with 4.00 % WTP sludge brick give a compressive strength of 20.58 kg/cm$^2$. Many researchers have used the WTP sludge which was oven dried. In the present study the settled sludge used in casting the brick was air dried. It is also noticed that the compressive strength of the sludge based bricks casted in the present study shows better results when compared with the studies conducted by other researchers.

## 4. CONCLUSIONS AND RCOMENDATIONS

### 4.1 CONCLUSIONS

Based on both experimental as well as field studies conducted (as discussed in chapter 4), following conclusions have been made

- Optimization studies on filtration process showed that the volume of FBW is minimum and filtered water production efficiency is maximum when filtration rate is 8 m$^3$/m$^2$/hr and filter run volume of 560 m$^3$/m$^2$.
- Results of filter back wash studies reveals that the duration of back washing can be reduced by three minutes without affecting the effluent quality, which in-turn reduces the quantity of back wash water by 11 percent.
- Optimization studies on back wash procedure indicate that alum dosing at the rate of 50 mg/l with reduced duration back wash is best method which reduces the quantity of back wash water by 18 percent.
- Results of tube settler studies showed that for settling flocculent particles optimum inclination was found to be $55^0$ and the optimum settling velocity for flocculent settling was 2.76 mm/min during which 81 percent turbidity removal was observed (Turbidity < 3 NTU).
- For recycle stream the optimum settling velocity for flocculent sludge is 54.80 mm/min which gives a turbidity removal efficiency of 60 percent, during which the turbidity was less than 16 NTU.
- Tube settler study showed that reuse of FBW should be economical in large and medium scale water treatment plants.
- Characteristic studies of WTP sludge show that, it can be used in brick manufacturing as a substitute to clay which improves the color and finishing to the brick.
- Characteristics of bricks made with WTP sludge-brick earth, conform to the standard characteristics of the brick as per IS: 1070-1992.
- The temperature commonly being practiced in most of the brick manufacturing units will be about $950^0$C. However, in the present study the brick has been sun dried over a period of seven days, which reduces the amount to be spent in heating the bricks made out of sludge –Brick earth.
- Brick produced with 35 % WTP sludge confirms to class 11 of BIS standard with compressive strength 111.65 kg/cm$^2$.

### 4.2 RECOMMENDATIONS

- For complete analysis of settling of coagulated sludge in tube settler it is proposed to study the optimum sliding rate of sludge and to determine the corresponding inclination of tube settler.
- It is proposed to conduct detailed bacteriological characteristics studies on the treated FBW water, which enable us to know the possibility of direct usage of filter back wash water.
- Characteristic study of WTP sludge show that sludge contains fine clay which is rich in metallic oxides. The presence of metallic oxides gives an appealing color and good finish to the bricks. These properties are very much essential in making ornamental bricks. Hence a detailed study is required to be conducted to know the potentiality of WTP sludge for making ornamental bricks.

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