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MSC.THESIS ON

THE APPLICATION OF HIGHRATE TUBE SETTLER - THE CASE OF LEGADADI WATER SUPPLY TREATMENT PLANT

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The Application of High Rate Tube Settler - The case of Legadadi Water Supply Treatment Plant

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science to the Addis Ababa Institute of Technology School of Civil and Environmental Engineering, Water supply and Environmental Engineering Stream.

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I, Obsa Bayissa, do here by declare to the Senate of Addis Ababa University that this thesis is entirely original work and all other materials are duly acknowledged. This work has not been submitted for any academic degree award at any University.

Declaration

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Abstract

In modern water supply treatment plant high rate settler units achieve effective settling process than conventional sedimentation tank. This high rate settler can be considered during the new sedimentation tank construction and also existing sedimentation tanks can be modified by including such units.

This study was aimed at the assessment and evaluation of the application of high rate tube settlers in the case of Legadadi Water Supply Treatment plant by two main methods. The first one is by comparing and evaluating the performance of settling process of the sedimentation tank that the high rate tube settler is provided for it and the one without it. The second method contained the pilot scale experiment developed at this treatment plant to evaluate and asses the performance of the existing one.

The comparatives and experimental results concluded optimistically that the high rate tube settler can provide better performance than that of the conventional sedimentation tanks. The comparative results indicates that the performance in production efficiency increase by 34.5% and the effects of HRTS on filtration units saves 35.11% water use for filter back washing. Additionally the pilot experimental result due to high rate tube settlers' shows that the production efficiency increased by 35.30%, detention time decreased by 33.7%, turbidity reduction is increased by 76.65% and the chemical amount required is reduced significantly.

Therefore; from the results of the two study it is possible to conclude that the application of high rate tube settlers provides effective sedimentation process ,positive effect on filtration unit, and cost effective in(structural and land cost of sedimentation tank, chemical cost and other operational costs). The results of the study offered to recommend that the Legadadi Water Supply treatment can upgrade and improve the efficiency of process relative to the pilot scale results and; Other Water Supply institutions have to use this high rate tube settler to gain all important advantageous to be achieved.

Key Words- Legadadi Water Supply Treatment, High Rate Tube Settlers, Addis Ababa Ethiopia

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List of Abbreviations

A AWWSA	- Addis Ababa Water and Sewerage Authority
A_E	- Effective surface area
CA	- Coagulant Aid
DN	- Nominal Diameter
D	- Diameter
f	- Fractional factor
HDP	- High density pipe
Ho	- Depth of the basins
HRTS	- High Rate Tube Settler
Lo	- length of the basin
L	- Litre
LDTP	- Legadadi Treatment Plant
MCM,	- Million cubic meters
NTU	- Normal Turbidity Unit
P	- Wetted perimeter
Q	- Flow rate
Q ld	- Flow rate of Legadadi
Q ps	- Flow rate of pilot scale
RSF	- Rapid Sand Filter
Rpm	- Revolution per minute
SLR	- Surface Loading Rate
SOR	- Surface Over flow Rate

Sp	- Surface Project
T	- Turbidity
t_d	- detention time
V	- basin volume
V_C	- critical velocity
V_s	- Settling velocity
V_f	- flow velocity
WSTPT	- Water Supply Treatment Plant

1. Introduction

1.1 General

In providing water supply, the quality of supplied water should be safe to drink. Such demand imposes stress upon the water utility institutes to provide water which is free from organisms and from chemical substances that may be hazardous to health. In addition absence of turbidity, colour and disagreeable taste or smell is prime concern.

In most regions of the world, high turbidity is one of the main characteristics of the surface water. Pre-treatment is therefore often necessary for water treatment plants using surface sources taken from the streams. Sedimentation is one of the most widely used unit operation for removal of turbidity and to concentrate solids in many diversified fields in sedimentation tank.

The conventional type of settling tank is mostly rectangular shape with average length about 2-3 times of width. The depth is about 2-3 meters and the detention time is about 1-2 hours. This type of tank requires large area and high construction cost (***Faraji, G***., 2013).

In 1904, HAZEN proposed the theory for an ideal basin that the removal of settle able material was a function of the surface area of the basin, and was independent of the detention time and depth. He pointed out that doubling the surface area by inserting one horizontal tray would double the capacity of the basin. He felt that trays spaced at intervals as low as 1 in. would be very desirable if the problems of sludge removal could be resolved. CAMP (1946) presented a design for a settling basin with horizontal trays spaced at 6 in**.** The minimum distance he left was permissible for mechanical sludge removal. In 1968, CULP, HANSEN, and RICHARDSON proposed that the use of very small diameter tubes by some inclination angles would overcome sludge removal problems and the detention time could be reduced to 10-15 min. Based on such principles, many researchers have been done to find the most suitable values of tube-parameters such as diameter, length, and inclination angles generally called it high rate tube settler (HRTS) for the efficient and effective sedimentation process.

Even if different scientists and researchers provide ultimate solution for improving the settling efficiency by improving HRTS performance, there is luck of an effective use of this material in different important application area.

1.2 Statement of the Problem

Turbidity is one of the main problems in water supply treatment plant. Surface water that is required for water supply need to be treated in treatment plant. One of the treatment process required for removal of turbidity is a sedimentation unit. This unit operation or settling process is a function of surface area of the sedimentation basin. Therefore removing sediments/particles in sedimentation tanks takes large area of the tank.

The other problems of the normal settling process in settling tank is low efficiency, takes long time ,low quality of clarified water and requires high costs . For this reason different researchers and scientists seek and provide ultimate solution like high rate settler for improving the settling efficiency.

Today, different settling systems are commercially available which could lead to a cost-effective system. But the problem is that developing countries do not use or, use inappropriately this important technology due to lack of knowledge of its high advantage and application clearly or in shortage of skilled manpower and finance.

1.3 Research Questions

It is already observed that different high rate settler systems are commercially available which could lead to a cost-effective system and the main problem is that absence of applying everywhere due to lack of observing its different advantageous and availability of the technology.

Therefore the main points to be raised as research questions that seek answer to be:

How and in how much; the application of this HRTS:

- Increase the efficiency of the settling unit, Decrease the cost of settling process, decrease construction cost of sedimentation tank; and effect of application of HRTS on the filtration unit of the treatment plant?

1.4 Objectives of the study

1.4.1 General objective

To asses, evaluate and describe the role and application of the High rate tube settler in the water supply treatment plant systems and to investigate the performance of the tube settler in the sedimentation unit process of Legadadi Water Supply Treatment Plant.

1.4.2 Specific Objectives

- To evaluate the role of the tube settler in improving settling efficiency in comparison to conventional sedimentation tank.
- To assess the benefits of tube settler in sedimentation process, effect in filter unit efficiency, Sedimentation tank structural and land costs.
- To give recommendation on the application of HRTS based on the case of Legadadi water supply treatment plant that high rate tube settlers is provided and pilot scale experimental results.

1.5 Scope of the study

This research was carried out to attain the objectives raised based up on two methods. One by taking experiment on pilot scale tube of inclined settler. The Second one is by doing a case study of Legadadi treatment plant that has high rate settlers. Therefore the study limited to discuss how the high rate settler increase the efficiency of sedimentation process, decrease sedimentation process cost, decrease structural and land cost of treatment plant.

1.6 Significance of the study

In most towns of Ethiopia the source of water supply is surface water of high turbidity in that the towns use treatment plant to clarify the required demand for supply. The main parts of the clarification processes mostly involve the removal of turbidity in the sedimentation unit process.

The study provides relevant information for the water supply utilities that have treatment plants; so that they introduce use of HRTS increases the efficiency of their water treatment process, minimize cost and time, increase quality and production rate. The HRTS can be provided to the new water treatment plant and also can be refitted to the existing Treatment unit.

2. Literature review

2.1 Evolutions of Tube Settlers

The removal of suspended and colloidal materials from water by gravity separation is one of the most widely used unit operation in water treatment. Sedimentation is the term applied to the separation of suspended particles that are heavier than water, by gravitational settling. The terms sedimentation and settling are used interchangeably.

An accelerated gravity settling or removal of particles in suspension by gravity settling takes place in sedimentation basin or settling tank. The efficiency of settlement of the particles in normal settling zone or settling tank will be increased by considering the properties of the particles, types and size of the tanks.

The other methods of increasing the efficiency of the settling process can be by providing high rate settlers like inclined tube or plate settlers. These settlers are shallow settling devices consisting of stacked offset trays or bundles of tubes of various geometries that are used to enhance the settling characteristics of sedimentation basins.

High rate sedimentation is the use of shallow gravitational settlers with detention period of not more than 15 minutes to achieve comparable or even better settling efficiencies normally attained in the conventional sedimentation tanks having detention time of usually more than 2 hours (Metcalf and Eddy, 2003).

The above idea was originally suggested by HAZEN (1904) (Faraji, 2013). Who claimed that the removal is a function of the overflow rate and for a given discharge it is independent of the detention time. He recognised that the proportion of sediment removed in a settling basin is primary a function of the surface area of the basin and it is independent of the detention time. He pointed out that doubling the surface area by inserting one horizontal tray would double the capacity of the basin. He then suggested that if the basin was cut up by a series of horizontal plates into a large number of shallow passages, the increase in efficiency would be very great. The problem was sludge removal from a horizontal tray i.e. the method of cleaning because cleaning would be required much more frequently.

CAMP explored the above concept extensively in 1946. He determined that settled solids accumulate into a mass. When the weight of the mass exceeds the shear resistance of the settler surface the mass slides down the 55^0 angle and off of the surface as a clump *(Joe Brauch Maurer Research).*

BRAHAM et al. (1956) reported one of the first attempts on practical application of tray-settling principle. Several shallow settling compartments were formed by a series of conical, circular trays placed one above the other. The solids collected on each tray were scraped to a centrally located sludge collection tube which then transports the sludge to the bottom of the tank. CULP, HANSEN, and RICHARDSON (1968) had described two basic tube configurations; essentially horizontal and steeply inclined. They described that the operation of the essentially horizontal tube settlers was co-ordinated with that of the filter which was used to clarify the tube settler effluent. (A. Evren Tugtas). Saleh and Hamoda (1999) stated that high-rate settlers, which show much better performance than conventional settlers, have a good potential for upgrading of the sedimentation basins especially during the peak flows.

Accordingly; the evolution of high rate settlers increase from time to time for the application of efficient water and waste water treatment plant. The conceptual theory and its application improve the settling pattern of discrete particles in a sedimentation unit process of the plants.

2.2 Design Criteria for High rate Tube Settlers

The design of sedimentation basins is governed by different basic criteria's like the quantity of water to be treated, the selected detention time and the selected surface loading rate (or overflow rate). The surface loading rate is defined as the ratio between the surface areas of the tank and can be expressed in units of flow rate per unit of basin surface area.

For the design purpose, the first ideal sedimentation theory of sedimentation basin is given by Hazen (1904) that he indicates the removal ratio of suspended material provided. And he assumes the following ideals for horizontal settling basins.

- The flow is horizontal, steady and uniform velocity.
- The concentration of each particle size is the same along the vertical at inlet.
- The solid particle is removed from suspension once it reaches the bed.

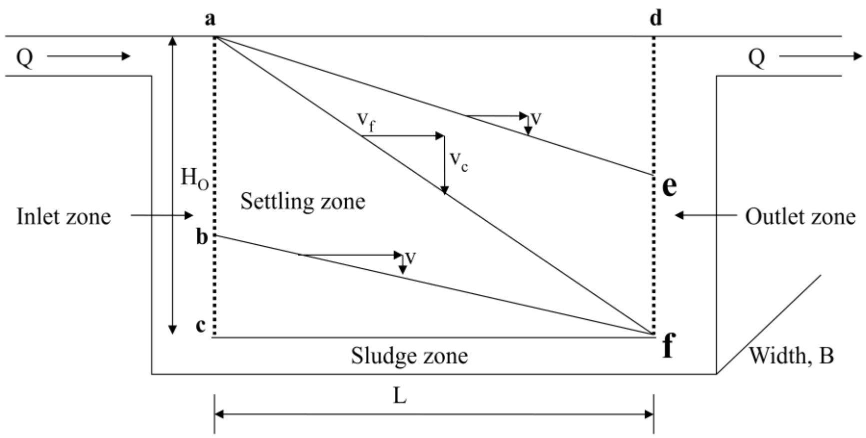


Figure 2-1: Ideal settling path of discrete practices in a horizontal flow basin (Agizew, 2014)

Camp (1946) described the theory of settling pattern of discrete particles in an ideal rectangular basin as straight lines where all particles with similar settling velocities move in parallel paths.

Therefore the detention period is defined as time required for suspension to reach the bottom of basins, i.e. the ratio of Q/A show that the efficiency of a sedimentation basin depends on surface loading rate (SLR).

$$t = \frac{V}{Q}$$

$$\mathrm{Vc} = \frac{\mathrm{Ho}}{\mathrm{td}} = \mathrm{Vc} = \mathrm{SOR} = \frac{\mathrm{Q}}{A} ; \mathrm{A} = \frac{\mathrm{Q}}{L * W}$$

$$\mathrm{Vs} = \frac{\mathrm{Q}}{W * H}$$

$$\mathrm{Vf} = \frac{\mathrm{L}}{\mathrm{td}}$$

$Vs=V_f$, ideally Particles move forward (vs.) with the same velocity as the liquid (v_f)

Where;

SOR = surface overflow rate or settling velocity in (m3 /m 2/hr)

t = detention time (hr)

Q = flow rate (m3 /day)

V = basin volume (m3)

VC = the critical velocity (m/hr)

Vs = the settling velocity of the particles.

Vf = the flow velocity of liquids

H = Depth of the basins (m)

L = the length of the basin

Here, from the ideal basin theory it is clear that the surface area of the basin is a critical design feature. Therefore high rate settlers employee a set of parallel pipes or plates arranged horizontally or inclined to provide multiple settling areas.

Similarly, the settling areas of high rate tube settlers depend on Tube length, Tube cross-sectional area, and the separation space and inclination angles of the tubes. In addition to these parameters the efficiency of settling tube performance will depends/varies with raw water characteristics.

The opening configuration shapes of high rate settlers can be manufactured in (square, rectangular, tubes, hexagonal).

By considering and adjusting this complex process the effective removal of the particles is succeeded by using these high rate settler methods.

2.3 The Practical Applications of Tube Settlers

Today, gravity sedimentation units generally incorporate tube settlers to improve removal efficiencies. The main practical application of using this media are; Increasing Surface area of Sedimentation tank, decreasing Settling or detention time, Turbidity reduction, Cost (Construction cost, Land cost and Sedimentation process cost).

2.3.1 Increase Surface area of Sedimentation tanks

A major objection to the use of settling basins is that they require a large floor area, and the footage of floor area can be expensive. If this is a problem, the settling basin can be decreased by adding obstructions inside of the settling basin to increase rates of settling. Tube settlers, can be used to do this. *(. Ebeling 1987)*

Inclined tubes significantly increase the allowable up flow velocity in a clarifier (based on horizontal tank area) by increasing the settling area, thereby allowing a higher peak flow to be treated in a given tank surface area.

Based on theory of sedimentation basin and the ratio of *Q/A* show that the efficiency of a sedimentation basin depends on surface loading rate (SLR), and as effective surface area is increased, the SLR is decreasing.

Therefore from the theory, it is possible to project the area and verify the design of inclined tube settler of inclined pipes as the following. The Figure 2.2 shows an example of schematic of inclined pipes.

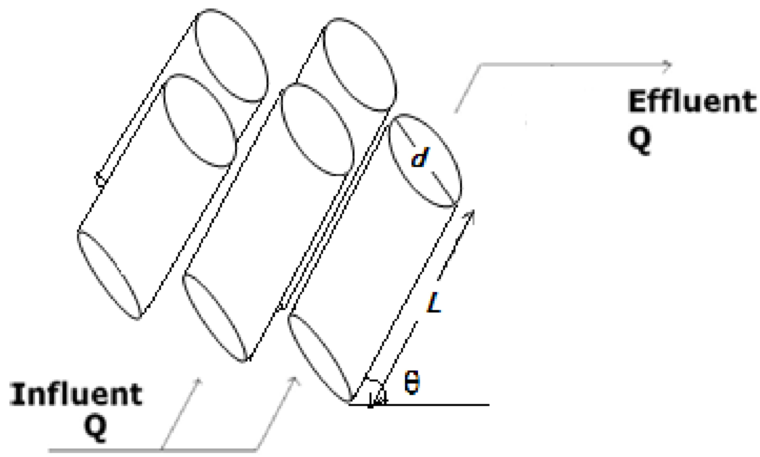


Figure 2-2: Schematic of inclined tubes (A. Faraji1, 2013)

From the SOR equation;

$$R = \frac{Vod}{\nu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where R, V_o, d_H and υ are the Reynolds number, average flow velocity (m/s), hydraulic diameter of the channel (m), and kinematic viscosity of water (m^2/s), respectively.

Where the hydraulic diameter of the channel is given by:

$$d_H = \frac{4A}{P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

Where *A and P* are sectional area (m2) and wetted perimeter of the pipe channel (m), respectively.

The average flow velocity is given by:

$$\frac{Q}{NA} = \frac{QN\pi d2}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where; N and *d* are the *number* of tubes and the *diameter* of tubes (m), respectively.

The surface loading rate of high rate settlers is given by:

$$\frac{SLR}{SOR} = \frac{Q}{A}E \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where A_E is the effective surface area (m2) which is given by:

$$AE = Ld\cos\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Therefore the total effective area of the packages of tube settler is given as:

$$AE\ tot = N\ Ld\cos\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where, *L* and *θ* are the length of tubes (m) and the angle of tubes relative to horizontal (degree), respectively. (***A. Faraji1, 2013)***

Different international manufacturers of high rate settlers have their own standard area projection and design of inclined high rate tube settlers. Here below, example is from literature called Modules of lamellaires of DEGREMONT standard manufactures (DEGREMONT, 2011 France).

Mostly; the DEGREMONT tube settler is hexagonal types of configuration. The surface area projection of modules of lamellaires as:

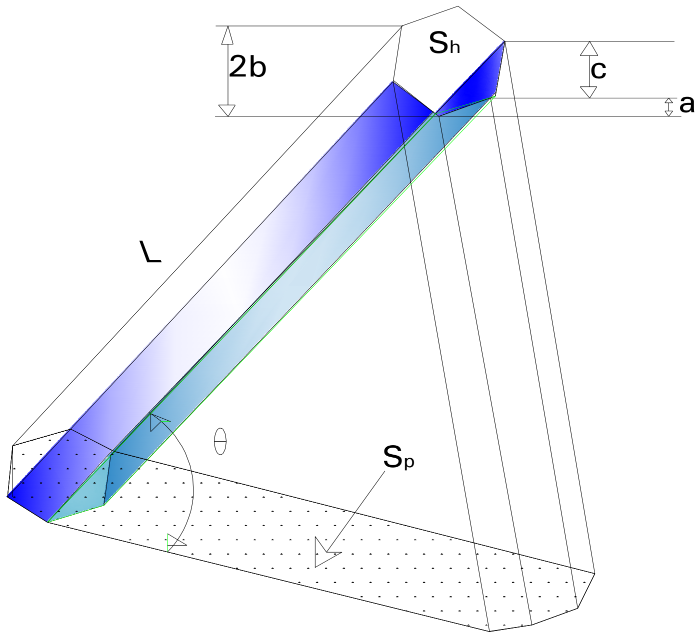


Figure 2-3: Surface area projection of hexagonal types of tube settlers, (DEGREMONT, 2011).

Surface Projection Sp:

$$Sp = (a + 2c) * L * \cos\theta \quad (m2)$$

Where; L=Length of tube settlers

θ=Angle of inclination of the lamellar tubes.

The horizontal cross sectional area of the tubes settlers:

$$Sh = 2b * \frac{a+c}{Sin\theta} \qquad (m2)$$

From the (Hazen relations); the projected area ratio to the horizontal cross sectional area (Ks);

$$Ks = \frac{Sp}{Sh} \quad (M2/m2)$$

Therefore; $$Ks = \frac{L\ \ a+2c\ *\cos\theta * Sin\theta}{2b*(a+c)}$$

In the case of DEGREMONT profile;

$\theta=60^o$

a=30.5mm

2b=50mm

c=13.6

L=750mm

Using these values for the Ks;

$$Ks = \frac{L \quad a+2c \ *\cos\theta*\mathrm{Sin}\theta}{2b*(a+c)}$$

$$Ks = \frac{750 \quad 30.5+213.6 \ *\cos 60o*\mathrm{Sin}60}{(50*(30.5+13.6)}$$

Thus; Ks=8.49m2/m2, that the projected surface is increased by 8.49m2/m2.

2.3.2 Settling or detention time

TCHOBANOGLOUS (1979) and RICH (1973) stressed upon the influence of depth on the clarification process, the higher the settling depth the larger the detention time. Due to, the required particle removal is optimized by decreasing the settling depth by using tube settlers and the detention time is decreased because the particles gets the inclined surface of the tubes soon.

But the settling time can varies with different factors like diameter of the tubes, inclination angle, and length of the tube settlers. For example; In a 5 cm diameter tube, the farthest distance any particle must settle is from the top of the tube to the bottom. If the particle’s settling rate is 2.5 cm/minute it will take only two minutes for the particle to reach the bottom. In contrast, if the same particle were to settle in a 3 m deep tank, it would take 120 minutes (2 hours) for it to fall to the tank bottom (*Ives*, 1984).

2.3.3 Turbidity reduction:

The percentage of turbidity removal using high-rate settling module is better than the turbidity removal without high-rate settling module.

HANSEN et al. (1969) observed that if the tube is inclined at an angle of greater than 45 degrees, then the sediments accumulated on the surface of the tube begins to move down after reaching certain. This counter current flow of the solids aids in the agglomeration of particles into larger, heavier flocks which are able to settle against the upwardly flowing liquid.
CULP and HANSEN (1969) had performed the tests to find the tube performance in settling efficiency based on the factors; Tube length, Tube cross-sectional area, Rate of flow, and inclination angle. Based on the factors the turbidity reduction due to application of tube settler is varied from (60-80) %.

2.3.4 Cost (Construction cost, Land cost and Sedimentation process cost)

Sedimentation is one of the most commonly used processes in the field of water treatment. It was estimated that about 1/3 of the total capital investment is spent on this unit operation, for this reason, economical alternatives should be considered in the modern water treatment systems (**Sow, Kim Leng, 1983).**

Many authors claimed that tube settler could provide same or even better performance than that of the conventional sedimentation tank with relatively low cost. The broad advantages of cost concern due to Applications of high rate tube settlers are; the sedimentation process cost, the construction costs and land costs.

2.4 Factors Affecting Tube Settlers Performance

Some drawbacks of tube settlers include:

The accumulation of sludge on the tube surfaces which may cause simplicity and the outflow quality to deteriorate (Brauch, 1977).

Once the tubes begin to fill with fine solids settling out of the water flow, the water velocity rates through the tubes will increase due to reduced tube cross sectional area. As this happens and resistance to flow increases, water begins to seek a least resistance approach and will eventually simply by pass the tubes, thereby eliminating any solids capture at all. Therefore, periodic cleaning is necessary, but cleaning the settling deck is a dirty, nasty job that nobody likes to do and as a result is often neglected. In turn, neglect leads to poor performance of the settling device and subsequent deterioration in water quality. For this reason, it does not recommend tube settlers for use in highly loaded systems.

Tube settlement tanks should be frequently drained down and the tubes cleaned to remove any accumulated material. It should be removed upstream by stream jets water or during maintenance.

3. Methodology of the Study and Materials

3.1 Data Collection

The source of data involved both primary and secondary data sources. For the study, the primary data was gathered from experimental results and case study.

The experimental one was based developing a pilot scale physical model of sedimentation unit process of treatment plant with pilot tube settler. The pilot tube settler experiment was taken at Legadadi Water Supply Treatment Plant with the available water treatment laboratory.

Additionally, assessing and evaluating the application of high rate tube settler in the case of Legadadi Water Supply Treatment Plants was considered as case study.

Secondary data was collected from reports, Journals, books and from different web sources.

3.2 Data analysis and Synthesis

The collected data was analysed in different forms like literature reviews, tables, charts, figures and synthesised for the required objectives of the research.

3.3 The Applications of High rate Tube Settlers in The Case of Legadadi Water Supply Treatment Plant

3.3.1 Background

The Legedadi reservoir, located in east of Addis Ababa, was constructed in 1967. The purpose of the reservoir was to supply drinking water for the city of Addis Ababa. In 1999 Dire dam, with a capacity of 19 MCM, was commissioned to supplement water supply by Legedadi reservoir in order to meet the increasing water demand of the city that the treated water is delivered to the city by gravity pipe line (AWWSA, 2010)

The raw water from two reservoirs is treated at the same treatment plant called Legadadi treatment plant constructed with three stages (Stage I, Stage II and Stage III). Each stage contains the clarifier and rapid sand filter units, in that the Stage I has two Sedimentation tanks and eight units of Rapid Sand Filter, Stage II has two Sedimentation tanks and ten units of Rapid Sand Filter, and Stage III has one Sedimentation tanks and four units of Rapid Sand Filter.

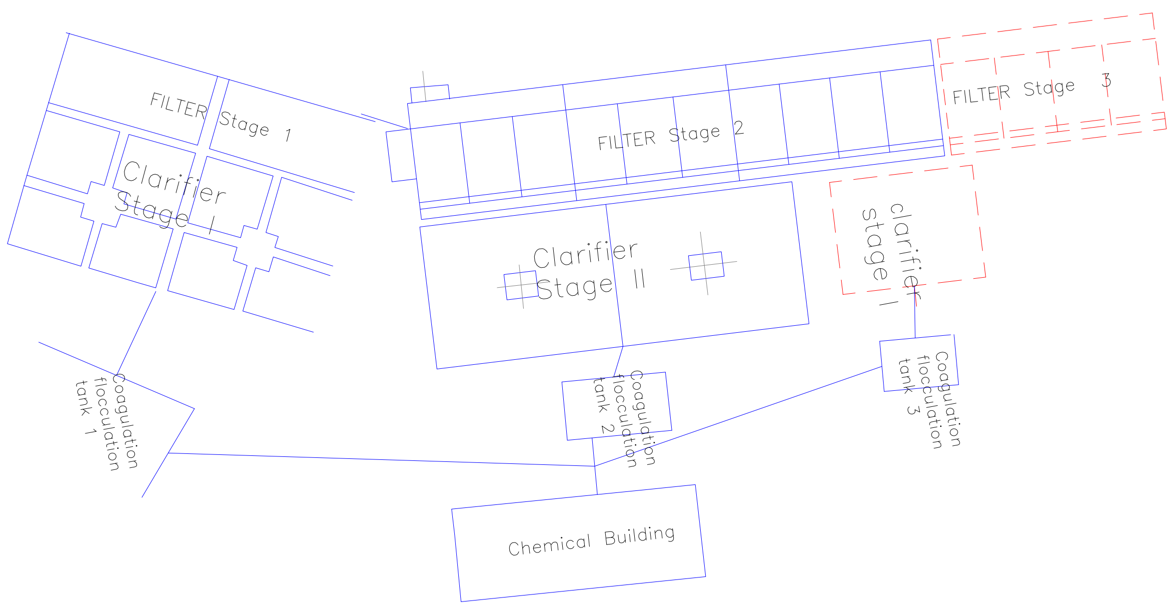


Figure 3-1: Diagrammatic layout of Legadadi Water Supply Treatment pant

Having implemented the proposed works for the treatment plant, the rehabilitated (stage I and II) and expanded (Stage III) treatment capacity of Legedadi could reach up to 192,000, m3/day. The optimum design and production capacity of stage I and II is 150,000m3/day. In order to achieve this increased capacity, the existing Stage I and II treatment units have to be renovated and rehabilitated. The new treatment unit (stage III), net design capacity is 26,500m3/day (AWWSA, 2010).

One of the optimization methods of the treatment plant capacity is use of high rate tube settlers in the sedimentation unit of the plant to increase the sedimentation efficiency and production increments applying in different stages.

This research was targeted to observe the typical advantageous of high rate tube settlers application in the water supply treatment in the case of this treatment plant.

The proposed case study assessed the application of HRTS in sedimentation efficiency (increasing production efficiency), decrease the structural and land costs of required sedimentation tanks, and the effects of using this HRTS on the filtration units of the treatment plant.

3.3.2 Applications of Laminar package Tube Settlers

3.3.2.1 Efficiency of Sedimentation Process/Treatment

The Applications of high rate tube settlers can be observed from taking comparison between the sedimentation tanks with HRTS and the one without HRTS. In the case of Legadadi Water Supply Treatment plant, there is about six years of data of clarified water production (Q), of Stage I without HRTS and Stage II with HRTS.

Therefore by analyzing the production data (Q) of the two stages of treatment plant, numerically and empirically, it is possible to observe the advantages of HRTS in the Sedimentation tanks of these treatment Plants. In addition to production efficiency (Q), the further application can be observed in cost benefit like structural cost and land cost due to using HRTS.

The Ideal settling basin principle can applicable for the two sedimentation tanks of Legadadi Water Supply Treatment Plant because of both are Horizontal Sedimentation tanks.

As discussed in the Literature review part increasing surface area , the theory of sedimentation basin and the ratio of Q/A show that the efficiency of a sedimentation basin depends on surface loading rate (SLR).

$$\mathrm{Vc} = \frac{\mathrm{Ho}}{\mathrm{td}} = \mathrm{Vc} = \mathrm{SLR} = \frac{\mathrm{Q}}{\mathrm{A}} = \frac{\mathrm{Q}}{\mathrm{L} * \mathrm{W}}$$

$$\mathrm{Vs} = \frac{\mathrm{Q}}{\mathrm{W} * \mathrm{H}}$$

$$\mathrm{Vf} = \frac{\mathrm{L}}{\mathrm{td}}$$

- V_s=V_f, ideally Particles move forward(V_s.) with the same velocity as the liquid(V_f)

Therefore;

1. $\frac{\mathrm{Q}}{\mathrm{W}} * \mathrm{H} = \frac{\mathrm{L}}{\mathrm{td}}$

$$\mathrm{td} = \frac{\mathrm{W} * \mathrm{Ho} * \mathrm{L}}{\mathrm{Q}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2. $\mathrm{SLR} = \mathrm{VC} = \frac{\mathrm{Ho}}{\mathrm{td}} = \frac{\mathrm{Q}}{\mathrm{A}}$

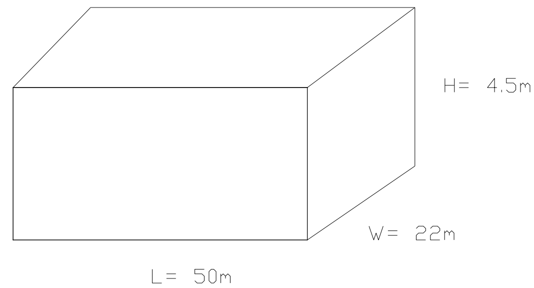
$$\mathrm{td} = \frac{\mathrm{W} * \mathrm{H} * \mathrm{L}}{\mathrm{Q}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Therefore in the case of Legadadi,

Let,

Stage I

(Sedimentation tank without HRTS)



Stage II

(Sedimentation tank with HRTS)

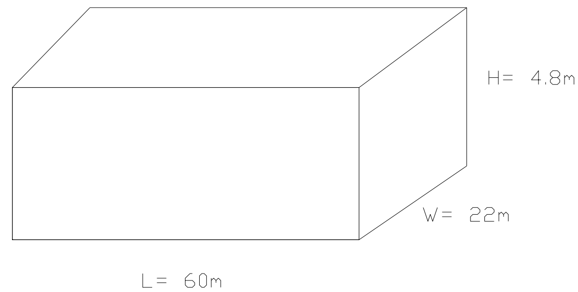


Figure 3-2: Legadadi horizontal sedimentation tanks sizes stage I and II

$$Q = \frac{W * H * L}{td}$$

$$\text{Thus;} \quad Q1 = \frac{W1 * H1 * L1}{td1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{for stage I}$$

$$Q2 = \frac{W2 * H2 * L2}{td2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{for stage II}$$

$t_{d1}=t_{d2}$, detention time for stage I and II respectively.

$$Q1 = \frac{W1 * H1 * L1}{td1}$$

$$Q1 = \frac{22m*4.5m*50}{td1}$$

$$Q1 = \frac{4950m3}{td}$$

$$Q2 = \frac{W2 * H2 * L2}{td2}$$

$$Q2 = \frac{22m * 4.8m * 60}{td2}$$

$$\mathbf{Q2 = 6336m3/td2}$$

$$\text{Let}, Q1 * f = Q2, f = \text{factor}$$

$$f = Q2/Q1$$

$$f = 6336m3/4950m3$$

$$\mathbf{f = 1.28}$$

Q2=1.28Q1……..In settling basin capacity factor of the water produced from stage II to water produced from stage I.

Since the HRTS was applied for stage II and not for Stage I, it is possible to have a comparison of both stages based on:

- Q produced from stage I before use of HRTS symbolized as Q1
- Q produced from stage I if HRTS used symbolized as Q1*
- Q produced from stage II after use of HRTS symbolized as Q2
- Q produced from stage II if HRTS was not used symbolized as Q2*

Therefore; $1. Q1 *= \frac{Q2}{1.28}$, is the value of stage I produced if HRTS is applied.

$2. Q2 *= 1.28Q1$, is the value of stage II produced if HRTS was not applied.

Additionally having the area comparison, it is possible to calculate the area required to produce Q1*(if HRTS is used) and Q2 (without use of HRTS);

Thus to calculate the area;

$\mathrm{SLR} = \frac{\mathrm{Ho}}{\mathrm{td}} = \frac{\mathrm{Q}}{\mathrm{A}},$

Where $\mathrm{A} = \mathrm{L} * \mathrm{W}$ and $\mathrm{Q} = \frac{\mathrm{A} * \mathrm{Ho}}{\mathrm{td}}$

$$\mathrm{Q1} = \frac{\mathrm{A1} * \mathrm{Ho}}{\mathrm{td}}$$
$$\mathrm{Q2} = \frac{\mathrm{A2} * \mathrm{Ho}}{\mathrm{td}}$$

$\mathrm{Q1} = \frac{\mathrm{A1}*(*)\ \mathrm{Ho})}{\mathrm{td}}$, (*)..............Multiplying of.

$$\mathrm{Q2} = \frac{\mathrm{A2} * (*)\mathrm{Ho}}{\mathrm{td}}$$

Where; A1 is area of Stage I sedimentation tanks.

A2 is area of Stage II sedimentation tanks.

A1* is area required to produce Q1* (if HRTS will applied)

A2* is area required to produce Q2 (if HRTS was not applied)

$\mathrm{Q1} = \mathrm{fQ1} * \ldots\ldots.\mathrm{f}, \mathrm{Area\ factor}$

$\mathrm{Area\ factor} = \frac{\mathrm{Q1}}{\mathrm{Q1}} *, \mathrm{A1} *= \mathrm{fA1}$ and

$\mathrm{Q2} = \mathrm{fQ2} * \ldots\ldots.\mathrm{f}, \mathrm{Area\ factor}$

$$\mathrm{f} = \frac{\mathrm{Q2}}{\mathrm{Q2}} *, \mathrm{A2} = \mathrm{fA2} *$$

From the Legadadi Water Supply treatment plant, there is a recorded data of raw water to the clarifier and daily production from 2008 to 2014. The data is taken for both stages of treatment plant (stage I, without use of HRTS and stage II with use of HRTS).To analyses the efficiency of sedimentation process and other use of HRTS, the (2008 to 2014 year annual data is taken as a sample because it is full data measured by AWWSA (AWWSA 2008-2014).

Table 3-1 below the average daily raw water and treated water flow rates of six year is summarized that going to be used for the comparison of treated water flow rate efficiency with and without HRTS.

Table 3-2:Legadadi Water Supply Treatment Plant, Average daily raw water flow rate vs. Treated water flow rate for Stage I and Stage II Treatment Plant.

S.no	Month	Stage I with out use of HRTS		Stage II with use of HRTS	
		Average daily raw water inflow rate (m3/d)	Average daily treated water out flow rate (m3/d)	Average daily raw water inflow rate (m3/d)	Average daily treated water flow rate (m3/d)
1	Sebtember	58,099.20	55,338.67	112,780.80	108,181.11
2	October	58,099.20	55,356.17	112,780.80	108,216.11
3	November	58,099.20	55,356.17	112,780.80	108,216.11
4	December	58,099.20	55,363.17	112,780.80	108,230.11
5	January	58,099.20	55,356.17	112,780.80	108,216.11
6	February	58,099.20	55,912.67	112,780.80	108,407.73
7	March	58,099.20	56,108.67	112,780.80	108,799.73
8	April	58,099.20	56,045.67	114,048.00	109,940.93
9	May	58,099.20	55,856.69	114,048.00	109,563.00
10	June	58,099.20	55,849.70	114,048.00	109,549.00
11	July	58,099.20	55,734.20	114,048.00	109,318.00
12	August	58,099.20	55,723.70	114,048.00	109,297.00

Using the arithmetical relation methods, here in the table below ,the comparison of treated water production efficiency and area required is performed between the stage I (without HRTS) and stage II (with HRTS).

Table 3-1 : Comparisons of treated water production of stage I with Stage II (if HRTS is provided for Stage I)

Month	Average daily Production (Q1) of Stage I	Average daily Production (Q2) of Stage II after used HRTS	Average daily Production of stage I (Q1*) if HRTS used,Q1*=Q2/1.28	Efficiency of Production of Stage I if HRTS is provided (%)*Eff=(Q1*-Q1)/Q1*)100	Factor Area required,f=Q1*/Q1,A1*=fA1	Area required to Produce Q*1 with out HRTS ,A1*=f*A1= f*(50*22)	Additional Surface Area,A=A1*-A1,A1=(50*22=1100m2)	Efficiency Area saved if HRTS is provided (%)*Eff=((A1-1100)/A1*)100
Sebtember	55,338.67	108,181.11	84,516.49	*34.52*	1.53	1679.99	579.99	*34.52*
October	55,356.17	108,216.11	84,543.84	*34.52*	1.53	1680.00	580.00	*34.52*
November	55,356.17	108,216.11	84,543.84	*34.52*	1.53	1680.00	580.00	*34.52*
December	55,363.17	108,230.11	84,554.77	*34.52*	1.53	1680.00	580.00	*34.52*
January	55,356.17	108,216.11	84,543.84	*34.52*	1.53	1680.00	580.00	*34.52*
February	55,912.67	108,407.73	84,693.54	*33.98*	1.51	1666.22	566.22	*33.98*
March	56,108.67	108,799.73	84,999.79	*33.99*	1.51	1666.41	566.41	*33.99*
April	56,045.67	109,940.93	85,891.35	*34.75*	1.53	1685.78	585.78	*34.75*
May	55,856.69	109,563.00	85,596.09	*34.74*	1.53	1685.67	585.67	*34.74*
June	55,849.70	109,549.00	85,585.16	*34.74*	1.53	1685.66	585.66	*34.74*
July	55,734.20	109,318.00	85,404.69	*34.74*	1.53	1685.59	585.59	*34.74*
August	55,723.70	109,297.00	85,388.28	*34.74*	1.53	1685.59	585.59	*34.74*

From the table above; it is easy to observe that the production rate is increased by about (29,355.01 m3/day and the area required can be minimized by about 580.07m2) in average if HRTS is provided for Stage I as the comparison result. The percentage gained in increasing the production rate and decreasing the area required is about 34.5% if HRTS is provided for stage I.

In addition, to observe the production rate efficiency and area required for Stage II if HRTS was not provided for it, there is another arithmetical relation analysis between stage I and stage II in table below.

Table 3-2: Comparisons of treated water production of stage II with Stage I (if HRTS was not provided for Stage II)

Month	Average daily Production (Q1) of Stage I	Average daily Production (Q2) of Stage II after HRTS	Value of Q2*,without use of HRTS,Factor of stage II to Stage I=Q*2=1.28Q1	Efficiency of Production of Stage II after HRTS is provided,%Eff=((Q2-Q2*)/Q2)100	Area Factor,f=Q2/Q*2,A2=fA2*	Area required to Produce Q*2 with out HRTS Q2=fQ2*,A2=A2*(*)f =(60*22)*f	Additional Surface Area,A=A2-A2*,A2*=(60*22=1320 m2)	Efficiency Area saved if HRTS is provided (%),Eff=((A2-1320)/A2)100
Sebtember	55,338.67	108,181.11	70,833.49	34.52	1.53	2015.98	695.98	34.52
October	55,356.17	108,216.11	70,855.89	34.52	1.53	2016.00	696.00	34.52
November	55,356.17	108,216.11	70,855.89	34.52	1.53	2016.00	696.00	34.52
December	55,363.17	108,230.11	70,864.85	34.52	1.53	2016.00	696.00	34.52
January	55,356.17	108,216.11	70,855.89	34.52	1.53	2016.00	696.00	34.52
February	55,912.67	108,407.73	71,568.21	33.98	1.51	1999.47	679.47	33.98
March	56,108.67	108,799.73	71,819.09	33.99	1.51	1999.69	679.69	33.99
April	56,045.67	109,940.93	71,738.45	34.75	1.53	2022.93	702.93	34.75
May	55,856.69	109,563.00	71,496.56	34.74	1.53	2022.80	702.80	34.74
June	55,849.70	109,549.00	71,487.62	34.74	1.53	2022.79	702.79	34.74
July	55,734.20	109,318.00	71,339.78	34.74	1.53	2022.71	702.71	34.74
August	55,723.70	109,297.00	71,326.34	34.74	1.53	2022.70	702.70	34.74

Again from the table above; If HRTS was not provided for stage II, the production rate would be decreased by about (37,978.22 m3/day and the area required to be maximized by about 696.08m2) in average as the comparison result. The percentage gained in increasing the production rate and decreasing the area required is about 34.5% since HRTS is provided for stage II.

3.3.2.2 Effects of HRTS on Filter unit Process

Back washing is a passing of water upward through the filter media at a velocity sufficient to expand the bed and wash out the accumulated solids. This accumulated solid is the solids transferred from clarifier to rapid sand filter (RSF).

The accumulated solids in the filter media causes; head loss through the filter exceeds the design value, and turbidity breakthrough causes the effluent quality to be less than a minimum acceptable level. This effect depends up on the amount of solids accumulated in the filter, and its concentration depends on the efficiency of sedimentation unit. This means if the efficiency of solid removal in the sedimentation unit is high, the amount of solids transferred to the filtration unit is less and vice versa.

The variation of such conditions needs an adjustment of process in the filter unit, like back wash duration increasing; back wash frequency increasing that increases the costs of back washing at all.

The application of high rate tube settlers (HRTS) in sedimentation unit increases the efficiency of solid removal in high rate, so that the solids transferred to the filter unit is less.

One of the objectives of this research is to observe the effects of HRTS in decreasing the amount of solids transferred to the filter unit. And the study is focused in the case of Legadadi treatment plant as follows.

As it is explained under the application of HRTS in the *Efficiency of Sedimentation Process* section in the case of Legadadi Water supply treatment plant, the comparison was taken between the sedimentation tanks with HRTS and the one without HRTS Stage I and Stage II respectively.

Similarly; these two stages use as a case to observe the application of HRTS effects on the filter unit of the treatment plant. Here; the comparison based on the back wash time (frequency), volume of water required for back wash and costs of water uses for back wash.

According to AWWSA (on the Legadadi Treatment Plant(LDTP); the no of filter back washed, back wash duration time and volume of water consumed for back washing is recording daily.

For example, the filter back wash data recorded for six months of 2006/2014 for two stages of treatment plan, taken from (LDTP, Chemical consumption and Operating Machinery data No. (1701 to 1750, 1751 to1800), 3851 to 3900, 3901 to 3950)) is summarized as table below.

Table 3-3: The filter back washed no. in a days of six months of stage I and Stages II

Days in March Month	Filter back wash no..		Days in April Month	Filter back wash no..		Days in May Month	Filter back wash no..		Days in June Month	Filter back wash no..		Days in July Month	Filter back wash no..		Days in August Month	Filter back wash no..	
	Stage I	Stage II		Stage I	Stage II		Stage I	Stage II		Stage I	Stage II		Stage I	Stage II		Stage I	Stage II
1	**5**	**4**	1	**3**	**3**	1	**2**	**5**	1	**5**	**5**	1	**4**	**3**	1	**4**	**6**
2	**5**	**5**	2	**2**	**2**	2	**5**	**5**	2	**4**	**4**	2	**5**	**5**	2	**5**	**7**
3	**4**	**5**	3	**2**	**5**	3	**5**	**6**	3	**5**	**6**	3	**5**	**6**	3	**3**	**7**
4	**5**	**6**	4	**4**	**3**	4	**4**	**6**	4	**5**	**5**	4	**5**	**6**	4	**3**	**5**
5	**4**	**6**	5	**4**	**5**	5	**0**	**3**	5	**5**	**5**	5	**5**	**6**	5	**5**	**6**
6	**4**	**5**	6	**2**	**4**	6	**4**	**6**	6	**4**	**4**	6	**6**	**6**	6	**4**	**5**
7	**3**	**5**	7	**2**	**5**	7	**5**	**5**	7	**0**	**0**	7	**3**	**6**	7	**4**	**6**
8	**5**	**4**	8	**2**	**3**	8	**4**	**6**	8	**5**	**5**	8	**5**	**6**	8	**4**	**6**
9	**4**	**6**	9	**3**	**5**	9	**5**	**6**	9	**5**	**5**	9	**4**	**6**	9	**3**	**6**
10	**5**	**5**	10	**3**	**5**	10	**5**	**5**	10	**3**	**6**	10	**4**	**4**	10	**4**	**2**
11	**4**	**4**	11	**4**	**5**	11	**5**	**5**	11	**5**	**4**	11	**5**	**6**	11	**0**	**7**
12	**5**	**5**	12	**5**	**2**	12	**5**	**4**	12	**5**	**5**	12	**3**	**6**	12	**4**	**7**
13	**3**	**5**	13	**4**	**5**	13	**0**	**0**	13	**3**	**4**	13	**4**	**5**	13	**4**	**4**
14	**3**	**4**	14	**3**	**3**	14	**4**	**5**	14	**3**	**5**	14	**4**	**4**	14	**5**	**6**
15	**4**	**3**	15	**3**	**3**	15	**4**	**5**	15	**3**	**4**	15	**3**	**6**	15	**5**	**6**
16	**4**	**6**	16	**4**	**4**	16	**5**	**3**	16	**3**	**6**	16	**0**	**0**	16	**4**	**6**
17	**4**	**4**	17	**0**	**0**	17	**5**	**3**	17	**3**	**3**	17	**3**	**6**	17	**3**	**8**
18	**3**	**6**	18	**5**	**4**	18	**5**	**4**	18	**4**	**3**	18	**5**	**6**	18	**5**	**6**
19	**3**	**4**	19	**5**	**5**	19	**5**	**4**	19	**2**	**5**	19	**3**	**6**	19	**3**	**8**
20	**3**	**5**	20	**4**	**6**	20	**4**	**3**	20	**4**	**5**	20	**3**	**6**	20	**5**	**7**
21	**3**	**3**	21	**3**	**4**	21	**4**	**3**	21	**4**	**5**	21	**4**	**6**	21	**6**	**6**
22	**0**	**5**	22	**3**	**6**	22	**5**	**5**	22	**5**	**6**	22	**3**	**6**	22	**3**	**7**
23	**0**	**0**	23	**5**	**5**	23	**5**	**5**	23	**5**	**4**	23	**3**	**6**	23	**4**	**7**
24	**4**	**6**	24	**3**	**4**	24	**3**	**5**	24	**4**	**5**	24	**5**	**5**	24	**4**	**8**
25	**0**	**0**	25	**3**	**4**	25	**3**	**5**	25	**5**	**6**	25	**0**	**0**	25	**3**	**7**
26	**4**	**4**	26	**5**	**5**	26	**4**	**5**	26	**4**	**4**	26	**3**	**6**	26	**5**	**6**
27	**4**	**5**	27	**4**	**5**	27	**4**	**4**	27	**3**	**4**	27	**4**	**4**	27	**4**	**6**
28	**0**	**3**	28	**4**	**2**	28	**5**	**6**	28	**5**	**5**	28	**0**	**0**	28	**6**	**7**
29	**4**	**4**	29	**5**	**2**	29	**4**	**5**	29	**5**	**4**	29	**4**	**7**	29	**5**	**8**
30	**2**	**3**	30	**4**	**3**	30	**4**	**6**	30	**4**	**5**	30	**5**	**6**	30	**5**	**7**

By taking the average daily no. of filter back washed of six months, it is possible to calculate the volume of water required for filter back washing for two stages in days.

The volume of water for one filter bed back washing consumption is 315m3 for 15min. duration of filter back wash run time. (AAWSA, 2006/2014)

Here in the table below, the volume of water required for filter back washing required in a day

Table 3-4: The filters back wash Water volume required in a days of months for stage I and Stages II

The six months average no.of filter back washed per day.		The total back wash water volume required of day in m3. Total volume=(315m3* Filter no. back washed in a day)	
Stage I	Stages II	Stage I	Stages II
3.83	4.33	1207.50	1365.00
4.33	4.67	1365.00	1470.00
4.00	5.83	1260.00	1837.50
4.33	5.17	1365.00	1627.50
3.83	5.17	1207.50	1627.50
4.00	5.00	1260.00	1575.00
2.83	4.50	892.50	1417.50
4.17	5.00	1312.50	1575.00
4.00	5.67	1260.00	1785.00
4.00	4.50	1260.00	1417.50
3.83	5.17	1207.50	1627.50
4.50	4.83	1417.50	1522.50
3.00	3.83	945.00	1207.50
3.67	4.50	1155.00	1417.50
3.67	4.50	1155.00	1417.50
3.33	4.17	1050.00	1312.50
3.00	4.00	945.00	1260.00
4.50	4.83	1417.50	1522.50
3.50	5.33	1102.50	1680.00
3.83	5.33	1207.50	1680.00
4.00	4.50	1260.00	1417.50
3.17	5.83	997.50	1837.50
3.67	4.50	1155.00	1417.50
3.83	5.50	1207.50	1732.50
2.33	3.67	735.00	1155.00
4.17	5.00	1312.50	1575.00
3.83	4.67	1207.50	1470.00
3.33	3.83	1050.00	1207.50
4.50	5.00	1417.50	1575.00
4.00	5.00	1260.00	1575.00
Average daily back wash water volume of six months,in m3		*1186.5*	*1510.25*

Table 3-5: The volume of Water treated per day and volume of Water required for back wash for Stage I and Stage II

Stage	Average daily treated water volume, m3/day	Back Wash Water volume,m3/day	%ge of volume for back washing
Stage I	55,791.07	1,186.50	2.13
Stage II	109,431.75	1,510.25	1.38

From the table to treat 55,791.07m3/day, the volume of water consumed for filter back wash is 1186.50m3 on stage I and to treat 109431.75m3/day, the volume of water consumed for filter back wash is 1510.25m3 for stage II.

By assuming the stage II is without HRTS, it consumes the volume of water proportional to the stage I for filter back wash, because the rate and duration of filter back wash for one cycle is the same 315m3 for one filter back wash and 15min. duration respectively.

Therefore, Let , 1186.50m3=55,791.07m3/day

X=109,431.75m3/day

X= (1186.50*109431.75)/55791.07m3

X=2327.27m3

Thus, 2327.27m3 volume of water is required to wash the filter on Stage II without HRTS per day. The difference is (2,327.27m3-1,510.25m3)=817.02m3/day, in percentages, % Safe amount= [(2,327.27m3-1,510.25m3)/ 2,327.27m3]*100 =35.11% /day which it is much significant.

3.4 The Pilot Scale Experiment of High rate tube Settlers

3.4.1 Design and Construction of Pilot Scale Sedimentation tanks

3.4.1.1 Types and Parameter contents of pilot scale Sedimentation tank

The type of sedimentation tank preferred is horizontal types of sedimentation tank. This type of sedimentation tank is selected due to the purposes of; the settling tank of Legadadi treatment plant is horizontal in that the pilot scale to be simulates the case. As it is described in detail in literature review the settling process is based on the theory of rectangular horizontal settling basin that the efficiency of a sedimentation basin depends on surface loading rate (SLR).

The pilot treatment plants contents of the Coagulation/Flocculation tanks and settling tanks. In the coagulation flocculation, the chemicals coagulant and coagulant aid added to the raw water in that the macro flocks are formed for easier settling in settling tanks. In settling tank the particles settled down where the clarifier water is flow up. The weir over flow collection is structured with the up flow clarifier to collect the clarified water.

3.4.1.2 The design and Proportional capacity of pilot scale

As it is reviewed in the literature; the design of sedimentation basins is governed by different basic criteria’s like the quantity of water to be treated, the selected detention time and the selected surface loading rate (or overflow rate).

Therefore; for the purpose of this pilot scale design, the basic criteria used is the surface loading rate (surface over flow rate) and detention time of the particles in the tanks, because the objective of designing it is to evaluate the application of High rate tube settlers .

Additionally; for the design principles of rectangular settling tanks; the inlet zone, the settling zone, the sludge zone and the outlet zone is considered for the design of this pilot scale.

In the inlet zone, the velocity of flocculated water must be reduced and the flow spread evenly over the cross section of the settling tank. For this purpose; the inlet pipes from the flocculant tank is provided with perforated part in the bottom of settling tank to distribute the water evenly and for slow water up flow. Here, again to arrest the velocity of up flow water the saddles is provided along over the perforated in let pipes in the tank to dissipate the energy of up flow water, in that the settled particle is absented from disturbance instead of quiescent settling .

The settling zone of the pilot is provided with enough space for installations of high rate tube settlers, easier sludge removal, to minimize short circuiting and provided with freeboard.

The sludge zone of the pilot plant is designed with required sludge depth and the drain valve for the deposited sludge removal is provided.

The outlet zone of the settling tank is provided at the end of the tank with over flow weir and launder. The sample for the experiment is taken here at the out let of the pilot.

The design of the size of the pilot scale plant is determined based on the different design standards ratios. For horizontal up flow clarifiers the dimensional ratio Length to Depth and Width to Depth is (2:1 to 4:1 and 3:1 to 6:1) respectively for small sizes of up flow clarifiers (M. Ebeling).The capacity /Size of the pilot plant is proportionally related with the case work plant (Legadadi treatment plant) based on the factor surface over flow rate (SOR).

This pilot scale sedimentation tank size determined (L=1.5m, W=1m and D=0.8m) is almost proportionally related with the legadadi treatment plant size of stage II sedimentation tank (L=60, W=22 and D=4.8m)

The Pilot scale Sedimentation tank The Legadadi treatment plant Sedimentation
tank (Stage II)

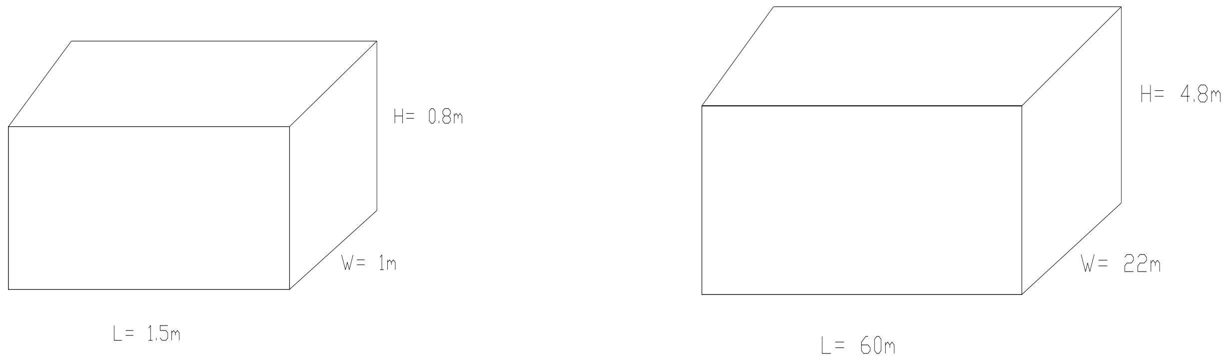


Figure 3-3 : The pilot scale and legadadi treatment plant sedimentation tanks proportional capacity

The surface Loading rate (SLR/SOR) of the settling tank is given as:

$$\mathrm{SOR} = \frac{Q}{A} = \frac{Q}{L*W}$$

$$td = \frac{V}{Q},\ \ V, = \text{Volume of the water}$$

And from;

$$Vs = \frac{Q}{W*H}$$

$$Vf = \frac{L}{td}$$

$$\text{Where } Vs = \frac{Q}{W*H} = Vf = \frac{L}{td}$$

$$\frac{Q}{W*H} = \frac{L}{td}$$

$$td = \frac{W*Ho*L}{Q}$$

$$Q = \frac{W*Ho*L}{td}$$

In the case of pilot scale settling tank:

$$Qps = \frac{W*Ho*L}{td} = (1m * 1.5m * 0.8m) \quad = 1.2m3/td$$

Q ps Flow rate of pilot scale

- In the case of Legadadi treatment plant sedimentation tank (Stage II)

$$Qld = \frac{W*Ho*L}{td} = (22m * 60m * 4.8m) \quad = 6336m3/td$$

Q ld Flow rate of Legadadi

The proportional capacity of the rates = $\frac{Qld}{Q\ ps}$ = 6336m3/td/1.2m3/td

For similar detention time;

$$Qld = (6336m3/1.2m3)\ Q\ ps$$

$$Qld = 5280Q\ ps$$

3.4.1.3 Types / configuration of High rate tube settlers and its area projection to the tank

In this study, the type of High rate tube settler used is hexagonal types of tube settlers, because of; the Legadadi treatment plant where this case study done is uses such kinds of PVC laminar packages.

Figure 3-4: The hexagonal types of high rate tube settler (the one used for Legadadi and pilot)

During the application of this high rate tube settler for this pilot experiment; the parameters and factors like, Inclination angle of the tube, tube diameter and tubes length is considered to design the surface area projection and identifying its efficiency.

The surface area projection of this type of hexagonal tube settler is designed based up on the theory of increasing surface of tube settlers like ;DEGREMONT principles as it is reviewed in literature.

Therefore, by taking the parameters to be considered, the Surface area projection is calculated as below.

- *Inclination angle: 55^0 for assessing the case of Legadadi treatment i.e. the inclination angle used for it is 55^0 ,*
- *The tube Length: The tube length taken for this typical experiment is 30cm, based on the pilot sedimentation tank depth.*
- *The internal diameter size shown below for hexagonally configuration types of tube settlers.*

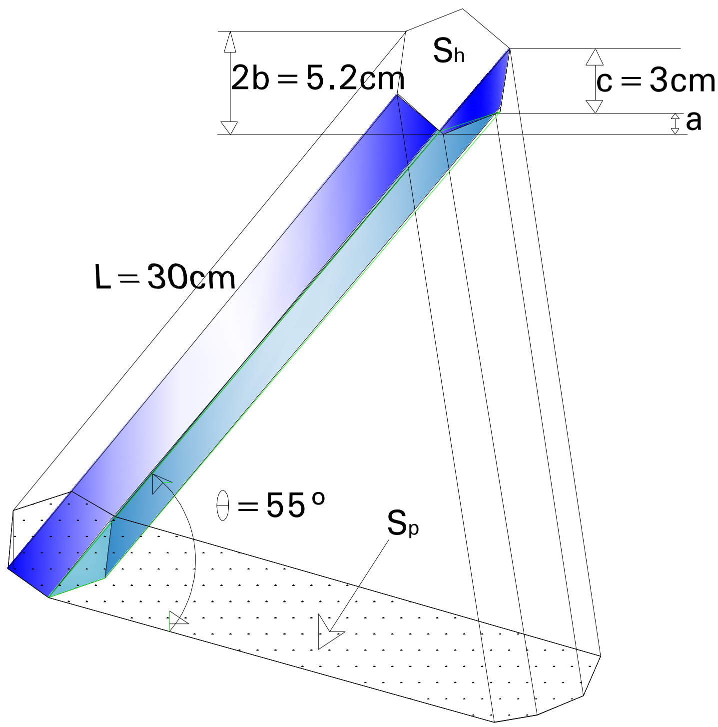


Figure 3-5: The configuration and Surface area projection of hexagonal types of tube settlers used for pilot experiment.

The Surface Projection Sp:

$Sp = (a + 2c) * L * \cos\theta \quad (m2)$

Where; L = Length of tube settlers

θ = Angle of inclination of the lamellar tubes.

$Sp = (a + 2c) * L * \cos\theta$

$Sp = (30mm + 2 * 30mm) * 300mm * \cos(550)$

$Sp = 15486.56mm2$

The horizontal cross sectional area of the tubes settlers:

$Sh = 52mm * (30 + 30)/ (Sin550mm2$

$Sh = 2555.75mm2$

The projection ratio; $Ks = Sp/Sh = 6.06\ m2/m2$

Or, from the (Hazen relations); the projected area ratio to the horizontal cross sectional area (Ks);

Therefore; $$Ks = \frac{L\ \ a+2c\ \ *\cos\theta*\sin\theta}{(2b*\ \ a+c\ \ )}$$

Using these values for the Ks;

$$Ks = \frac{L\ \ a+2c\ \ *\cos\theta*\sin\theta}{(2b*(a+c)}$$

$$Ks = \frac{300\ \ 30+2*30\ \ *cos55*Sin55}{52*(30+30)}$$

$Ks = 6.10m^2/m^2$

Thus; Ks=6.10m2/m2, is a ratio that the projected surface is increased.

Therefore, the surface area is projected by 6.10; the capacity of water to be produced will be, calculated from the surface over flow rate relation.

$$SOR = \frac{Q}{A}$$

Where SOR=is the Q m3 amount of water produced /sec per m2 of area, in conventional Settling tank

Q_C=the water produced/clarified from the surface area Ac

Ac=the conventional surface area

Accordingly; Let; A_p = the area projected,

Q_p=The Q produced /clarified after use of HRTS

SOR=is the Q m3 amount of water produced /sec per m2 of area, after use of HRTS which is equal with conventional one

Therefore; $\mathrm{SOR} = \mathrm{Qc/Ac}$

$$\mathrm{Qc} = \mathrm{Ac} * \mathrm{SOR} \ldots\ldots \text{for conventional one;}$$

$$\mathrm{Qp} = \mathrm{Ap} * \mathrm{SOR}$$

$$\mathrm{Ap} = 6.10\mathrm{Ac}$$

$$\mathrm{Qp} = 6.10\mathrm{Ac} * \mathrm{SOR}$$

Here, for the pilot scale, the total surface area increased is =6.10*(Ac), =6.10*(1.5*1) =9.15m2.

Note*: The surface area projected due to application of HRTS for Legadadi WSTPT sedimentation tank of Stage II is;

$$\mathrm{Ks} = \frac{\mathrm{L} \;\; \mathrm{a+2c} \; *\cos\theta*\sin\theta}{2\mathrm{b}*(\mathrm{a+c})}$$

Where; L=1000mm and other parameters are similar with for pilot

$$\mathrm{Ks} = \frac{1000 \;\; 30 + 2 * 30 \;\; \cos 55 * \sin 55}{52 * (30 + 30)}$$

Ks=13.56m2/m2, where the total surface area is increased to =13.56*(50*22) =13.56*(1100) =14916m2.

3.4.1.4 The General and detail systems of the pilot treatment plant

The systems of pilot scale treatment plant; for the purpose of this experiment; mainly contains the coagulation flocculation tank and the settling tank with weir over flow channels.

The coagulation flocculation tank is where addition of coagulant is added to raw water and mixing is takes place to formation of flocks called coagulation flocculation process. For this specific experiment the tank is designed by overlaying different size of tanks. The over laid tanks are about three tanks in which the two above ones are small in size and the third bottom one is large. The first two tanks are perforated in very small opening at their bottom. The purpose of this bottom perforated overlaid tanks is two. One to increase the coagulation process because the coagulated water spread from one perforated tank to other vertical tanks in forming hydraulic jump over lay which helps the full mixing of coagulants with raw water. Additionally the water stayed in the tank for a moment that it is used for the formation of micro flocks before it arrived in the settling tank.

The settling tank contains the inlet zone, settling zone, the sludge zone and outlet zone as it explained in detail under the design of proportional capacity of pilot scale above. The laminar package/tube settler is installed in the settling zone to increase the settling efficiency. Here below, are the detail drawings of the systems experimental pilot scale treatment plant.

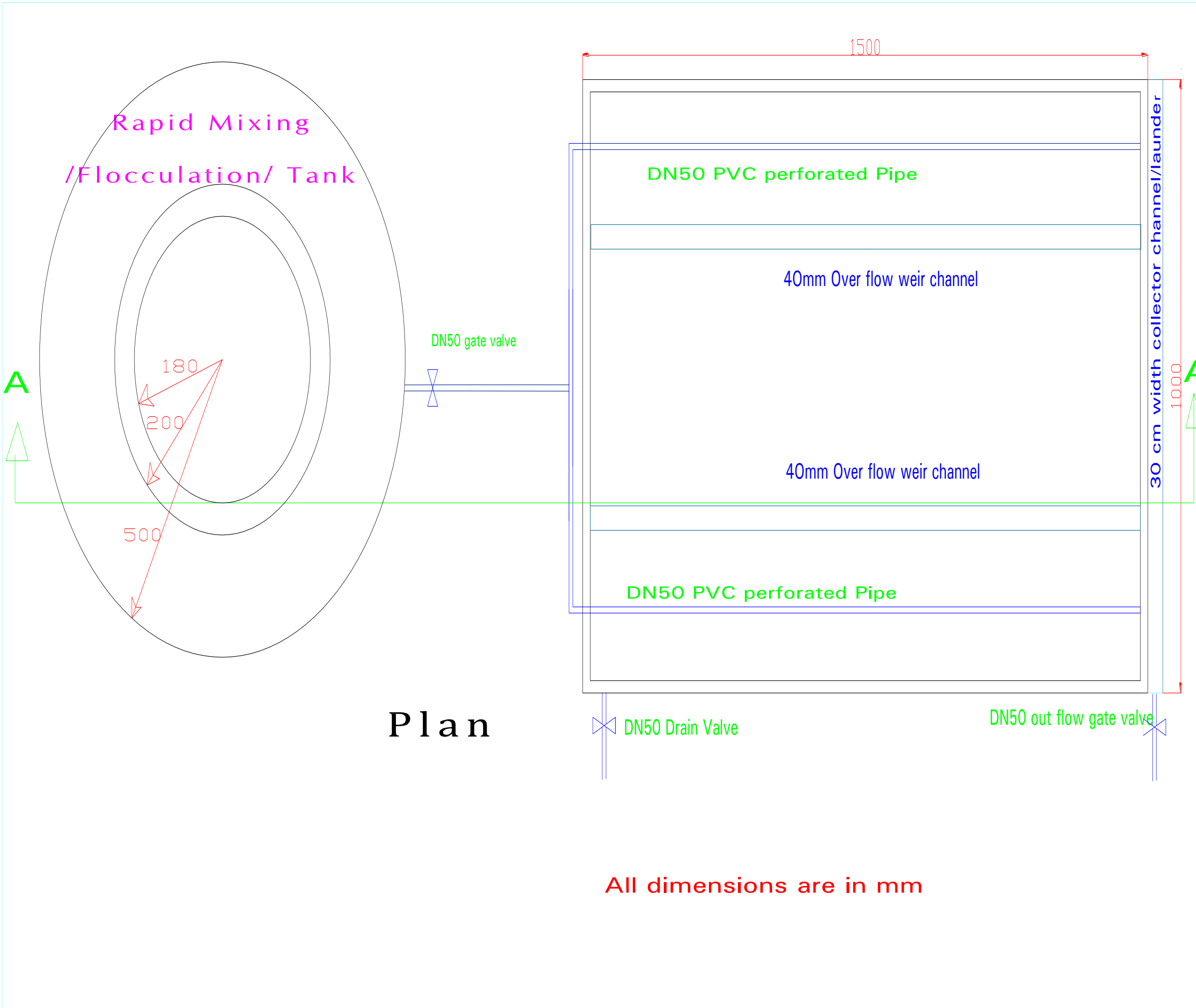


Figure 3-6: The detail drawings of the pilot scale treatment plant (plan view)

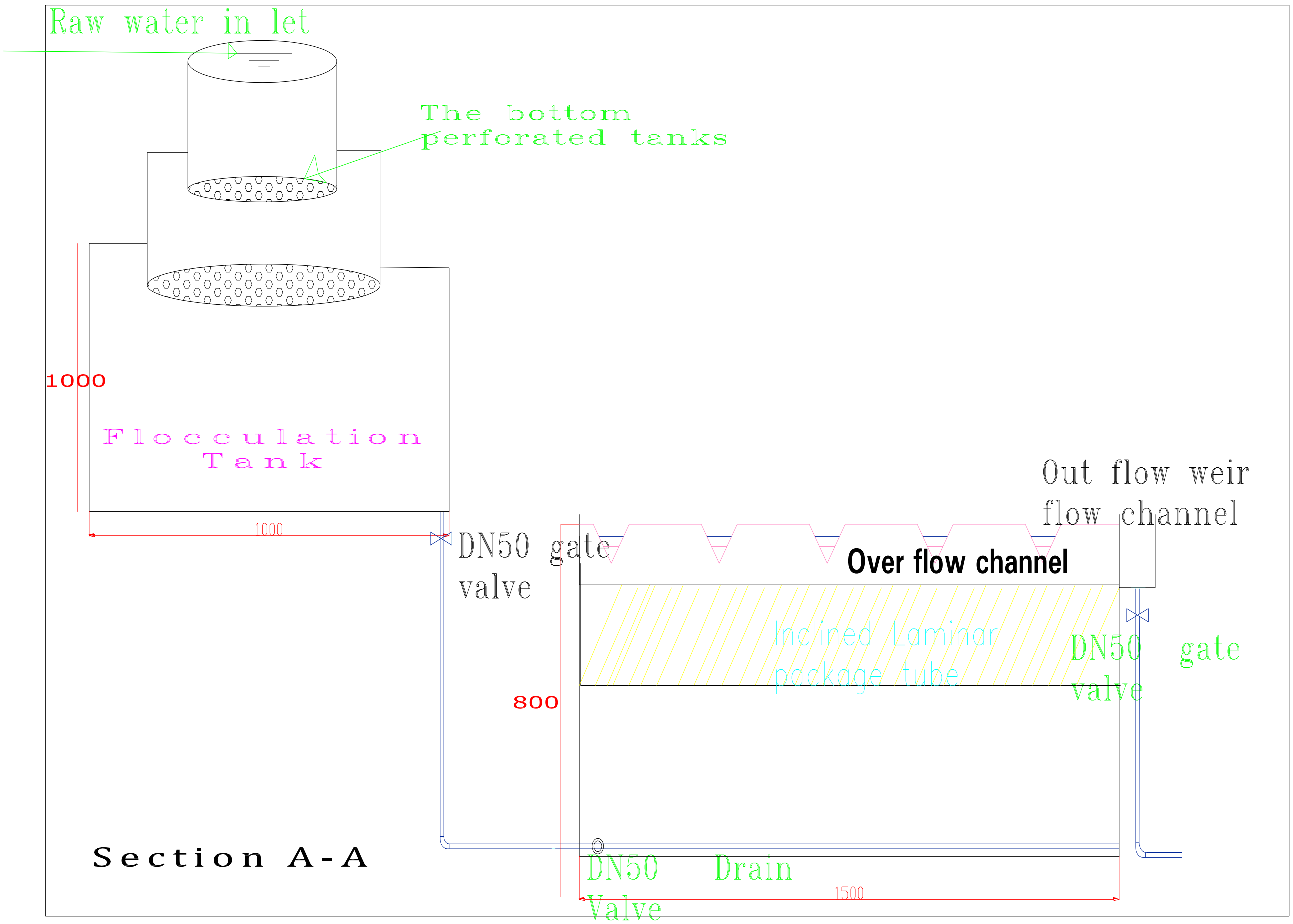


Figure 3-7: The detail drawings of the pilot scale treatment plant (Section view)

3.4.1.5 Construction of Pilot Scale Sedimentation tank

The pilot scale treatment plant is constructed and installed at the Legadadi treatment plant.

The activity was executed according to the design specified dimensionally as well as system configuration. The main parts of the plant are constructed by different materials available on the markets. For example; different sizes of plastic tanks are used as the coagulation flocculation tanks and the settling tank is constructed from metal sheets/plates in work shop. The required standard types of pipes and fittings are supplied and installed to the required parts of the plant.

Here; the construction material required and used for the construction of the pilot plant are summarized in the table below.

Table 3-6: Materials required for pilot scale treatment plant construction

S.no	Material description	Unit	Quantity
1	**Tanks**		
1.1	A 2 mm thick metal plate used for the construction of 1.2m3 pilot scale settling tank in workshop collection weir and over flow weir channels	m2	7
1.2	About 50L plastic tanks used as coagulation tanks	no	2
1.3	About 500L plastic tanks used as flocculation tank	no	1
2	**Pipes and Fittings**		
2.1	DN25 HDP pipe for raw water inlet	m	15
2.2	DN50 PVC pipe used for taking water from coagulation flocculation tank to settling tank	m	8
2.3	2" Valve sockets	no	2
2.4	2" GIS sockets	no	4
2.5	ISO Tee	no	1
2.6	2" Gate valve	no	2
2.7	1" Gate valve	no	1
2.8	2X1 reducer	no	1
2.9	2" HDP Male adaptor	no	2
2.10	A 2" 90^0 Elbow	no	4
3	A 30cm long of PVC laminar package /High rate tube settlers/ inclined at 55^0 covered about $1.5m^2$ areas.	m^2	1.5

Figure 3-8: photos of the constructed and installed systems of the pilot plant.

3.4.2 Experimental Process Types and Methods

3.4.2.1 Sample Types and Conditional Parameters

As it is explained under the general methodology of this study, this experimental type and process is targeted to answer the objectives of the research. Accordingly the experiment basically focuses on the applications of high rate tube settlers in the sedimentation process by using HRTS.

Hence, the experimental types and conditional parameters considered for the experiments are:

- Checking the solid removal efficiency at different detention time of constant flow rate,
- Observing the detention time required due to using of HRTS,
- Observing the required clarified water flow rate in consideration of turbidity and detention time that leads to analysis the production rate efficiency. Thus, the variation of production rate efficiency directly related with the cost for sedimentation process like surface area required (structural cost and land cost).
- In addition, the effect of using this HRTS on the chemical dosage required to be assessed. Here, the chemical required are coagulant and coagulant aids. Coagulant is a type of chemical added to the water that destabilizing colloids in neutralizing the negative charges called coagulation. So this chemical size is determined by so called optimum coagulant dosage that required destabilizing the whole particles in the water that it can't possible to vary its dosage. And coagulant aid is a type of chemical added to the coagulated water that used for the forming of agglomeration of destabilized particles into large size particles known as flocks which called flocculation process. As the particle size increase, the settling velocity increases that it effectively removed. Based on the theory of increasing settling velocity is about decreasing detention time and the application of HRTS is also decreasing detention time in that it add an efficiency even if the amount of coagulant is less. Therefore with the application of HRTS, the experiment would assess the coagulant aid dosage variation that if this coagulant dosage is decreased the cost of supply and apply might decreased.
- Finally; the pilot scale experimental results observed and analyzed would projected to the case of Legadadi treatment plant to evaluate the efficiency of the treatment plant.

Therefore based up on the above listed sample types and methods; the general experimental types and conditional parameters are summarized in table 3.7.

Table 3-7: General experimental types and conditional parameters

1.Checking solid removal efficiency by keeping up flow clarifier out flow (Q) constant ,chemical dosage constant and at diffrent detention time.

Trial no.	Q,l/sec. *eg*	Detention time, in min *eg*	Chemical dosage ,mg/l		*Turbidity,NTU*	
			Coagulant	Coagulant aids	Before use of HRTS	After use of HRTS
1	Q1	t1	C1	CA1		
2	Q1	t2	C1	CA1		
3	Q1	t3	C1	CA1		
4	Q1	t4	C1	CA1		
5	Q1	t5	C1	CA1		

2.Checking solid removal efficiency by keeping (upflow clarifier production (Q) and detention time(t)) constant, by using diffrent chemical dosage.

Trial no.	Chemical dosage ,mg/l		Upflow production Q,l/sec	Detantion time,min	Turbidity ,NTU	
	Coagulant	Coagulant aids			Before use of HRTS	After use of HRTS
1	C1	CA1	Q1	t1		
2	C1	CA2	Q1	t1		
3	C1	CA3	Q1	t1		
4	C1	CA4	Q1	t1		
5	C1	CA5	Q1	t1		

Note: The symbols in the table above indicates (Q=flow rate in L/sec, C1=Coagulant, CA=Coagulant aid, t=detention time, T=Turbidity and HRTS=High Rate Tube Settlers)

3.4.2.2 Materials and Methods used for experiments

a. Materials

The materials and apparatus used for this experimental research are a types of materials used at scientific laboratory and modified materials used during running the experimental process. The main materials used are summarized in table below.

Table 3-8: Experimental apparatus used for conducting the experiments

S.no	Apparatus/materials
1	A PVC HRTS/ Hexagonal Laminar package
2	The jar and jar test apparatus like beakers
3	1L volumetric flask
4	Distilled/wash water
5	Graduated measuring cylinders(25ML,50ML)
6	Medical tool called Intra Venus set use as flow meter
7	A 25L volume barrel
8	20L and 10L volume containers for storing chemical stock media.
9	A 5L,2L and 1L volume container for adding of coagulant and coagulant aids
10	A lot of (0.5L -1L) plastic bottles used for taking sample
11	Watch time
12	Turbid meter (HACH 200AN)
13	Cuvaet
14	Cleanol, and others

b. Methods

The general experimental systems and methods followed during conducting these experiments are; the raw water taken from legadadi reservoir provided for samples at the treatment plant is connected with pilot scale plant. The raw water is taken to the over laid coagulation flocculation tank by different flow rates. The chemicals like coagulants and coagulant aids are added to these tanks. After the water is coagulated and flocculated in these tanks then it flows to the pilot settling tank. In the settling tank the water is clarified for different specified times and the samples taken at the outlet of over flow collector channel that is taken to laboratory for turbidity checking.

Here; the specific methods and steps taken for full experimental process is listed in detail as follows:

1. The Jar test

The jar test is conducted to determine the optimum coagulant and flocculant dosage required to coagulate the water that help to simulate the coagulation and flocculation processes.

The type of chemicals (coagulant and coagulant aid) used in the case of this research are ***polyelectrolyte (Diallyl Dimethyl Ammonium Chloride Polymer)*** **and** *(Polyacrylicamid)* respectively.

The optimizations coagulant (polyelectrolyte***)*** *is* conducted using the jar test apparatus. The apparatus allowed six beakers to be agitated simultaneously. The beakers were filled with 500 ml of turbid water and were agitated for 4 min at 100 rpm (rapid mix) and 20 min at 40 rpm (slow mix) after the coagulant is added to form micro flocks. For the last it was allowed for 20 min of sedimentation. Then the final turbidity in each jar is measured and the lowest residual turbidity indicates the optimum coagulant dosage required.

The amount of coagulant dosage added for test is as in the table below and the results of the jar test shows that the optimum dosage of alum is 6 mg/L. At optimum dosage, turbidity decreased from 245 NTU to 6.7NTU corresponding to a turbidity removal of 97.27%.

Table 3-9: Coagulant dosage jar test results

Coagulant Dosage (mg/L)	Turbidity (NTU)	Turbidity Removal (%)
4	66.9	72.69
5	17.6	92.82
6	**6.7**	**97.27**
7	11.7	95.22
8	36.8	84.98
9	78.4	68.00
Raw water turbidity(NTU)=245		

Or the following Plot reveals the residual turbidity against coagulant dose

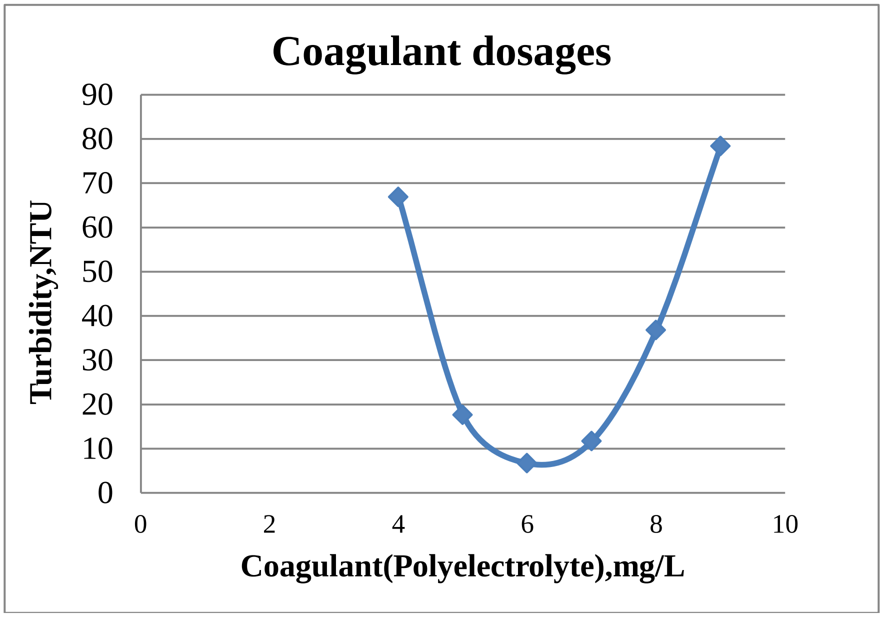


Figure 3-9: The coagulant dosages of jar test results

The coagulant aid is added to the beakers at the last 2min of slow mixing that it can able to form macro flocks. Here, to determine the coagulant aid dosage, the jar test is conducted repeatedly by using optimum coagulant dosage of 6mg/l, and then the coagulant aid added to the beaker at the last 2min of slow mixing.

Accordingly, from this result is 0.2mg/L of coagulant aid is used.

Table 3-10: Coagulant aid dosage

Coagulant aid (mg/L)	Detention time,(min)	Turbidity (NTU)
0.1	25	6.9
0.15	22	6.7
0.2	**20**	**6.7**
0.25	15	6.8
0.3	10	6.6

Here, 0.2mg/L is taken as coagulant aid considering the average required detention time and other factors like chemical cost, toxicity limit, and increasing flock formation duration chance.

Therefore; the 6mg/L and 0.2mg/L of coagulant and coagulant aid is used respectively, for this typical experiment

2. Preparation and Addition of chemicals (Coagulants and Coagulant aids) to the pilot plant system

As it is determined from jar test above the dosage required for this specified experimental are 6mg/L and 0.2mg/L of coagulant and coagulant aids respectively.

The chemicals required and added to the system is prepared and stocked as follows.

1. Coagulants

The Jar test result of the dosage is 6mg/L

Let the volume of one clarifying cycle of the tank is 1200L

Therefore; the chemical dosage required for 1200L is:

6mg=1L

X=1200L

X=7200mg≈8000mg=8g

Let the stock media preparation is by 5L distilled water/8g, (A 5L is measuring container used for stock preparation in this experiment).

Now, the flow of coagulant can be adjusted according to the flow rate of raw water to the flocculent tank proportionally.

For example: For the raw water flow rates of 0.5L/sec or 25L/50sec,the amount of flow rate of coagulant can adjusted as follows.

5L=50min. =1200L

X=50sec. =25L

X=104 ML/50sec or 25ml/15sec., of coagulant flow from the stock to be required.

2. Coagulant aids

It is the same as procedure followed with coagulant stock preparation and addition.

Therefore;

The jar test result=0.2mg/L

Let the volume of one clarifying cycle of the tank is 1200L

Therefore the chemical dosage required for 1200L is:

0.2mg=1L

X=1200L

X=240mg=0.24 g

; Let the stock media preparation is by 5L distilled water/0.24g.

Now, the flow of coagulant aid can be adjusted according to the flow rate of raw water to the flocculent tank proportionally.

For example: For the water flow rates of 0.5L/sec or 25L/50sec,the amount of flow rate of coagulant can adjusted as follows.

5L=50min. =1200L

X=50sec. =25L

X=104ML/50sec or 25ml/15sec., of coagulant aid flow from the stock to be required

Figure 3-10: Photo’s Preparation and addition of coagulant and coagulant aid to the system

Here; after the stock preparation completed and flow rate of both raw water and chemicals is adjusted; the different flow rate for raw water is adjusted by using a 25L barrel use as a flow meter with in different minutes of time. Example, for the flow rates of 0.5L/sec., the 25l barrel to be filled within 50sec.And the continuous flow of chemical (coagulant and coagulant aid) is adjusted by medical dropping valve/Intra Venus set) that is easy to control the flow rates. The amount of flow controlled by this instrument is checked by filling of graduated measuring cylinder of 25 ml use as flow meter.

Based up on the above listed methodological procedure, the amount of raw water flow rates and chemical added is summarized in the below table for different experimental steps and conditions required.

Table 3-11: Raw water flow rates and chemical dosage addition rates

1.Checking solid removal efficiency by keeping up flow clarifier out flow (Q) constant ,chemical dosage constant and at diffrent detantion time.						
Trial no.	Raw water flow rates Q,l/sec.	Time in sec. ,to fill 25L container use as flow meter	Detantion time,min	Chemical dosage ,mg/l		
				Coagulant (L/25L water)	Time in sec.,to fill 25 ML container use as flow meter	Coagulant aids (L/25L water) and drop time is same with coagulant
1	0.33	75.00	60min	0.056	**23**	75.00
2	0.40	62.50	50min	0.067	**19**	62.50
3	0.44	56.25	30min	0.074	**17**	56.25
4	0.50	50.00	20min	0.083	**15**	50.00
5	0.67	37.50	15min	0.111	**11**	37.50

For the objectives of checking solid removal efficiency by keeping using different coagulant aid dosages with constant raw water flow rates (Q1) and detention time (t), the same procedure to be follow as the above steps. The only difference is the amount of coagulant aid dosage variation and Q and t are constant. Here, the concentration of coagulant aid is varied from (CA1=1mg/l, CA2=0.15mg/l,CA3=2mg/l,CA4=2.5mg/l and CA5=3mg/l) is used.

For example, the following experimental types conducted for 0.33l/sec., of raw water flow rates for different coagulant aid concentration (CA1=1mg/l, CA2=0.15mg/l,CA3=2mg/l,CA4=2.5mg/l and CA5=3mg/l) within 0.0104L of /25L of water flow.

Table 3-12: Raw water flow rates with different coagulant aid dosage rates.

2.Checking solid removal efficiency by keeping (upflow clarifier production (Q) and detention time(t)) constant, by using diffrent chemical dosage.					
Trial no.	Chemical dosage ,mg/l			Upflow production Q,l/sec	Detantion time,min
	Coagulant (L/25L water)	Coagulant aids (L/25L water)			
1	0.104	CA1=0.1	0.104	0.33	60
2	0.104	CA2=0.15	0.104	0.33	60
3	0.104	CA3=0.2	0.104	0.33	60
4	0.104	CA4=0.25	0.104	0.33	60
5	0.104	CA5=0.3	0.104	0.33	60

3. Taking the clarified water Sample and checking for turbidity

After the settling process is done with different parameters and experimental conditions listed above, the clarified water sample is taken according to item required. The taken sample is checked for turbidity in the laboratory and the results observed are registered to the considered conditions specified for further analysis.

Figure 3-11: Clarified water samples and checking turbidity in laboratory,(Legadadi WSTPT site and AWWSA Laboratory)

4. Experimental Results and Discussions

4.1 Experimental Results

After all clarifying process is completed under different conditions; the sample is checked in the laboratory, the analytical result is observed and recorded to the considering parameters. Accordingly the results is recorded as in table 4-1 for checking solid removal efficiency by keeping up flow clarifier out flow (Q) constant ,chemical dosage constant and at different detention time. And also for checking the solid removal efficiency by keeping (up flow clarifier production (Q) and detention time) constant by using different chemical dosage; for further discussions.

Table 4-2: Turbidity observed at different detention time (t).

Trial no.	Q,l/sec.	Detention time, in min	Chemical dosage ,mg/l		*Turbidity,NTU*	
			Coagulant (mg/l)	Coagulant aids (mg/l)	Before use of HRTS	After use of HRTS
1	0.33	60	6	0.2	42.06	9.82
2	0.40	50	6	0.2	58.36	24.60
3	0.44	45	6	0.2	66.23	36.42
4	0.50	40	6	0.2	70.00	40.98
5	0.67	30	6	0.2	108.44	86.36

*Note *; The initial Turbidity of the raw water is 251 NTU*

Table 4-3: Turbidity observed at different coagulant aids.

Trial no.	Upflow production Q,l/sec	Detantion time,min	Chemical dosage ,mg/l		Turbidity ,NTU	
			Coagulant (mg/l)	Coagulant aids (mg/l)	Before use of HRTS	After use of HRTS
1	0.33	60	6	0.1	47.25	13..00
2	0.33	60	6	0.15	43.96	11.22
3	0.33	60	6	0.2	42.06	9.82
4	0.33	60	6	0.25	40.32	9.10
5	0.33	60	6	0.3	38.72	8.46

*Note *; The initial Turbidity of the raw water is 251 NTU*

4.2 Experimental Results Analysis and Discussions

As it explained the results of this typical experiment is observed and recorded in above tables. Here below, the analysis of the result is discussed for different important conditions considered during the experiment with and without the applications of high rate tube settlers (HRTS).

These are:

- The solid removal efficiency gained due to use of HRTS.
- Efficiency gained in detention time due to use of HRTS.
- Efficiency gained in production efficiency (Q), that is relating with settling tank size and cost (Structural and Land cost) and,
- The chemical cost effective.

4.2.1 The solid removal efficiency gained due to use of HRTS

Based on the conditional parameter of checking solid removal efficiency with constant flow rates and different detention time before and after use of HRTS is analyzed in table below.

Table 4-4: The solid removal efficiency at different detention time

Trial no.	Q,l/sec.	Detention time, in min	Chemical dosage ,mg/l		*Turbidity,NTU*		Solid/Turbidity removal efficiency (%)
			Coagulant (mg/l)	Coagulant aids (mg/l)	Before use of HRTS	After use of HRTS	
1	0.33	60	6	0.2	42.06	9.82	76.65
2	0.40	50	6	0.2	58.36	24.60	57.85
3	0.44	45	6	0.2	66.23	36.42	45.01
4	0.50	40	6	0.2	70.00	40.98	41.46
5	0.67	30	6	0.2	108.44	86.36	20.36

As it is able to observe from the above table; the turbidity of clarified water with and without HRTS with similar factor is quite different. As detention time is increased and turbidity is tends to the acceptable level; the removal efficiency is much increased.

For example; at the 0.33l/s flow rates, 60min. detention time and the same coagulant and coagulant aid dosage, the clarified water turbidity is 42.06 NTU without HRTS and 9.82 NTU with HRTS application that the removal efficiency is about 76.65% due to HRTS used.

4.2.2 Efficiency gained in detention time due to use of HRTS

One of the advantages aimed and observed of application of HRTS is increasing the efficiency of detention time. Accordingly, by taking the basics of turbidity value at detention time (t), it is possible to relate and find the efficiency gained due to use of HRTS. From the above table (4.3), Let the turbidity value 42.06NTU is observed at 60min detention time without application of HRTS, and turbidity value (42.06 NTU) is observed at 39.8 min detention time (by interpolating the values from the table).

Therefore, to get 42.06 NTU turbidity values it takes a 60min.detention time without HRTS and 39.8 min., with the application of HRTS, which the percentage efficiency observed is about 33.7%.

4.2.3 Efficiency gained in production efficiency (Q), that is relating with settling tank size and cost (Structural and Land cost).

From the above result analyzed that the removal efficiency increased and detention time decreased due to applications of HRTS; in the principle of settling process the production efficiency (Q) can increase. Here, to figure out the results of the typical experiment, again the relation depends on the basics of turbidity removal. From the above table (4.3), Let the turbidity value 42.06 NTU is for the flow rates 0.33 l/sec. without application of HRTS, and turbidity value (42.06 NTU) is for 0.51*l/sec* flow rates (by interpolating the values from the table) with HRTS. Therefore, the production rate is increased from 0.33 l/s to 0.51 l/s due to using HRTS in that the percentage of production efficiency is increased by 35.3%.

Based on the theory of sedimentation basin; the efficiency of a sedimentation basin depends on surface loading rate (SLR) that the production (Q) is directly proportional to the sedimentation tank surface area i.e. SOR=Q/A, In detail; SOR=Q/A

Where= (W*L*H)/td=V/td

Therefore; in the case of the above experimental result;

Let, $Q1 = 0.33 l/s \text{ in } 60min, \text{for without use of HRTS}$

$Q2 = 0.51\ l/s \text{ in } 39.8min, \text{for with use of HRTS}$

Accordingly; $Q1 = \frac{L1 * W1 * H1}{td1}$

$$Q2 = \frac{L2 * W2 * H2}{td2}$$

$$Q1 = \frac{L1 * W1 * H1}{td1} = \frac{V1}{td1}$$

$$Q2 = \frac{L2 * W2 * H2}{td2} = \frac{v2}{td2},$$

Assuming it takes 60min. to produce 42.06 NTU of 0.33L of clarified water without use of HRTS,

$$0.33l/s = \frac{v1}{60min}, = (0.33 * 60)\ l\ min./sec. = 19.8$$

$$0.51l/s = \frac{V2}{39.8min}, = (0.51 * 60)\ l\ min./sec = 30.6$$

Thus, let, $V2 = fV1, f = \frac{V2}{V1}, f = \text{Volume factor}$

$$f = \frac{30.6}{19.8} = 1.55$$

Therefore, to produce $0.51\ l/s$, the size of the tank required for this pilot is; $V2 = 1.55\ (V1)$ where the size of pilot settling tank, $V1 = L * W * D = (1.5m * 1m * 0.8m) = 1.2m3, V2 = 1.55(1.5 * 1 * 0.8) = 1.86m3$. The original volume of the pilot plant is 1.2m3(1.5m*1m*0.8m). Therefore; the additional volume required is 0.66m3(1.86-1.2) m3.The application of HRTS is saves about 0.66m3 size of additional tank that 35.5% in percentages.

4.2.4 The chemical cost effective

The application of HRTS has a significant advantage in reducing the chemical cost, from the experiment observed. Here, in the table below the turbidity reduction with and without HRTS is different in large figure. So by having a constant flow rate, detention time and same coagulant dosage; the turbidity observed due to application of HRTS can be comparable in considering coagulant aids variation. For example here below; the coagulant aid 0.1mg/l is used to reduce turbidity to 13.00 with use of HRTS and a coagulant aid 0.3mg/l is only reduce the turbidity to 38.72 without using HRTS.

Table 4-5: Coagulant aids dosage variation effect on turbidity reduction

Trial no.	Upflow production Q,l/sec	Detantion time,min	Chemical dosage ,mg/l		Turbidity ,NTU	
			Coagulant (mg/l)	Coagulant aids (mg/l)	Before use of HRTS	After use of HRTS
1	0.33	60	6	0.1	47.25	13..00
2	0.33	60	6	0.15	43.96	11.22
3	0.33	60	6	0.2	42.06	9.82
4	0.33	60	6	0.25	40.32	9.10
5	0.33	60	6	0.3	38.72	8.46

Therefore since such difference is observable at pilot plant, the size and cost expend for it is significantly reduced at industrial/Water supply treatment plant with the use of HRTS.

5. Projection of the experimental results and Analysis of pilot to the case of Legadadi Water Supply Treatment Plant

The application of HRTS is observed in detail in both the case of legadadi treatment plant and in the pilot scale experimental result analysis.

The advantages observed in the case of legadadi is the daily production (Q) increasing in about 34.5% the numerical analysis result done between different stages of the treatment plant sedimentation tank with and without application of HRTS. Additionally advantage observed from the case analysis result is that save of costs in constructing additional settling tank by applying HRTS, which enables to represent about 34.5% of the existing settling tank size in area.

Considering the similar factor observed in the case, the pilot scale experiment is focused on the parameters and conditions used to evaluate and asses the case results efficiency and performance. Accordingly; as it discussed previously, the pilot scale experimental parameters and result observed are, the turbidity removal efficiency, and decrease in detention time, the clarifying water production (Q) efficiency, the size of settling tanks and the chemical dosages are the main considered parts. Since the other listed parameters observes are interdependent, here it is enough to project the results of parameters, the efficiency of clarifying production, detention time and the chemical dosage required.

- The clarified water production efficiency (Q) in the legadadi case is observed to about 34.5% and in that of the pilot experiment is about 35.3% in that the clarified water turbidity from both cases is below 10NTU almost similar.
- The proportional capacity ratio legadadi stage II to experimental pilot scale found is Qld=5280Qps.

  By taking the 0.33l/sec of pilot scale clarifying standard;

$$\text{Qld} = 5280 * (0.33)\ \text{l/sec}$$

$$\text{Qld} = 1742.4\text{l/sec}$$

But from average daily production recorded for six year, the Qld=1252.09 l/sec.

Form the relation, the experimental pilot scale can perform more than by about 490.31l/s if it is projected to the treatment plant scale. Or the %performance of the pilot is 28%, i.e [(1742.4-1252.09)/1742.4) over the selected treatment plant.

- The detention time taken is about 84 min. in the case of legadadi stage II sedimentation tank after use of HRTS calculated from daily production of 108,181m3/day (1252.09L/sec),

  I.e. $Q = V/td. = (60m * 22m * 4.8m)/td,$

  $td = (6336m3/1252.09L)\ Sec.$

  $td = [(6336000L/1252.09L)/(60)]\ min.$

  td=84.33min, which takes about 60min.to produced from the pilot with almost similar turbidity content; that exceeds in 28 % production efficiency.

- The cost for chemical (the coagulant aid) can be reduced in high rates by reducing the dosages required in applying these HRTS materials.

6. Conclusions and Recommendations

6.1 Conclusion

The application of high rate tube settler can play an important role in the modern water supply treatment plant. This thesis work assessed its applicability based on two methods. The first one is the validation of HRTS by comparing the sedimentation process performance of tanks with HRTS and without HRTS of the Legadadi water supply treatment plant. The second one is the experimental study done on the pilot scale plant before and after use of HRTS.

The result obtained from two cases is concludes as the following:

1. The Legadadi case

- From the daily clarified water production of six years data recorded and analyses done of two sedimentation tank with and without application of high rate tube settler; the one with HRTS is more efficient by 34.5% than that of without HRTS. The percentage exceeded is only due to HRTS and other factors are all similar.
- The result indicates that the size of the tank decreased by about 34.5%, as the efficiency of clarified water production is increased by about 34.5% due to the application of HRTS. This outcome enables to decide that the cost of sedimentation process like operational and material cost required is minimized by 34.5% and the structural and land cost required is decreased by similar proportion.
- It is observed that the application of high rate tube settlers (HRTS) have an effect on the efficiency of filtration unit of treatment plant by increasing the efficiency of solid removal in high rate in sedimentation tank, so that the solids transferred to the filter unit is less. This case is studied on Legadadi treatment plant filter unit's comparison of their sedimentation tanks provided with HRTS and without HRTS; based on the back wash time (frequency) and volume of water required for back wash. Accordingly, from the analysis result there is about 35.11% of water volume per day is saved due to applications of HRTS which is much significant. Additionally; on the filtration process the cost for 35.11% of water lost for back washing is minimized and the cost for filter operation like power cost is saved by similar percentage.

2. The pilot scale experimental result:

- **Efficiency gained in production efficiency (Q):** From the typical experimental result done on this pilot scale; the clarified water production rate is increased from 0.33 *l/s* to 0.51 *l/s* due to only using HRTS; in that the percentage of production efficiency is increased by 35.30%.

- **Efficiency gained in settling tank size relating with Structural and Land cost:** Based on the theory of sedimentation basin; the efficiency of a sedimentation basin production (Q) is directly proportional to the sedimentation tank size. From this principal analysis on the pilot scale experimental result the size of the tank is decreased from 1.86m3 to 1.2m3 because of the use of HRTS, which saves about 0.66m3 size of additional tank that is 35.50% in percentages.
- **The detention time and solid removal efficiency gained due to use of HRTS:** The other important result observed from this pilot scale experiment is the decrease of settling time from 60min to 39.8min and the solid removal efficiency is increased by 76.65% due to the application of HRTS.

- **Effective of HRTS on the chemical (coagulant aid) dosage:** The application of HRTS has a significant advantage in reducing coagulant aid dosage. From the pilot experiment. The experimental result indicates that; the coagulant aid 0.1mg/l is used to reduce turbidity to 13.00 NTU with use of HRTS and a coagulant aid 0.3mg/l is only reduce the turbidity to 38.72 NTU without use of HRTS ;by having a constant flow rate, detention time and same coagulant dosage; .
- **Projection of the pilot experimental results and findings; to the case of Legadadi WSTPT:** From the capacity proportion of pilot scale plant to the Legadadi treatment plant found; the experimental result shows that the pilot plant performs about 28%more in clarifying efficiency and takes 60 min detention time which takes 84.33min to the legadadi treatment plant to yield almost similar turbidity content of clarified water.

- **Projection of the pilot experimental results to the different values in Literatures:** From the pilot experiment result observed the findings values like, decrease in detention time and turbidity reduction (33.7% and 76.65%) are almost related to the literature values (40-98) % and (60-80) % detention time and turbidity reduction respectively due to HRTS. The interval variation in literature values are varied due to the tube settler’s configuration like size/diameter, length, inclination angles and the flow rates of the water. But the results like Production efficiency, Effects of HRTS on filter units, chemical dosage reductions and Costs (structural, land, chemical and operational costs) are the main findings by this research in figure that can’t find in literatures in values rather than theoretical idea.

6.2 Recommendation

This study has shown that the application of HRTS has an important role in water supply treatment plant. The following recommendations are suggested; based on the result obtained from the case study and experimental work; for the specific case (legadadi) and for the future general use of HRTS in water supply treatment plant.

- As the result observed from the experimental work and projected to the case of the Legadadi water supply treatment, the treatment couldn’t yield the optimum efficient by the HRTS can add value. Therefore the performance of this treatment unit can able to up graded to require amount meaning that the efficiency observed from pilot by further studying the other factors like raw water inlet to the sedimentation tanks and decreasing detention time.
- The pilot experimental result shows that; the application of HRTS has a significant advantage in reducing coagulant aid dosage; so that the Legadadi treatment plants with HRTS can vary and reduce the coagulant aids , from the currently using amounts added (0.2mg/L) to at least (0.1mg/L) ,because it leads to be chemical cost effective.
- Generally by observing the advantage achieved due to application of HRTS, the water supply institution have surface water treatment plant have to provide this materials. For example; Ethiopia in which high amount of water supply source is surface water in that currently about 44 functional water supply treatment plant is found and a lot is under construction; only one treatment plant is used this HRTS .Therefore, these water supply treatment plant institution have to use this effective material by further studying on the availability and cost analyses in the future.

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