

**DEVELOPMENT AND EVALUATION OF INCLINED
TUBES CLARIFIER FOR RECHARGE OF
SURPLUS CANAL WATER**

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF TECHNOLOGY
in
SOIL AND WATER ENGINEERING
(Minor Subject: Civil Engineering)**

By

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CERTIFICATE-I

This is certified that the thesis entitled, “**Development and Evaluation of Inclined Tubes Clarifier for Recharge of Surplus Canal Water**” submitted for the degree of **M.Tech.**, in the subject of **Soil and Water Engineering** (Minor Subject: **Civil Engineering**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Mhetre Shruti Ravikiran (L-2019-AE-237-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation has been fully acknowledged.

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CERTIFICATE II

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ABSTRACT

An inclined tubes clarifier was designed and fabricated to handle a flow of 1.8 l/s to filter silt loaded canal water. PVC media of one meter length were attached one over the other to form the inclined tubes through which canal water was passed from bottom side and clarified water was obtained as outflow from the top of clarifier. The inclined tubes clarifier was tested for different suspended loads in the canal water in range of 500 mg/l to 3000 mg/l for pumping rate of 0.3 l/s to 2.1 l/s. The clarifier gave 85% Total Suspended Solids (TSS) removal efficiency for low flow rates (0.3 to 0.8 l/s) and above for flow rates beyond 0.8 l/s Total Suspended Solids (TSS) removal efficiency reduces drastically. Also, at all the flow rates the efficiency was found 6 % higher for Total Suspended Solids (TSS) >2000 mg/l in comparison to Total Suspended Solids (TSS) concentration of below 1000 mg/l. The clarifier makes no significant difference to the Total Dissolved Solids, Electrical Conductivity and pH of the canal water.

Keywords: Inclined tubes Clarifier, Total suspended solids, turbidity, groundwater, recharge, canal water, sludge

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ABBRIATIONS

%	:	percentage
EC	:	Electrical Conductivity
l/s	:	Liter per second
mg/l	:	milligram per litre
NTU	:	Nephleometric Turbidity Units
pH	:	Potential of hydrogen
ppm	:	Parts per million
SS	:	Suspended Solids
TDS	:	Total Dissolved Solids
TS	:	Total Solids
TSS	:	Total Suspended Solids
$\mu\text{S}/\text{cm}$:	Microsiemens per centimetre

CHAPTER I

INTRODUCTION

India is the world's largest consumer of groundwater where groundwater provides 60% of the nation's irrigation supply. The continuous pressure on increasing agricultural production to meet the requirement of the ever increasing population of India has resulted in the over exploitation of groundwater. The Central Ground Water Board (CGWB) has reported that 82% of the area of Punjab has substantial fall in the water level (Anonymous 2017). In 2009, according to study using GRACE satellite data, showed that 109 km³ of groundwater has been lost across the states of Punjab, Haryana and Rajasthan from 2002 to 2008 (Baweja *et al* 2018).

Groundwater recharge is an important process for sustainable groundwater management and replenishing the depleting groundwater. It is being used for variety of purposes which include increasing the well yield, reduction in land subsidence, improvement in quality of groundwater, storage of stream water during period of high excess flow, reduction of flood flow, prevention of sea water intrusion and upcoming of brackish water in coastal area.

The exact pretreatment operations are required depend on the type of water source, the nature of the recharge process and the intended use of the recovered water. Water used to recharge the ground water must receive a sufficiently high degree of treatment prior to recharge so as to prevent any degradation of native ground water quality. The presence of suspended solids in water can severely impede the performance of recharge structure due to clogging (Martin *et al* 2013). The suspended solids can be inorganic (e.g., clays, silts and fine sands) or organic (e.g., algae, bacterial flocks and sludge particles).

Nowadays, in monsoon season plenty of water is available. During rainy days there is reduction in irrigation demand and hence surplus canal water may be diverted for recharge. Also, in recent years, the Punjab state has witnessed an increase in winter season rainfall. The major crop during this season is wheat and requires 4-5 irrigations only. The excess canal water either during monsoon or winter season can be used to augment groundwater. However, the direct recharge of canal water is not possible as it possesses high silt loads especially during the monsoon season. High silt content in the canal water will progressively reduce recharge rates of recharge wells and filter capacity of filters. The recharge rate is inversely proportionally to the amount of suspended solids i.e. the recharge rate decreased with increase in suspended load (Gupta 2018).

Many researchers have developed different types of filters for improving water quality of harvested rainwater but very few studies have focused on improving surplus canal water quality for aquifer recharge. Most systems developed for water treatment (silt removal) involve settling by gravity, because its cost is lesser than alternative systems. These types of systems involve sedimentation process which requires large areas and big tanks, especially for fine suspension particles which are slow settling. The detention time for settlement of suspended particles is in hours, therefore there is a need to reduce size and costs of the sedimentation treatment and increase their efficiency. Sludge management and disposal is one of the most difficult and challenging tasks of filtration while, in inclined tubes much easier to handle sludge.

Inclined tube settler systems are relatively inexpensive technology predominantly used to enhance the performance of conventional sedimentation tank. Inclined tubes clarifiers contain a series of inclined tubes, which provide a large effective settling area within a considerably smaller footprint. In addition to its economic importance, it has other benefits, as it provides an opportunity for the clarifier units to be located and operated inside, decreasing some of the problems related to algal growth, clogging due to blowing debris accumulation and odor control, which can occur for outdoor units. Inclined tubes clarifiers are ideal for applications where the solids loading is variable and solid sizing is fine (McKean 2010). Settling efficiency of the inclined tubes clarifier is increased due to the Boycott effect which explains that inclined tubes effectively increase the settling area. Solid particles will settle at the lower part of the tubes and will be ultimately collected at the bottom of the clarifier unit. The clarified water will flow out at the top and the sludge can be removed periodically from the bottom. Performance of inclined tubes filter depends on number of factors such as incoming water quality, volume of tank, spacing of plates, number of tubes, inclination of the tubes, length of the tubes, particle characteristics, diameter of tube etc. The effectiveness of sedimentation tanks is dependent upon the geometric parameters and inclination of the tubes (Sarkar *et al* 2007). Accurate dimensions of the clarifier results in high turbidity removal efficiency of 90 – 95%.

This system has been extensively used in a range of industrial, construction and environmental remediation applications. Inclined tubes clarifiers are designed for separating inorganic solids from suspensions under certain conditions. However there design and efficiency has to be tested for canal water filtration. The major challenge for surface water recharge is the removal of suspended load for the long term feasibility of any recharge structure. Surplus canal water is available in lean water demand periods which can be used for ground water recharge. Inclined tubes clarifiers may prove to be effective in removing

suspended loads of water with an added advantage of not getting clogged, as is the general problem with traditional gravel filters. However no comprehensive study has been done regarding the design consideration of inclined tubes clarifier with respect to improvement in canal water quality so as to use surplus canal water for recharge. The present study is therefore undertaken with following objectives:

1. To design and fabricate an inclined tubes clarifier to clarify surplus canal water for recharge.
2. To study efficacy of inclined tubes clarifier for silt removal from canal water.

CHAPTER II

REVIEW OF LITERATURE

The primary objective of present study is to develop and evaluate inclined tubes clarifier for recharge of surplus canal water. This chapter gives a brief review of research work carried out and methodology followed by earlier researchers. This chapter gives a review of research work that throw light on the existing knowledge in the area of interest. Consistent with the objectives of study the review of literature has been presented chronologically under the following subheads:

2.1 Groundwater Exploitation and Need of Recharge

2.2 Evaluation of Inclined Tubes Clarifier

2.3 Design Criteria for Inclined Tubes Clarifier

2.4 Practical Applications of Inclined Tubes Clarifier

2.1 Groundwater Exploitation and Need of Recharge

In recent years, groundwater depletion has increased from 126 km³ in 1960 to 283 km³ in 2000 (Wada *et al* 2012). Hertig and Gleeson (2012) observed that in arid and semiarid regions, level of groundwater was decreased due to the over exploitation of groundwater sources. The water table is also becoming lowered which ultimately beyond the reach of existing wells. However, well has become more deepened to reach groundwater. In India, where the water table has gone hundreds of feet more down due to the enhanced activity of well pumping. Artificial recharge is the one of method to replenish the groundwater sources and which improves groundwater quality.

Aggarwal *et al* (2009) analyzed that in Punjab due to change in cropping pattern irrigation requirement increases results water table declining.

Lapworth *et al* (2010) studied the intensive irrigation in north-west India has led to growing concerns over the sustainability of current and future groundwater abstraction. The widespread occurrence of modern tracers in deep groundwater (>60% of sites had >10% modern recharge) suggests that there was low regional aquifer anisotropy and that deep aquifers were recharged by a significant component of recent recharge via vertical leakage. Stable isotope and noble gas results at all depths conform to modern meteoric sources and annual average temperatures, with no evidence of significant regional recharge from canal leakage in this study area close to the Himalayas.

Tripathi *et al* (2016) assessed the impact of government policy on groundwater depletion in Punjab. Results of study reveal that government policy on groundwater policy

increased has impact on groundwater table. Due to implementation of paddy subsoil preservation act the groundwater level have improved.

Most of groundwater studies on groundwater depletion has emphasized on the need to restrict the groundwater levels by reducing over exploitation and practicing various groundwater recharge techniques to augment the sources.

2.1.1 Different techniques for groundwater recharge

Selection of suitable method depend upon many factors such as geological and soil condition, topographical features, quality and quantity of water available for groundwater recharge and social acceptability of such schemes. Groundwater recharge technique was effective in low lying area for improving groundwater and its quality. By using rain water and canal water through surface spreading and well injection technique depletion of groundwater can be prevented (Narjary *et al* 2014)

Palaniswami and Kandaswamy (1990) studied 10 percolation tanks in Coimbatore district of Tamil Nadu state for economic evaluation. It was indicated that the total number of wells benefitting due to these 36 well was only about 144 ha. Observed the poor performance of these percolation tanks was attributed to inadequate rainfall and poor location of percolation of ponds.

Khepar *et al* (2001) found that surface drain can be used to recharge surplus canal water during off seasons. This study included a network of surface drains were constructed during that season for controlling waterlogging and flood can be used for artificial recharge of groundwater. The surplus canal was regulated in such a way that the release rate match with seepage loss in the drain section.

Kaledhonkar *et al* (2003) installed two recharge tube wells in the bed of old Sirsa branch canal to recharge groundwater. In injection tube method, recharge was done by feeding fresh water in depletion aquifer directly. Location and depth of recharge tube well selected from resistivity survey. Filter pit was used to prevent the entry of sediment and suspended solid in recharging water.

Eusuff and Lansey (2004) utilized wastewater effluent for artificial recharge. Objective of recharge structure was to store water for future use. The reclaimed water was used primarily for non- potable purposes but under increasing stresses shifting to potable use is likely to happen. Water quality then becomes a more pressing concern. Soil aquifer treatment (SAT) was used to improve the quality of water during groundwater transport and infiltration. SAT model was developed by considering water quality, environment concern and monetary.

Bhattacharya (2010) observed that rate of recharge in artificial recharge technique was higher than natural condition of recharge. Injection wells were used for artificial recharge near Ghaggar river basin using canal water. In this study, at one atmosphere pressure injection rate was initially 43.8 litres per second. The pressure was increased after 5 hours to two atmosphere and observed that recharge rate reduced to 3.5 litres per seconds after a few days.

Sayana *et al* (2010) installed roof top rain harvesting system in the St. Peter's Engineering College campus in Chennai. Studied the response of groundwater due to such artificial recharge. This study was conducted during 2004 to 2007. Hydraulic conductivity was determined by pumping test. Study was concluded that roof top harvesting played imported role in groundwater replenishment.

Narula (2014) constructed recharge structures in seven different villages near village pond at certain depth recharge potential. It is calculated by recharge runoff potential of seven recharge structures, observed that plan was feasible.

Emily *et al* (2016) studied that drywells can be used to recharge groundwater by facilitating storm water infiltration. Widespread use of drywells for groundwater recharge was prevented due to contamination. Contamination of drywells can be prevented by its proper maintenance. Quality and quantity of influent storm water, land use near well and hydrogeological setting affect effectiveness of wells for recharge.

Patel and Desai (2017) studied the comparison between cost estimation of rain water drainage with and without recharge well. Results of this study show that drainage system with recharge well help in improving groundwater quality and quantity. This economic analysis helps in designing of recharge well.

2.1.2 Clogging problem of recharge well

Clogging is major obstacle in aquifer storage and recovery (ASR) applications, causes declines in recharge rates and ultimately the failure of artificial recharge systems. Prior to artificial recharge, source water can be pre-treated via sedimentation, coagulation, filtration, advanced oxidation, and disinfection to lessen the clogging potential. The major requirement for infiltration water is to be silt-free. Silt may be defined as the content of undissolved solid matter, usually measured in mg/l, which settles in stagnant water with velocities which do not exceed 0.1 m/hr.

The 45 μ m membrane filter index (MFI) used to estimate the clogging potential of water that has to be infiltration using recharge wells (Olsthoorn 1982). Pyne(1995) showed that hydraulic conductivity of aquifer has an influence on clogging rate, but rate was also not quantified. MFI is measured for certain water type, depends on the square of pores size of

filter that is used to measure the MFI. The pores size of media where the water is infiltrated in, estimated from grain size distribution and it is related to hydraulic conductivity of that medium. The theoretical relation between MFI and clogging rate as published Olsthoorn (1982) showed yield values that are close to the actual field measurements. Predicted clogging rate using this new theoretical relation are compared to measured rates in recharge wells used for aquifer thermal energy storage. That compared to measured clogging rates in ASR wells as published by Pyne(1995).

2.2 Evaluations of Inclined Tubes Clarifier

Sedimentation is the removal of suspended and colloidal materials from water by gravity separation method. Sedimentation basin or settling tank can be accelerate to particles to settle down. Efficiency of separation of Suspended particles from the water by accelerated gravity settling into the sedimentation tank depends on properties of the particles, types and size of the tanks.

Settling efficiency of sedimentation tank increased 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.

Hazen (1904) found and measured initially about the inclined plate clarifier, or lamella. He observed that the proportion of sediment removed in a settling basin is a primary function of the surface area of the basin and it is independent of the detention time. Also he proved that by increasing surface area by inserting one horizontal tray, increases capacity of basin.

Frei (1941) reported that efficiency of the suspended solids removal increased from 41 to 61 percent by inserting three circular, steel and radial-flow trays to an existing primary sewage clarifier.

Camp (1946) assumed a uniform velocity profile of the tank and thus the particles followed a straight trajectory in passing through the tank. He then presented a design for a settling basin with horizontal trays spaced at 12.24 cm (6 in) which he left the minimum distance for mechanical sludge removal. The basin had a detention time of 10.8 min, a velocity of $168 \text{ m}^3 / \text{m}^2\text{-h}$, and overflow rate of $27 \text{ m}^3 / \text{m}^2\text{-d}$. Outlet orifices were used to distribute the flow over the width of the trays.

Schmitt and Voigt (1949) arranged water treatment plant with two-tray settling basin. The trays were kept in series and spaced at 4.75 m (15 ft) and were cleaned by draining and hand-hosing.

Dresser (1951) reported that in water treatment plant the trays were spaced at 1.524 cm (5 ft) and sludge removed by gravity. He observed that the difficulties encountered in proper distribution of flow to a large number of trays and sludge removed from closely spaced trays.

Fischerstrom (1955) observed that most of particles settled at a Reynolds number of 500 (limit of laminar flow at 32°F). He observed that Reynolds number could be lower to the laminar flow range by increasing the wetted perimeter, or inserting longitudinal, horizontal or vertical baffles in the basin.

Braham *et al* (1956) attempted first practical application of tray-settling which was patented in 1915. Several shallow settling compartments which were formed with series of conical, circular trays placed one above the other. Sludge collected on each tray collected centrally and transported to the bottom of tank.

Hazen and Culp (1967) reported that longitudinal flow through the tubes with diameter of few inches offered theoretically optimum hydraulic conditions for sedimentation. Such tubes often provide very low Reynolds number. This showed that even with largest tube and highest flow rate the Reynolds number was only 96 which was far below the upper limit of laminar flow of 500.

Culp *et al* (1968) described the two basic tube settler systems, horizontal tube settler and the steeply inclined tube settler, where both of them were commercially available. He concluded that continuous sludge removal is possible only for inclined tubes at an angle of 60 degrees to the horizontal.

Hansen *et al* (1969) concluded that if tubes inclination angle is greater than 45 degrees, then sediments accumulated on the surface of the tube and begins to move down after reaching a certain depth. This counter current flow of the solids aids in the agglomeration of particles into larger, heavier flows which are able to settle against the upwardly flowing liquid.

Yao (1970) developed a mathematical model for tube settlers with the assumptions that the flow is laminar and one-dimensional and that the suspended particles are discrete. He established relationship between the shape of the tube, relative length and the angle of inclination upon the settling efficiency.

Yao (1973) based on his previous model and coordinates system, arrived at an important equation of overflow rate against the shape factor, relative length and the angle of inclination. He discussed about higher the raw water turbidity, higher the removal efficiency for all overflow rates.

Amin (1974) found that the steeply inclined tube settler performs better than the essentially horizontal tube settler in terms of higher flow rate ($10 \text{ m}^3/\text{m}^2\text{-h}$ compared with $2.45 \text{ m}^3/\text{m}^2\text{-h}$). Shorter detention time (5.5 min compared with 20 min) and higher efficiency (80% compared with 60-70%).

Chen (1979) developed a model based upon the hydraulic conditions in the tube and eventually arrived at a formula which is similar to the equation for overflow rate developed by YAO in 1973. From this new model, he suggested that the relative length of 14.9 m and the flow rate should keep below $10.7 \text{ m}^3/\text{m}^2\text{-h}$.

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.

2.3 Design Criteria for Inclined Tubes Clarifier

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).

Moir (1991) developed a liquor-apparatus involves one tank, inlets to suspension to be clarify, outlet for clarified water and residue solids. Majority of setting congregations each containing a heap of downwardly slanted plates mounted around a vertical assortment channel. Sludge can be settled down downwardly broadening channel that leads directly into sludge hopper. The plates were ideally funnel shaped or pyramidal and are equipped for being clipped together by a push fit. A downwardly broadening skirt was given.

Krofta *et al* (1993) designed flat tank with rectilinear bottom wall gets raw water for clarification by buoyancy. Tank contains set of exhibit of lamellae arranged vertically situated way. Buoyancy happens in each channel which is ideally disposed. A couple of unlimited chains or the like turn close by the tank to move a progression of commonly dispersed, paddle-like lamellae through the tank. Sliding seals got to the edge or edges of the lamellae disconnect singular channels or gatherings of channels, as they travel through the tank. The channels lock and move a section of water through the tank with significantly without disturbance.

Jardin (2008) based on comprehensive cost investigation for the development of the Finnentrop WWTP, incorporation of lamella separators in the biological treatment stage was given need as ideal answer for increment the solids fixation. The general development project incorporated the recreation of the previous essential clarifier into an essential settling tank

with short maintenance times and the utilization of the leftover volume for pre-denitrification. Four lamella separators were situated in the existing carousel type activated sludge tank. With the lamella assemblies ensuring it was conceivable to proceed with activity of the current optional settling tanks. To control an adequate solids concentration in the activated sludge tank and to abstain from any over-loading of the secondary settling tank, a recently evolved sidestep methodology was applied. With a controlled mixing of direct effluent from the lamella separators and the substance of the activated sludge tank, the solids concentration of the influent to the optional settling tank could be kept up at an estimation of 2.2 kg/m^3 . The lamella separator idea didn't represent any critical changes in the slime attributes and the general elimination of nutrients and organic carbon was discovered to be endless supply of the operational lamella technique.

Tarpagkou and Pantokratoras (2014) developed lamella gravity settler is utilized for water treatment as sedimentation tank. Viable surface territory for settlement is increased by the inclined plates than the traditional tanks. Mathematical model used to reproduce the elements and stream construction of a rectangular sedimentation tank for consumable water through a multiphase methodology, utilizing computational liquid dynamic techniques. Arrangement of inclined parallel plates (lamellar settlers) and another with a customary plan these two setups have been analyzed. Assessed the impact of both lamellar settler in the process productivity. The mathematical examinations considered independently for both, had the present mathematical methodology contemplated the entire sedimentation tank with a full scale arrangement of inclined parallel plates. The outcomes show that the lamellar settler impact the stream field and increment the sedimentation efficiency in comparison with the convectional design.

Wiess (2014) prescribed that lamella clarifier utilized for the sedimentation of particles in wastewater. The treatment of waste water streams is proposed which expands the arrangement of arrangements past conventional settling tanks. Surface spill over was put away in a tank and finally treated by utilizing little, persistently worked lamella clarifier. The low throughput stream will yield great treatment productivity at a little footprint. As a huge operational benefit, the lamella might be cleaned mechanically. At last, the stream and the slop which will be shipped off the downstream treatment plant will be limited. Another similar strategy is proposed to evaluate an identical level of waste water treatment, either by accomplishing an equivalent yearly volume of treated waste water. The new arrangement was contrasted and a conventional settling tank as indicated by current German plan rules.

2.4 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.

2.4.1 Increase surface area of sedimentation tanks

Kolisch and Schirmer (2004) studied that lamella positioned at outlet of biological treatment stage already remove part of biomass in the activation basin prevent it from reaching the final clarification stage. This preliminary separation system reduces solids concentration in biological treatment system without negative impact on final clarification and therefore also lowers the basin capacity needed, with positively effect on costs.

Fujisaki & Terashi (2005) developed lamella settler, where in inclined parallel plates arranged the vertical in way. In this investigation they introduced "H" sewage treatment plant in Kitakyushu city, tube settler was introduced in a tank with 80 cm lengths, 50 cm statures and 1 cm widths. In this investigation four kind of cylinder pioneer are utilized, two of which are roundabout cross-segment of distance across 55 and 70 mm, and a length of 1 m, tendency plot for the one is 60° for first cylinder and 75°, 60°, 45° for the subsequent cylinder. Other two cylinders have a rectangular cross-area with measurements 200×60 mm and a length of 500 mm for the first and 200×15 mm and length of 600 mm the subsequent cylinder, slanted with a point 60° for both. In view of the after effects of the laboratory and on location tests, it was shown that the new cylinder settler framework is successful for the upgrade execution of settling tank. It is additionally appeared from a mathematical assessment that the settling tank introduced with the new framework has amazingly elite contrasted and the conventional settling tank.

McKean (2010) studied the effectiveness of a lamella clarifier unit for primary treatment of domestic wastewater was investigated. The trial was divided in to three operational phases: Phase I – operation of a conventional primary sedimentation tank; Phase II: operation of a lamella clarifier for primary settlement; Phase III – operation of lamella clarifier for primary settlement in conjunction with a chemical coagulant (aluminium chlorohydrate). The performance of the lamella clarifier was assessed in terms of the biochemical oxygen demand (BOD), suspended solids (SS), total nitrogen and total phosphorus removal efficiencies. Results demonstrated that the lamella clarifier unit performed favourably when compared to the conventional primary sedimentation tank, with BOD and SS removal efficiencies of 30 % and 57 % respectively (Phase II). The operation of the lamella clarifier in conjunction with coagulant (Phase III) enhanced nutrient removal, thereby improving the overall performance of the system.

Faraji *et al* (2013) conducted pilot study to examine the possibility of applying one and two stage inclined tube settlers instead of conventional secondary clarifiers. Tube diameter in first stage tube settler was wide as conventional sediments tank but, in second stage diameter was narrow to increase efficiency. The results indicated that tube settler removes TSS and turbidity in short detention times. The average removal of TSS, BOD and COD, in a 20 minute detention time in the tubes, in the one-stage tube settler pilot plants was 97.6%, 96.4% and 96.36% respectively, while in the conventional secondary sedimentation basin was 98.2%, 99% and 98.6% respectively. There was a good agreement between theoretical analyses and experimental results of the pilot plant. Two-stage tube settlers in the series could improve hydraulic condition and removal efficiency of TSS, in comparison with the one-stage tube settler. The average TSS removal, in shorter detention times than that the one-stage, was 97.8 %.

Balwan *et al* (2016) described an investigation to consider the impact of the length and angle of the tube settler on the quality. An investigation led on a pilot scale model which was introduced at water treatment plant. The model had closed tank associated with four PVC containers of 4.5 cm breadth from the top, addressing the tube settler which was associated from the opposite finish to the lower part of collector basin. The influent water to the base tank has been circulated air through and coagulated. The length and tendency of the cylinders were flexible. The length of these cylinders differed as 60 cm, 50 cm and 40 cm and they were introduced at tendency point 45° and 60° with the horizontal. The surface flood rate was kept at 35000 l/m²/hr. The outcomes showed that the productivity increases with increase the length of the tubes and tendency of the tube settler. The ideal evacuation was noticed for the length 60 cm and tendency 45°.

Gurjar *et al* (2017) installed a pilot scale model of sedimentation tank aimed to emphasize the performance of tube settler unit. In view of increasing demand of water for society, a modification was required in conventional sedimentation tank (e.g. high rate settling). The detention time is reduced up to 10-15 min from 2-4 hrs which was very less as compare to conventional sedimentation tank. The average efficiency of turbidity removal is 70-80% in modified unit as compare to conventional tube settler unit.

Sofyan *et al* (2018) installed lab-scale tube settler model at Colentina to evaluate the performance and effect of the inclination of tube settler on the effluent quality. It consist four separate circular tubes of 27 mm inner diameter, with a length of 150 cm each were used at different inclination angles of 48, 54 and 60 degrees. A pilot scale model of coagulation-flocculation followed by sedimentation unit was prepared.

2.4.2 Settling or detention time

Kołodziejczyk and Banaś (2012) designed laboratory lamella settling tank utilized for cross-current or counter-current sedimentation process. The final device design was created to get the appropriate dispersion of flow velocity. The recreations permitted the determination of the appropriate development of the tank, in which the velocity distributions in progressive channels are similar to the fulfilment of lamella, which will permit it to charge uniform stream of fluid (suspension). The utilization of mathematical techniques for demonstrating the stream in the settling tank permitted to adjust the design of the device at the beginning phase. The settling tank permits sedimentation to occur in the two arrangements with the protection of an indistinguishable sedimentation surface. This idea permits a correlation of processes in these frameworks at a given indistinguishable surface load.

Subramani *et al* (2012) designed a research facility scale tube settler model at "Chavasseryparamba" water treatment plant, Kerala. They created pilot scale, five modules of the tube settler, tubes with an inward measurement of 4 cm, and a length of 40 cm, the tubes were introduced at a point 30°, 35°, 40°, 55° and 60° with the horizontal for each setup. The main objective of this investigation was to decide the efficiency of removing the sludge from the filter's backwash water (FBW). Results showed that the ideal tendency point was 55° for settling the flocculent particles, and the ideal settling velocity was 2.76 mm/min.

2.4.3 Turbidity reduction

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

Culp and Hansen (1969b) 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%.

Hansen *et al* (1969) observed that if the tube was 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 were able to settle against the upwardly flowing liquid.

Salem *et al* (2011) found that the main prerequisite for accomplishing compelling partition conditions in inclined plate settler channels (IPS) are its pressure driven execution and conveyance of suspensions between settler channels, the two of which rely upon inlet setup. In this investigation three distinctive inlet design were utilized to investigate the impact

of taking care of seat scale IPS by means of a nozzle distributor on its water powered execution and separation proficiency. Exploratory and Computational Fluid Dynamic (CFD) examinations were done to assess the hydraulic qualities of the IPS. Contrasting the test results and the anticipated outcomes by CFD recreation suggests that the CFD programming can assume a valuable part in considering the hydraulic execution of IPS, which added to progress of its division effectiveness.

Mohammed *et al* (2011) developed a clarifier to examine the proficiency of traditional Clariflocculator units alongside the tube settler unit was introduced at Mosul Unified Water Project in Iraq. The assessment were continued average removal efficiency of turbidity and phytoplankton algae. Results showed that the turbidity evacuation efficiency of tube settler units was run (< 30 NTU) and the quantity of phytoplankton algae was 45–59 cells/ml, while results showed that the ordinary Clariflocculator units were more productive at higher turbidity levels (> 30 NTU) and the quantity of phytoplankton algae went between 63–75 cell/ml.

Liu *et al* (2020) stated that stormwater quality management has become an increasingly important topic. Pollutants from construction, urban, and agricultural runoff sources create adverse water quality impacts to receiving water bodies. Among these sources, suspended sediment has a significant influence on water quality and further acts as a media for transporting pollutants. Current stormwater treatment practices remove large, rapidly settleable, soil particles; however, fine soil particles tend to remain suspended and contribute to elevated turbidity conditions. A need exists for an economical and passive treatment mechanism for the removal of suspended solids. Lamella settlers have been shown to enhance soil particle capture by increasing surface area and reducing settling distance. The objective of this research was to identify and optimize design configurations for a lamella settler system in treating a variety of synthetic soils. Five types of synthetic soils suspended in simulated stormwater at 500, 1000, and 5000 mg/L concentration were treated using system configurations of three lamella settler reactors at 0.5, 1.0, and 1.5-h residence times. Statistical analyses through a full factorial method followed with a regression analysis and analysis of variance (ANOVA) test suggested that there was a significant difference exists between these experimental variables and turbidity levels. An optimized lamella settler reactor providing 1.8 cm (0.7 in.) settling space with 1.5-h residence time reduced turbidity by up to 90% when compared to a control reactor without lamella plates and a 0.5-h residence time. In addition, particle size distribution analysis indicated a decrease in the D90 by up to 84%, which showed that the optimized reactor was effective in capturing larger diameter soil particles.

CHAPTER III

MATERIALS AND METHODS

This chapter includes the description of study, criteria for design and location of installation of inclined tubes clarifier, development and fabrication of inclined tubes clarifier and methodology for estimating the quality parameters of canal water. Accordingly, the chapter is divided into the following sections:

3.1 Principal of Inclined Tubes Clarifier

3.2 Design Considerations of Inclined Tubes Clarifier

3.3 Selection of Site for Field Evaluation

3.4 Evaluation of Performance of Inclined Tubes Clarifier

3.1 Principal of Inclined Tubes Clarifier

The working of inclined tubes clarifier is based on settling of sediments under gravity. Inclined tubes clarifier design consists of baffle plates of one meter in length which are attached to one other to form series of inclined tubes introduced inside the sedimentation tank. The water enters from the top of the clarifier and flows down underneath of the inclined tubes. Water then flows up inside the clarifier between the inclined tubes. The suspended solids settles on the tubes surface. Suspended solids slides down to the bottom of the clarifier due to gravity, collected in the hopper as sludge. Desludging can be performed as per requirement.

The angle at which solid flow occurs dependent on several parameters viz., particle size, particle shape and surface texture, liquid viscosity, liquid surface tension, type of settler plate material.

3.2 Design Considerations of Inclined Tubes Clarifier

3.2.1 Flow rate

In general, the design of inclined tubes clarifiers is dependent on flow rate verses the separation chambers and effective surface area which is also called the projected surface area. The slower the flow, the better the result. The flow velocity at which a clarifier can operate successfully is directly proportional to the length of the clarifier and inversely proportional to the depth. In the present case, the clarifier was designed to handle flow rate of $1.8 \text{ m}^3/\text{hr}$.

3.2.2 Settling velocity of particle

Stokes law used to determine the settling velocity (V_s) of particles in water is a function of particle size (diameter²), density difference between particle and water, kinematic viscosity of the water. Settling velocity of discrete particles determined by using the Stokes equation,

$$V_{\text{particle settling}} = \frac{g \times (\gamma_{\text{particle}} - \gamma_{\text{water}}) \times dia^2}{(18 \times \nu_{\text{kinematic}})} \quad \dots(1)$$

Where,

V_s is the particle's settling velocity (m/s)

g is the gravitational acceleration (m/s^2)

γ_{particle} is the density of the particles (kg/m^3)

γ_{water} is the mass density of the fluid (kg/m^3)

$\nu_{\text{kinematic}}$ is the kinematic viscosity ($kg/m \times s$)

d is the diameter of the settling particles (m)

3.2.3 Hydraulic retention time

Hydraulic retention time is the length of time particle or a volume of water remains in a reactor. It is an important design parameter that was used for computing the volume and sizing the clarifier.

$$HRT = \frac{w}{V_s \times \cos \theta} \quad \dots(2)$$

Where,

HRT- Hydraulic Retention Time (sec)

w – Width of tube (m)

V_s – Settling velocity of particle (m/s)

θ - Angle between inclined tube and horizontal surface

3.2.4 Rising velocity of effluents in tubes (V_e)

It was obtained as a water velocity projection on the vertical axis. It should be lower than the fall velocity of the particles to be removed.

$$V_e = \frac{\text{Effluent flow}}{\text{cross section area of settler}} \quad \dots(3)$$

Where, V_e - Rising velocity of effluents (m/s)

3.2.5 Length of the tube (L)

$$L = t \times (V_e - V_s \times \sin \theta) \quad \dots(4)$$

Where, t - Hydraulic retention time(sec)

V_e - Rising velocity of effluents(m/s)

V_s - settling velocity(m/s)

3.2.6 Number of tubes (N)

$$N = \frac{\text{area of tube settler}}{\text{width of tubes} \times \text{dia. of tubes}} \quad \dots(5)$$

3.2.7 Tube spacing and material of tubes

Tubes were made up of PVC deck media. Typical tubes spacing of 50 mm is generally provided for easy flow of water (Johnson *et al* 2009). The sludge present in water settles on tubes and slides down the tubes due to its inclination and collected in hopper.

3.2.8 Angle of inclination

The angle at which solid flow occurs dependent on several parameters like particle size, particle shape and surface texture, liquid viscosity, liquid surface tension, type of settler tube material. The inclination for tubes provided is in between 50-70° from horizontal, which allow for self-cleaning. Generally, the inclined tubes clarifier requires approximately 50% space of conventional sedimentation basins as they to provide a large settling area due to their projected area (Kucera 2011).

3.2.9 Sedimentation tank

Sedimentation tank is allowed for observation of the flow and water recirculation system. It comprised of pumps, pipes and other hydraulic connections. Sedimentation tank contain the tubes inclined at an angle. The minimum length to width ratio of 2:1 should be provided.

3.2.10 Feed point and feed outlet

Entrance of feed is at least 20% above the base of tubes which provides minimum disturbance of the settling zones at the base of tubes. The sludge free water move out of the sedimentation tank through outlet opening on freeboard.

3.2.11 Hopper

It is the lower portion of the sedimentation tank in which the sludge is collected. The side walls of the hopper are at 45 degree angle. The sludge collected in hopper can be removed periodically by opening the valve at the bottom of the settling tank.

3.3 Selection of Site for Field Evaluation

The site (lat. 30°53'46"N and long. 75°48'06"E) adjacent to the water outlet from Sidhwan canal near veterinary girl's hostel, Punjab Agricultural University, Ludhiana was selected for evaluating the performance of inclined tube clarifier. Field study was conducted in the months of April to August of the year 2021. Water sample and field data analysis were done at Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana.

3.4 Evaluation of Performance of Inclined Tubes Clarifier

3.4.1 Inflow and outflow measurement

Inflow and outflow is measured by volumetric method (Michael 2008). Inclined tubes clarifier operated on different inflow rates (i.e. 0.3 l/s, 0.4 l/s, 0.5 l/s, 0.6 l/s, 0.8 l/s, 1 l/s, 1.3 l/s, 1.5 l/s , 1.8 l/s and 2.1 l/s) with different suspended load at regular interval time. Desired flow was maintained with the help of flow rate control valve (Fig. 3.1).



Fig. 3.1: Flow rate control valve

3.4.2 Water quality analysis

The testing of canal water samples were carried out before and after clarification through inclined tube clarifier.

3.4.2.1 Water sampling

Canal water samples were collected in bottles for analysis. Then further samples were analyzed for parameters like pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solid (TSS) and Total Solids (TS).

The quality of canal water varied significantly within the monsoon period. Solids can be suspended or dissolved. Sum of suspended and dissolved solids will give total solid of sample. The principle constituents of dissolved solids are calcium, magnesium, sodium and potassium salt. Dissolved solid may produce aesthetically displeasing colour, taste and odour. Estimation of total suspended solids is necessary to determine the rechargeable water containing the total suspended load is within permissible limit.

3.4.2.2 Turbidity

Turbidity of water determined the transparency of water. It increases with large number of tiny particles that are invisible to naked eyes present in water sample. Turbidity is measured in NTU: Nephelometric Turbidity Units (Fig.3.2). Turbidity is measured by

Nephelometer or Turbidity meter. In Nephelometer, light beam is passed through the water sample and turbidity is determined by intensity of light scattered at 90 degree.

- 1) In sample compartment insert the test tube containing turbidity free distilled water and set zero of Nephelometer at 0.
- 2) After that for the calibration of Nephelometer insert the test tube filled with Formazine solution of 100 NTU into sample compartment and using the knob set 100 reading on instrument.
- 3) Shake the sample whose turbidity is to be determined put into the sample compartment. Find out the reading on Nephelometer.



Fig. 3.2: Nephelometer

3.4.2.3 Total solids

Total solids is the addition of settleable and dissolved solids in solution (Fig.3.3). Typically expressed in mg/l or ppm. The total solids were measured in Soil and Water Engineering laboratory at Punjab Agricultural University, Ludhiana. The following procedure was used

- a) The beaker to be used for measurement were cleaned and dried in oven and was immediately weighed before use.
- b) A sample volume of 100 ml was chosen and a measured volume of well mixed samples were poured in empty beakers
- c) Then the samples were kept in oven at 103-105 °C temperature for evaporation.

- d) After complete evaporation of water, the beaker weight was measured.
- e) Total Solids was calculated by using the measured values in formula

$$\text{Total solids (mg/l)} = \frac{(\text{weight of dried residue in beaker})\text{mg} \times 1000}{\text{ml of sample taken}}$$



Fig. 3.3: Oven drying of samples

3.4.2.4 Total dissolved solids (TDS)

Total dissolved solids (TDS) measures the quantity of minerals, salts, metals, cations or anions dissolved in water. Total dissolved solids is measured in mg/l or ppm. Total dissolved solids in water samples was measured by using EC- pH meter. The EC-pH meter probe was dipped in sample and the reading was noted (Fig. 3.4).



Fig. 3.4: EC- pH meter

3.4.2.5 Total suspended solids (TSS)

Total suspended solids (TSS) is weight of oven drying of suspended particles trapped in filter of 2 μm or smaller nominal pore size at constant temperature of 105°C. Total suspended solids is one of the parameter to assess the water quality in waste water treatment plants. TSS is measured in mg/l or ppm. The TSS of the water samples were measured by following formula:

$$\text{TSS (mg/l)} = \text{Total solids (mg/l)} - \text{Total dissolved solids (mg/l)}$$

3.4.2.6 pH

The pH of water is measure of acidity or alkalinity of the water on scale of 0-14. The water with $\text{pH} < 7$ is considered acidic. Generally, pH range for surface water is 6.5 to 8.5 and for groundwater is 6 to 8.5. The corrosivity of water is determined by measuring of alkalinity and pH.

The pH of water was determined EC-pH meter (Fig.3.4)

3.4.2.7 Electrical conductivity

Electrical conductivity of substance is the ability to conduct electricity. Electrical conductivity is due to the transmission of current by ions presented in solution. Thus, conductivity increases as water dissolved ionic species increases. Electrical conductivity is measured by EC- pH meter (Fig.3.4).

3.4.2.8 Removal efficiency of inclined tubes clarifier

Removal efficiency of the inclined tubes clarifier are determined using concentration of particular water quality parameter before and after filtration. Removal efficiency of inclined tubes clarifier is decided by following formula:

$$\text{Removal efficiency (\%)} = 1 - \frac{\text{Concentration of output sample}}{\text{Concentration of input sample}} \times 100$$

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, the design and evaluation of the inclined tubes clarifier is presented through the results obtained by the analysis of various water quality parameters by the methods given in Chapter III. The results of study are presented in subsequent sections.

4.1 Design of inclined tubes clarifier

4.1.1 Settling velocity

For given study the design was done for average influent flow rate of 1.8 m³/hr at plant. Diameter of suspended solids was considered as 0.00032 mm. Specific gravity of suspended solids and water is 1.2 and 1 g/ml respectively. The kinematic viscosity of water 0.01 cm²/sec. The cross section of tube settler is 1.250×1.250×2.500 m³. Angle of inclination of tubes to horizontal is 55°. Cross section size of tube is 281 mm (L) and 37 mm (W) respectively.

From Stoke's law, settling velocity of particles (V_s) is,

$$V_{\text{particle settling}} = \frac{g \times (\gamma_{\text{particle}} - \gamma_{\text{water}}) \times \text{dia}^2}{18 \times \nu \text{ kinematic}} \quad (4.1.1)$$

Substituting the corresponding values,

$$\begin{aligned} &= \frac{981 \times (1.2 - 1) \times (0.00032)^2}{18 \times 0.01} \\ &= 1.1 \times 10^{-4} \text{ m/sec} \end{aligned}$$

4.1.2 Hydraulic retention time

$$\text{HRT} = \frac{w}{V_s \times \cos \theta} \quad (4.1.2)$$

Where, w is width of tubes

$$\begin{aligned} &= \frac{0.281}{1.1 \times 10^{-4} \times \cos 55^\circ} \\ &= 4454 \text{ sec} \end{aligned}$$

4.1.3 Rising velocity of effluent

Rising velocity of effluent in tubes will be,

$$\begin{aligned} V_e &= \frac{\text{Effluent flow}}{\text{cross section area}} \quad (4.1.3) \\ &= \frac{1.8}{1.250 \times 1.250 \times 3600} \\ &= 3.2 \times 10^{-4} \text{ m/sec} \end{aligned}$$

4.1.4 Length of tube

$$\begin{aligned} L &= t \times (V_e - V_s \sin \theta) \quad (4.1.4) \\ &= 4454 \times (3.2 \times 10^{-4} - 1.1 \times 10^{-4} \times \sin 55^\circ) \\ &= 1.023 \text{ m} \end{aligned}$$

4.1.5 Number of tubes

$$N = \frac{\text{area of tube settler}}{\text{width of tubes} \times \text{dia. of tubes}} \quad (4.1.5)$$
$$= \frac{1.250 \times 1.250}{0.037 \times 0.281}$$
$$= 150.28 \approx 150$$

4.2 Development and Fabrication of Inclined Tubes Clarifier

Inclined tubes clarifier was developed with number of inclined PVC tubes which are inserted in clarifier (Fig.4.1).



Fig. 4.1: Fabrication of Inclined Tubes Clarifier

The inclined tubes clarifier was fabricated with mild steel and PVC tubes (Fig 4.2).



Fig. 4.2: Inclined Tube Clarifier Installation

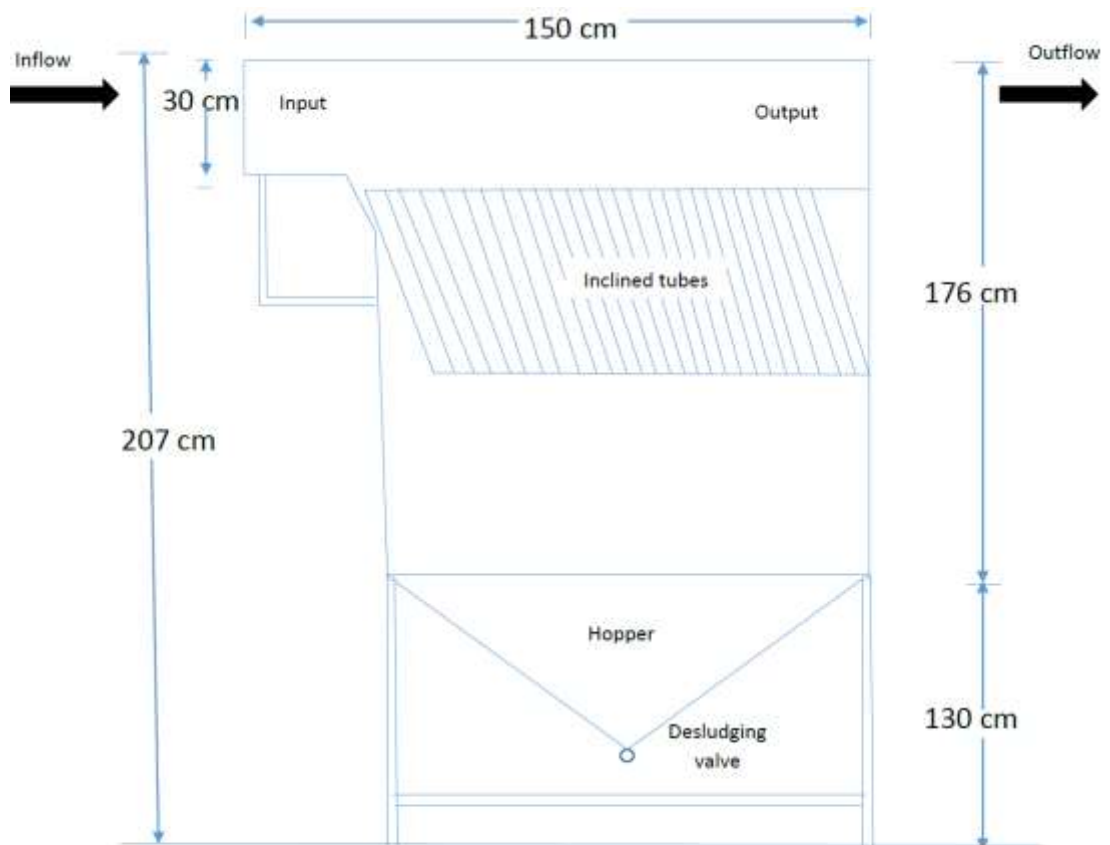


Fig. 4.3: Layout of Inclined Tubes Clarifier

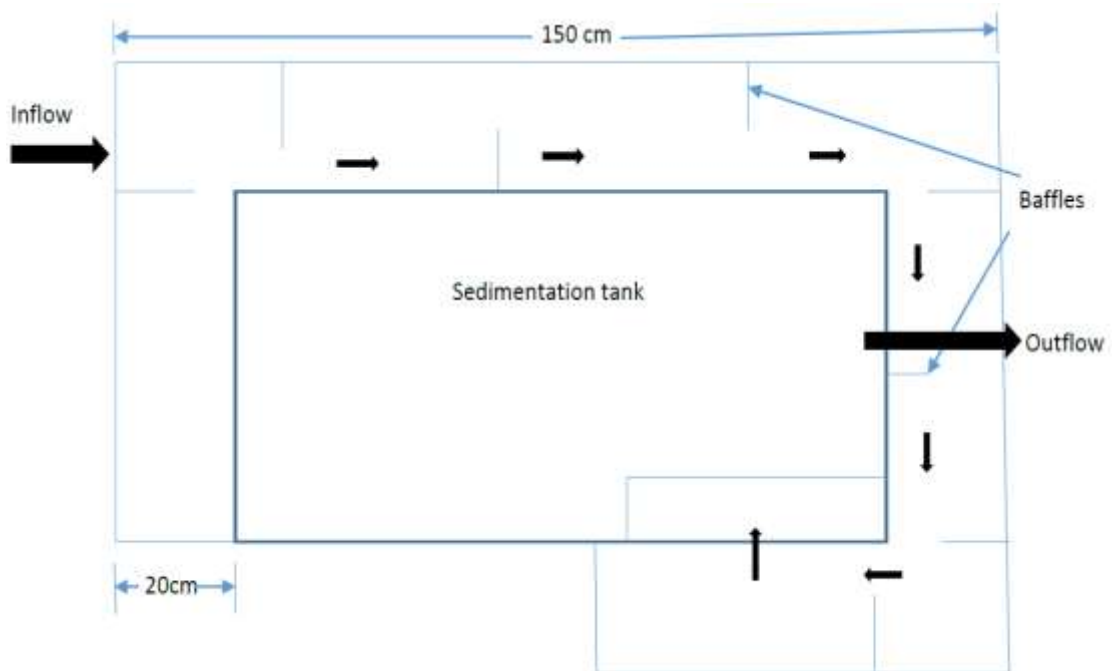


Fig. 4.4: Top view Inclined Tubes Clarifier

It consists of parts: feed inlet, settling area, sludge collection hopper, desludging valve at bottom and feed outlet. The inlet has an arrangement of ball valve to control the flow. All the tubes were placed 1 meter below the outlet level, so that it forms the settled/clear water zone above. A hopper bottom shape was provided at bottom below the settling zone to accumulate the sludge. Outlet drain pipe with valve was attached to the hopper bottom on either side for desludging operation (Fig 4.5).



Fig. 4.5 Desludging valve

4.3 Water Quality Analysis of Inclined Tubes Clarifier

The canal water samples were collected before passing through the inclined tubes clarifier and the water samples were collected from the outlet after 30 min interval on different flow rates. Water quality parameters of canal water before and after passing through inclined tubes clarifier were analyzed for different sediment loads (<1000 and >2000 mg/l) and flow rates (0.3 to 2.1 l/s) on different Total Suspended Solids (TSS) ranges were tested and reported in Tables 4.1 through 4.12.

The canal water quality was analyzed for parameters viz. total suspended solids, total solids, turbidity, electrical conductivity and pH. The different TSS ranges are determined and variation of water quality parameters with these ranges was observed. All parameters values before filtration were found to be much higher than the permissible limit.

4.3.1 Variation in Total Suspended Solids and Turbidity

The average TSS values before and after filtration as well removal efficiency of the clarifier for different flow rates is presented in Tables 4.1 through 4.10. The change in TSS in after passing through inclined tubes clarifier presented in Fig. 4.6.

Table 4.1 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 0.3 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS(mg/l)			Turbidity(NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.3	Below 1000	824	79	90.41	51	5	90.20
		862	86	90.02	54	8	85.19
		891	84	90.57	54	5	90.74
		926	92	90.06	56	4	92.86
	Average efficiency	90.26			89.74		
	1000-1500	1189	107	91.00	57	3	94.74
		1281	124	90.32	57	5	91.23
		1384	123	91.11	59	9	84.75
		1447	137	90.53	61	4	93.44
		1464	142	90.30	63	6	90.48
	Average efficiency	90.65			90.92		
	1500-2000	1687	164	90.28	64	4	93.75
		1748	179	89.76	65	3	95.38
		1749	169	90.34	68	3	95.59
		1773	146	91.77	105	7	93.33
		1792	156	91.29	105	8	92.38
		1812	153	91.56	112	15	86.61
		1829	154	91.58	103	14	86.41
		1832	146	92.03	79	12	84.81
		1836	138	92.48	84	13	84.52
		1859	135	92.74	78	12	84.62
	1687	164	90.28	64	4	93.75	
	Average efficiency	91.38			89.74		
Above 2000	2004	144	92.81	85	14	83.53	
	2053	147	92.84	92	12	86.96	
	2145	153	92.87	96	11	88.54	
	2163	153	92.93	99	15	84.85	
	2210	174	92.13	102	16	84.31	
	4123	195	95.27	105	7	93.33	
	4279	172	95.98	85	14	83.53	
Average efficiency	93.54			86.92			
Overall efficiency (%)	91.65			89.30			

At discharge rate of 0.3 l/s, the overall TSS removal efficiency is 91.65%. The removal efficiency was around 90% for the suspended load ranges from 1000-1500 mg/l. Also, the TSS removal efficiency was higher at the maximum load of above 2000 mg/l which is 93.54%. As the suspended load increased, the removal efficiency also increased (Table 4.1).

At discharge rate of 0.4 l/s, the overall TSS removal efficiency was 91.11%. When the TSS concentration range above 2000 mg/l, the removal efficiency was found to be 91.76% (Table 4.2). The removal efficiency was around 88% for the suspended load ranges from 1000-1500 mg/l.

Table 4.2 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 0.4 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.4	Below 1000	945	84	91.11	76	11	85.53
		952	92	90.34	78	9	88.46
		986	94	90.47	79	7	91.14
		988	102	89.68	79	10	87.34
		994	105	89.44	82	9	89.02
	Average efficiency	90.20			88.28		
	1000-1500	1185	122	89.70	83	10	87.95
		1208	107	91.14	84	11	86.90
		1216	107	91.20	84	10	88.10
		1247	133	89.33	84	11	86.90
		1257	112	91.09	86	13	84.88
		1474	132	91.04	87	13	85.06
		1487	125	91.59	89	12	86.52
		1489	142	90.46	96	10	89.58
	1494	127	91.50	97	9	90.72	
	Average efficiency	90.78			87.40		
	1500-2000	1503	131	91.28	98	8	91.84
		1524	130	91.45	104	12	88.46
		1534	131	91.43	106	13	87.74
		1541	132	91.42	110	11	90.00

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.4	1500-2000	1543	133	91.38	112	13	88.39
		1578	134	91.51	102	18	82.35
		1579	134	91.51	114	14	87.72
		1723	133	92.28	103	18	82.52
		1745	149	91.46	110	11	90.00
		1756	156	91.12	123	17	86.18
		1782	138	92.26	124	12	90.32
	Average efficiency	91.55			87.77		
	above 2000	2153	178	91.73	121	14	88.43
		2186	179	91.81	123	16	86.99
		2294	190	91.72	124	20	83.87
		2203	181	91.78	123	15	87.80
	Average efficiency	91.76			86.77		
Overall efficiency (%)	91.11			87.63			

At discharge rate of 0.5 l/s, the overall TSS removal efficiency was 90.49%. The removal efficiency ranges from 88-90% for sediment load below 1000 mg/l and ranges from 89-91% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 91.78% (Table 4.3).

Table 4.3 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 0.5 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.5	Below 1000	875	84	90.40	77	12	84.42
		884	94	89.37	78	5	93.59
		881	86	90.24	78	10	87.18
		945	94	90.05	79	11	86.08
		963	112	88.37	81	13	83.95
		988	107	89.17	82	12	85.37
	Average efficiency	89.59			86.76		

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)			
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)	
0.5	1000-1500	1243	128	89.70	82	13	84.15	
		1265	111	91.23	84	19	77.38	
		1286	134	89.58	91	10	89.01	
		1304	125	90.41	92	13	85.87	
		1314	107	91.86	92	13	85.87	
		1435	156	89.13	93	12	87.10	
		1435	156	89.13	94	10	89.36	
		1437	129	91.02	97	19	80.41	
		1437	129	91.02	112	13	88.39	
	Average efficiency		90.34			85.28		
	1500-2000	1501	153	89.81	112	10	91.07	
		1673	195	88.34	113	11	90.27	
		1709	148	91.34	114	14	87.72	
		1722	150	91.29	114	16	85.96	
		1748	159	90.90	116	12	89.66	
		1843	162	91.21	118	10	91.53	
		1854	153	91.75	119	16	86.55	
		1972	180	90.87	120	12	90.00	
	Average efficiency		90.68			89.09		
	Above 2000	2079	174	91.63	124	15	87.90	
		2094	169	91.93	124	16	87.10	
		2113	172	91.86	126	15	88.10	
		2125	176	91.72	128	11	91.41	
	Average efficiency		91.78			88.62		
	Overall efficiency (%)	90.49			87.23			

At discharge rate of 0.6 l/s, the overall TSS removal efficiency was 88.59%. The removal efficiency ranges from 86-88% for sediment load below 1000 mg/l and ranges from 86-89% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 91.51% (Table 4.4).

Table 4.4 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 0.6 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.6	Below 1000	854	99	88.41	94	13	86.17
		864	117	86.46	96	13	86.46
		877	113	87.12	96	10	89.58
		892	106	88.12	97	11	88.66
		942	108	88.54	98	11	88.78
		983	114	88.40	102	9	91.18
		985	113	88.53	102	11	89.22
		984	137	86.08	102	13	87.25
	Average efficiency	87.70			88.41		
	1000-1500	1104	152	86.23	103	9	91.26
		1104	124	88.76	103	10	90.29
		1119	126	88.73	104	11	89.42
		1120	142	87.32	104	13	87.50
		1122	154	86.27	105	12	88.57
		1123	128	88.60	106	13	87.74
		1124	146	87.01	110	12	89.09
		1456	186	87.20	112	16	85.71
		1478	158	89.31	113	15	86.73
		1482	154	89.60	115	13	88.70
	Average efficiency	87.90			88.50		
	1500-2000	1503	196	86.96	116	25	78.45
		1507	185	87.72	117	28	76.07
		1512	178	88.23	118	29	75.42
		1821	201	88.96	118	21	82.20
		1943	216	88.88	123	25	79.67

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.6	1500-2000	1946	223	88.54	124	24	80.65
		1983	204	89.70	125	22	82.40
		1993	214	89.26	129	9	93.02
		1863	187	89.95	128	11	91.41
		1979	256	87.04	129	15	88.37
	Average efficiency	88.52			82.76		
	above 2000	2213	185	91.64	124	18	85.48
		2204	198	91.02	123	21	82.93
		2189	196	91.05	123	21	82.93
		2194	279	87.28	126	23	81.75
	Average efficiency	91.51			83.09		
Overall efficiency (%)	88.59			85.92			

At discharge rate of 0.8 l/s, the overall TSS removal efficiency was 85.00%. The removal efficiency ranges from 81-85% for sediment load below 1000 mg/l and ranges from 84-85% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 86.31% (Table 4.5).

Table 4.5 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 0.8 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.8	below 1000	845	145	82.84	43	8	81.40
		856	162	81.07	45	8	82.22
		872	146	83.26	45	9	80.00
		985	138	85.99	46	12	73.91
		998	145	85.47	47	5	89.36
	Average efficiency	83.72			81.37		
	1000-1500	1237	174	85.93	47	6	87.23
		1242	186	85.02	48	5	89.58
		1243	223	82.06	48	6	87.50

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
0.5	1000-1500	1248	194	84.46	48	7	85.42
		1249	216	82.71	49	18	63.27
		1257	194	84.57	49	9	81.63
		1256	206	83.60	50	13	74.00
		1426	235	83.52	51	13	74.51
		1428	236	83.47	62	9	85.48
		1453	216	85.13	63	15	76.19
		1478	243	83.56	73	11	84.93
		1486	148	90.04	78	12	84.62
		1489	147	90.13	84	12	85.71
	Average efficiency	84.93			81.54		
	1500-2000	1524	233	84.71	84	15	82.14
		1526	235	84.60	85	15	82.35
		1550	248	84.00	97	22	77.32
		1554	237	84.75	102	21	79.41
		1563	226	85.54	103	23	77.67
		1578	236	85.04	103	16	84.47
		1596	228	85.71	104	25	75.96
		1627	240	85.25	114	16	85.96
		1634	252	84.58	114	28	75.44
		1635	253	84.53	122	26	78.69
		1639	234	85.72	114	15	86.84
		1647	242	85.31	113	21	81.42
		1680	236	85.95	116	21	81.90
	Average efficiency	85.05			80.74		
	above 2000	2015	295	85.36	112	18	83.93
		2043	294	85.61	135	19	85.93
		2142	287	86.60	132	21	84.09
		2254	296	86.87	134	24	82.09
		2148	276	87.15	132	22	83.33
	Average efficiency	86.31			83.87		
	Overall efficiency (%)	85.00			81.55		

At discharge rate of 1.0 l/s, the overall TSS removal efficiency was 84.54%. The removal efficiency ranges from 81-83% for sediment load below 1000 mg/l and ranges from 80-85% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 84.54% (Table 4.6).

Table 4.6 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 1.0 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
1.0	below 1000	842	154	81.71	54	9	83.33
		856	146	82.94	58	12	79.31
		867	162	81.31	58	12	79.31
		947	158	83.32	58	20	65.52
		998	164	83.57	63	13	79.37
		942	156	83.44	63	22	65.08
	Average efficiency	82.71			75.32		
	1000-1500	1363	196	85.62	64	15	76.56
		1363	193	85.84	64	18	71.88
		1428	278	80.53	65	17	73.85
		1438	284	80.25	65	14	78.46
		1489	254	82.94	67	11	83.58
		1363	196	85.62	64	15	76.56
	Average efficiency	83.03			76.87		
	1500-2000	1652	261	84.20	67	15	77.61
		1673	265	84.16	68	13	80.88
		1683	303	82.00	68	15	77.94
		1694	258	84.77	72	12	83.33
		1712	291	83.00	76	24	68.42
		1716	264	84.62	81	11	86.42
		1729	290	83.23	83	14	83.13
		1735	292	83.17	102	13	87.25
		1754	266	84.83	103	18	82.52
1765		290	83.57	112	14	87.50	
1775		267	84.96	114	12	89.47	
1775	287	83.83	115	15	86.96		
Average efficiency	83.86			82.62			

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
1.0	above 2000	2825	432	84.71	115	15	86.96
		2843	482	83.05	116	11	90.52
		3845	552	85.64	114	16	85.96
		3862	572	85.19	128	21	83.59
		3872	677	82.52	126	23	81.75
		4972	687	86.18	129	21	83.72
	Average efficiency	84.54			85.41		
Overall efficiency (%)	83.62				80.70		

At discharge rate of 0.5 l/s, the overall TSS removal efficiency was 81.65%. The removal efficiency ranges from 65-78% for sediment load below 1000 mg/l and ranges from 72-83% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 81.65% (Table 4.7).

Table 4.7 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 1.2 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
1.2	Below 1000	841	288	65.76	38	10	73.68
		845	293	65.33	39	12	69.23
		856	296	65.42	43	11	74.42
		933	197	78.89	46	12	73.91
		942	209	77.81	48	12	75.00
		986	204	79.31	48	11	77.08
	Average efficiency	72.08			73.89		
	1000-1500	1024	283	72.36	52	11	78.85
		1196	295	75.33	53	13	75.47
		1272	282	77.83	54	13	75.93
		1285	283	77.98	56	11	80.36
1423		253	82.22	57	18	68.42	

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
1.2	1000-1500	1425	292	79.51	57	15	73.68
		1425	239	83.23	58	10	82.76
		1445	279	80.69	61	11	81.97
		1452	246	83.06	63	11	82.54
	Average efficiency	79.13			77.77		
	1500-2000	1645	281	82.92	63	12	80.95
		1838	349	81.01	63	18	71.43
		1864	378	79.72	63	16	74.60
		1944	374	80.76	67	17	74.63
		1972	389	80.27	72	19	73.61
		1986	353	82.23	74	17	77.03
	Average efficiency	81.15			75.37		
	above 2000	2407	522	78.31	75	17	77.33
		2445	514	78.98	76	19	75.00
		2483	435	82.48	78	17	78.21
		2388	486	79.65	79	21	73.42
		2392	497	79.22	81	13	83.95
		3436	678	80.27	82	15	81.71
		5746	423	92.64	83	21	74.70
	Average efficiency	81.65			77.75		
	Overall efficiency (%)	78.69			76.42		

At discharge rate of 1.5 l/s, the overall TSS removal efficiency was 71.16%. The removal efficiency ranges from 61-71% for sediment load below 1000 mg/l and ranges from 69-77% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 74.94% (Table 4.8).

Table 4.8 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 1.5 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS(mg/l)			Turbidity(NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
1.5	below 1000	845	249	70.53	37	16	56.76
		847	269	68.24	39	17	56.41
		853	242	71.63	45	22	51.11
		862	245	71.58	46	21	54.35
		892	252	71.75	54	16	70.37
		945	363	61.59	54	15	72.22
		981	348	64.53	37	16	56.76
	Average efficiency	68.54			60.20		
	1000-1500	1095	335	69.41	57	11	80.70
		1115	324	70.94	57	12	78.95
		1163	317	72.74	57	16	71.93
		1184	315	73.40	62	13	79.03
		1340	326	75.67	63	13	79.37
		1340	457	65.90	67	14	79.10
		1437	498	65.34	68	19	72.06
	Average efficiency	70.49			76.68		
	1500-2000	1637	432	73.61	76	22	71.05
		1642	498	69.67	78	21	73.08
		1678	504	69.96	78	29	62.82
		1684	530	68.53	79	25	68.35
		1705	379	77.77	81	21	74.07
1709		538	68.52	81	22	72.84	
1754		542	69.10	82	24	70.73	
1754		484	72.41	83	21	74.70	
Average efficiency	71.20			70.95			
above 2000	2043	541	73.52	84	22	73.81	
	2186	564	74.20	86	25	70.93	
	2256	586	74.02	130	22	83.08	
	2259	556	75.39	134	24	82.09	
	3462	996	71.23	125	24	80.80	
	4586	856	81.33	84	22	73.81	
Average efficiency	74.94			78.40			
Overall efficiency (%)	71.16			71.88			

At discharge rate of 1.8 l/s, the overall TSS removal efficiency was 64.76%. The removal efficiency ranges from 56-67% for sediment load below 1000 mg/l and ranges from 61-70% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 69.76% (Table 4.9).

Table 4.9 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 1.8 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS(mg/l)			Turbidity(NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
1.8	below 1000	812	361	55.54	84	26	69.05
		763	304	60.16	86	30	65.12
		863	394	54.35	88	29	67.05
		886	338	61.85	89	32	64.04
		845	328	61.18	90	29	67.78
		892	388	56.50	91	36	60.44
		994	342	65.59	93	27	70.97
		983	323	67.14	93	38	59.14
	Average efficiency	60.28			65.45		
	1000-1500	1189	386	67.54	95	30	68.42
		1222	491	59.82	96	28	70.83
		1228	493	59.85	98	34	65.31
		1243	404	67.50	101	32	68.32
		1320	549	58.41	101	35	65.35
		1489	556	62.66	102	34	66.67
		1476	586	60.30	106	37	65.09
		1463	586	59.95	116	29	75.00
	Average efficiency	62.00			68.12		
	1500-2000	1522	536	64.78	86	28	67.44
		1526	545	64.29	87	32	63.22
		1534	594	61.28	84	31	63.10
		1542	586	62.00	81	31	61.73
		1573	573	63.57	94	33	64.89

Flow rate (l/s)	TSS range (mg/l)	TSS(mg/l)			Turbidity(NTU)		
		Initial	Final	Removal efficiency (%)	Initial	Final	Removal efficiency (%)
1.8	1500-2000	1576	586	62.82	92	35	61.96
		1578	524	66.79	83	36	56.63
		1732	548	68.36	84	35	58.33
		1740	539	69.02	87	34	60.92
		1742	563	67.68	128	33	74.22
		1781	532	70.13	118	36	69.49
		1783	577	67.64	124	35	71.77
		1785	548	69.30	126	41	67.46
		1796	647	63.98	128	35	72.66
	Average efficiency	65.83			65.27		
	above 2000	2435	756	68.95	125	36	71.20
		2653	826	68.87	126	31	75.40
		3456	924	73.26	124	35	71.77
		4896	1264	74.18	123	35	71.54
		4785	1268	73.50	124	38	69.35
		4271	1443	66.21	118	34	71.19
		4635	1584	65.83	119	41	65.55
		5876	1896	67.73	114	42	63.16
		5406	1774	67.18	115	46	60.00
	Average efficiency	69.76			68.79		
Overall efficiency (%)	64.76			66.70			

At discharge rate of 2.1 l/s, the overall TSS removal efficiency was 57.00%. The removal efficiency ranges from 49-56% for sediment load below 1000 mg/l and ranges from 54-62% for suspended load of 1500-2000 mg/l concentration. For TSS concentration range above 2000 mg/l, the TSS removal efficiency was higher at 57.89% (Table 4.10).

Table 4.10 Average removal efficiency of TSS and Turbidity at various TSS concentration for flow rate 2.1 l/s

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)		
		Initial	Final	Removal Efficiency (%)	Initial	Final	Removal Efficiency (%)
2.1	Below 1000	852	414	51.41	81	32	60.49
		887	386	56.48	85	30	64.71
		886	394	55.53	86	32	62.79
		975	387	60.31	87	31	64.37
		989	384	61.17	89	41	53.93
		978	491	49.80	90	46	48.89
		996	484	51.41	98	42	57.14
	Average efficiency	55.12			58.90		
	1000-1500	1320	604	54.24	99	41	58.59
		1322	584	55.82	99	38	61.62
		1328	562	57.68	84	44	47.62
		1342	544	59.46	84	41	51.19
		1356	548	59.59	105	40	61.90
		1484	562	62.13	110	42	61.82
		1482	682	53.98	114	41	64.04
	1496	679	54.61	124	42	66.13	
	Average efficiency	57.19			59.11		
	1500-2000	1504	646	57.05	78	33	57.69
		1543	637	58.72	84	32	61.90
		1546	633	59.06	84	38	54.76
		1547	709	54.17	86	34	60.47
		1563	678	56.62	62	36	41.94
		1578	626	60.33	84	34	59.52
1596		684	57.14	84	35	58.33	
1829		746	59.21	104	41	60.58	
1842		787	57.27	103	46	55.34	
1846	781	57.69	102	48	52.94		

Flow rate (l/s)	TSS range (mg/l)	TSS (mg/l)			Turbidity (NTU)			
		Initial	Final	Removal Efficiency (%)	Initial	Final	Removal Efficiency (%)	
2.1	1500-2000	1847	693	62.48	105	41	60.95	
		1848	810	56.17	106	34	67.92	
		1853	842	54.56	145	36	75.17	
		1859	891	52.07	126	42	66.67	
	Average efficiency		57.32			59.58		
	above 2000	2453	1053	57.07	95	34	64.21	
		4563	1844	59.59	94	36	61.70	
		5123	2456	52.06	86	38	55.81	
		5478	2536	53.71	125	35	72.00	
		5236	2546	51.38	124	35	71.77	
		5489	2243	59.14	136	41	69.85	
		5471	2187	60.03	135	42	68.89	
		7453	2223	70.17	134	45	66.42	
	Average efficiency		57.89			66.33		
Overall efficiency (%)	57.00			60.81				

Variation of TSS with the flow rate

The TSS removal efficiency decreases with increase in flow rate and was found to be maximum at 0.3 l/s (Fig. 4.7). It was observed that for flow rates ranging from 0.3 to 1.0 l/s, removal efficiency varied between 85% and 92% but as the flow rate increased beyond 1.2 l/s, the removal efficiency also decreased nearly to 55% for 2.1 l/s as flow rate. The removal efficiency was nearly 55% for flow rate of 2.1 l/s as compared to 91% for flow rate of 0.3 l/s. So, the size of detention tank must be big enough to have high amount of flow rate and good removal efficiency. Low settling time is provided by high velocity water and thus the efficiency decreases with the increase in flow rate. The overall removal efficiency varied with flow rates. At different flow rates, the average removal efficiency was higher at lower flow rates (0.3 – 0.6 l/s). At all flow rates, more removal efficiency was observed at higher TSS concentration (Fig. 4.7).

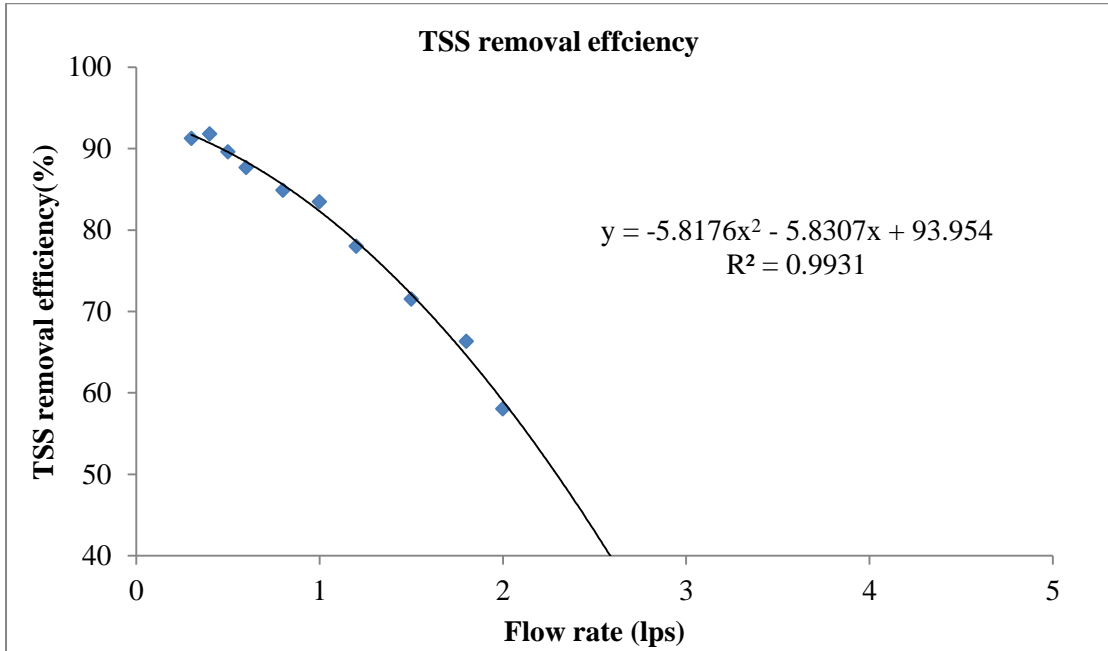


Fig. 4.6: Effect of flow rate on TSS removal efficiency of inclined tubes clarifier

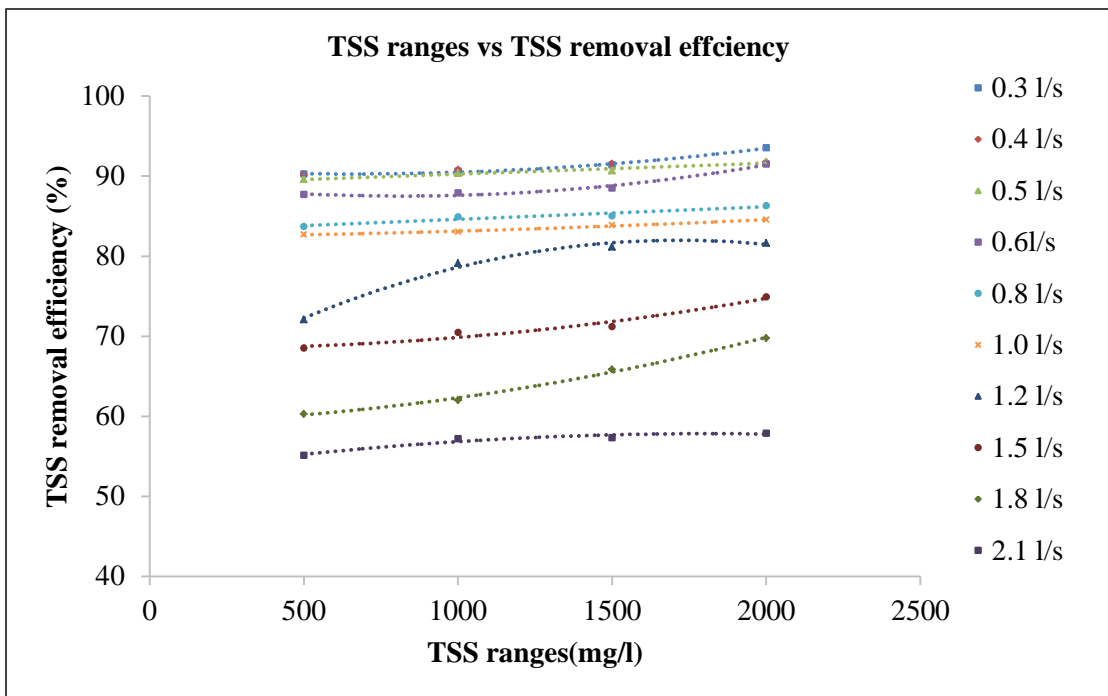


Fig. 4.7: Variation in different flow rates for different TSS ranges w.r.t. TSS removal efficiency

4.2.2. Turbidity

The turbidity was analyzed from the water samples taken before and after passing through inclined tubes clarifier are presented in Table 4.1-4.10 for different flow rates.

Turbidity was analyzed with respect to different TSS ranges. At discharge rate of 0.3 l/s, the overall turbidity removal efficiency is 89.30% which is higher removal efficiency. As similar to TSS removal efficiency, for above 2000 mg/l TSS concentration range the turbidity removal efficiency was higher which is 92.16% (Table 4.1). Similarly for other flow rate, the turbidity removal efficiency was higher for above 2000 TSS concentration range comparative to other TSS range (Table 4.1-4.10). As the suspended load increases, the turbidity removal efficiency also increases.

Variation of turbidity with the flow rate

The existing data, given by the system, are analyzed through plots to observe the relationship between turbidity and flow (Fig. 4.8). As the flow velocity increases, the percentage of turbidity removal decreases. High flow velocity causes re-suspension of settled particles and also scouring of settled sludge surface. Effluent turbidity begins to deteriorate, hence the efficiency of tube settler starts to decrease.

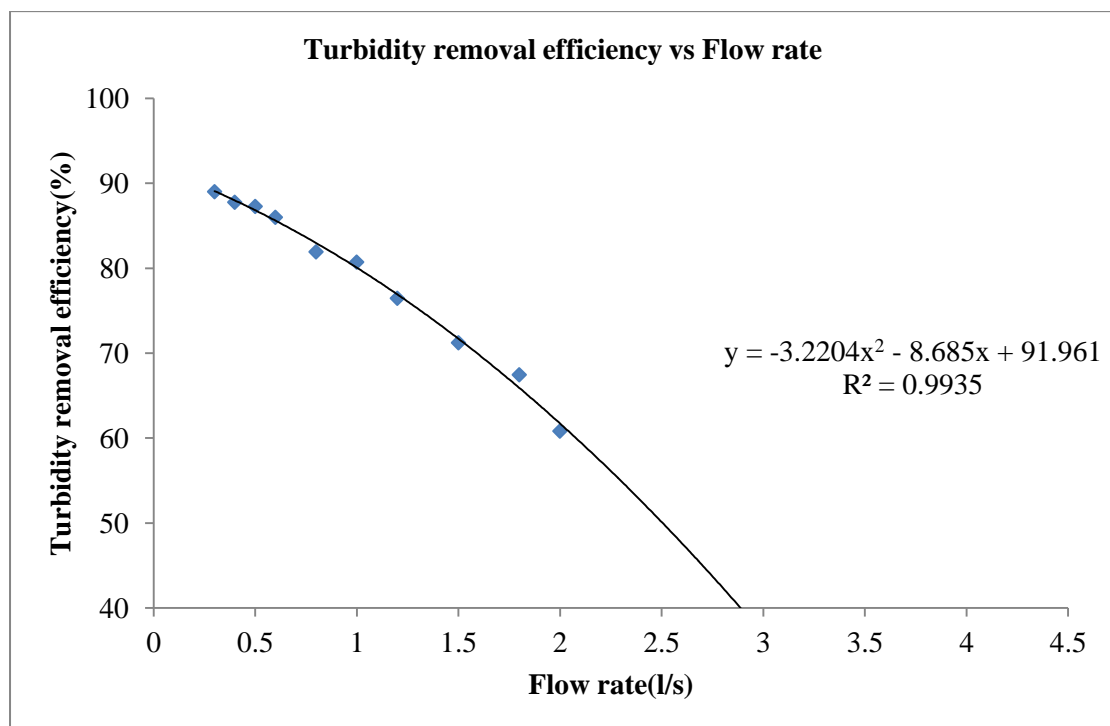


Fig. 4.8: Effect of flow rate on turbidity removal efficiency of inclined tubes clarifier

The experiment was conducted for different flow rate and water from outlet was collected to measure its suspended load (Fig. 4.9). It was found that, at low flow rates (0.2 to 0.6 l/s) the removal efficiency ranges between 90-95%. As the flow rate increased beyond 2 l/s the removal efficiency decreased to 55% irrespective of the suspended load concentration. With increase in flow rate, the efficiency reduces due to decreased in the retention time of suspended water in detention tank.

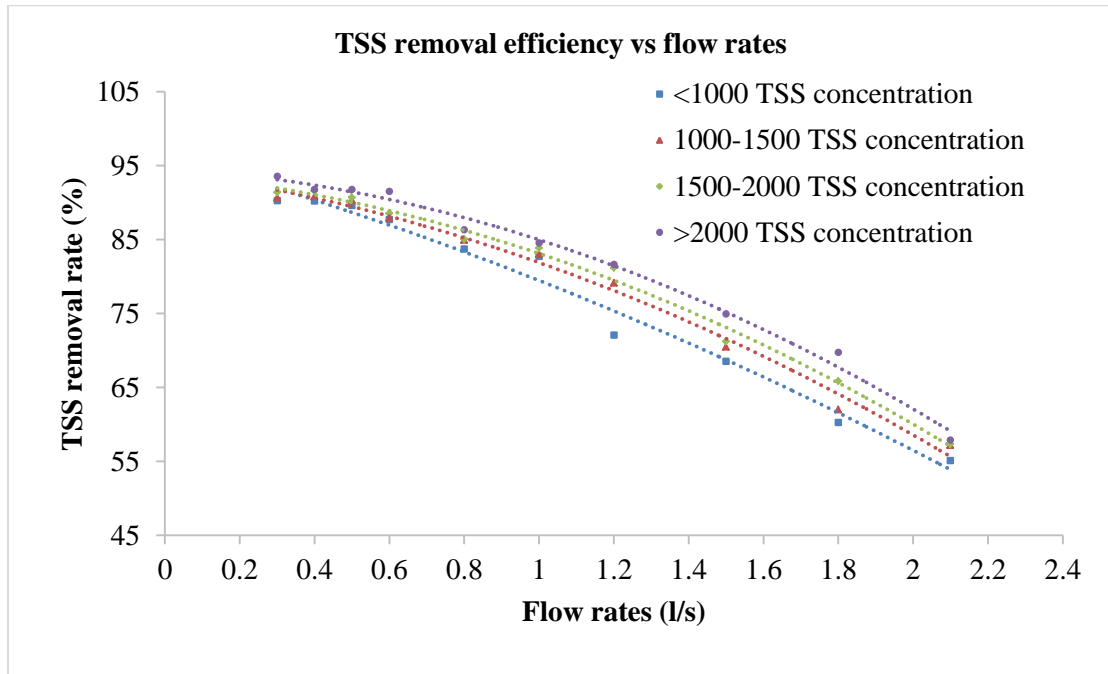


Fig. 4.9: Variation in different TSS ranges for different flow rates w.r.t. TSS removal efficiency

4.2.3 Total Dissolved Solids

The initial TDS values for different TSS ranges were presented in Table 4.11. It was observed that, there was very little variation in TDS values with respect to flow rates and different TSS concentration.

The TDS was analyzed from the water samples taken before and after passing through inclined tubes clarifier are presented in Table 4.12. There is about 7-10% reduction was observed in samples values after passing through the inclined tubes clarifier with respect to different flow rates.

4.2.4. Electrical Conductivity

The initial EC values for different TSS ranges were presented in Table 4.11. It was observed that, there was very little variation in EC values with respect to flow rates and the different TSS concentration.

The EC was analyzed from the water samples taken before and after passing through inclined tubes clarifier are presented in Table 4.12. There is about 3-5% reduction was observed in sample values after passing through the inclined tubes clarifier with respect to different flow rates.

4.2.5 pH

The initial pH values for different TSS ranges were presented in Table 4.11. The pH was analyzed from the water samples taken before and after passing through inclined tubes

clarifier are presented in Table 4.12. It was observed that, there was no variation in pH values with respect to flow rates and the different TSS concentration.

Table 4.11 Initial values of TDS, EC and pH for different TSS concentration

TSS range (mg/l)	Initial TDS	Initial EC	Initial pH
< 1000	153	284	6.98
	162	310	6.98
	162	336	7.01
	168	329	7.05
	177	338	7.06
	183	332	7.02
	189	349	7.12
	192	345	6.93
	195	357	6.98
	165	362	6.48
1000-1500	145	287	7.40
	134	273	7.40
	137	264	7.41
	137	268	7.51
	146	254	7.54
	149	263	7.71
	153	264	7.78
	145	301	8.02
	134	304	8.03
	137	310	8.05
1500-2000	137	241	7.40
	146	237	7.41
	131	204	7.43
	134	289	7.46
	134	294	7.47
	137	249	7.48
	143	246	7.48
	146	273	7.55
	146	243	7.58
	152	339	7.62

TSS range (mg/l)	Initial TDS	Initial EC	Initial pH
2000 <	173	236	7.31
	176	176	7.34
	131	241	7.35
	134	274	7.35
	134	287	7.36
	137	241	7.52
	167	275	7.54
	188	271	7.58
	191	276	7.62
	194	294	7.73

Table 4.12 Initial and final TDS, EC and pH at various TSS range for different flow rates

Flow rate (l/s)	TDS (mg/l)		EC (μ S/m)		pH	
	Initial	Final	Initial	Final	Initial	Final
0.3	153	142	284	278	6.98	6.96
	162	158	310	294	6.98	6.92
	162	146	336	284	7.01	7.00
	168	161	329	314	7.05	7.02
	177	158	338	263	7.06	7.03
0.4	183	154	332	313	7.02	6.99
	189	162	349	326	7.12	7.09
	192	179	345	345	6.93	6.97
	195	173	357	348	6.98	7.09
	165	173	362	359	6.48	6.36
0.5	145	135	287	274	7.40	7.36
	134	127	273	265	7.40	6.32
	137	112	264	251	7.41	7.34
	137	124	268	253	7.51	7.41
	146	138	254	236	7.54	7.42
0.6	149	134	263	249	7.71	7.63
	153	147	264	253	7.78	7.62
	145	134	301	295	8.02	7.64
	134	121	304	297	8.03	7.52
	137	122	310	284	8.05	7.48

Flow rate (l/s)	TDS (mg/l)		EC ($\mu\text{S/m}$)		pH	
	Initial	Final	Initial	Final	Initial	Final
0.8	137	121	241	236	7.40	7.25
	146	134	237	231	7.41	7.38
	131	126	204	198	7.43	7.26
	134	129	289	274	7.46	7.35
	134	128	294	261	7.47	7.42
1.0	137	127	249	235	7.48	7.35
	143	132	246	238	7.48	7.26
	146	131	273	256	7.55	7.21
	146	127	243	234	7.58	7.34
	137	114	241	237	7.40	6.42
1.2	173	236	216	211	7.43	7.31
	176	146	247	234	7.48	7.34
	131	124	339	328	7.56	7.35
	134	120	276	267	7.42	7.35
	134	116	348	337	7.48	7.36
1.5	137	117	284	274	7.61	7.52
	167	154	357	345	7.67	7.54
	188	146	243	235	7.84	7.58
	191	176	275	264	7.89	7.62
	194	182	234	228	7.78	7.73
1.8	171	169	287	281	7.38	7.36
	174	165	268	259	7.38	7.37
	183	174	248	235	7.38	7.2
	189	176	156	142	7.38	7.36
	189	178	246	245	7.46	7.43
2.1	189	176	275	267	7.6	7.36
	154	148	286	273	7.63	7.59
	154	151	284	278	7.86	7.63
	116	111	213	204	7.46	7.41
	112	110	243	236	7.32	7.28



Fig. 4.10: Inclined tube clarifier while operation

4.8. Statistical analysis for inclined tubes clarifier for different TSS ranges

Statistically at lower flow rates (up to 0.5 l/s), performance of inclined tubes clarifier showed significant difference in between TSS loading rate less than 1000 and beyond 2000 mg/l (Annexure I). Similar trends follows the turbidity. Change in turbidity was also significant in the water samples before and after filtration in clarifier (Annexure II). At higher flow rates (above 0.5 to 2.1 l/s) there is no significant difference was observed in performance of inclined tubes clarifier with respect to TSS loading rate. Also, there was no significant difference was observed for EC, TS, TDS and pH (Annexure-III, IV, V and VI).

CHAPTER V

SUMMARY

The continuous pressure on increasing agricultural production to meet the requirement of the ever increasing population of India has resulted in the over exploitation of groundwater. Augmentation of groundwater through artificial groundwater recharge is the need of the hour. During monsoon season, canal water are loaded with coarse as well as fine sediments. However, the clogging of recharge well due to suspended load in the water has been the major constraint for successful long-term operation of recharge systems. To prevent clogging of recharging well removal of suspended load is much needed. Thus, the present study is therefore undertaken with following objectives:

1. To design and fabricate an inclined tubes clarifier for surplus canal water recharge.
2. To study efficacy of inclined tubes clarifier for silt removal from canal water.

Inclined tubes clarifier was designed, fabricated and installed near water outlet from Sidhwan canal, Punjab Agricultural University, Ludhiana. The system was made operational with the different flow rate and TSS concentrations and analyzed the effect of inclined tubes clarifier on water quality. Water quality analysis has been done with different parameters i.e., TSS, TS, TDS, EC and pH. From the results and discussion, following conclusions were drawn:

1. The designed inclined tubes clarifier gave removal efficiency of TSS above 90% at a flow rate up to 0.5 l/s and above 85% up to a flow rate of 0.8 l/s.
2. Above 1 l/s, the removal efficiency of TSS decreased rapidly.
3. At higher TSS values, there was a slight improvement in the removal efficiency of inclined tube clarifier at all flow rates.
4. For all flow rates, there is no impact on pH values before and after filtration.
5. There is 7-10% average reduction in TDS and 3-5% average reduction in EC values.
6. Variation in turbidity follows the same trends as that of Total Suspended Solids.

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ANNEXURE I

Statistical analysis for TSS removal efficiency within different TSS ranges

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
0.3	<1000	-	-	-	-
	1000-1500	0.70 ^{NS}	-	-	-
	1500-2000	4.90 ^{NS}	1.21 ^{NS}	-	-
	>2000	13.27**	6.60**	11.07**	-
0.4	<1000	-	-	-	-
	1000-1500	0.75 ^{NS}	-	-	-
	1500-2000	2.56 ^{NS}	2.55 ^{NS}	-	-
	>2000	3.94**	3.07**	1.22 ^{NS}	-
0.5	<1000	-	-	-	-
	1000-1500	2.01 ^{NS}	-	-	-
	1500-2000	2.01 ^{NS}	1.82 ^{NS}	-	-
	>2000	17.10**	5.14**	5.14**	-
0.6	<1000	-	-	-	-
	1000-1500	0.32 ^{NS}	-	-	-
	1500-2000	1.79 ^{NS}	0.64 ^{NS}	-	-
	>2000	1.98 ^{NS}	2.88 ^{NS}	1.62 ^{NS}	-
0.8	<1000	-	-	-	-
	1000-1500	0.95 ^{NS}	-	-	-
	1500-2000	1.16 ^{NS}	0.14 ^{NS}	-	-
	>2000	4.07 ^{NS}	1.58 ^{NS}	2.43 ^{NS}	-
1.0	<1000	-	-	-	-
	1000-1500	0.20 ^{NS}	-	-	-
	1500-2000	1.46 ^{NS}	0.58 ^{NS}	-	-
	>2000	1.95 ^{NS}	0.80 ^{NS}	0.57 ^{NS}	-
1.2	<1000	-	-	-	-
	1000-1500	2.49 ^{NS}	-	-	-
	1500-2000	3.02 ^{NS}	2.44 ^{NS}	-	-
	>2000	4.09 ^{NS}	1.75 ^{NS}	0.34 ^{NS}	-

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
1.5	<1000	-	-	-	-
	1000-1500	2.42 ^{NS}	-	-	-
	1500-2000	0.93 ^{NS}	0.02 ^{NS}	-	-
	>2000	2.63 ^{NS}	1.91 ^{NS}	2.00 ^{NS}	-
1.8	<1000	-	-	-	-
	1000-1500	0.73 ^{NS}	-	-	-
	1500-2000	4.31 ^{NS}	0.02 ^{NS}	-	-
	>2000	4.36 ^{**}	1.91 ^{NS}	2.00 ^{NS}	-
2.1	<1000	-	-	-	-
	1000-1500	1.12 ^{NS}	-	-	-
	1500-2000	1.18 ^{NS}	0.24 ^{NS}	-	-
	>2000	0.76 ^{NS}	0.28 ^{NS}	0.31 ^{NS}	-

**Significant at 1 percent level (p < 0.01)

NS – Not Significant

ANNEXURE II

Statistical analysis for turbidity removal efficiency within different TSS concentration ranges

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
0.3	<1000	-	-	-	-
	1000-1500	0.48 ^{NS}	-	-	-
	1500-2000	2.35 ^{NS}	1.49 ^{NS}	-	-
	>2000	1.92 ^{**}	2.07 ^{**}	2.31 ^{**}	-
0.4	<1000	-	-	-	-
	1000-1500	1.19 ^{NS}	-	-	-
	1500-2000	0.60 ^{NS}	2.92 ^{NS}	-	-
	>2000	0.91 ^{**}	0.06 ^{**}	0.05 ^{**}	-
0.5	<1000	-	-	-	-
	1000-1500	0.75 ^{NS}	-	-	-
	1500-2000	1.01 ^{NS}	1.77 ^{NS}	-	-
	>2000	0.81 ^{**}	0.43 ^{**}	1.11 ^{**}	-
0.6	<1000	-	-	-	-
	1000-1500	0.75 ^{NS}	-	-	-
	1500-2000	1.01 ^{NS}	0.81 ^{NS}	-	-
	>2000	1.01 ^{NS}	0.64 ^{NS}	4.41 ^{NS}	-
0.8	<1000	-	-	-	-
	1000-1500	0.18 ^{NS}	-	-	-
	1500-2000	0.56 ^{NS}	1.07 ^{NS}	-	-
	>2000	0.56 ^{NS}	0.64 ^{NS}	4.41 ^{NS}	-
1.0	<1000	-	-	-	-
	1000-1500	0.13 ^{NS}	-	-	-
	1500-2000	0.06 ^{NS}	2.58 ^{NS}	-	-
	>2000	2.93 ^{NS}	0.80 ^{NS}	0.57 ^{NS}	-
1.2	<1000	-	-	-	-
	1000-1500	1.04 ^{NS}	-	-	-
	1500-2000	1.21 ^{NS}	0.38 ^{NS}	-	-
	>2000	2.81 ^{NS}	0.47 ^{NS}	1.06 ^{NS}	-

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
1.5	<1000	-	-	-	-
	1000-1500	7.02 ^{NS}	-	-	-
	1500-2000	5.40 ^{NS}	7.58 ^{NS}	-	-
	>2000	4.99 ^{NS}	0.04 ^{NS}	2.08 ^{NS}	-
1.8	<1000	-	-	-	-
	1000-1500	0.63 ^{NS}	-	-	-
	1500-2000	6.10 ^{NS}	2.41 ^{NS}	-	-
	>2000	6.10 ^{NS}	6.54 ^{NS}	4.85 ^{NS}	-
2.1	<1000	-	-	-	-
	1000-1500	1.21 ^{NS}	-	-	-
	1500-2000	3.28 ^{NS}	0.16 ^{NS}	-	-
	>2000	0.89 ^{NS}	2.62 ^{NS}	1.79 ^{NS}	-

**Significant at 1 percent level (p < 0.01)

NS – Not Significant

ANNEXURE III

Statistical analysis for TS removal efficiency within different TSS concentration ranges

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
0.3	<1000	-	-	-	-
	1000-1500	1.79 ^{NS}	-	-	-
	1500-2000	2.40 ^{NS}	0.16 ^{NS}	-	-
	>2000	8.76 ^{NS}	6.95 ^{NS}	2.78 ^{NS}	-
0.4	<1000	-	-	-	-
	1000-1500	0.85 ^{NS}	-	-	-
	1500-2000	0.61 ^{NS}	0.66 ^{NS}	-	-
	>2000	0.62 ^{NS}	0.12 ^{NS}	0.56 ^{NS}	-
0.5	<1000	-	-	-	-
	1000-1500	2.01 ^{NS}	-	-	-
	1500-2000	2.20 ^{NS}	0.04 ^{NS}	-	-
	>2000	0.90 ^{NS}	0.80 ^{NS}	0.80 ^{NS}	-
0.6	<1000	-	-	-	-
	1000-1500	2.01 ^{NS}	-	-	-
	1500-2000	2.20 ^{NS}	0.04 ^{NS}	-	-
	>2000	0.90 ^{NS}	0.80 ^{NS}	0.78 ^{NS}	-
0.8	<1000	-	-	-	-
	1000-1500	0.77 ^{NS}	-	-	-
	1500-2000	1.69 ^{NS}	8.38 ^{NS}	-	-
	>2000	1.43 ^{NS}	2.75 ^{NS}	0.54 ^{NS}	-
1.0	<1000	-	-	-	-
	1000-1500	2.97 ^{NS}	-	-	-
	1500-2000	2.82 ^{NS}	4.77 ^{NS}	-	-
	>2000	0.58 ^{NS}	5.99 ^{NS}	5.99 ^{NS}	-
1.2	<1000	-	-	-	-
	1000-1500	1.65 ^{NS}	-	-	-
	1500-2000	0.47 ^{NS}	1.96 ^{NS}	-	-
	>2000	0.19 ^{NS}	4.46 ^{NS}	1.70 ^{NS}	-

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
1.5	<1000	-	-	-	-
	1000-1500	1.94 ^{NS}	-	-	-
	1500-2000	2.85 ^{NS}	0.15 ^{NS}	-	-
	>2000	1.39 ^{NS}	9.81 ^{NS}	9.14 ^{NS}	-
1.8	<1000	-	-	-	-
	1000-1500	1.58 ^{NS}	-	-	-
	1500-2000	0.97 ^{NS}	1.16 ^{NS}	-	-
	>2000	0.19 ^{NS}	1.89 ^{NS}	0.83 ^{NS}	-
2.1	<1000	-	-	-	-
	1000-1500	1.96 ^{NS}	-	-	-
	1500-2000	2.40 ^{NS}	2.90 ^{NS}	-	-
	>2000	4.64 ^{NS}	7.13 ^{NS}	0.85 ^{NS}	-

**Significant at 1 percent level (p < 0.01)

NS – Not Significant

ANNEXURE IV

Statistical analysis for TDS removal efficiency within different TSS concentration

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
0.3	<1000	-	-	-	-
	1000-1500	0.18 ^{NS}	-	-	-
	1500-2000	0.07 ^{NS}	1.22 ^{NS}	-	-
	>2000	0.15 ^{NS}	0.39 ^{NS}	2.78 ^{NS}	-
0.4	<1000	-	-	-	-
	1000-1500	0.62 ^{NS}	-	-	-
	1500-2000	1.37 ^{NS}	2.01 ^{NS}	-	-
	>2000	0.98 ^{NS}	1.55 ^{NS}	0.25 ^{NS}	-
0.5	<1000	-	-	-	-
	1000-1500	3.76 ^{NS}	-	-	-
	1500-2000	1.43 ^{NS}	6.44 ^{NS}	-	-
	>2000	1.44 ^{NS}	1.98 ^{NS}	2.02 ^{NS}	-
0.6	<1000	-	-	-	-
	1000-1500	0.75 ^{NS}	-	-	-
	1500-2000	2.28 ^{NS}	1.34 ^{NS}	-	-
	>2000	1.24 ^{NS}	0.33 ^{NS}	4.65 ^{NS}	-
0.8	<1000	-	-	-	-
	1000-1500	0.75 ^{NS}	-	-	-
	1500-2000	2.28 ^{NS}	1.34 ^{NS}	-	-
	>2000	1.24 ^{NS}	0.33 ^{NS}	0.33 ^{NS}	-
1.0	<1000	-	-	-	-
	1000-1500	0.05 ^{NS}	-	-	-
	1500-2000	2.46 ^{NS}	1.59 ^{NS}	-	-
	>2000	0.57 ^{NS}	2.21 ^{NS}	0.95 ^{NS}	-
1.2	<1000	-	-	-	-
	1000-1500	0.77 ^{NS}	-	-	-
	1500-2000	0.46 ^{NS}	0.76 ^{NS}	-	-
	>2000	4.47 ^{NS}	1.81 ^{NS}	4.00 ^{NS}	-
1.5	<1000	-	-	-	-
	1000-1500	1.94 ^{NS}	-	-	-
	1500-2000	2.85 ^{NS}	0.15 ^{NS}	-	-
	>2000	1.39 ^{NS}	9.81 ^{NS}	9.14 ^{NS}	-

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
1.8	<1000	-	-	-	-
	1000-1500	1.84 ^{NS}	-	-	-
	1500-2000	0.75 ^{NS}	1.69 ^{NS}	-	-
	>2000	0.19 ^{NS}	0.95 ^{NS}	0.52 ^{NS}	-
2.1	<1000	-	-	-	-
	1000-1500	1.23 ^{NS}	-	-	-
	1500-2000	0.03 ^{NS}	0.89 ^{NS}	-	-
	>2000	0.74 ^{NS}	0.94 ^{NS}	0.43 ^{NS}	-

**Significant at 1 percent level ($p < 0.01$)

NS – Not Significant

ANNEXURE IV

Statistical analysis for change in EC within TSS concentration

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
0.3	<1000	-	-	-	-
	1000-1500	0.28 ^{NS}	-	-	-
	1500-2000	1.68 ^{NS}	1.31 ^{NS}	-	-
	>2000	1.28 ^{NS}	1.31 ^{NS}	0.75 ^{NS}	-
0.4	<1000	-	-	-	-
	1000-1500	2.26 ^{NS}	-	-	-
	1500-2000	0.58 ^{NS}	1.73 ^{NS}	-	-
	>2000	6.81 ^{NS}	3.63 ^{NS}	0.60 ^{NS}	-
0.5	<1000	-	-	-	-
	1000-1500	1.83 ^{NS}	-	-	-
	1500-2000	0.45 ^{NS}	3.67 ^{NS}	-	-
	>2000	0.09 ^{NS}	1.91 ^{NS}	2.06 ^{NS}	-
0.6	<1000	-	-	-	-
	1000-1500	2.12 ^{NS}	-	-	-
	1500-2000	0.69 ^{NS}	3.56 ^{NS}	-	-
	>2000	0.07 ^{NS}	2.34 ^{NS}	0.57 ^{NS}	-
0.8	<1000	-	-	-	-
	1000-1500	0.17 ^{NS}	-	-	-
	1500-2000	7.22 ^{NS}	3.06 ^{NS}	-	-
	>2000	0.17 ^{NS}	3.06 ^{NS}	0.30 ^{NS}	-
1.0	<1000	-	-	-	-
	1000-1500	2.01 ^{NS}	-	-	-
	1500-2000	0.08 ^{NS}	0.71 ^{NS}	-	-
	>2000	1.16 ^{NS}	1.79 ^{NS}	1.07 ^{NS}	-
1.2	<1000	-	-	-	-
	1000-1500	0.31 ^{NS}	-	-	-
	1500-2000	0.08 ^{NS}	0.25 ^{NS}	-	-
	>2000	1.11 ^{NS}	0.73 ^{NS}	1.14 ^{NS}	-

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
1.5	<1000	-	-	-	-
	1000-1500	1.47 ^{NS}	-	-	-
	1500-2000	0.03 ^{NS}	0.82 ^{NS}	-	-
	>2000	0.35 ^{NS}	4.60 ^{NS}	0.21 ^{NS}	-
1.8	<1000	-	-	-	-
	1000-1500	1.84 ^{NS}	-	-	-
	1500-2000	0.71 ^{NS}	1.69 ^{NS}	-	-
	>2000	0.12 ^{NS}	0.91 ^{NS}	0.52 ^{NS}	-
2.1	<1000	-	-	-	-
	1000-1500	1.89 ^{NS}	-	-	-
	1500-2000	0.80 ^{NS}	0.22 ^{NS}	-	-
	>2000	0.02 ^{NS}	0.77 ^{NS}	0.59 ^{NS}	-

**Significant at 1 percent level ($p < 0.01$)

NS – Not Significant

ANNEXURE V

Statistical analysis for change in pH within in

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
0.3	<1000	-	-	-	-
	1000-1500	0.44 ^{NS}	-	-	-
	1500-2000	1.76 ^{NS}	1.97 ^{NS}	-	-
	>2000	2.54 ^{NS}	2.51 ^{NS}	0.75 ^{NS}	-
0.4	<1000	-	-	-	-
	1000-1500	2.26 ^{NS}	-	-	-
	1500-2000	0.58 ^{NS}	1.73 ^{NS}	-	-
	>2000	6.81 ^{NS}	3.63 ^{NS}	0.60 ^{NS}	-
0.5	<1000	-	-	-	-
	1000-1500	1.11 ^{NS}	-	-	-
	1500-2000	2.31 ^{NS}	2.23 ^{NS}	-	-
	>2000	2.11 ^{NS}	5.60 ^{NS}	0.41 ^{NS}	-
0.6	<1000	-	-	-	-
	1000-1500	1.81 ^{NS}	-	-	-
	1500-2000	3.30 ^{NS}	0.63 ^{NS}	-	-
	>2000	0.81 ^{NS}	1.23 ^{NS}	1.82 ^{NS}	-
0.8	<1000	-	-	-	-
	1000-1500	0.92 ^{NS}	-	-	-
	1500-2000	2.63 ^{NS}	0.16 ^{NS}	-	-
	>2000	0.52 ^{NS}	2.25 ^{NS}	3.43 ^{NS}	-
1.0	<1000	-	-	-	-
	1000-1500	3.10 ^{NS}	-	-	-
	1500-2000	1.00 ^{NS}	0.03 ^{NS}	-	-
	>2000	0.82 ^{NS}	1.06 ^{NS}	1.25 ^{NS}	-
1.2	<1000	-	-	-	-
	1000-1500	1.07 ^{NS}	-	-	-
	1500-2000	0.14 ^{NS}	1.16 ^{NS}	-	-
	>2000	0.60 ^{NS}	3.10 ^{NS}	0.53 ^{NS}	-

Flow rate	TSS concentration	<1000	1000-1500	1500-2000	> 2000
1.5	<1000	-	-	-	-
	1000-1500	0.67 ^{NS}	-	-	-
	1500-2000	4.43 ^{NS}	1.41 ^{NS}	-	-
	>2000	6.49 ^{NS}	2.06 ^{NS}	0.88 ^{NS}	-
1.8	<1000	-	-	-	-
	1000-1500	2.11 ^{NS}	-	-	-
	1500-2000	0.30 ^{NS}	1.08 ^{NS}	-	-
	>2000	1.78 ^{NS}	2.06 ^{NS}	0.88 ^{NS}	-
2.1	<1000	-	-	-	-
	1000-1500	0.63 ^{NS}	-	-	-
	1500-2000	0.80 ^{NS}	0.93 ^{NS}	-	-
	>2000	5.29 ^{NS}	4.84 ^{NS}	1.80 ^{NS}	-

**Significant at 1 percent level ($p < 0.01$)

NS – Not Significant

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