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PERFORMANCE OF THE TUBE SETTLER CLARIFICATION AT DIFFERENT INCLINATION ANGLES AND VARIABLE FLOW RATE

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Abstract: Sedimentation tanks are a major and important component of the wastewater treatment plants, where the cost of construction for traditional tanks may represent up to 30% of the total cost of the plants, as well as sedimentation tanks occupy relatively large areas and often require long retention times to separate the suspended solids from the liquid. High-rate tube settlers are one of the practical solutions for the development of treatment plants, especially sedimentation tanks, lamella systems can be used instead of conventional sedimentation basins or for upgrade and increase their capacity and efficiency. In addition to their high efficiency, they require much less space compared to conventional sedimentation tanks. The current study was developed to evaluate the performance of the tube settler and the effect of the inclination of tube settler on the effluent quality. In the practical experiments, tube settler unit consisting of 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 & installed at Colentina Laboratory Complex-UTCB for this purpose.

Keywords: lamella tube settler, industrial wastewater, Reynolds number, surface load rate.

1. Introduction

Water is the core of life, the quantity, and quality of available water is important as it is highly consumed by the human for various activities, drinking, bathing, irrigation, livestock, industrial activities etc. Population growth, accelerated urbanization and the expansion of centralized water supply and sewerage systems have increased the demand of water. On the other hand, industrial activity contributes significantly to the increasing world demand for water. Water is an important component of many industrial processes, as economic activity increase the demand for water for industrial uses increases dramatically in parallel with economic activity. The biggest and main challenge is to provide sufficient water to meet this growing demand for water, and to maintain its quality to make it usable for various activities.

The higher the overall consumption of water resources, the more the quantities of wastewater, this requires the expansion of wastewater treatment and the construction of additional treatment plants all over the world. But in many countries this is still far from the potential of those countries and therefore the development of stations in those countries and increases their capacity is essential to meet the challenges of increasing demand for water. Separation of particles from suspension is a major process in wastewater treatment, since this process has a direct impact on the following treatment components, as well as on the overall performance of treatment plant. Removal of suspended and precipitated solids from water and wastewater is required prior to use, reuse/recycle, or discharge water. Sedimentation is classified as one of the most economical separation methods, which utilize to separate organic and inorganic solids from the water and wastewater, under certain conditions.

Sedimentation is a more effective process in removal of inorganic rather than organic solids, due to the clear difference in densities between particles and fluid. The amount of the difference in densities is reflected directly on the detention time required for solids to settle in the bottom of the basin, big difference reduces the required settling time. Coagulation-flocculation process encourage the organic and inorganic substances and some dissolved substances in the wastewater to agglomerate with each other and forming a larger masses (flocs) which are settled more easily than their components. Sedimentation basins represent an important part of the treatment plants, for drinking water and wastewater treatment, where their construction and operation occupies approximately 30% of the plant [1]. To reduce size and costs of the sedimentation basins and increase their efficiency, several attempts have been made. High rate sedimentation is a certain advance technique has been developed to reduce the cost and size of sedimentation units. Tube settler systems are relative inexpensive technology predominantly used to enhance the performance of conventional sedimentation tank. Tube settler determine an increase of the capacity of the settling tanks, greatly reduce the retention time, improve effluent water quality and reduce the operation cost [2].

In general, a retention time of 4-5 hours is sufficient to remove flocculated particles in conventional sedimentation tanks [3]. In contrast to conventional settling tanks, the use of shallow depth settling tanks enables to reduce the retention time of settling to be a few minutes only with proper coagulation and flocculation upstream [4]. The retention time mainly depends on the type of lamella module and the surface loading rate. The surface loading of the basin is conveniently calculated from the area of the basin which is covered by the settling module and it is usually ranging from 1.5 to 8.8 m/h [5]. The use of lamella systems is very effective, especially when there is a limited surface available since the area required for the lamella settling ranging from one-third to a quarter of the required area for conventional sedimentation basins [6]. The small footprint for lamella systems represents a very important feature. 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 [7].

Typical lamella systems consist of inclined plastic or, metal plates, or multiple tubular channels usually installed at a certain angle inside the settling tank with a vertical depth of about 2 m. This innovation provides a shorter settling depth thus reduce the pathway of the particles compared to traditional settling ponds. In wet-weather applications, the use of plate settlers is effective as it reduces the cost and space requirements to construct settling clarifiers for peak wet-weather flows [8]. Lamella systems are often added to existing settling tanks to enhance their efficiency, especially if flows are required to be increased beyond original design conditions [9]. Lamella applications are widely used in water and wastewater industry, usually applied after chemical coagulation process as in the present study, but also it can be used without chemical enhancement. The classic location for Lamella is in primary clarifiers, German researchers have investigated two other locations, at the end of the aeration tanks or at the entrance to secondary settling tanks. In both locations, the objective is to reduce the concentration of the mixing-liquor suspended solids (MLSS) which enters the secondary settling tanks, thereby increasing the peak flow capacity of the secondary settling tanks [10]. Originally, the basic idea of the tube settler systems was developed in the United States [11].

The single unit of the tube settler system consists of a group of pipes and channels contiguous with each other or tilted parallel plates. Individual tubes or ducts usually have a small cross-sectional area, which may be, square, rectangular, circular, V-shapes, or even hexagonal. Tube modules are usually made of lightweight PVC or similar materials, with uniformly spaced which could be used with or without a supporting frame. Lamella clarification provided the condition to significantly reduce the Reynolds number, which is usually very low, compared to Reynolds number in the conventional sedimentation tanks, so the turbulence will be minimized or even eliminated. Turbulence effectively deteriorates the quality of the effluent water, thus lowering the overall efficiency of the treatment plant. Also, turbulence may also determine re-suspension of the settled particles. Due to their high-rate gravity sedimentation, lamella settling process has received more attention over the previous years.

Amod Gurjar et al. Int., 2017 conducted a pilot scale model and installed in WTP at Nagpur Region. The model consists of six square tubes, with a length of 1.0 m each. The cross-sectional area for each tube is 25 cm^2. The tubes have been installed at an angle of 60º with horizontal.

The study was based on the measurement of the turbidity removal efficiency at a retention time of 15 minutes and rate of flow of 4 l/minute. The results show that the average removal efficiency of the unit is 70-80% higher than the conventional unit [12].

Kshitija Balwan et al., 2016 developed an experiment to study the effect of the length and angle of the tube settler on the effluent quality, they conducted a pilot scale model and installed at Ichalkaranji municipal water treatment plant. The model had one closed base tank which connected from the top by four PVC tubes of 4.5 cm diameter representing the tube settler which was connected from the other end to the bottom of collector basin. The influent water to the base tank has been aerated and coagulated. The length and inclination of the tubes were adjustable. The length of these tubes varied as 60 cm, 50 cm and 40 cm and they were installed at inclination angle 45º and 60º with the horizon. The surface overflow rate was kept at 35000 $l/m^2/hr$. The results showed that the removal efficiency increases with increasing the length of the tubes and also with a decrease of inclination of the tube settler. Also, the results showed that the optimum removal was observed for the length 60 cm and inclination 45° [2].

A Faraji et al., 2013 Conducted a pilot scale model and installed at the Ekbatan wastewater treatment plant (EWTP) (located in the west of Tehran), to examine the possibility of applying the tube settler as a secondary clarifier for wastewater treatment, the pilot model consists of single and two-stage of tube settler. The tube's diameter had an inner diameter of 5 cm in the first stage, and 1.2 centimeter in the second stage and the length of the tube in both stages was 60 cm. The diameter of the main body of the settlers was 20 cm, with an inclination angle of 45 degrees with the horizontal. The results showed that the hydraulic conditions in the two-stage tube settler had better performance than the single-stage tube settler. They have said that may be determined by the reduction of the tube diameter (from 5 to 1.2 cm) in the second stage. The results also showed that the one-stage tube settler were highly efficient in removal and during a very short detention time compared to the conventional sedimentation basin, where the average removal efficiencies of TSS, BOD and COD in the single-stage tube settler were, 97.6%, 96.4%, and 96.36%, respectively, at 20 minutes, while the average removal efficiencies the secondary conventional sedimentation basin of EWTP were 98.2%, 99%, and 98.6%, respectively, at HRT of 6-8 hours. The result also showed that the two-stage tube settler has better hydraulic conditions than the single-stage, where results of its effluent were better-compared with single-stage tube settler with a shorter residence time. It was found, that the optimal residence time in the two-stage tube settler was 15 minutes with the average Total suspended solids removal efficiency of 97.8 %. The study concluded that use of the tube settler systems significantly reduce the required area and minimize the pollution in the emergency conditions and it can be also used instead of secondary conventional sedimentation tank [13].

Fujisaki & Terashi, 2005 studied the possibility of improving the efficiency of the sedimentation basin using inclined tube settlers. They conducted a pilot scale model and installed at "H" sewage treatment plant in Kitakyushu City, the model was installed in the final settling basin. Tube settler was set in a tank with 80 cm lengths, 50 cm heights, and 1cm widths. Four types of settler tube are used in the experiments, two of which have a circular cross-section of diameter 55 and 70 mm, and a length of 1 m, the inclination angle was 60º for the first one tube and 75º, 60º, and 45º for the second tube. Other two tubes have a rectangular cross-section and with dimensions, 200*60 mm and a length of 500 mm for the first, and 200*15 mm and a length of 600 mm the second tube, with an inclination angle of 60º for both, the model is placed inside the final settling basin. The results showed that the new tube settler system (the vertical arrangement of the tube settler) is highly effective for improving the sedimentation tank performance [14].

Hanan Fouad et al., 2016 conducted a study to assess the efficiency of seven full-scale WTPs located in Cairo and Giza in Egypt. These plants have a different type of clarifiers, Pulsator and square Clariflocculators. The evaluation was based on the efficiency of average removal of turbidity, bacteria, and algae during summer and winter. The results showed that the tube settler clarifiers are more efficient in most cases than the other sedimentation systems, where the tube settler clarifiers achieved the highest removal efficiency of turbidity, bacteria, and algae. As well as the tube settler clarifiers have a higher surface overflow rate by 2.5 times of it for Pulsator clarifiers and the Square Clariflocculators. The results also showed that the Lamella plate clarifiers have almost equal efficiency in removing the bacteria and the algae to the other sedimentation systems like Pulsator clarifiers and the Square Clariflocculators systems, although it had a higher surface overflow rate. Also, it was less effective in removing turbidity [15].

Mohammed S., & Abeer H., 2011 Conducted a study to evaluate the efficiency of conventional Clariflocculator units with tube settlers units located at Mosul Unified Water Project in Iraq, by studying the efficiency of removal of the turbidity and phytoplankton algae. Results showed the superiority of tube settlers units in the removal of turbidity a low turbidity level (< 30 NTU) and the number of phytoplankton algae was ranged (45–59) cells/ml, whereas results showed that the conventional Clariflocculator units were more efficient at higher turbidity levels (> 30 NTU), and the number of phytoplankton algae ranged between (63–75) cell/ml [16].

Subramani, and Thomas, 2012 conducted a laboratory scale tube settler model at "Chavasseryparamba" water treatment plant, Kerala. They fabricated five modules of the tube settler with a different inclination angle, tubes used in this pilot scale have an inner diameter of 4 cm, and a length of 40 cm, the inclination angle of the tubes were 30º, 35º, 40º, 55º and 60º with the horizontal for each setup. One of the objectives of this study was to determine the efficiency of removing the sludge from the filter's backwash water (FBW). Through the experiments on tube settler for treatment of filter backwash water, they pointed out that both theories of discrete particles settling and flocculent settling are applicable for the treatment of FBW. Results showed that the optimum inclination angle was 55º for settling the flocculent particles, and the optimum settling velocity was 2.76 mm/min [17].

2. Theory of shallow depth settling

Shallow depth theory is based on a number of assumptions, including that the discrete particles which have a uniform shape, size and specific gravity will settle down with a velocity v_t (Eq.1) in an ideal settling tank.

$$v_t = \left[\frac{4g\,(\rho_s - \rho)d}{3C_D \rho} \right]^{\frac{1}{2}} \tag{1}$$

Where: v_t = particle settling velocity, m/s, ρ_s = density of particle, kg/m^3, ρ = density of fluid, kg/m^3, g = acceleration due to gravity, m/s^2, d = diameter of the sphere, m, and CD = drag coefficient.

If the flow velocity through the settling basin can be represented by take a small parcel water moves along the length of the basin (l), during a certain time(t_1), and the discrete particle in the same parcel settle through the depth of the tank (d) during (t_2), where the time(t_1) and (t_2) are calculated as the follows.

$$t_1 = \frac{l}{v_f} \text{ , and } \quad t_2 = \frac{d}{v_t}$$

To remove all particles in that parcel before leaving the settling basin, t_1 should always be less than t_2, and the maximum value of v_f can be obtained by equating t_1 to t_2, i.e.,

$$\frac{l}{v_f}(Max) = \frac{d}{v_t}$$

$$v_f\,(\text{Max}) = \frac{l v_t}{d} \tag{2}$$

Since Q=Av_f

Where Q= flow rate (m^3/s), A= cross sectional area of the basin (m^2), and v_f =horizontal velocity (m/s).

$$Q=A\frac{lv_t}{d} \qquad (3)$$

If the cross-sectional area of the settling basin is fixed, to increase the flow through the basin to the maximum, (l/d) ratio should be made as large as possible, by increasing the length and/or by decreasing the depth of basin, and making it as shallow as possible [3]. Decreasing the depth of the basin can be done by inserting trays along the height of the basin, so the surface area can be multiplied by several times as the number of trays increased.

Based on the sedimentation basin theory the efficiency of the sedimentation basin depends upon the surface loading rate (SLR), the efficiency increase as the surface loading rate decrease [11].

$$SLR = V_C = \frac{Q}{A}$$

Where: Q, A, and VC, are flow rate (m^3/s), surface area of the basin (m^2), and critical settling velocity (m/s) respectively. The surface loading rate in high rate settler can be calculated by the flowing equation [18];

$$SLR = \frac{Q}{\sum A_P} \qquad (4)$$

Where: A_p is the projected area of the tubes (m^2).

Reynolds number is an important factor usually used as an indicator to determine the flow regime, which is specified by using the following equation;

$$\mathrm{Re} = \frac{\rho \upsilon R_h}{\mu} \qquad (5)$$

Where: Re, υ, R_h, ρ, and μ are Reynolds number, water velocity (m/s), hydraulic radius, fluid density, and viscosity of the water respectively. Water velocity in the tubes can be calculated using the following equation;

$$\upsilon = \frac{Q_W}{3600\pi(\frac{d}{2})^2} \qquad (6)$$

Where: υ, Q_w, and d, are water velocity (m/s), water flow rate (m^3/h), and pipe Inner diameter (m).

3. Research objectives

The main objectives of the study were:

i. To measure the influence of the tube settler upon industrial wastewater at varied flow rates.

ii. To study the effect of inclination of tubes (48, 54, 60 degree, with horizontal) on the removal of efficiency.

4. Materials and methods

The materials and methods used during the experimental trials are presented in the followings;

i. Pilot-Scale Equipment

A pilot scale was fabricated and installed at Water Supply and Sewerage "Colentina" Laboratory - Technical University of Civil Engineering of Bucharest-Romania. Perspex glass panels of 6 mm thick were used in the construction of the model and it mainly consists of: individual, raw industrial wastewater tank, chemical addition unit, coagulation-flocculation basin, coagulant dosing tank, polymer dosing tank and tube settler unit processes that together provide a complete coagulation-flocculation and sedimentation treatment process.

This pilot-model enables to study the coagulation, flocculation and settling processes separately or simultaneously. The actual view of the pilot module illustrated in Figure 1.

The coagulation-flocculation unit had an overall volume of 144.5 litres and consists mainly of two joined basins forming one unit. Coagulation basin consists of two chambers, the function of the smaller chamber is to mix the coagulant with the incoming raw industrial wastewater and distribute the mixture down to the main coagulation chamber. The flocculation basin also consists of two chambers, the primary chamber used to mix the coagulated industrial wastewater with polymer and to distribute the mixture down to the main flocculation chamber. Both basins have drainage valves at bases, and are equipped with variable speed mechanical mixers for rapid and slow stirring. The dosing rates of chemical reagents flowing from the dosing tanks to the coagulation & flocculation tanks are controlled by peristaltic pumps. Industrial wastewater is pumped from the raw wastewater basin to the first compartment of the coagulation basin by a metering pump.

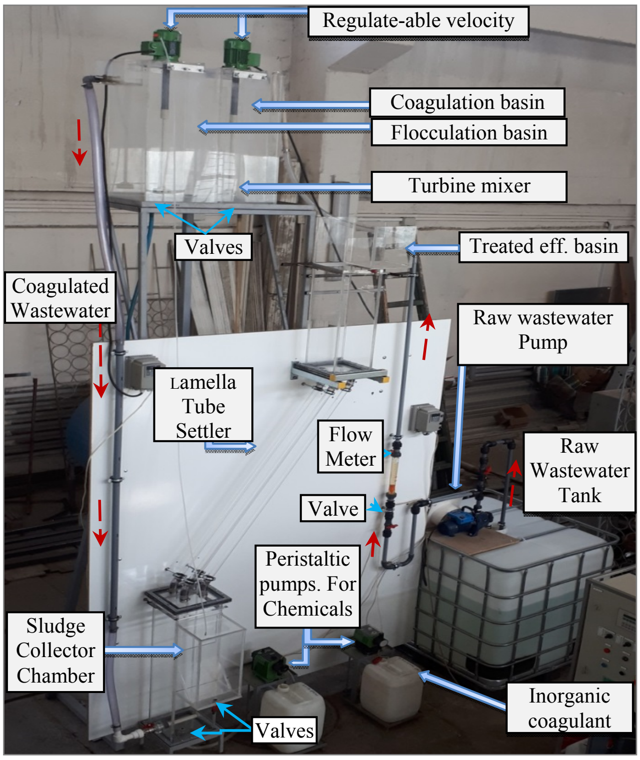

Fig.1 - Pilot scale model.

To ensure sufficient mixing in the raw wastewater basin as well as flow control, wastewater circulation through pipe loop was done for this purpose, as shown in figure 1. In the coagulation basin, raw wastewater was mixed with the coagulant by a mechanical flash mixer (vertical shaft with blades). Thereafter, the coagulation wastewater flows to the first compartment of the flocculation basin and then to the main compartment of the flocculation basin where the slow mixing will take place by a mechanical mixer.

After the coagulation-flocculation unit, the coagulated wastewater flows into sedimentation system, which consists of three connected components: inlet unit (distribution basin), tube settler unit and outlet unit. The first unit consists of two chambers, the largest ones, which represents the entry chamber of water, is connected sideways to the sludge collection chamber; both chambers have drainage valves and are connected to the sewer system through drainage pipes. This unit is connected from the top by four circular tubes with a length of 150 cm each. The vertical depth of each tube is 129.9, 121.35, and 111.47 cm at inclination angles of 60, 54, and 48 degrees respectively. Each tube settler had an inner diameter of 27 mm and cross-sectional area of 5.7 cm2, representing the tube settler. The inlet unit is directly connected to the flocculation basin by a transfer tube with an inlet valve.

The end of this tube is a closed end and extends inside the unit. The water flows to this unit through several downward-oriented holes. The main objective of these holes is the correct distribution of coagulated water and minimization of water turbulence at the bottom of the unit. The inclination of the tube settler is adjustable. The other side of the tubes is connected to the outlet or treated water basin. This basin is a mobility unit, where is possible to change its location, to allow for the settling tubes to form a different inclination angle (48, 54, and 60) with the horizon as is shown in figure 2.

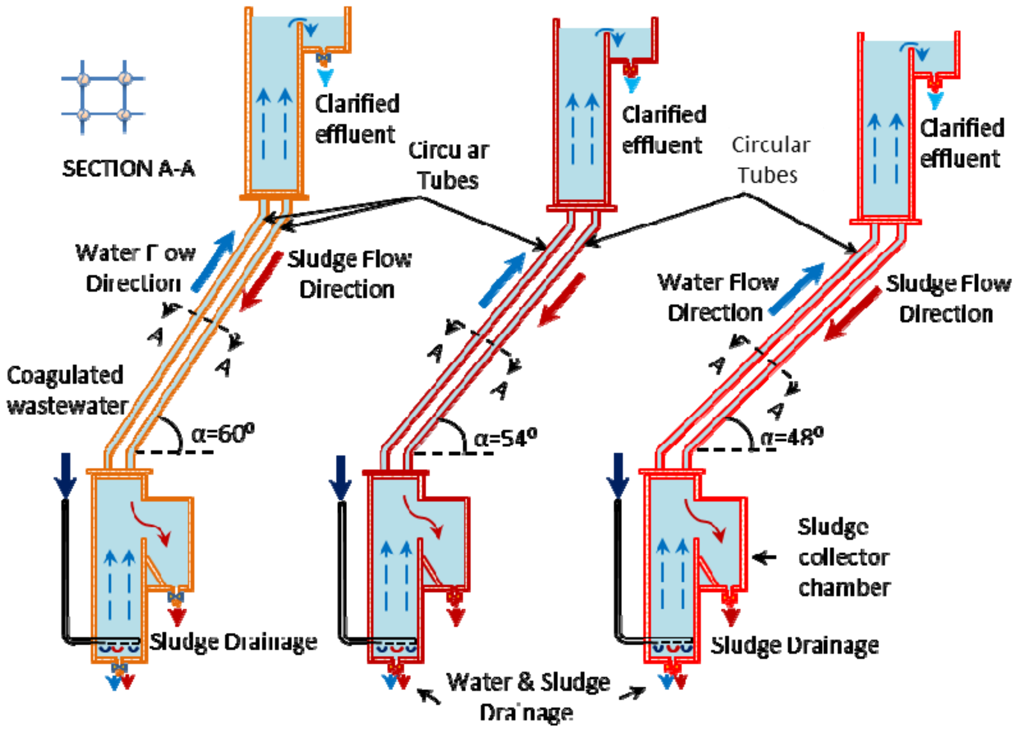

Fig.2 - Scheme for a sedimentation unit at different inclination angles for tube settler.

The treated wastewater was collected by small collector basin located on the upper side of the outlet unit. Water flow can be controlled by a flow meter and a butterfly valve, the delivery of chemicals from dosing tank to the coagulation-flocculation unit have been controlled by two peristaltic pumps. The pilot-scale designed to operate in counter-current mode, where the direction of water flows is contrary to the sludge flow direction.

In the coagulation tank, raw industrial wastewater sample was mixed with the coagulant by a mechanical flash mixer (vertical shaft with blade) at 120 rpm. Thereafter, the coagulated wastewater flowed to the first compartment of the flocculation, wherein the slow mixing at 40 rpm was taken place, under the effect of a mechanical mixer (vertical shaft with blade).

ii. Industrial wastewater

Industrial wastewater effluents from a meat processing plant located in Bucharest, capital of Romania, was selected as raw water to operate the laboratory model. The meat industry is an important and vital sector of the food industry. Effluents from these industries have an important effect on the environment and often producing high polluted wastewater [19]. Effluents from meat processing plant are generally characterized by their high content of organic ingredients and relatively high consumption of water whether the water included in the products or those used in preparation of meat products, in addition to a large part used in the cleaning and removal of fat from the preparation and packaging machines, in addition to cleaning works for the factory itself and the work involved in the use of various chemicals from detergents and disinfectants to cover the strict health conditions imposed on the food industry in general and the meat industry in particular, due of their direct effect upon the health of the consumers. It is also characterized by the presence of different concentrations of salts and flavors and additives in addition to the colors that are part of many products, as well to the preservatives that are usually added to those products to protect them from deterioration of quality and rot as long as possible.

iii. Experimental wastewater

Characterization of wastewater was carried out according to the standard methods procedures for water and wastewater tests [20]. Several chemical agents were used for initial laboratory experiments such as ferric chloride ($FeCl_3$), aluminum sulfate ($Al_2(SO_4)_3.18H_2O$) and poly-aluminum chloride MOPAC, to determine the most efficient coagulant. Following a series of experiments, ferric chloride ($FeCl_3$) demonstrated highest removal efficiency and was subsequently applied to wastewater from meat processing plants through a pre-established laboratory model. To determine the optimal dose of coagulant a Standardized jar testing procedure with automated jar test equipment (Flocculator-2000) in six glass beakers of 1-Liter capacity, were employed for experiments. pH values of the raw wastewater were measured by digital pH meter and were adjusted to the desired values by using 1.0 M (H_2SO_4), or 1.0 M (Na OH). After determining the optimal dose and the optimal pH values, using Jar test device. pH value of the raw wastewater was adjusted using the above-mentioned chemicals with the use of the pH meter to the obtained optimum value through the Jar test experiments. Peristaltic pumps were calibrated with each flow rate before the running the laboratory module, as well the coagulant was prepared daily to avoid aging. Cleaning the laboratory model units after each operating cycle was carried up, to sweep-out of the settled sludge and chemicals from the model using the tap water, to avoid influence of the residual particles in the model with subsequent cycle results, and disposable it into the sewage system through the drainage valves attached to each unit of the laboratory model. The pilot scale was operated at different flow rates (0.2, 0.15, 0.1, 0.05, and 0.035 m^3/h).

5. Results and discussions

i. Results

As mentioned earlier, after a series of tests upon the meat processing industry wastewater, the best removal rates for the main contamination parameters were obtained using ferric chloride ($FeCl_3$), which was selected to operate the laboratory model for all cycles. In the coagulation chamber, raw industrial wastewater has been mixed with the coagulant by a mechanical flash mixer at 120 rpm. Thereafter, the coagulated wastewater flowed to the flocculation chamber, wherein the slow mixing at 40 rpm was taken place, under the effect of a mechanical mixer. After that, the coagulated wastewater flowing under the influence of the difference in the head-loss, the coagulated liquid enters the sedimentation unit through a connecting pipe as shown in figures 1, and 2. The samples were taken at the inlet and outlet of the pilot module at intervals of the operating cycle for each flow rate for laboratory tests. The removal efficiency of the pollutant parameters was obtained using the following equation:

$$\mathrm{Re}\,moval\,(\%) = \left[\frac{(Ci - Cf\,)}{Ci}\right] * 100$$

Where, C*i* and C*f* represent the initial and final concentrations of each parameter.

The 0.2 m^3/h a flow rate was selected initially to operate of the pilot plant model with the inclination angle of 54º with the horizontal for the tube settler unit. From the experimental operation, it was observed that the suspended particles (flocs) rushed strongly towards the top of the tube settler unit and they arrived into the treated effluent basin, where the water velocity has exceeded the settling velocity of most particles, therefore, the tube settler unit was unable to capture most of them in this unit, the flow of the particles through the tube at this rate is illustrated in Figure 3. A disturbance was observed in the inlet basin, where the water currents in this basin did not allow the sludge to settle in a smooth manner, which has greatly affected the quality of treated water. Therefore, the results of the removal efficiency at this flow rate were neglected.

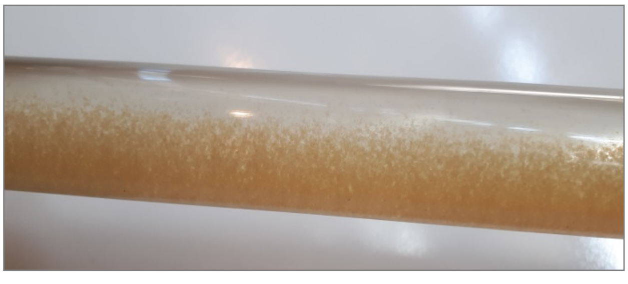

Fig.3 - Flocs behavior in the intermediate part of the tube settler at flow rate of 0.2m3/h.
(at Inclination Angle 54º)

The laboratory model was operated at a flow rate of 0.15 m^3/ h, a constant flow rate was applied to operate the module, while the inclination of the tube settler unit was adjusted to be 60º, 54º and 48º with horizontal for each operating cycle. The variations in removal efficiency at each inclination angle for the tube settler unit were achieved at the flow rate 0.15 m^3/h is illustrated in figure 4.

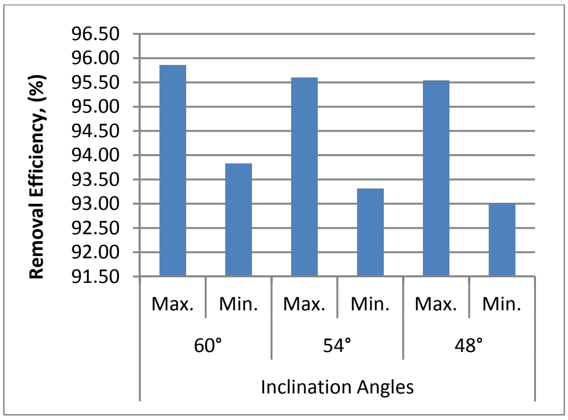

Fig.4 - Maximum and minimum removal rates of turbidity vs. inclination angles of the tube settler unit, at flow rate 0.15 m^3/h.

New operating cycles were conducted at a flow rate of 0.1m^3/h to study the effect of the variation in the flow rate on the removal efficiency of pollutants. Figure 5 illustrates the variation in the removal efficiency of turbidity at an inclination angle of 60º, 54º, and 48º for the tube settler unit at the flow rate 0.1m^3/h.

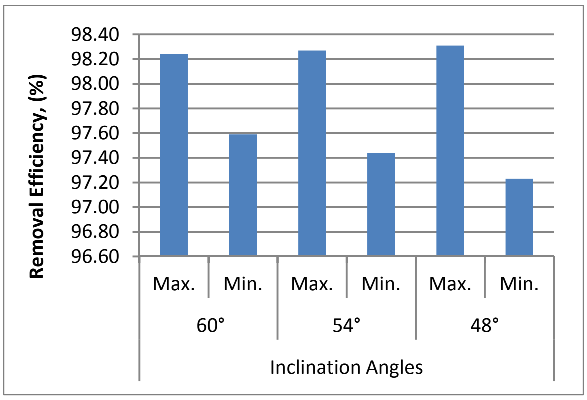

Fig.5 - Maximum and minimum removal rates of turbidity vs. inclination angles of the tube settler unit, at flow rate 0.1 m^3/h.

An additional reduction in the flow rate was adopted to operate the laboratory model to be 0.05m^3/h and the impact of this reduction on the removal efficiency at different inclination angles for the tube settler unit was measured. Figure 6 illustrates the variation in removal efficiency of the turbidity in the chemically treated wastewater at inclination angles of 60º, 54º, and 48º for the tube settler unit at the flow rate 0.05m^3/h.

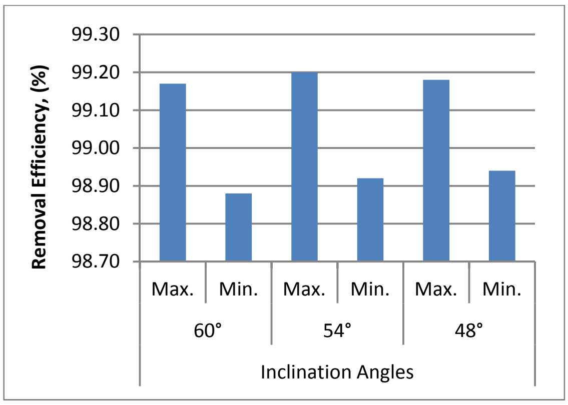

Fig.6 - Maximum and minimum removal rate of turbidity vs. inclination angles of the tube settler unit, at flow rate 0.05 m3/h.

The last operating cycle was performed at a flow rate 0.035m^3/h, as well the variation in removal efficiency of the turbidity in the treated effluents at inclination angles of 60 º, 54º, and 48º for the tube settler unit at the flow rate 0.035m^3/h was graphically plotted as is shown in Figure 7.

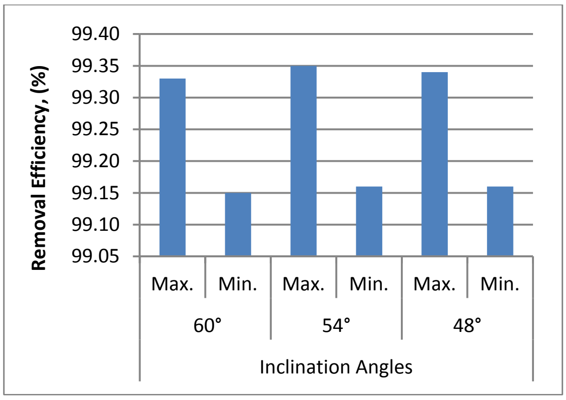

Fig.7- Maximum and minimum removal rate of Turbidity vs. inclination angles of the tube settler unit, at Flow Rate 0.035 m^3/h.

During the operation of the laboratory module, water velocity through the tube settler unit was varied from $2.42*10^{-2}$ to $4.24*10^{-3}$ m/s with changing the flow rate. A significant improvement in the flow regime through the tube settler unit was observed, especially at the lower and upper zones of the tubes. Reynolds number was varied from 500 at flow rate of 0.2m^3/h, to 88 at flow rate of 0.035 m^3/h. Figure 8 shows the results of Reynolds values calculations plotted with the average flow velocity. The flow regime of the last two operation cycles at a flow rate of 0.05 and 0.035 m^3/h was less than 200 as is shown in the figure, researchers recommend that the flow in the plate or tube settler systems should be laminar, some of them recommended that the Reynolds should be less than 200 and they preferred value is less than 50[21].

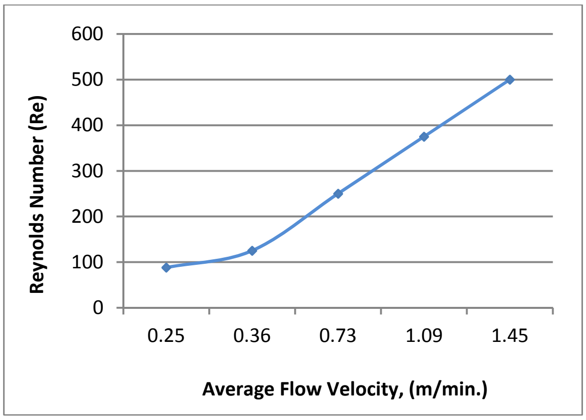

Fig.8 - Relationship between the Reynolds number and average flow velocity.

The relationship between the optimum removal percentage of Turbidity resulting from operating the laboratory module at a varied flow rate, and the surface loading rate (SLR) at inclination angles of 60º, 54º, and 48º for the tube settler unit, is illustrated in figure 9.

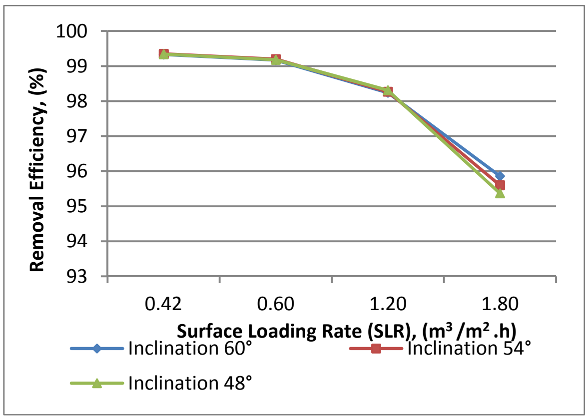

Fig.9. Relationship between the highest percentage of Turbidity removal and surface loading rate (SLR)

ii. Discussion

The results showed that there was no significant variation in the removal ratios when the laboratory model was operated at constant surface load rate (SLR), although changing the inclination angle of the tube settler, compared with the variation in the removal efficiency resulting of reduction of the surface flow rate, where it was observed that the removal efficiency was dramatically improved as the SLR reduce.

A significant improvement was observed in the quality of wastewater when the surface load rate was reduced from (1.8 to 1.2 m3/m2,h), while the removal efficiency of the pollutants increased at a lower rate when the surface loading rate was reduced from (0.6 to 0.42 m3/m2,h), as is shown in figure 9.

Determination of the flow pattern in the sedimentation tanks in general or in tube settler systems gives an idea of the behavior of the flow in these tubes, in order to deduce the effect of such behavior on the suspended particles. The presence of a highly turbulent flow will be an obstacle to the sedimentation of suspended particles on the bottom surfaces of the tubes. Reduce the disturbance in the flowing current down to the laminar regime is the key to capture these particles in the settling unit and achieving the targets of the separation process. The highest removal ratios were achieved at the Reynolds values of 125, and 88, both values were less than 200, which It is the recommended value to operate tube settler systems [21].

There is a slight variation in the efficiency of the removal during running the laboratory model. This variation is either positive as a result of increasing the removal efficiency, or negative so the quality of the treated wastewater deteriorates. When operating the laboratory model for relatively long periods at a constant flow rate and at each inclination angles of the used inclination of the tube settler unit. If the accumulation of sludge on the bottom surfaces of the tubes faced a relatively strong stream of water inside the tubes, water current tries to re-suspension of settled particles and trying to return them to the water stream resulting deterioration in the quality of treated water. The reason for the improvement in the efficiency of removal can be traced back to entrapped more particulate matter in the atmosphere of the settled sludge in the inlet settling basin, as the sludge column increase the chance of entrapping more of those particles increase. Figure 10 presents the settled sludge within the inlet unit.

Fig.10. Sludge settled at the bottom surface of the inlet, and sludge collector chambers.

Through the results achieved and observing the behavior of the sludge during the trials, the angle of inclination 54º of the tube settler unit showed optimum behavior, where very good removal rates were achieved with the self-cleaning performance was very satisfactory. The main parameters in the treated effluent, TSS, BOD, and COD, were determined according to the standard methods for the examination of wastewater and the variation in the optimum percentage removals with the change in the flow rate at the inclination angle of 54° was plotted as is illustrated in figure 11.

The final output of the laboratory plant, when operated at a flow rate of 0.035m^3 /h, and at an inclination angle of 54 ° for the tube settler unit, is a clear effluent that can be reused in multiple purposes. Figure 12 presents a photograph for samples from meat industry effluents before and after the chemical treatment

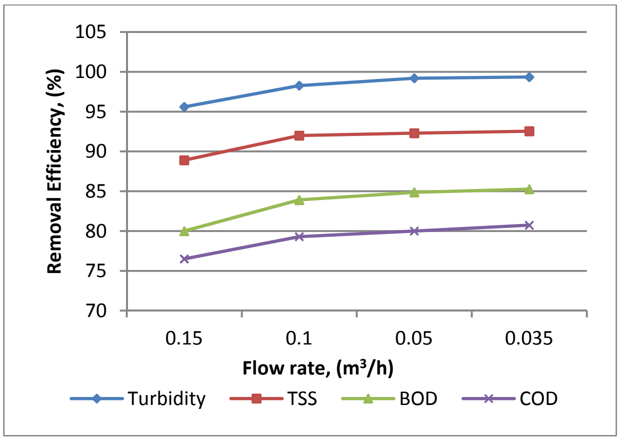

Fig.11. Relationship between the optimum percentage removal of Turbidity, TSS, BOD, and COD and the flow rate, at inclination angle of 54°.

Fig.12. Samples of meat processing wastewater before and after chemical treatment.

6. Conclusions

Based on the experimental tests conducted using the tube settler module, the conclusion is summarized in the following points;

- In general, the tube settler unit was very efficient in removing the flocculated particles at all inclination angles of the tube settler unit.
- Use of tube settler system after chemical treatment of the effluents from meat processing industry represents an effective sedimentation process.
- Through the results, the effect of changing the surface load rate (SLR) on the removal rates is much greater than the effect of changing the angle of inclination of the tube settler on the removal rates.

- The removal efficiency at the low values of the Reynolds number yields the highest rate at all inclination angles of the tube settler unit.
- The determinant factor for selecting the optimal inclination angle is the efficiency of the self-cleaning, in addition to achieving high removal ratios.

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