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COMPARING THE SETTLING CHARACTERSTICS OF INDUSTRIAL, DOMESTIC, AND COMBINED WASTEWATER*

Diaa S. El Monayeri, Nabil N. Atta, Sameh M. El Mokadem, Emad H. EL Gohary**

Dept. of Environmental Engineering, Faculty of Engineering, Zagazig University, Egypt

ABSTRACT

The addition of industrial WW to domestic WW should make a variation in its characteristics in terms of alkalinity, density and viscosity, TSS concentration and distribution, organic acid content, and heavy metals. This variation could affect the performance of primary settling tanks that received combined industrial and domestic WW. In the present study two different types of industrial WW were mixed with domestic WW in order to study the settling behaviors of combined WW by the aid of batch settling tests. Results showed that, at a RT range of (1.5 -2.5 hr), and a SLR range of (30 – 50 m/d), the removal efficiency of TSS ranged between 56 and 72% for Domestic WW, from 44 to 56% for Industrial WW type A, and from 52 to 65% for Industrial WW type B. Industrial WW type A caused a decrease in TSS removal efficiency by 10% and 17% when mixed with domestic WW at mixing ratio 25% and 50% (industrial) respectively, while the industrial WW type B, showed no significant effect in TSS removal ratio when mixed with domestic WW. The flocculent settling velocities of the three types of wastewater could be calculated and compared.

KEY WORDS: batch settling, combined WW, domestic WW, flocculent settling, industrial WW, primary sedimentation tank, TSS removal.

COMPARAISON DES CHARACTERSTICS DECANTATION DES INDUSTRIELLE, EAUX USÉES DOMESTIQUES ET COMBINÉ

RÉSUMÉ

L'ajout de l'industrie WW à WW domestique devrait faire une variation de ses caractéristiques en termes d'alcalinité, de la densité et de la viscosité, de la concentration et de la distribution TSS, teneur en acides organiques et les métaux lourds. Cette variation pourrait affecter les performances des décanteurs primaires qui ont reçu combinés industriel et domestique WW. Dans la présente étude deux types de WW industrielle ont été mélangés avec WW nationale afin d'étudier les comportements de décantation du combiné WW à l'aide de tests par lots de décantation. Les résultats ont montré que, dans une plage de température ambiante (1,5 -2,5 h), et une gamme de reflex (30 - 50 m / j), l'efficacité d'élimination des TSS se situait entre 56 et 72% pour WW intérieur, 44 à 56% pour Industrial WW type A, et de 52 à 65% pour Industrial WW type B. un type WW industrielle a entraîné une diminution de l'efficacité retrait TSS de 10% et de 17% lorsqu'il est mélangé avec intérieur WW au rapport de mélange de 25% et 50% (industriel) respectivement, tandis que le B WW industrielle type, n'a montré aucun effet significatif du ratio de retrait TSS lorsqu'il est mélangé avec WW domestique. Les vitesses de sédimentation des floculants les trois types d'eaux usées pourraient être calculés et comparés.

MOTS CLÉS: décantation lot, combinée WW, WW domestique, débourbage floculant, industriel WW, bassin de décantation primaire, l'élimination TSS.

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** Contact author (+2 012 2489 6315)

1. INTRODUCTION

The industrial wastewater disposal into surface water and/or land has become a vital issue to consider especially when it becomes a threat to the aquatic life and surrounding environment. The characteristics of industrial waste waters can differ considerably both within and among industries. The impact of industrial discharges depends not only on their collective characteristics, such as BOD and the amount of TSS, but also on their content of specific inorganic and organic substances.

About 50 % of the industries in Egypt, on statistical analyses done for 37 industries in Egypt, violate the Egyptian environmental law and discharge their untreated effluents into the public sewage network (Abou-Elela et al.2, 2005) leading to deterioration problems in the sewage pipe network, pump stations, settling tanks, the biological activity during treatment in WWTPs and threatening the aquatic life in streams and rivers; specially that industrial WW could contain massive loads of toxic materials and increase the cost and environmental risks of sludge treatment and disposal (Abdel Wahab1, 2000).

Disposal of industrial WW (raw or/ partially treated) into the existing Domestic WWTPs is a common practice in the industrial cities in Egypt such as: 10th of Ramadan city, New Nubaria city, and New Borg El Arab city (El Monayeri et.al.[9], 2011).

10th of Ramadan city is considered to be the largest industrial city in Egypt. Currently, there are two sources for industrial wastewater in this city: the first source includes industrial waste only, whereas the second source includes the industrial waste coming from the boundaries of the residential area combined with domestic sewage. Combined domestic and industrial wastewaters (About 55% industrial WW) are then pumped to the WWTP. The efficiency of TSS removal in primary settling tanks (PST, during 2010) ranged from 30% to 45% compared to international standards (50% to 70%, Metcalf & Eddy [11], 2003). When comparing this case by another case such as Abu Rawash WWTP (Giza, Egypt), which receives domestic WW only, the efficiency of TSS removal in PST ranged from 50% to 65 %. There is a clear reduction in the removal efficiency of TSS in PST in case of 10th of Ramadan WWTP due to the mixing of industrial and domestic WW despite that the operational parameters (Retention time = 2.4hr and Surface loading rate = 26 m/d) coincide with those in the international standards (El Gohary et al. [8], 2012). The addition of industrial WW to domestic WW should make a variation in its characteristics in terms of temperature, pH, alkalinity, density and viscosity, TSS concentration and distribution, organic acid content, and heavy metals.

El Gohary et al. [8] (2012) studying the effect of mixing industrial and domestic WW on settling behaviors in primary settling tanks using domestic WW of (TSS = 226 mg/l) and industrial WW of (TSS = 630 mg/l). El Gohary concluded that TSS removal efficiency ranged from 51 to 61% for Domestic WW and from 35 to 45% for Industrial WW. Also, concluded that at mixing ratio of 25% and 50% industrial WW, the TSS removal efficiency reduced by (8 - 12%), and by (18 - 22%) respectively.

The objective of the present research is to study the effect of varying TSS concentration and type of Industrial WW when mixed with domestic WW on the settling behaviors using batch settling tests.

2. FLOCCULENT SETTLING AND PRIMARY SEDEMINTATION TANKS (PST)

Primary settling is one of the eldest methods used in wastewater treatment and it is still popular today due to its simplicity and low operational costs. An increase of primary clarification removal efficiency usually leads to a reduction of air demand for activated sludge process, a decrease of solids loading on secondary clarifiers and waste activated sludge thickeners, and an increase in digester gas production. An efficiently designed and operated PST should remove from 50 to 70% of TSS (Metcalf & Eddy [11], 2003).

There are four different types of settling that occurs in PST depending on the concentration and the interaction between particles (Di Giovanni and Holdich [7], 2009):
a. *Discrete (free) particle settling (type I)*: particles settle without interaction since the concentration of the suspension is low;
b. *Flocculent settling (type II)*: particles initially settle independently, but they start to aggregate so that the velocity of settling will increase;
c. *Hindered settling (type III)*: the concentration of particles is high so that the inter-particle forces hinder the settling of the particles;
d. *Compression settling (type V)*: the concentration of particles is so high that the settling of the particles at one level is mechanically influenced by particles on lower levels.

The predominate type of settling that occurs in PST is type II (flocculent settling). Flocculation, which produces larger particles, causes the settling velocity of the particles to change as they settle. In flocculent settling, particle removal efficiency is governed by: overflow rate, depth, concentration and type of particles, and settling time.

Gray [10] (1999) stated that, the degree of flocculation is dependent on the depth of settling, the velocity gradients in the system, the concentration of the particles, and the range of particle size. Gray also reported that, the degree of flocculation is indicated by the slope of the iso-removal contour lines, increasing as the slope increase.

Due to the lack of literature in satisfactorily explaining the flocculent settling process, experiments have been conducted in pilot-scale columns to determine the over-flow rate required for a given removal. Unlike the discrete settling of non flocculent suspensions the settling behavior of the flocculent suspension is not amenable to mathematical description using physics laws such as those of Newton's and Stokes's. Thus it has been a common practice to employ laboratory column testing as the basis for the design of settling basin or the performance evaluation of the existing basin handling flows containing flocculent suspension (Pise [14], 2011).

Chung and Kyung [5] (2002) evaluated the reliability of four mathematical models; Berhouex and Stevens [4] (1982), San[15] (1989), Ozer [13] (1994), and the rule-based method-that can be used to fit flocculent settling data. Each approach was critically reviewed for its strengths and limitations, and investigated for its fitting capability using the data obtained from the authors' research and the related references. Chung and Kyung concluded that San's, Ozer's, and rule based method approaches are effective in analyzing flocculent settling data, and can generate reliable and reproducible design. However, they recommended using Ozer's approach to fit flocculent settling data due to its mathematical simplicity and consistency. The mathematical expression is as follow:

$$P = (\frac{C}{C_o} \times 100) = f\ T^a\ Z^b \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where: P= suspended sediment concentration percentage (%), C_0= initial concentration of suspended sediment (mg/l), C= concentration of suspended sediment (mg/l), T= settling time (s), Z= depth (m), and f, a, b = regression coefficients.

An empirical flocculent settling velocity model is derived by Chung and Soonwoong [6] (2004) based on the one-dimensional vertical continuity equation and Ozer's flocculation equation. The resulting flocculent settling equation is expressed as:

$$V_s(T,Z) = -\frac{aZ}{T(b+1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Equation (2) describes instantaneous settling velocity (Vs) as a function of settling time (T) and depth (Z) using the regression coefficients from Ozer's settling equation (a and b). The flocculent settling parameters (a and b) were obtained from regression analysis of column settling test data to determine temporal and spatial changes in settling velocity (Vs) due to flocculation.

3. MATERIALS AND METHODS

3.1. Wastewater:

Three types of wastewaters were used in this study:
The first type: is domestic, collected from PST distribution chamber of El-Asslogy WWTP (Zagazig, Egypt).
The second type: is industrial WW (type A), collected from the inlet chamber of the anaerobic oxidation ponds (The industrial zone, 10th of Ramadan city). These ponds receive about 130,000 m^3/d of mixed waste water collected for the city's heavy industries such as: Plastic and synthetic materials manufacturing, textile mills and dyeing, electroplating, feeding industries to the automotive industry, transport equipment industry, the cable and electrical wires industry, household appliances industry, electrical equipment industry, garment industry, spinning and weaving industry, iron and steel manufacturing, non ferrous metals, and leaser tanning and finishing.
The third type: is industrial WW (type B), collected from the sewage pumping station of 1st industrial area (The industrial zone, Quesna city). This area produce about 15,000 m3/d of mixed wastewater from industries such as: Pulb and paper mills, food industries, edible Oils, and pharmaceutical industries.

Table 1 shows the physicochemical proprieties of the wastewater used in this study, which has been analyzed in the laboratory of El-Asslogy WWTP according to the American Standard Methods for the Examination of Water and Wastewater (APHA [3], 1998).

3.2. Laboratory Long Settling Column:

Two long settling columns were used in this study. The columns are made of clear plastic (Acrylic) to visually observe the process. Each column is 3.0 m in length and 15.0cm in internal diameter [as recommended by several investigators: Gray [10] (1999); Metcalf and Eddy [11] (2003); Ying and Sansalone [17] (2011)]. Sampling ports (0.5 inch valves) are uniformly spaced along the length of the column (0.5, 1.0, 1.5, 2.0 and 2.5m from the top) as shown in Fig. 1 in order to study the effect of depth on settling efficiency. Two plastic tanks (60 lit. capacity) were used to store the wastewaters to feed the columns. Theses tanks were placed at a height of about 3.5m from the basement to assure enough pressure to fill the columns without pumping. Each tank was connected to the bottom of the column through PVC pipe (0.5 inch). Filling of the columns simultaneously took about 3 minutes, and at the same time manual stirring was done in the feeding tanks to ensure a uniform distribution of SS along the entire depth of the column.

4. EXPERIMENTAL PROGRAMS

The experimental work was carried out in four runs. In the 1^{st} run, the two columns filled with the domestic WW and the industrial WW (Type A) separately. After the initial sample was taken from each column at the beginning of the experiment,

Table 1: The physicochemical proprieties of the wastewater

Parameter	Unit	Domestic WW	Industrial WW (type A)	Industrial WW (type B)
pH-Value	-	6.9	6.00	6.5
Temperature	o C	23.0	23.0	23.0
COD	mg/l	623	2020	1970
TDS	mg/l	763	2400	1270
TSS	mg/l	470	1100	1350
VSS	mg/l	442	360	840
VSS/TSS	---	0.95	0.33	0.62
Oil & grease	mg/l	63	240	67

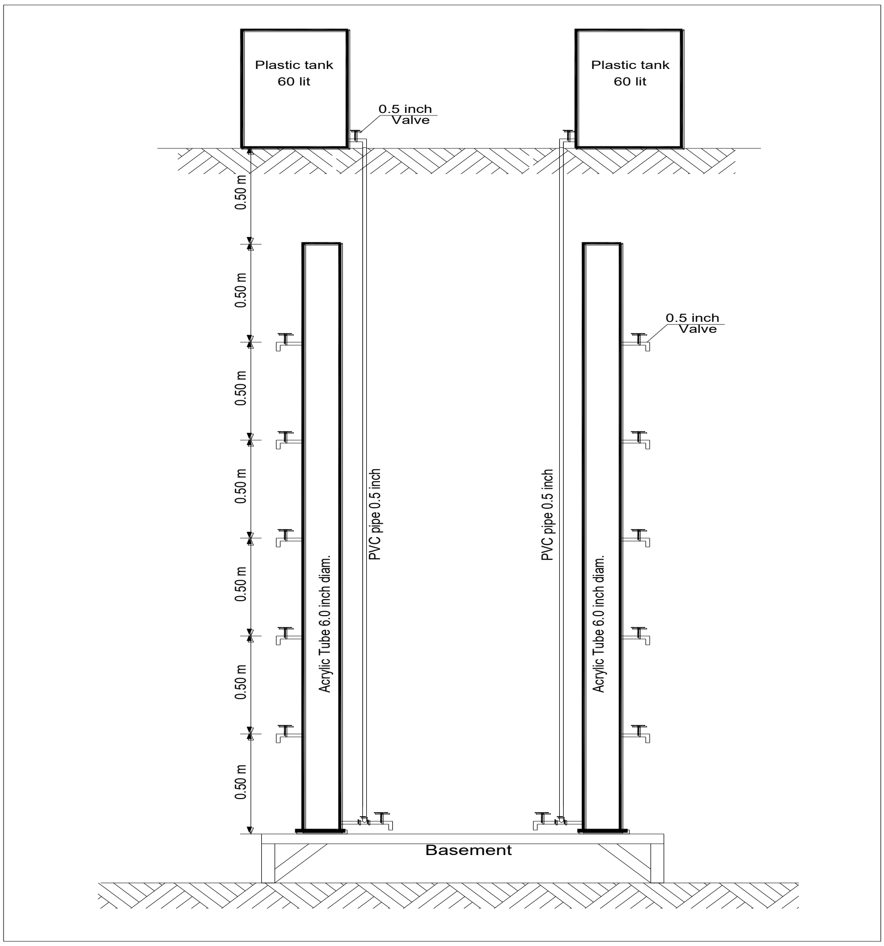

Fig. 1: A schematic view of the laboratory long settling columns

samples were taken from each port (0.5, 1.0, …, 2.5m) at uniform time intervals (10, 30, 60, 120, 180 min). No samples were taken from the lower 0.5 m which is considered to be sludge zone. The collected samples from the two columns (About 52 samples /run) were analyzed for TSS concentration using TSS meter (DR2800) and results were tabulated. In the 2nd run, the two columns were equipped with mixed WW (25% and 50% industrial WW), and samples were taken and analyzed as done in the 1st run. The same procedure was done in the 3rd and 4th runs, but using the domestic WW and the industrial WW (Type B). The overall removal ratio of TSS was determined using the Iso-removal contour lines method (Metcalf & Eddy [11], 2003) and will illustrated later.

5. RESULTS AND ANALYSIS

TSS concentrations obtained at various sampling depth at constant time intervals for different types of wastewater are used to calculate the percentage removal. Percentage removals were then computed at various times and depths and plotted on a graph with respect to depth, and sampling time. Iso-removal contour lines were constructed on this graph. These data could be numerically integrated over the depth of the column to determine the overall removal efficiency (method details are reported in Metcalf & Eddy [11], 2003). These overall removal values could be plotted versus surface loading rate (SLR) and settling time as shown in Figs. 2 and 3.

Fig. 2 showed that, at (RT of 1.5 – 2.5hr, and SLR of 30 – 50 m/d), the removal efficiency of TSS ranged from 56 to 72%

for Domestic WW, from 44 to 56% for Industrial WW type A, from 51 to 65 % for mixed WW (25% industrial WW type A), and from 47 to 60 % for mixed WW (50% industrial WW type A).

Results indicated that although the initial TSS conc. of industrial WW type A (1100 mg/l) was much higher than that of domestic WW (470 mg/l), TSS removal efficiency of industrial WW recorded lower values compared to domestic WW by about 22%. Also, Fig. 2 showed that, TSS removal efficiency decreases as the mixing ratio of industrial WW increases. At mixing ratio of 25% and 50% of industrial WW type A, the TSS removal efficiency reduced by (7.0 - 10%), and by (16 - 17%) respectively.

Results of this pilot study comply with the operating results of 10th of Ramadan city WWTP which receives mixed wastewater (about 55% industrial). It is clear that mixing of industrial and domestic WW reduces TSS removal efficiency in PST. These results confirm that, the addition of industrial WW to domestic WW should make a variation in its characteristics in terms of temperature, pH, alkalinity, density and viscosity, TSS concentration and distribution, organic acid content, and heavy metals. This variation could affect the settling behavior of mixed wastewater.

Sundstrom et al.[16] (1973) stated that, the overall settling type II process depends upon both the flocculating and settling characteristics of the particle, density and viscosity of the fluid. The flocculation of particles depends upon many factors, such as the nature of the surface of particles, the presence of charges, shape, and density.

The physicochemical properties of both domestic and industrial WW type A shows that, the domestic particulate solids are mainly organic matter (VSS/TSS=0.96), where as that of the industrial WW are inorganic matter (VSS/TSS=0.33), this mean that the flocculation of SS in domestic WW is much better than that of industrial WW, which result in an increase of TSS removal efficiency for domestic WW.

Degremont [12] (2002) reported that, viscosity of wastewater increases with the higher content of dissolved solids. As shown in table 1 TDS of the industrial WW type A is about 2400 mg/l while that of domestic WW is 763 mg/l. This means that the viscosity of domestic WW is less than that of industrial WW type A, which results in an increase of TSS removal efficiency for domestic WW. Also, the oil and grease content of domestic WW (63 mg/l) is much less than that of industrial WW (240 mg/l), this mean that the viscosity of domestic WW is less than that of industrial WW type A, which result in an increase of TSS removal efficiency for domestic WW.

Fig. 3 showed that, at (RT of 1.5 – 2.5hr, and SLR of 30 – 50 m/d), the removal efficiency of TSS ranged from 54 to 70% for Domestic WW, from 52 to 65% for Industrial WW type B, from 53 to 67 % for mixed WW (25% industrial WW type B), and from 52 to 64 % for mixed WW (50% industrial WW type B). These results indicated that the settling behaviors of the industrial WW type B is very close to that of Domestic WW, and there is no significant effect of mixing such type of industrial WW with Domestic WW on the settling behaviors. Also these results confirm that, the effect of mixing industrial WW with domestic WW on the settling behaviors is not absolute, but it depends upon the nature of the industrial WW and its composition.

Fig. 4 shows a comparison of TSS removal efficiency between the two types of the industrial WW (type A&B). Although they have a close TSS concentration, Type B achieved higher TSS removal ratio (52 – 65%) compared to type A (44-56%) with % of increase 16-18%. This is due to the nature and composition of each type of wastewater. Industrial WW type B contains higher content of organic SS (VSS/TSS = 0.62) compared to that of industrial WW type A (VSS/TSS = 0.33), which mean that

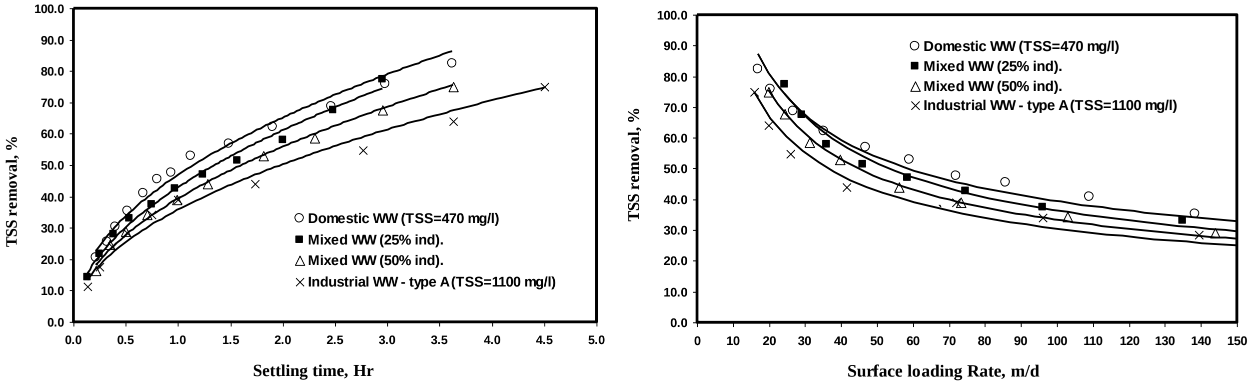

Fig. 2: TSS removal efficiency versus settling time and surface loading rate (for Domestic and industrial WW type A)

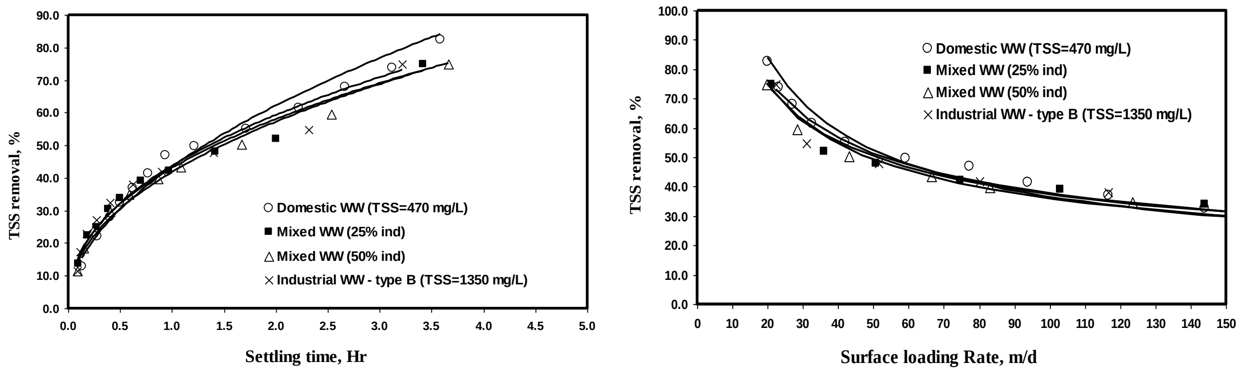

Fig. 3: TSS removal efficiency versus settling time and surface loading rate (for Domestic and industrial WW type B)

the flocculating characteristics of type B is much better than that of type A. As shown in table 1 TDS of the industrial WW type A is about 2400 mg/l while that of type B is 1270 mg/l. This means that the viscosity of WW type B is less than that of industrial WW type A, which results in an increase of TSS removal efficiency for WW type B. Also the oil content of type B (67 mg/l) is much less than that of type A (240 mg/l), which mean that the viscosity of type B is less than that of type A, resulting in an increase of TSS removal efficiency for industrial WW type B more than type A.

Fig. 5 shows the effect of SS concentration on the TSS removal ratio for the same type of wastewater. In a previous study (El Gohary et al. [8], 2012) the TSS removal efficiency ranged between 35% and 45% for industrial WW type A with SS concentration of 630 mg/l.

In the present study the TSS removal efficiency ranged between 44% and 56% for industrial WW type A with SS concentration of 1100 mg/l. This indicated that, the TSS removal efficiency increased by (24-26%) as the SS concentration increased from 630 to 1100 mg/l. This result confirms the findings of the many researchers [Gray [10] (1999); and Ying and Sansalone [17] (2011)], the rate at which particles coalesce is related to the frequency of collisions between particles. The collision frequency is proportional to the concentration of particles. The concentration of suspended solids affects the flocculation process of particles, and then affects TSS removal efficiency.

6. DETERMINATION OF FLOCCULENT SETTLING VELOCITY (VS)

For determining flocculent settling velocity, equations 1&2 were used. First, results of batch settling tests were converted to the remaining concentration of TSS in order to use equation 1 and by the aid of Matlab program the regression coefficients (a, b

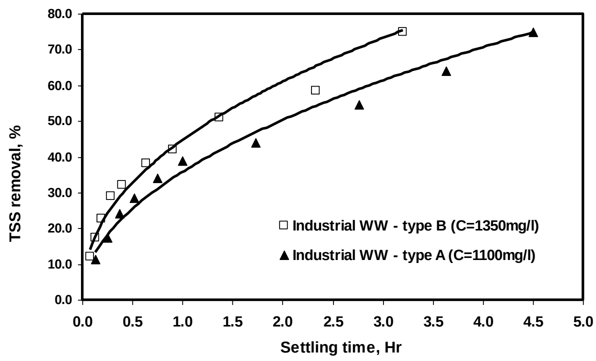

Fig. 4: Comparison of TSS Removal efficiency between the industrial WW types A&B

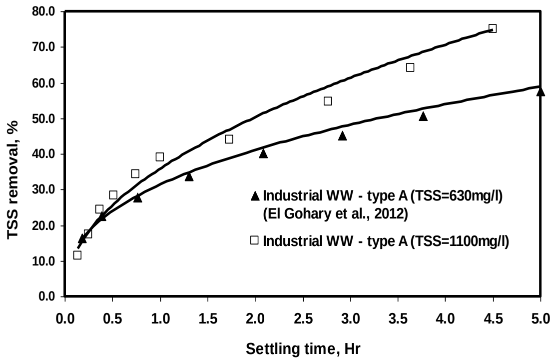

Fig. 5: Effect of SS concentration of Industrial WW on TSS Removal efficiency

and f) could be determined as shown in Table 2. Then equation 2 used to determine the flocculent settling velocity at different settling time and depth.

Fig. 6 shows a comparison of calculated temporarily flocculent settling velocities using equation 2 between the three types of wastewater. Results indicated that, at water depth of 0.5m, the settling velocity reduced from 0.77 to 0.04 m/hr for the domestic WW, from 0.45 to 0.03 m/hr for industrial WW type B, and from 0.28 to 0.02 m/hr for industrial WW type A. At water depth of 2.5m, the settling velocity reduced from 3.83 to 0.21 m/hr for the domestic WW, from 2.24 to 0.12 m/hr for industrial WW type B, and from 1.39 to 0.08 m/hr for industrial WW type A. It is clear that the domestic WW achieved higher settling velocities more than that of the industrial WW types A & B. This is may be referred to that, the flocculating characteristics of the domestic particulate solids is much better than that of the industrial WW.

Also it should be notice that, WW type B achieved higher settling velocities more than type A. This is may be referred to that, the flocculating characteristics of the type B particulate solids is much better than that of type A, and at the same time it has a viscosity less than that of type A.

Fig. 6 shows that, at a settling time of 0.16 hr, settling velocity (for Domestic WW) increases from 0.77 m/hr at a depth of 0.5m to 3.83 m/hr at a depth of 2.5 m. This is due to the change in TSS concentration during the same time over depth.

The fact that the iso-settling velocity lines are curvelinear (nonlinear) means that settling velocity is changing with time and depth. For discrete settling, the iso-settling velocity lines would be linear. Therefore, it is possible to say that flocculation increases the settling velocity of particles.

7. CONCLUSION

Results of this study confirm the fact that the mixing of industrial wastewater with Domestic wastewater affects the settling characteristics of water. The degree of this effect depends on the nature and composition of industrial wastewater (eg. SS concentration, VSS/TSS fraction, and viscosity). Based on the observation and results obtained from this study, the following points are concluded:
1- At a settling time of (1.5 – 2.5hr), and a SLR of about (30 – 50 m/d), TSS removal

Table 2: Regression analysis results for flocculent settling tests

wastewater type	a	b	f
Domestic WW	-0.292	0.143	52.585
Industrial WW type A	-0.183	0.097	62.709
Industrial WW type B	-0.16	0.072	57.538

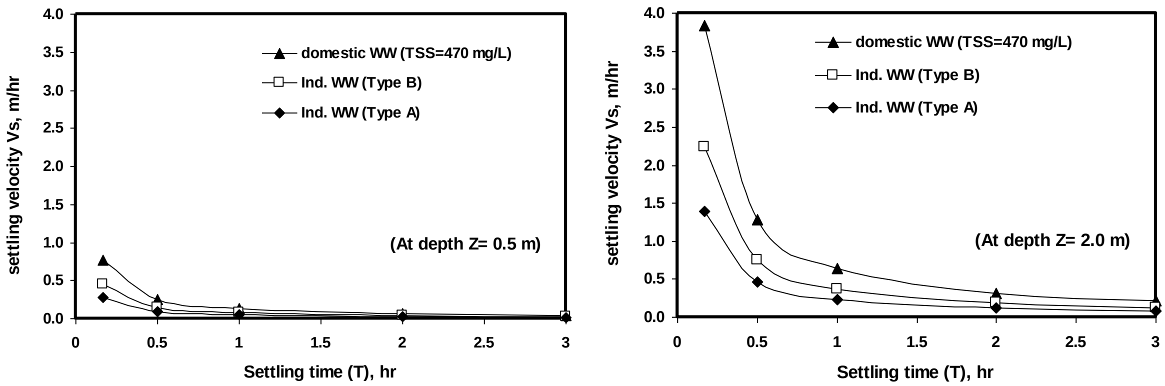

Fig. 6: Comparison of settling velocity between the three types of WW (at water depth; Z= 0.5 & 2.5m)

efficiency ranged from 56 to 72% for Domestic WW, and from 44 to 56% for Industrial WW type A, and from 52 to 65% for industrial WW type B.
2- At mixing ratio of 25% and 50% of industrial WW type A with domestic WW, the TSS removal efficiency reduced by 10% and 17% respectively, while mixing of industrial WW type B did not cause a noticeable impact on TSS removal efficiency.
3- SS concentration affects the removal efficiency of TSS. When SS concentration increased from 630 to 1100 mg/l (for industrial WW type A), TSS removal efficiency increased from (35 – 45%) to (44 – 56%).
4- The settling velocity lines are curvelinear (nonlinear) means that settling velocity is changing with time and depth.

In conclusion it would be advisable to study the nature and quality of wastewater to be treated whether it is purely domestic, purely industrial or a mixture of both to be able to perform an optimum design with a guaranteed level of performance and treatment efficiency at minimum possible cost.

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