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# VARIATION OF TURBIDITY OF LIQUID-SOLID MIXTURES IN THE WASTEWATER SETTLING PROCESS

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***Abstract***

*Our paper presents the results of experimental determinations, in the laboratory, on stationary settling columns, in which the process of sedimentation of solid particles from a liquid-solid mixture prepared for this purpose could be followed. Mixtures of distilled water with different concentrations of $CaCO_3$ (2, 4, 6, 8 and 10%) were introduced in the 5 columns of the Armfield apparatus. In bottles of determined volume were prepared solutions from the same liquid-solid mixture, but with fixed concentrations, respectively, of 6, 4, 2, 1, 0.5 mg/mL. These bottles were used as a standard for checking the turbidity of the liquid in the stationary columns in areas of 10 cm on the 940 mm height of the column, for 100 min. The distribution of turbidity of the liquid, in height, in the different zones of the experimental column, was verified with several mathematical functions. The obtained results validated our predictions regarding the variation of the turbidity on the column height according to a power distribution law, and the obtained graphs presented high values of the correlation coefficient. They can be useful for decanter designers and wastewater treatment specialists.*

***Key words***: *liquid turbidity variation, power distribution law, sedimentation, solid-liquid mixture, wastewater.*

## INTRODUCTION

Water is the most important resource for life. Many people around the world suffer from a lack of fresh and clean drinking water (Sastry et al., 2013).

The transition of the human community from the traditional lifestyle to modernization and urbanization has involved the destruction of valuable non-renewable natural resources and the disintegration of the environment. Thus, in modern societies, proper wastewater management is a necessity, not an option (Harashit, 2014). Wastewater reuse has become an absolute need.

In order to meet the conditions of use, the improvement of water quality is achieved through a treatment process, which depends on the nature and state of dispersion of the mineral or organic substance obtained.

Minerals or organic substances can exist in three states dispersed in water: dissolved substances, colloidal suspensions and weight suspensions (Ciobanu M.G., 2010).

Demands for industrial and domestic wastewater treatment, in order to avoid environmental pollution and, in particular, contamination of pure water resources, have become national and international problems.

Wastewater treatment is a rather sensitive topic, including health and environmental, sociological and environmental and business sustainability issues for wastewater organizations and companies (Anjum et al., 2016).

In this regard, innovative, inexpensive and efficient methods of purification and cleaning of wastewater before discharge into any other water systems are needed (Moh et al., 2007; Holt et al., 2005; Chen et al., 2000).

One of these methods is the decantation or sedimentation of wastewater, a process by which solid particles with a higher density than water are separated from the liquid-solid mixture under the action of gravitational force (von Sperling, 2007; Adams et al., 1990).

Removal of solids is probably the main method of water purification in treatment plants.

The most significant phase of this process is the separation of sludge and particles suspended in water by gravity (Hasim et al., 2017; Lyn et al., 1992; Bajcar et al., 2011). Sedimentation was seen as a process of changing the concentration of solid particles upwards from the bottom of a settling vessel due to the downward movement of solids. (Concha & Burger, 2002; Cheng, 1997). This can be seen by changing the turbidity of the suspension at various points.

Turbidity in wastewater is caused by suspended matter such as clay, sludge, finely divided organic and inorganic matter, colored soluble organic compounds and plankton and other microscopic organisms (Harashit, 2014).

In stationary wastewater decanters, the liquid begins to clear from top to bottom due to deposits of solid suspensions at the bottom of the decanter. This clarification takes place in stages, in stages, a phenomenon that can be followed by checking the turbidity in several areas of the height of the decanter, at regular intervals (Zabava, 2020).

Total suspended solids (TSS) are the main vector of contaminants in the sewage system (Ashley et al., 2005).

According to the literature, it has been found that there are many different devices and methods used to perform sedimentation tests. Some of these are based on tracing the suspension clarification curve and involve filling a column with a suspension that is allowed to settle without disturbance, called static sedimentation (Gian, 2016; Ipate et al., 2019).

The static sedimentation method is very often applied in the stage of liquid-solid mechanical separation in the treatment of domestic and industrial effluents, but also in the treatment of drinking water (Ipate et al., 2019; Safta et al., 2013).

If a quantity of water is introduced into a column, in which solid particles decantable in suspension are found and left to stand, it is observed, after a period of time, that a clear area appears at the top of the water mass and stratification vertically, depending on the concentration, of the suspended particles that are decanted (Figure 1) (Safta et al., 2012; Sajeev et al., 2002).

In fact, three distinct areas are formed: an area of clear water at the top, a suspension area with particles in the process of settling in the middle and an area with concentrated sludge settled at the bottom.

These areas are separated by two interfaces: a clear water-suspension interface and a suspended-sludge concentrated sediment interface (Safta et al., 2012; Sajeev et al., 2002).

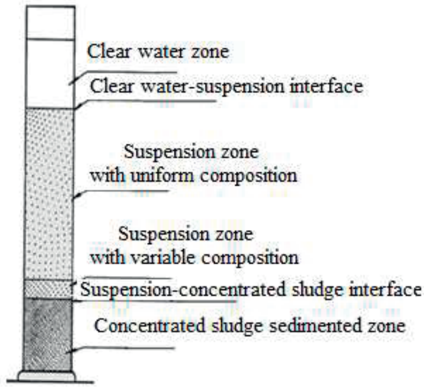


Figure 1. Decantation of a suspension in stationary column (Safta et al., 2012)

The slope of the clarification curve at the critical point represents the speed of the clarified water-suspension interface, when overlapping with the suspension-compacted interface. It should be mentioned that, for a stationary column sedimentation process, the sludge layer in compaction, corresponding to the critical point, has the highest height (Figure 2).

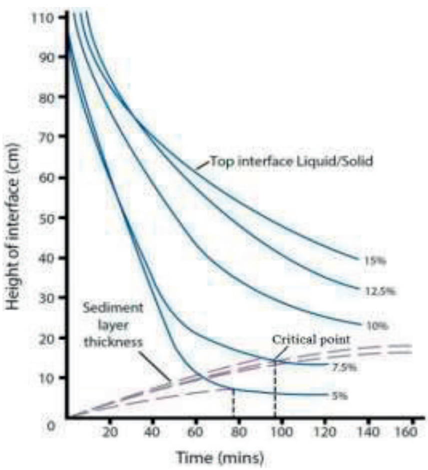


Figure 2. Scheme for determining the position of the critical point in the stationary column (Armfield, 2019)

Among the parameters that influence the behavior of suspended particles in the sedimentation process are the density of solid particles (Droppo et al., 2000), size and shape of solid particles (Florea, 1982; Furumai et al., 2002; Ghawi & Kriš, 2012), but also the temperature (Goula et al., 2008), density (Xiang et al., 2016) and fluid viscosity (Huang, 1981).

Our paper presents the results of experimental determinations, in the laboratory, on stationary settling columns, made of transparent material, in which the sedimentation process of solid calcium carbonate ($CaCO_3$) particles could be followed, from a liquid-solid mixture specially prepared for this purpose.

## MATERIALS AND METHODS

The determinations were performed on the laboratory stand W2 Sedimentation Studies Apparatus (ARMFIELD, UK - Figure 3) provided with five graduated glass columns, transparent, with an inner diameter of 50 mm and a useful height of 940 mm, which corresponds to a volume of 1850 mL (Safta et al., 2012). An aqueous suspension of $CaCO_3$ particles was used, having concentrations of 2%, 4%, 6%, 8% and 10%, respectively, corresponding to amounts of 37 g, 74 g, 111 g, 148 g and 185 g of $CaCO_3$. The amount of calcium carbonate corresponding to each concentration was added to each of the 5 columns, adding water to a suspension volume of 1850 mL, corresponding to a height of 940 mm. After placing the stopper, each column was stirred vigorously for a good homogenization of the liquid-solid mixture.

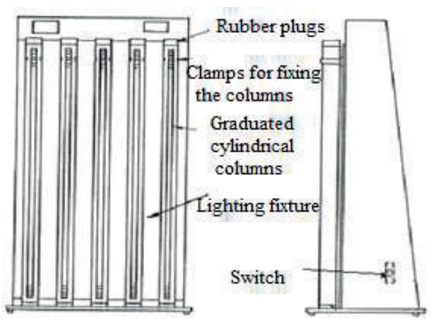


Figure 3. Schematic of the apparatus for the study of sedimentation in stationary column W2 - Armfield

The height of the columns was divided into eight zones of 100 mm, starting from top to bottom, each corresponding to a different zone of sedimentation of $CaCO_3$, as follows: zone 1, 940-840 mm; zone 2, 840-740mm; zone 3, 740-640 mm; zone 4, 640-540 mm; zone 5, 540-440 mm; zone 6, 440-340 mm; zone 7, 340-240 mm; zone 8, 240-140mm, according to Figure 4a.

The concentration of solid suspensions in the 8 zones was analyzed by fluid turbidity expressed in mg / mL.

The turbidity of the 8 zones was tested using standard samples, of different concentrations: 0.2 mg / mL, 0.5 mg / mL, 1 mg / mL, 2 mg / mL, 4 mg / mL and 6 mg / mL, prepared especially for this purpose in bottles of 100 mL. These were stirred throughout the sedimentation experiment prior to testing (verification) to prevent the deposition of solid $CaCO_3$ particles. Experimental recordings were made at 5 min intervals for 100 min, comparing each area in each graduated column with the standard samples (Figure 4b). In fact, it was analyzed how the concentration of the suspension decreases in each of the 8 areas, at intervals of 5 min, for a time of determinations of 100 min.

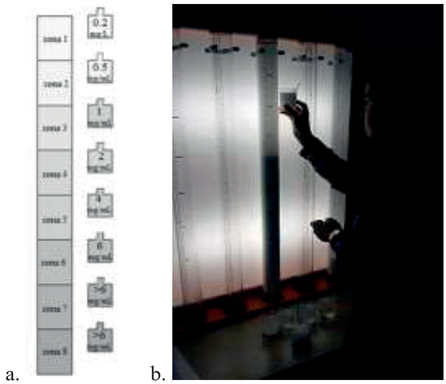


Figure 4. Dividing the column into 8 zones (a) and determining the turbidity of the 8 zones using standard samples (b)

At first, the suspension was placed in the graduated transparent column, provided with a rubber stopper so that the sedimentation process is influenced only by gravitational force.

The column was fixed on the support of the device with the clamps with which it is provided, the timer was turned on to determine at 5 min intervals the turbidity for the 8 established areas and the lighting system of the equipment was turned on for a good determination (test) of turbidity for each area.

Based on the recorded values, the turbidity variation curves over time for each area and column were plotted. The experimental data obtained were processed using the Microsoft Excel program, and the decrease of turbidity, the concentration of the suspension in each analyzed area followed a power distribution of the form:

$$Tb = a \cdot t^{-b}, \text{(mg/mL)} \quad (1)$$

where:

- Tb - turbidity of the suspension;
- t is the time, (s);
- a and b are process parameters, determined experimentally.

## RESULTS AND DISCUSSIONS

The results obtained after the sedimentation process in a stationary column (100 min), as well as the graphs drawn on their basis, for each zone, in each column, are presented below, in the order of the established concentrations.

*a) Distribution of solid particle concentration over time, for the 2% concentration column, analyzing all 8 determined zones (their turbidity)*

Table 1 shows the distribution of the concentration of solid particles over time, for the 2% concentration column, determined by analyzing the 8 zones.

Table 1. Experimental data of turbidity in the 8 zones for the concentration of suspension 2%

| Time, min | Concentration of zones, mg/mL | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 0 | | | | | | | | |
| 5 | 6 | | | | | | | |
| 10 | 4 | 6 | | | | | | |
| 15 | 2 | 4 | 6 | | | | | |
| 20 | 2 | 2 | 4 | 6 | | | | |
| 25 | 1 | 2 | 4 | 6 | | | | |
| 30 | 1 | 2 | 2 | 4 | 6 | | | |
| 35 | 1 | 2 | 2 | 2 | 4 | 6 | | |
| 40 | 1 | 2 | 2 | 2 | 4 | 6 | | |
| 45 | 1 | 2 | 2 | 2 | 2 | 4 | 6 | |
| 50 | 1 | 1 | 2 | 2 | 2 | 4 | 4 | 6 |
| 55 | 1 | 1 | 2 | 2 | 2 | 2 | 4 | 4 |
| 60 | 0.5 | 1 | 1 | 2 | 2 | 2 | 2 | 4 |
| 65 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| 70 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 |
| 75 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 |
| 80 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 | 1 |
| 85 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 |
| 90 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 |
| 95 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 |
| 100 | 0.5 | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 1 |

It can be seen that the liquid begins to clear from top to bottom, in stages, the turbidity having decreasing values over time, for each area analyzed

Figure 5 shows the correlation between the turbidity of the analyzed area and the turbidity change time, for the concentration of 2% $CaCO_3$.

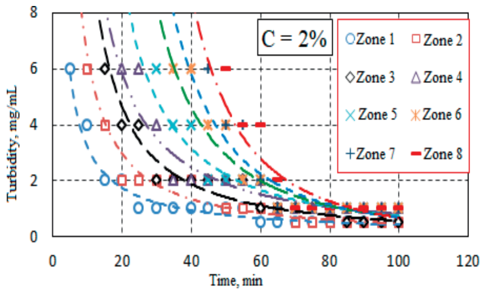


Figure 5. The variation of turbidity in time for the concentration column 2%

The last area to reach a turbidity of 0.5 mg/mL was zone 3. From the eight curves resulting from the representation of the experimental data obtained, it results that the highest value of the regression coefficient $R^2$ was obtained for the sedimentation zone 1, located in the highest position, 940-840 mm. The correlation coefficient $R^2$ was higher than 0.770 for all areas, which demonstrates a close link between the two parameters of the sedimentation process.

The correlation with the experimental data given by the coefficient $R^2$, together with the coefficients of the regression functions a, b, for the 2% concentration column, for the 8 sedimentation zones, is presented in Table 2.

Table 2. The values of the coefficients of the power regression function a, b and of the correlation coefficient $R^2$

| Zone | | Coefficients of the eq. (1) | | |
|---|---|---|---|---|
| | | a | b | $R^2$ |
| $C_{2\%}$ | 1 | 24.008 | 0.875 | 0.936 |
| | 2 | 87.203 | 1.13 | 0.905 |
| | 3 | 222.82 | 1.294 | 0.905 |
| | 4 | 226.24 | 1.223 | 0.895 |
| | 5 | 979.49 | 1.556 | 0,887 |
| | 6 | 8936 | 2.052 | 0.869 |
| | 7 | 31902 | 2.335 | 0.771 |
| | 8 | 234137 | 2.768 | 0.796 |

Analyzing the experimental data, as well as their graphical representation, it can be seen

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that the lowest concentration of solid particles, recorded at 100 min, for the first column had the value of 0.5 mg/mL. The first area that reached this value was sedimentation zone 1, in the 60th minute from the beginning of the determinations. The last zone that reached a turbidity of 0.5 mg / mL was zone 3 (740-640 mm). From the eight resulting curves, following the representation of the experimental data obtained, it results that the highest value of the regression coefficient $R^2$ was obtained for the sedimentation zone 1, located in the highest position 940-840 mm. In this first area, the correlation coefficient for the power dependence of the turbidity with time was $R^2 = 0.936$.

b) In the case of *the distribution of the solid particle concentration, for the 8 sedimentation zones, for the 4% concentration column*, was proceeded as in the first case.

Using the Microsoft Excel program, analogous to the sedimentation column with 2% suspension, following a power distribution law (eq. 1), the variation of the concentration of solid particles was plotted, expressed by turbidity over time.

From the analysis of the graph (Figure 6) it can be seen that the turbidity in each area decreases over time, the sedimentation zone 8 showing a correlation factor $R^2 = 0.933$. The lowest value of the correlation coefficient with function (1) was the one related to sedimentation zone 1 ($R^2 = 0.878$).

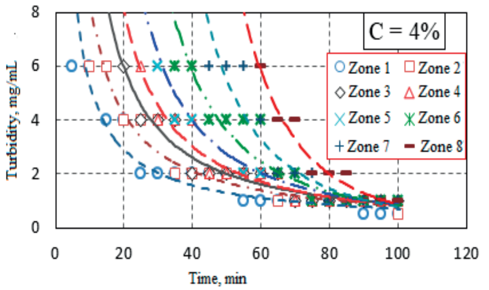


Figure 6. The variation of turbidity in time for the concentration column 4%

It can be seen that only the first two areas of the column reached a low value of the concentration of solid particles of 0.5 mg/mL $CaCO_3$ in suspension in the 100 minutes in which the recordings were made.

In this way, a first conclusion can be drawn, namely, as the concentration of solid particles in the water increases, the time required for their settling increases.

The distribution of the power regression function has the same form as in the case of the 2% concentration column (eq.1), the correlation of the experimental data given by the coefficient $R^2$, together with the coefficients of the regression functions a, b, for the 4% concentration column, for the 8 sedimentation zones are presented in Table 3.

In none of the zones was reached the turbidity level of 0.5 mg/mL $CaCO_3$ and in zone 8 of sedimentation only after minute 70 the concentration of solid particles decreases to 6 mg/mL.

Table 3. The values of the coefficients of the power regression function a, b and of the correlation coefficient $R^2$

| Zone | | Coefficients of the eq. (1) | | |
|---|---|---|---|---|
| | | a | b | $R^2$ |
| $C_{4\%}$ | 1 | 40.242 | 0.878 | 0.878 |
| | 2 | 86.919 | 1.01 | 0.894 |
| | 3 | 207.85 | 1.187 | 0.912 |
| | 4 | 529.84 | 1.401 | 0.916 |
| | 5 | 1840 | 1.664 | 0.910 |
| | 6 | 14135 | 2.115 | 0.893 |
| | 7 | 347492 | 2.826 | 0.911 |
| | 8 | 2E+07 | 3.712 | 0.933 |

c) *The distribution of the solid particle concentration by zones for the 6% concentration is shown in Figure 7.*

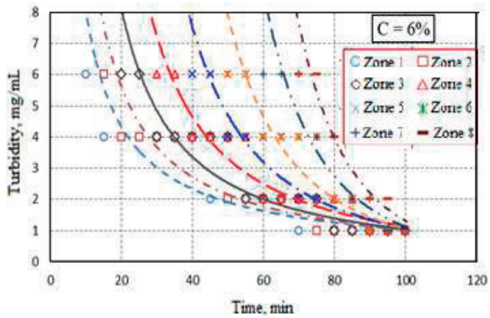


Figure 7. The variation of turbidity in time for the concentration column 6%

The correlation of the experimental data given by the coefficient $R^2$, is presented in Table 4.

Table 4. The values of the coefficients of the power regression function a, b and of the correlation coefficient $R^2$

| Zone | | Coefficients of the eq. (1) | | |
|---|---|---|---|---|
| | | a | b | $R^2$ |
| $C_{6\%}$ | 1 | 62.585 | 0.892 | 0.837 |
| | 2 | 128.24 | 1.045 | 0.846 |
| | 3 | 363.33 | 1.27 | 0.879 |
| | 4 | 1328.1 | 1.533 | 0,889 |
| | 5 | 18002 | 2.11 | 0.896 |
| | 6 | 657470 | 2.897 | 0.872 |
| | 7 | 1E+08 | 3.971 | 0.884 |
| | 8 | 9E+09 | 4.914 | 0.896 |

Following these results, it can be concluded that even in this case there is a power connection between the parameters turbidity - time.

d) *In the case of the 8% $CaCO_3$ concentration column, the distribution of the concentration of solid particles is shown in Figure 8.*

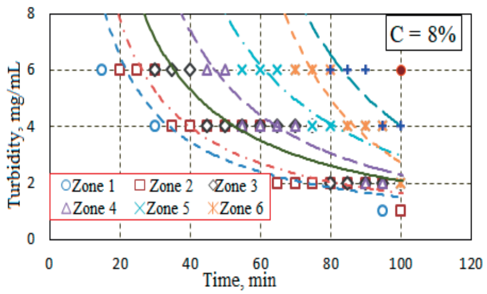


Figure 8. The variation of turbidity in time for the concentration column 8%

It can be seen that in the first sedimentation zone of the graduated column, the concentration level decreased to 6 mg/mL only after 15 minutes from the start of the experiment.

The content of solid particles is quite high, which causes an increase in the clarification time, so it was possible to check the concentration of 6 mg/mL in the sedimentation zone 8 only in minute 100.

According to the experimental data, six of the eight zones do not reach the concentration of 1 mg/mL after the 100 minutes of testing (sedimentation zone 3, zone 4, zone 5, zone 6, zone 7 and zone 8). Moreover, in the sedimentation zone 6 only in minute 100 is reached the concentration level of 2 mg/mL.

It was observed that, at this concentration value, the correlation coefficient had values between 0.701 (sedimentation zone 5) and 0.819 (sedimentation zone 2), decreasing values compared to the other three analyzed concentrations.

For zone 8, no values could be established for these coefficients because the concentration of 6 mg/mL was reached only in minute 100.

In order for wastewater to be discharged into an emissary, that to meet the permissible concentration level in solid particles, regardless of their nature, the settling time needs to be long, especially when the initial concentration is high.

The power distribution has the same shape as in (eq. 1), the correlation of the experimental data given by the coefficient $R^2$, together with the coefficients of the regression functions a, b for the 8% concentration column, for 7 sedimentation zones, are presented in Table 5.

Table 5. The values of the coefficients of the power regression function a, b and of the correlation coefficient $R^2$

| Zone | | Coefficients of the eq. (1) | | |
|---|---|---|---|---|
| | | a | b | $R^2$ |
| $C_{8\%}$ | 1 | 98.093 | 0.906 | 0.811 |
| | 2 | 140.31 | 0.965 | 0.819 |
| | 3 | 230.03 | 1.022 | 0.806 |
| | 4 | 812.42 | 1.274 | 0.734 |
| | 5 | 2150 | 1.43 | 0.701 |
| | 6 | 583487 | 2.664 | 0.749 |
| | 7 | 83698 | 2.158 | 0.735 |
| | 8 | - | - | - |

e) *The last column analyzed from the point of view of the concentration of solid particles was the one of 10% $CaCO_3$ concentration, its distribution presented in Figure 9.*

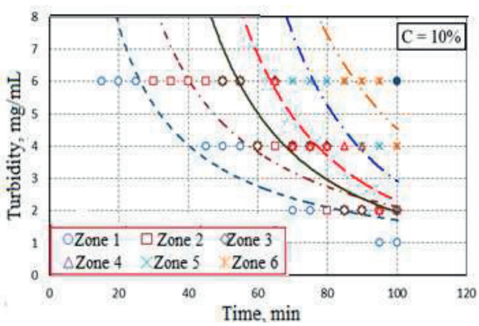


Figure 9. The variation of turbidity in time for the concentration column 10%

In the first sedimentation zone, the solid particle concentration level of 6 mg/mL was reached only in the 15th minute after starting the experiment, and the concentration of 4 mg / mL, also for this area, was reached only after 45 min. It can be seen that only in sedimentation zone 1 the concentration of 1 mg/mL is reached in minute 95, this being the lowest concentration of the suspension recorded in the 100 min.

According to the experimental data, in the sedimentation zone 8 the concentration of 6 mg/mL did not appear after the 100 min of testing. Moreover, it can be observed that, in zone 7 of sedimentation, the appearance of this concentration takes place only at minute 100, fact for which, for zone 7 and 8 could not be represented graphs of variation of turbidity in time, the last the represented area being the sedimentation zone 6.

The correlation of the experimental data given by the coefficient $R^2$, together with the coefficients of the regression functions a, b for the 10% concentration column, for 6 sedimentation zones, are presented in Table 6. For zones 7 and 8 no values could be set for these coefficients.

Table 6. The values of the coefficients of the power regression function a, b and of the correlation coefficient $R^2$

| Zone | | Coefficients of the eq. (1) | | |
|---|---|---|---|---|
| | | a | b | $R^2$ |
| $C_{10\%}$ | 1 | 127.69 | 0.937 | 0.729 |
| | 2 | 418.25 | 1.147 | 0.784 |
| | 3 | 9470.6 | 1.342 | 0.806 |
| | 4 | 41721 | 2.129 | 0.715 |
| | 5 | 544215 | 2.635 | 0.676 |
| | 6 | 116579 | 2.204 | 0.578 |
| | 7 | - | - | - |
| | 8 | - | - | - |

From the analysis of the graphs made for the five concentrations, it is observed that the lowest values of the correlation coefficient are obtained in this 10% concentration column.

Therefore, it is found that if the initial concentration of solids in the liquid-solid suspension is higher, the level of clear its difficult to achieve, and the sedimentation time is greater.

Thus, the experimental data obtained reinforce the conclusion that as the concentration of solid particles in a suspension increases, the time required to remove them by sedimentation is longer.

## CONCLUSIONS

Decantation or sedimentation is the process by which solid particles with a higher density than water is separated from the liquid-solid mixture under the action of gravitational force.

In order for wastewater to be discharged into an emissary, meaning to achieved the permissible concentration level in solid particles, regardless of their nature, the settling time needs to be long, especially when the initial concentration is high.

In stationary wastewater decanters, the liquid begins to clear from top to bottom due to deposits of solid suspensions at the bottom of the decanter. This clarification takes place in stages, meaning in steps, a phenomenon that can be followed by checking the turbidity in several areas of the height of the decanter, at regular intervals.

Research has shown that if the initial concentration of solids in the liquid-solid suspension is higher, the level of clear its difficult to achieve, and the sedimentation time is greater.

The experiment presented shows that the zonal variation of the suspension clarity can be represented by a law of variation of power type (or exponential type), and the parameters of the equation depend on the initial concentration of the suspension, without taking into account the particle size distribution of the solid particles or the temperature at which the settling process takes place.

The experimental results obtained can be useful for decanter designers and specialists in the field of wastewater treatment.

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