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THEORETICAL AND EXPERIMENTAL RESEARCH ON THE SEPARATION PROCESS OF IMPURITIES FROM WASTE WATER THROUGH DECANTATION

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***Abstract**: The paper presents the results obtained from the experimental research on the decantation processes for residual water (wastewater) on an experimental plant (pilot station) formed by two constructive varieties for the clarifiers with tangential inlet and spillway threshold: without a device for scraping (removing) decanted sludge (mud) and equiped with device for scraping sludge (mud). The compared analysis of sediment separating efficiency for the two types of clarifiers was conducted by measuring the time variation of the concentration of suspensions at the entrance and exit from the two types of clarifiers and developing some comparative charts for the concentration variation of the suspensions and the efficiency of clarifiers.*
***Keywords:** residual water, separation, sedimentation, impurity concentration, clarifier with tangential inlet, scraping equipment, separating efficiency.*

1. INTRODUCTION

Industrially used water, also called „waste water" or „residual water" comes from different production and processing processes ad, from a physical point of view, they represent multiphase fluids (mixtures). When stopping, the phases are separated by gravity by a downward movement (gravimetric separation), due to the differences in specific mass of the particles in the suspension, thus achieving a sedimentation or decantation process. The solid particles, which fall off to the bottom of the sedimentation vessel, form a solid – liquid mixture, more or less concentrated, in the form of a sediment called precipitate, slurry or sludge. Depending on the type of sediments and their state of dispersion wastewater, the particles, or impurities, have different dimensions. Thus there are discrete granulated particles (sand, gravel), colloidal particles (groups of molecules or substances of 0.5 … 500 nm size) and molecules or macromolecules in the case of dissolved substances of less than one nanometre in size [1; 2].

The equipment used the for gravimetric separation, called decantor, is composed by a sedimentation bazin, filled with suspension water that will be decanted, a device for recovering the cleared liquid (decanted water) that, usually, surpasses the basin surface and leaks above its level. Additionally, the clarifier is equipped with a device for eliminating (extracting) the sediment (precipitate) from the bottom of the basin. In the general case several distinctive areas can be identified in a decanter: the inlet area, the sedimentation area, the accumulation area of sediments (sludge area), and the evacuation area of sediments. The mixture containing sediments enters the inlet area in turbulent flow and distributes via a uniform, piston or plunger type motion of speed v_m in the entire cross-section of the basin [5; 6].

The connection between the distribution and the decanting area can be achieved by means of a wall with calibrated holes or by means of a deflector that ensures a steady, laminar flow of the water, free of turbulence (vortices). In reality, however, also secondary convection currents occur caused by the temperature differences and parasite flows generated by the differences in density of the various areas in the basin. These aspects evidently affect also the separation efficiency of the decanter. The sludge is evacuated swiftly and continuously from the sedimentation area without disturbing the aqueous solution; this is due to the evacuation area meant to ensure the necessary conditions such as to not disturb the flow in the sedimentation area and to collect the whole flow from the entire cross-section of the basin.

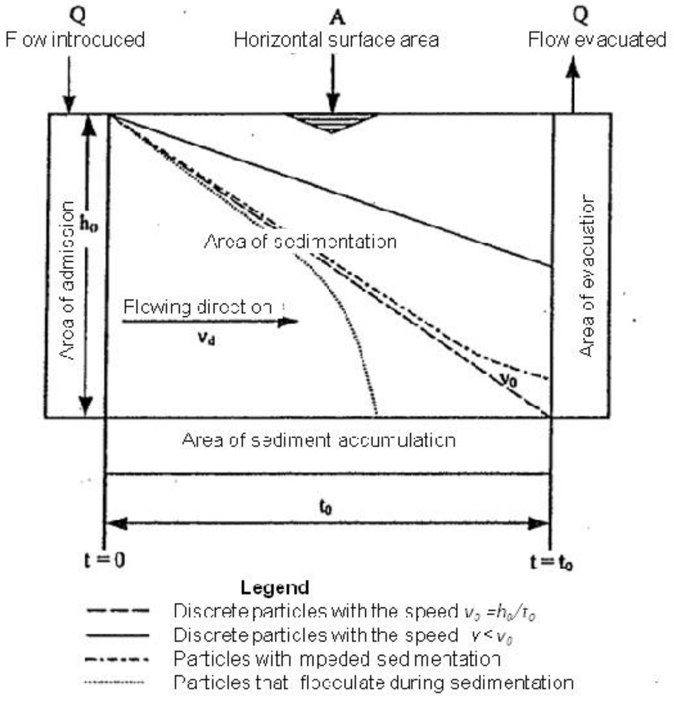

Figure 1: Diagram for defining the parameters of a conventional decanter

Consequently it can be assumed that the concentration of equal size suspended particles is the same in all points of the cross-section located at the end of the inlet area. In the sedimentation area the particles settle at the same speed v_s as the steady, static fluid. In reality, in the sedimentation basin the mixture subjected to decantation (water with sediments) moves horizontally to that a particle situated in suspension in this environment performs a movement composed with the absolute speed v_a (fig.2), resulted from summing up the two movements: the movement caused by the flowing of the mixture on a horizontal direction with the speed of transport v_m and the vertical sedimentation movement with the speed v_s caused by the gravitational field, meaning: $\vec{v}_a = \vec{v}_m + \vec{v}_s$. In a rectangular basin, where the height of the suspension water layer is H (Fig. 2), the maximum time necessary for achieving the sedimentation of a particle with a given diameter is calculated by the relation: $t_s = H/v_s$.

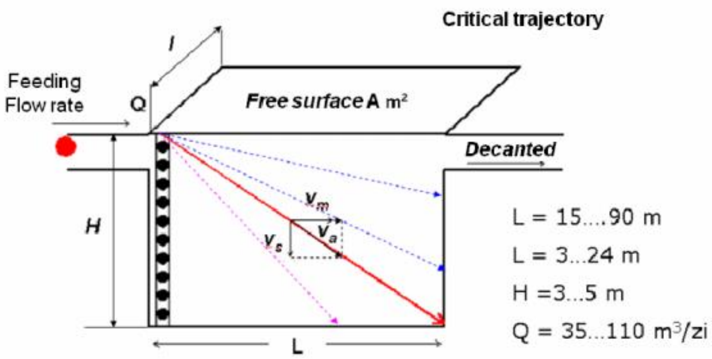

Figure 2: Schematic defining the parameters in a conventional decanter and the movement diagram for the particle in case of transversal (horizontal) circulation of the mixture (water with sediments)

If the useful length of the basin is L (s. Fig.2), the time t_0 for stationary movement of the fluid on the length of the basin with a sedimentation speed v_s is calculated by the relation: $t_0 = L/v_m$ .Due to the fact that a particle is considered sediment in the moment when it reaches the bottom of the decanter, in order to achieve the sedimentation of the particles in the moving is necessary that the time t_0 of fluid stationing in the basin to be

larger or at least equal to the time t_s necessary of particle sedimentation, expressed by the relation: $t_0 \geq t_s$.
Therefore, the condition of achieving the sedimentation process ($t_0 \geq t_s$) is expressed by the relations:

$$\frac{L}{v_m} \geq \frac{H}{v_s} \tag{1}$$

or

$$\frac{v_m}{v_s} \geq \frac{L}{H} \tag{2}$$

Because, generally, the dimensions L and H of the basin are known and the value of the sedimentation speed v_s for a certain type of suspension is also known, from relation (2) is obtained the relation through which is determined the limit value of the v_m speed of movement of the mixture:

$$v_m \geq v_s \cdot \frac{L}{H} \tag{3}$$

Relation (3) emphasis the fact that by reducing height H of the fluid layer in the decantation basin, v_m speed of movement of the mixture can be increased. Height H of the layer of fluid can't be reduced below a certain limit, because the situation may be reached where the separation of particles situated in suspension is done incompletely, the current of fluid also engaging a part of the particles laid on the bottom of the basin.
Considering a rectangular shaped basin (fig. 2), it result that the width l of the basin section depends on the value of the feeding flow Q, the height H of the basin and the average speed of movement (transport) v_m of the water in the basin section. From the known equation of continuity, namely $Q = H.l.v_m$, result the value of the basin width:

$$l = Q/ H.v_m. \tag{4}$$

and the free surface A of the decanter (Fig. 2) is determined with the relation:

$$A = L.Q/ H.v_m \tag{5}$$

The diagram of circulation of material flow in the case of a decanter (clarifier) is presented intuitively in figure 3, on the basis of which the equation of total balance and partial balance is established. The equation of total balance refers to the quantities of material that enter and exit the system and is expressed through the relation:

$$Q_0.\rho_0 = Q_1.\rho_1 + Q_2.\rho_2 \tag{6}$$

where:
Q_0, Q_1 and Q_2 are the volume flows for the water-suspensions mixture, the decanted (clear) water and respectively, of the precipitate (sludge);
ρ_0, ρ_1 and ρ_2 – densities of the water-suspensions mixture, the decanted (clear) water and respectively, of the precipitate (sludge);.

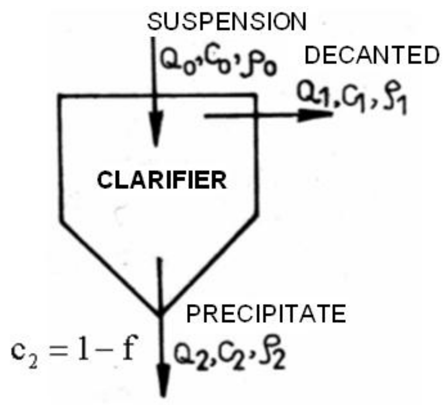

Figure 3: Diagram for the circulation of material flows in the case of a clarifier (decanter)

The partial balance equation refers to the content of solid particles situated in the material flows of the system and is express by the relation:

$$Q_0.\rho_0.c_0 = Q_1.\rho_1.\ c_1 + Q_2.\rho_2.c_2, \tag{7}$$

where c_0, c_1 and c_2 are the mass concentrations in solid particles from the mixture subjected to decantation (waste water), from the clear water (decanted water) and from the precipitate (sludge). The mass concentration *c* represents the quantity of impurities (particles), expressed in mass units on the volume unit and, normally, is expressed in mg/l.
If is considered, hypothetically, that the cleared water does not contain any solid particles, meaning that the clarifier ensures a total yield of detaining the particles of the waste water suspension, meaning $c_1 = 0$, the total balance equation is given by the relation:

$$Q_0 \cdot c_0 = Q_2 \cdot c_2 \tag{8}$$

and the partial balance equation obtains the from:

$$Q_0.\rho_0.c_0 = Q_2.\rho_2.c_2 \tag{9}$$

The volume flow of the decanted water (cleared) Q_1 depending on the volume flow Q_0 of the water-suspension mixture subjected to decantation is obtained from the relation above, meaning:

$$Q_1 = Q_0.\rho_0.c_0 / \rho_2.c_2 \tag{10}$$

Replacing relation (10) in the partial balance equation (7) is obtained the relation for calculating the volume flow of the decanted water Q_1 depending on the flow volume Q_0 of the mixture subjected to decantation, expressed in the form:

$$Q_1 = Q_0 \cdot \frac{\circ_0}{\circ_1} \cdot \left(1 - \frac{c_0}{c_2}\right) \tag{11}$$

From relations (13) and (14) is obtained the relation between the volume flow of the decanted water Q_1 and the one of precipitations Q_2, namely:

$$Q_1 = Q_2 \cdot \frac{\circ_2}{\circ_1} \cdot \frac{c_2}{c_0}\left(1 - \frac{c_0}{c_2}\right) \tag{12}$$

Due to the fact that the precipitate is presented in the form of sludge, characterized by a certain moisture *u* (expressed in %), the concentration in solid particles of the precipitate is determined with the relation:

$$c_2 = (1-u)/100 \tag{13}$$

Moisture *u* of the precipitate is defined by the ratio between the mass of the fluid phase in the precipitate (sludge) and the mass of the precipitate.
The efficiency of a clarifier is assessed by the percentage coefficient *E* of retaining impurities from used water, depending on the initial concentration c_0 and the final concentration c_1, defined by the relation:

$$E = \frac{c_0 - c_1}{c_1} \cdot 100 = \left(1 - \frac{c_0}{c_1}\right) \cdot 100 \quad [\%] \tag{14}$$

The value of the coefficient of separation *E* depends on the clarifier type and on the installations that equip it and, usually, has values comprised in the limits *E* = 35…65%

2. MATERIALS AND METHODS

The main objective of experimental researches consists in the compared analysis of functional performances of a clarifier with tangential inlet and spillway threshold built in two models: clarifier with simple construction, meaning without an additional system for scraping sludge deposits (called scraper) and modernized clarifier, additionally equipped with device for interior scraping of sludge deposits. By installing the scraper was aimed to keep the volume of decantation constant by the contiguous removal of sludge deposits from the inferior walls of the clarifier.

In order to establish the factors influencing the efficiency of the process of sedimentation in clarifiers for industrial waste water and finding the optimal constructive option for the clarifier, an experimental installation (pilot station) was built, which will allow to have a compared analysis between a model of clarifier without scraper and a model with scraper (Fig. 4). The experimental installation is built by the feeding vessel (tank) 1 (V-1), fitted with a mechanical agitator for homogenizing the composition of the residual water subjected to experiments and a centrifuge pump 2 (P-1) for feeding clarifiers D-1 (without scraper) and D2 (with scraper). The temperature of the used water when entering in the clarifiers is measured with electromagnetic flow meters 4 and 12, mounted on the feeding pipe of clarifiers D-1 and, respectively, D-2. The evacuating flow of the sludge is measured with electromagnetic flow meters 6, respectively 14, mounted at the exit of sludge pipes of clarifiers D-1 and D-2. The adjustment of the feeding flow for clarifier D-1 is done by the regulating valve 5, connected to the flow meter 4, and in the case of clarifier D-2, adjustment of the feeding flow is done by the regulating valve 13, connected to the flow meter 12. The adjustment of the evacuating flow for clarifiers D-1 and D-2 is done by the regulating valve 7, connected to the flow meter 6, respectively with the regulating valve 15, connected to the flow meter 14. The scraping organ 11 of clarifier D-2 is actuated mechanically from a driving device 9 situated in the exterior.

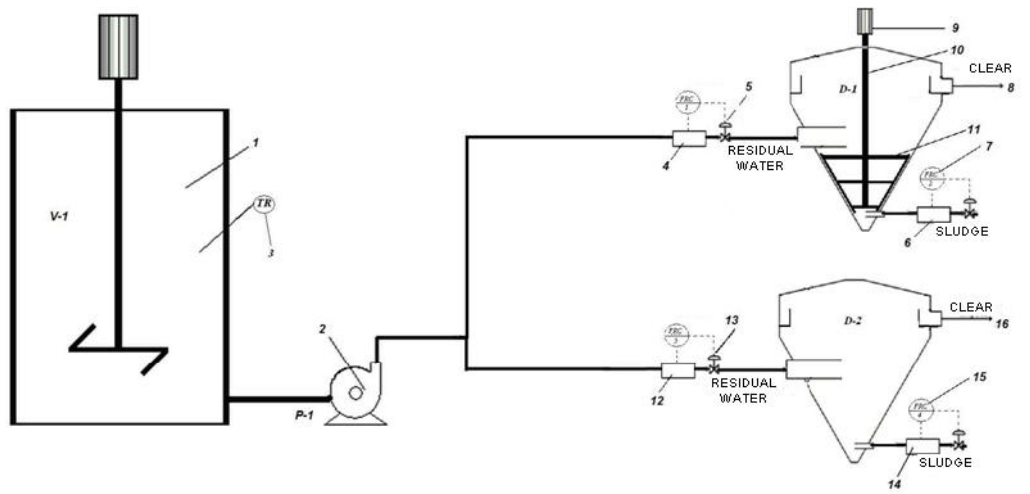

Figure 4: Diagram for the installation (pilot station) for conducting experiments on two options for clarifiers with tangential inlet and spillway threshold: D-1 - clarifier with scraper; D-2 clarifier without scraper: **1 –** vessel for feeding waste water (V-1)fitted with agitator; **2** – centrifugal pump (P-1); **3** – thermometer with thermal resistance; **4 –** flow meter for measuring the flow at the entrance in clarifier D-1; **5 –** valve for adjusting water flow when entering clarifier D-1; 6- flow meter for measuring the sludge flow when exiting clarifier D-1; 7- valve for adjusting the sludge flow when exiting clarifier D-1; 8 – pipe for evacuating clear liquid from clarifier D-1; 9 - equipment for driving the organ for scraping impurities (sludge); 10- drive shaft for the scraping organ; 11-organ for scraping impurities (sludge); 12- flow meter for measuring the flow at the entrance in clarifier D-2; 13- valve for adjusting water flow when entering clarifier D-2; 14- flow meter for measuring the sludge flow when exiting clarifier D-2; ; 7- valve for adjusting the sludge flow when exiting clarifier D-1; 15 – pipe for evacuating clear liquid from clarifier D-2

After filling vessel V-1 with used water subjected to testing, having a known initial concentration of impurities (determined by measuring), and pump 2 is started (P-1) for feeding clarifiers D-1, respectively D-2. In the process of filling clarifiers with used water, sludge in the inferior part is purged (eliminated) periodically in order to avoid the clogging of the system for evacuating clear water. In addition, after filling clarifier D-2, the device for mechanical evacuation of sludge with scraping organ 11 enters into operation, driven by the driving system 9 through drive shaft 10.

For the tests conducted, samples of material were periodically harvested and were measured the concentration of suspensions from the used waters introduced in clarifiers, from the clear liquid evacuated and from the sludge evacuated from the clarifier.

3. RESULTS AND DISCUSSIONS

Testing the operation of each option of experimental clarifier was achieved by harvesting samples at a 24 hour interval. For each sample were determined by measures the values of concentration of impurities (in mg/l) at the entrance of waste water in the two clarifiers, from the clear water and at the exit from the clarifier and from the sludge evacuated from clarifiers. By processing the data were determined by calculation the percentage values for the efficiency of the separation process *E* for each periodical testing, using relation (14). The result obtained after measuring and processing the data are summarized in Table 1. On the basis of experimental data mentioned in table 1 were built graphics that represent the variation of coefficients for the efficiency of separation *E (%)* of the clarifier depending on the initial concentration of the solid in the residual (waste) water at the entrance in the clarifiers. These graphics allow making a compared analysis of the separation process for each type of clarifier and the evolution in time of the separation efficacy for the two types of clarifiers studied.

Table 1: Results from experimental determinations conducted for the two types of clarifiers

Time	Solids concentration residual water	Clarifier with scraper *(D-1)*			Clarifier without scraper *(D-2)*		
		Solids concentration		Separation efficiency *E*	Solids concentration		Separation efficiency *E*
		clear	mud		clear	mud	
[hours]	[mg/l]	[mg/l]	[mg/l]	%	[mg/l]	[mg/l]	%
0	9687	4016	24591	58,54	5742	23704	40,72
24	8945	6462	25264	27,76	7459	24849	16,61
48	10308	3518	25662	65,87	5356	14150	48,04
72	10260	6852	28654	33,22	9094	19302	11,36
96	5730	3015	27962	47,38	3612	12758	36,96
120	6220	3050	16734	50,96	3440	12194	44,69
144	4248	2938	16572	30,84	3108	15846	26,84
168	3286	1804	9936	45,10	2162	8416	34,21
192	4320	1838	23350	57,45	2132	11532	50,65
216	9324	3812	29105	59,12	4536	17654	51,35
240	10706	4750	25388	55,63	5656	15130	47,17
264	8852	2946	25344	66,72	4200	15356	52,55
288	5674	3354	12598	40,89	3926	10420	30,81
312	9800	5182	15982	47,12	6064	12898	38,12
336	3250	2020	15176	37,85	2206	8760	32,12

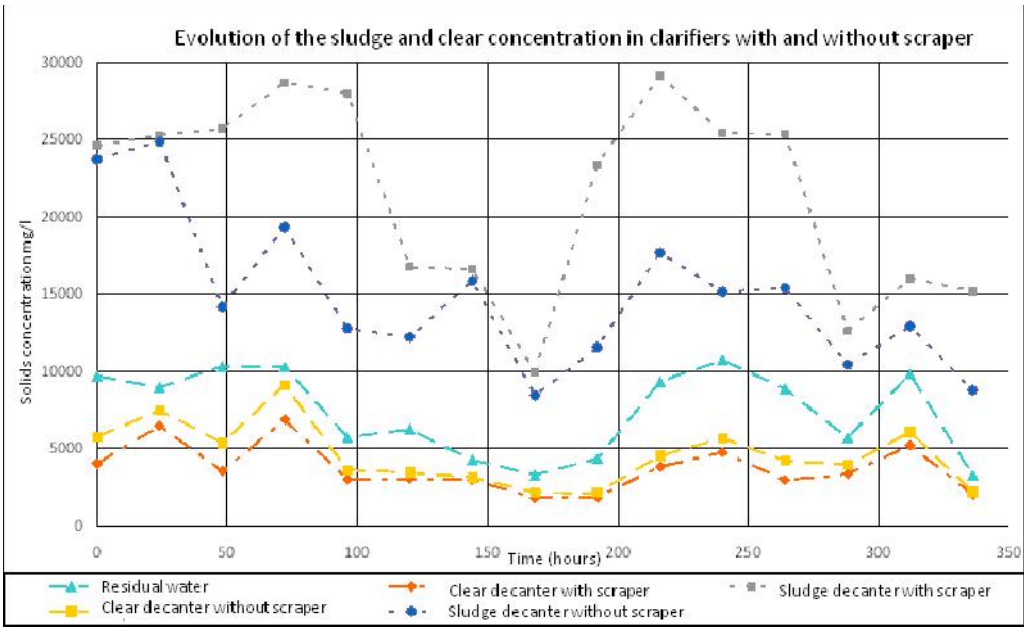

Figure 6: Variation in time of the concentration for the suspension in clear water and mud for the clarifier with scaper and without scraper

In figure 6 are presented the compared graphics for the time variation of the suspension's concentration in clear water and in mud for the two types of clarifiers and in figure 7 are presented the compared variations in time for the efficacity of separating for the two types of decantors (without scraper and with scraper).

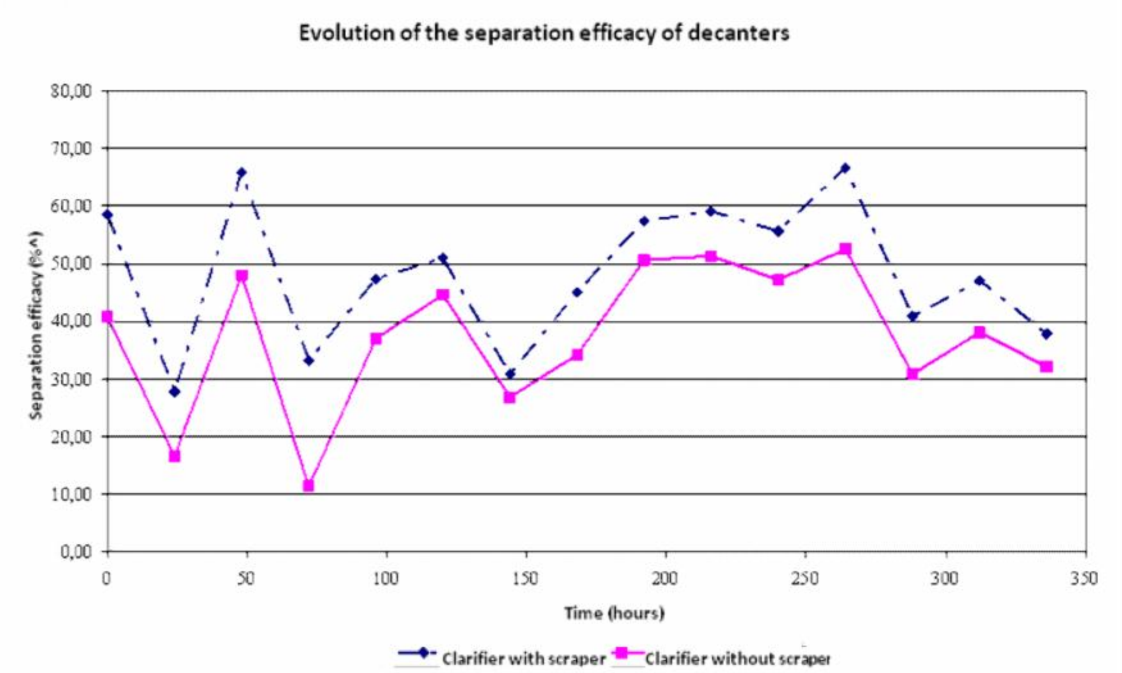

Figure 7: Variation in time of the efficacity of separating impurities in the clarifier with scraper and without scraper

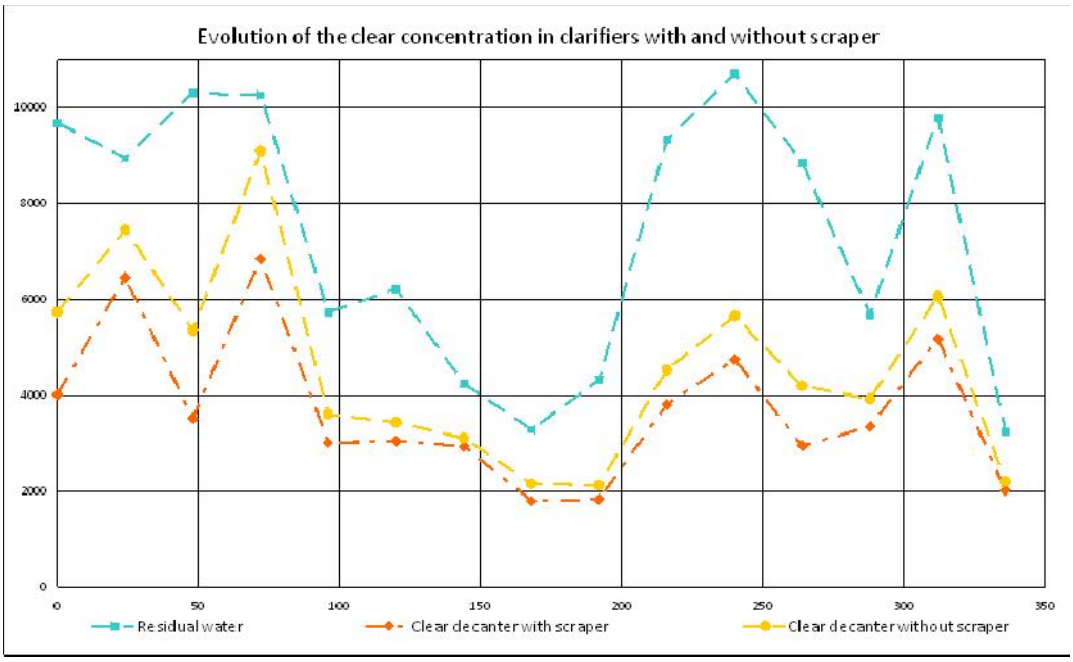

Figure 8: Variation in time of the concentration of the suspension in clear water for the two types of clarifiers

In figure 8 are presented the charts for the variation in time of the suspension's concentration of clear water and in figure 9, the variation of the suspension's concentration in mud for the two types of clarifiers (without scraper and with scraper).

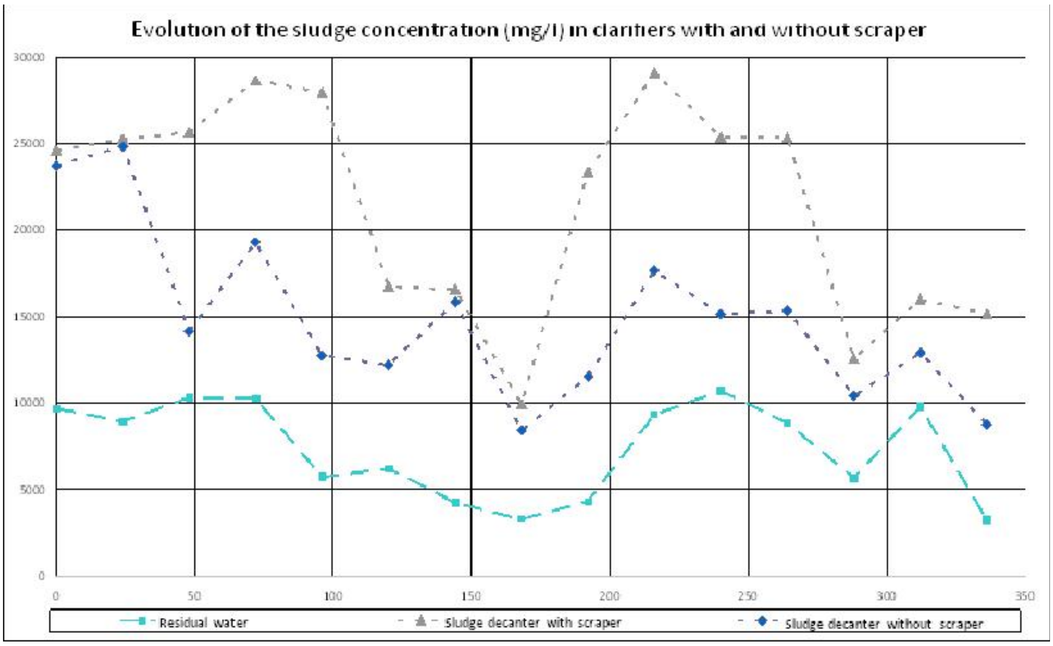

Figure 9: Variation in time of the suspension's concentration of mud for the two types of clarifiers

4. CONCLUSIONS

The efficiency of separating suspensions from residual waters is superior for the clarifiers with devices for scraping, compared to the one of the clarifiers without scraping devices, a fact leading to the reduction of solids concentration in the discharged (clear) water. Therefore, it is recommended to use clarifiers with tangential inlet and spillway threshold equipped devices for scraping the sludge, which come into operation automatically after filling the clarifier.

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