Clarification of the effluent of an anaerobic digestion process: comparative study of single-stage and double-phase processes, with addition of coagulant and without addition of chemical coagulant

Clarificación del efluente de un proceso de digestión anaerobia: estudio comparativo de procesos de una y dos fases, con adición de coagulante y sin adición de coagulante químico

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Abstract

A study of the phenomenon of sedimentation of sludge from the anaerobic digestion of codigestion phases and monostage was performed, compared with addition and without addition of coagulant, the dose and concentration required was determined in the laboratory by jar test, the concentration of $FeCl_3$ resulted in 15000 mg / l. The results of the sedimentation curves of the interface below codigestion phases fit the equation $y = 0.0861 x^2 -14.198 x + 970.63$, the interphase curves below co-digestion phases with addition of $FeCl_3$ fits an equation $y = 0.0714 x^2 - 12.512 x + 1008.4$, the interface above single-stage codigestion fits an equation $y = 0.0423 x^2- 6.3681 x + 917.91$, the interface below single-stage codigestion fits an equation $y = 0.0953 x^2 - 15.714 x + 975.1$, the interface above single-stage codigestion with addition of $FeCl_3$ fits an equation $y = 0.0393 x^2 - 5.196 x + 977.79$, the interphase below single-stage codigestion with addition of FeCl3 fits into an equation $y = 0.838 x^2 - 13.824 x + 981.43$.

Codigestion phases, Codigestion monostage, Anaerobic digestion, Coagulant, Sedimentation

Resumen

Se realizo un estudio del fenómeno de sedimentación del lodo proveniente de la digestión anaerobia de la codigestión fases y monoetapa, se comparó con adición y sin adición de coagulante, la dosis y concentración requerida se determinó en laboratorio mediante prueba de jarras, la concentración de $FeCl_3$ resulto de 15000 mg/l. Los resultados de las curvas de sedimentación de la interfase por debajo de codigestión fases se ajusta a la ecuación $y = 0.0861 x^2 -14.198 x + 970.63$, la de interfase por debajo de codigestión fases con adición de $FeCl_3$ se ajusta a una ecuación $y = 0.0714 x^2 - 12.512 x + 1008.4$, la de interfase por arriba de codigestión monoetapa se ajusta a una ecuación $y = 0.0423 x^2- 6.3681 x + 917.91$, la de interfase por debajo de codigestión monoetapa se ajusta a una ecuación $y = 0.0953 x^2 - 15.714 x + 975.1$, la de interfase por arriba de codigestión monoetapa con adición de $FeCl_3$ se ajusta a una ecuación $y = 0.0393 x^2 - 5.196 x + 977.79$, la de interfase por debajo de codigestión monoetapa con adición de $FeCl_3$ se ajusta a una ecuación $y = 0.838 x^2 - 13.824 x + 981.43$.

Codigestión fases, Codigestión monoetapa, Digestion anaerobia, Coagulante, Sedimentación

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Introduction

Chemical precipitation, discovered in 1762, was a method of wastewater treatment widely used in England as early as 1870. Lime was used in many cases as a precipitating agent, sometimes alone, but very often in conjunction with calcium chloride, magnesium chloride, alumina sulfate, ferrous sulfate, charcoal, and many other substances. Chemical treatment was also widely used in the United States in the late 1890s and early 1900s; but with the development of biological treatment the use of chemicals was abandoned. In the early 1930s some attempts were made to develop new methods of chemical treatment and a few chemical treatment plants were installed.

At present it is an effective treatment process for the removal of many contaminants. Coagulation with alumina, ferric sulfate, or ferrous sulfate and softening with lime both involve chemical precipitation. The removal of substances from water by precipitation depends mainly on the solubility of various compounds formed in water. For example, heavy metals are found as cations in water and many will form solid hydroxides and carbonates. These solids have low solubility limits in water. Thus, as a result of the formation of insoluble hydroxides and carbonates, the metals will precipitate out of solution.

With this we can say that it is one of the most commonly used processes in water treatment. In fact, experience with this process has produced a wide range of treatment efficiencies.

Sludge sedimentation

In many locations, the discharge of industrial effluents to sewers has resulted in wastewater that is not treatable by biological means. In such situations, physicochemical treatment is an alternative solution. The main drawback of this treatment method, which has limited its widespread use, is the handling and disposal of large volumes of sludge resulting from the addition of chemicals.

On the other hand, it is worth mentioning that sludge from treatment plants often has very variable compositions. In some cases, it is often able to flocculate by simple agitation or by the addition of a flocculant or flocculation aid (polyelectrolytes); in other cases, it is necessary to use a coagulant to accelerate the formation of flocs that can be precipitated (chemical precipitation as an aid to flocculation).

Features

In order for the treatment and disposal of the sludge produced in wastewater treatment plants to be carried out in the most effective way, it is important to know the characteristics of the solids and sludge to be processed. The characteristics are variable, depending on the origin of the solids and sludge, the time elapsed since their production and the type of process to which they have been subjected.

Amount of sludge

The handling and disposal of sludge resulting from chemical precipitation was in the past, and still is today, one of the major difficulties encountered in this treatment method. Sludge is produced in large volume in most chemical precipitation operations, often amounting to 0.5% of the volume of treated wastewater.

Chemical conditioning

The use of chemicals to condition the sludge for dewatering is economical because of the higher yields and flexibility of the results obtained. Chemical conditioning results in coagulation of solids and release of absorbed water. Conditioning is used prior to vacuum filtration and centrifugation. The chemicals used are ferric chloride, lime, alumina sulfate and organic polymers. It is recommended that chemicals be dosed and measured in liquid form to facilitate mixing with the digested sludge.

Dosage

The chemical dosage required for any given type of sludge is determined in the laboratory by means of jar type tests, which allow the chemical dosages to be determined. The types of sludge, listed in approximate order of increasing chemical requirement for conditioning, are as follows:

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1. Mixture of untreated (raw) primary sludge.

2. Mixture of raw primary sludge and trickling filter sludge.

3. Mixture of raw primary sludge and excess activated sludge.

4. Aerobically digested sludge.

5. Mixture of anaerobically digested primary and excess activated sludge.

6. Aerobically digested sludge (normally dewatered on drying beds without the use of conditioning chemicals).

The general objective of the present investigation is to deepen the phenomenon of sedimentation of sludge from anaerobic digestion of two processes such as Single and Double Phase, making a comparison with the addition of coagulant and without the addition of chemical coagulant in the sludge of the substrate of CODIGESTIÓN FASES and CODIGESTIÓN MONOETAPA. It is expected to follow a flocculated particle behavior as proposed by the tests carried out by Talmadge and Fitch (1955).

Justification

As the waste products of the process will be inorganic solids, liquids and gases. The gases should be extracted from the digester and processed to obtain energy, or simply burned and evacuated without use. The solid inorganic matter, due to its inert nature, should not present any problems for disposal. The objective pursued with the clarification of digester effluent is twofold. On the one hand, the concentration of the settled sludge should be as high as possible in order to minimize the volume of sludge to be transported to subsequent processes (e.g., dewatering, thickening, etc.) and, on the other hand, the supernatant liquids should be recirculated to the wastewater treatment process, so it is important that they have the lowest possible concentration of solids or organic matter.

Methodology

In this experiment, the phenomenon of sedimentation of the substrates CODIGESTION FASES and CODIGESTION MONOETAPA was studied by making a comparison with the addition of coagulant and without the addition of chemical coagulant as mentioned above.

Initially, the experimental plant consisted of three digesters with a capacity of 100 liters, to which an acid phase system was added as shown in Figure 1, which at first the three digesters were inoculated with digested sludge. The operating regime of the three digesters was in mesophilic monostage. The digesters were fed in the following way:

For this stage of the experiment, we worked only with the substrate mixture of FANGO plus FORSU, i.e. in CODIGESTION. Two different technologies were operated in a comparative manner as follows:

The CODIGESTION SINGLE-STEP DRYER

The digester CODIGESTION PHASES (1 Acidic Phase + 2 Methanogenic Phase). As shown in figure 1.

Sampling parameters

In addition, the following parameters are analyzed in each digester influent: pH, Temperature, Total Solids, Total Volatile Solids, Total Filtrable Solids, Biochemical Oxygen Demand, Organic Matter, Moisture and Ash.

The effluent: pH, Temperature, Total Solids, Total Volatile Solids, Total Filtrable Solids, Biochemical Oxygen Demand, Alkalinity, Volatile Fatty Acids and of the biogas produced: pressure, flow, %CH_4, %CO_2.

The analyses were carried out following the analytical methodology established by the "Standard Methods for the Examination of Water and Wastewater", APHA-AWWA-WPCF, and analogous to the Environmental Protection Agency (EPA).

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Figure 1 Phased co-digestion and single-stage co-digestion digesters

Sampling methodology

After having verified the satisfactory parameters of the effluent of the digesters, the sampling of the sludge from each of the digesters was carried out in a clean jar with a handle, graduated with a capacity of 2 liters, which was immediately taken to the laboratory, The measurement of these two parameters was carried out for 10 minutes and with constant agitation to avoid flotation or resuspension of the sludge until the reading remained stable. The point for the extraction of the samples were the outlets corresponding to the reactors of the sludge of the different substrates corresponding to MONOETAPE CODIGESTION and PHASE CODIGESTION respectively.

The rest of the sludge was deposited in a 1 L beaker, it was shaken manually for approximately 5 to 10 minutes, this was done to release the possible gases that had been trapped in the sample, then it was poured into a graduated cylinder of 1 L and the sedimentation or flotation time of the sludge was timed over time, The notes of the experiment were made in the record sheet, in this table it makes reference to the notes corresponding to the sampling date, the sample in question, the test number, as well as the start and end time of the experiment, the minutes at which the start interface was presented and its interfaces both above and below.

Determination of the optimum coagulant

To determine the optimum dosage of the different types of coagulants, we started with the lowest dosage and increased the dosage until we observed a significant change in sludge sedimentation.

As previously mentioned, the extraction and disposal of the sludge was limited, so the maximum amount of sludge available was 3 liters.

For the determination of the optimum coagulant, the "jar test" was carried out in 100 ml test tubes in which 50 ml of sludge were deposited.

Determination of the optimal coagulant dosage

For the determination of the optimum coagulant dosage, the "jar test" was also carried out in test tubes of 100 ml capacity in which 50 ml of sludge were deposited.

Figure 2 Tests of the optimum coagulant, as well as its optimum coagulant dosage

Chemical sedimentation

Once the above steps were completed, the sedimentation tests were carried out without the addition of coagulant and with the addition of coagulant, as follows:

1. One liter of sludge sample was placed in a graduated cylinder without the addition of coagulant.

2. Immediately afterwards, the same sample of sludge is placed in another graduated cylinder of one liter, but with the addition of the previously obtained dose of coagulant.

3. The sedimentation or flotation time of the sludge was timed over time, and the experiment was recorded on the log sheet.

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4. With the data recorded, we proceed to plot a graph for each of the tests, this is done with the milliliters vs. minutes over the time in which the experiments were carried out, at the end of these we proceed to make the comparison between the tests and proceed to record the observations.

Sample treatment

In the second stage of the experiment at the 90th minute of the CODIGESTION FASES and CODIGESTION MONOETAPA chemical sedimentation tests, the aliquots (without coagulant and with coagulant) of the last 5 tests were extracted, this was carried out by introducing a 10 ml pipette up to the interface free of sludge (supernatant), It is important that when introducing it, this is done with the end opposite to the tip covered with the index finger, this is done with the purpose of not introducing the sludge in the pipette, which can be found in the interface from above, and this can bring as consequence interferences in the analysis as in the results.

A small aliquot is obtained, which is discarded because it is the first one. The previous procedure is repeated as many times as necessary, until the volume necessary for COD and turbidity determination is obtained.

Determination of supernatant quality

After obtaining the aliquots of the supernatant of the substrates of PHASE CODIGESTION and MONOETAPE CODIGESTION respectively, as shown in Figure 3, the determination of the parameters corresponding to COD and Turbidity is carried out.

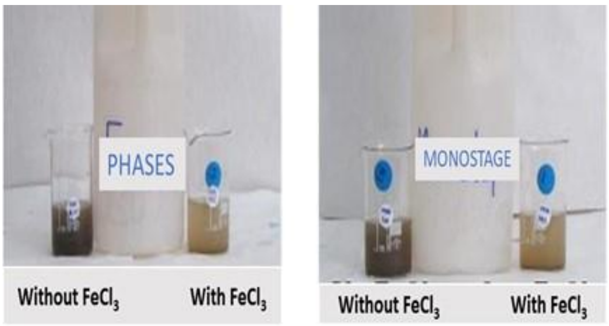

Figure 3 Obtaining the volume for the determination of COD and Turbidity parameters

Results

The main results obtained are summarized below:

Agitation variable

One of the main variables that directly influences the process of sludge sedimentation of the different substrates is the agitation.

For this purpose, the sludge was poured into a 1 L beaker and stirred manually for approximately 5 to 10 minutes. To immediately perform the sedimentation test.

The total of 56 sedimentation tests performed are shown in Table 1.

Substrate	Number of trials	1 Resuspension		2 Resuspension	
		Number of resuspensions	%	Number of resuspensions	%
Phase co-digestion without FeCl3	14	1	7	0	0
Phase Co-digestion with FeCl3	14	0	0	0	0
Codigestión de Monoetapa sin $FeCl_3$	14	1	7	0	0
Codigestion of Monostage with FeCl3	14	1	7	0	0

Sedimentation time variable

Another variable that influences the phenomenon of sedimentation in the mud of the different substrates. It is the time necessary for the sedimentation curve to stabilize and tend to an asymptotic value, not presenting the resuspension phenomenon.

For the 56 sedimentation tests that were carried out, we proceeded to obtain the necessary time. Until the value of the curve tends to horizontal, the type of substrate to which it corresponds, and the averages were as follows: The substrate CODIGESTION FASES in its two modes (with addition of FeCl3 and without addition of FeCl3) the average time was 101.4 minutes for each and finally the substrate CODIGESTION MONOETAPE in its two modes (with addition of FeCl3 and without addition of FeCl3) the average time was 100.4 minutes for each.

Therefore, the time required for the sedimentation curve to tend to a horizontal value is as follows:

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Substrate CODIGESTION MONOETAPA in its two modalities (with addition of $FeCl3$ and without addition of $FeCl_3$).

CODIGESTION FASES substrate in its two modes (with addition of $FeCl3$ and without addition of $FeCl_3$).

Variable gas production.

For the 56 trials that were carried out, the number of resuspensions was counted as well as the time in minutes that these occurred, which were as follows:

The CODIGESTION FASES substrate without addition of FeCl3 showed 1 trial that showed resuspension and this occurred at minute 58.

CODIGESTION FASES substrate without FeCl3 addition did not show any resuspension.
The substrate CODIGESTION MONOETAPE without addition of FeCl3 showed 1 trial with resuspension occurring at minute 21.

The substrate CODIGESTION MONOETAPE with the addition of FeCl3 showed 1 trial that presented a resuspension and this occurred at minute 33.

Variable type of substrate

Another variable that influences the sedimentation phenomenon is the comparison of substrates. The behavior was different in the two cases in general, in terms of: sedimentation velocity, resuspension, gas generation, compaction of the bottom interface, flotation of the top interface, etc.

To evaluate the effect of the addition of a chemical coagulant on the sedimentation properties, the following are mentioned:

Substrate Codigestion Phases without addition of $FeCl_3$

Of the 14 sedimentation assays performed with the CODIGESTION FASES substrate, 12 assays presented double interphase (85.7%). Two trials presented a single interphase (14.3%), and one trial presented a resuspension (7.14%).

Regarding the sedimentation of the substrate CODIGESTION PHASES it should be noted that here the interface above was very low, so the results were discarded as being of little relevance to our research.

On the other hand, the sedimentation curve of the interface below the substrate CODIGESTION PHASES fits a second degree polynomial form as shown in equation 1.

$$y = 0.0861\,x^2 - 14.198\,x + 970.63 \qquad (1)$$

As can be seen in Figure 4, which corresponds to the shape of the type 3 settling sedimentation model, presenting a parabolic shape that descends very smoothly for the first 20 minutes, then slowly smoothes out and finally remains constant at minute 70 with an interface of approximately 400 ml.

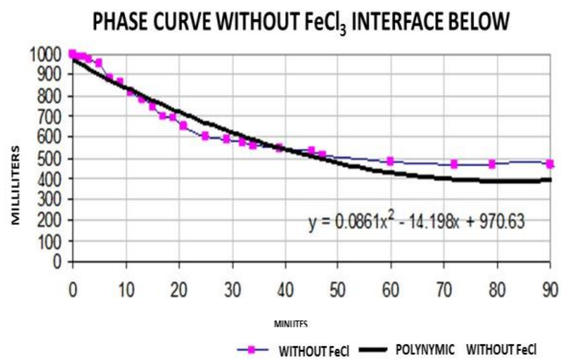

Figure 4 Representative curve of CODIGESTION FASES substrate without addition of coagulant over time

CODIGESTION PHASE substrate with addition of $FeCl_3$

The average $FeCl_3$ in the CODIGESTION FASES substrate in the trials was 1.93 ml in 50 ml of sludge.

The $FeCl_3$ concentration required for sedimentation of the PHASE CODIGESTION substrate was 15000 mg/l.

Of the 14 sedimentation tests performed on the CODIGESTION FASES substrate with FeCl3 addition, 14 tests showed double interphase (100%). 14 trials showed double interphase (100%). None of the tests showed any resuspension. The sedimentation curve of the interface below the substrate CODIGESTION PHASES with FeCl3 addition fits a second degree polynomial form, as shown in equation 2.

$$y = 0.0714\,x^2 - 12.512\,x + 1008.4 \qquad (2)$$

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As can be seen in Figure 5, which corresponds to the shape of the type 3 settling sedimentation model, presenting a parabolic shape that descends very smoothly during the first 30 minutes, then slowly smoothes out and finally remains constant at minute 70 with an interface of approximately 480 ml.

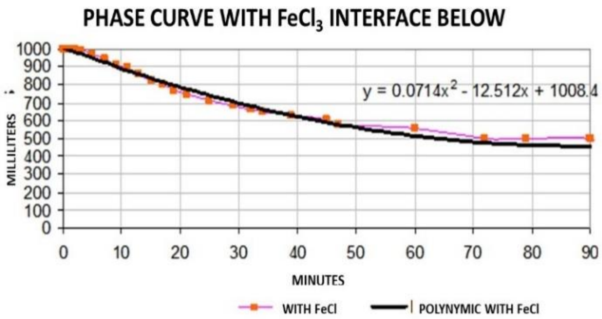

Figure 5 Representative curve of CODIGESTION FASES substrate with coagulant addition over time

Figure 6 shows comparatively the 2 representative curves of the PHASE CO-DIGESTION substrate without FeCl3 addition and with $FeCl_3$ addition.

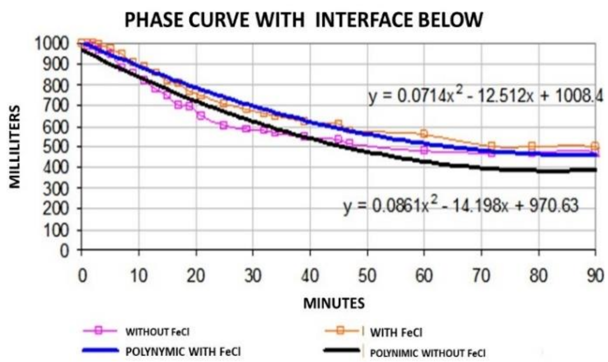

Figure 6 Integration of the representative curves of the substrate CODIGESTION PHASES with and without $FeCl_3$ addition

1. In the substrate CODIGESTION FASES without addition of $FeCl_3$ the resulting sludge-free supernatant is approximately 400 ml. In a time of 90 minutes. While on the other hand with the PHASE CODIGESTION substrate with addition of $FeCl_3$ the sludge free supernatant is approximately 500 ml.

2. The two curves of the substrate PHASE CODIGESTION without addition of FeCl3 and the substrate PHASE CODIGESTION with addition of $FeCl_3$ can be fitted to a second degree polynomial.

3. The two fitted representative curves have a very similar behavior, being displaced by approximately 100 ml from each other.

4. According to the results, the substrate CODIGESTION FASES with the addition of $FeCl_3$.

5. According to the results, the one with the highest compaction is the PHASE CO-DIGESTION substrate without $FeCl_3$ addition.

Substrate CODIGESTION MONOETAPA without addition of FeCl3

Of the 14 trials of the CODIGESTION MONOETAPA substrate, 14 trials showed double interphase (100%), and 1 trial showed resuspension (7.14%).

The sedimentation curve of the interface above the MONOETAPE CODIGESTION substrate conforms to a second degree polynomial form, as shown in equation 3.

$$y = 0.0423x^2 - 6.3681\,x + 917.91 \qquad (3)$$

As can be seen in Figure 7, which has the shape of a parabola that descends rapidly and irregularly in the first 20 minutes, and then descends very smoothly, until it finally remains constant at the 80th minute with an interface of approximately 700 ml.

The sedimentation curve of the interface below the substrate CODIGESTION MONOETAPA fits a second degree polynomial form, as shown in equation 4.

$$y = 0.0953x^2 - 15.714x + 975.1 \qquad (4)$$

As can be seen in Figure 7, which corresponds to the shape of the type 3 settling sedimentation model, presenting a parabolic shape that descends very rapidly in the first 20 minutes, then slowly smoothes out and finally remains constant at the 80th minute with an interface of approximately 320 ml.

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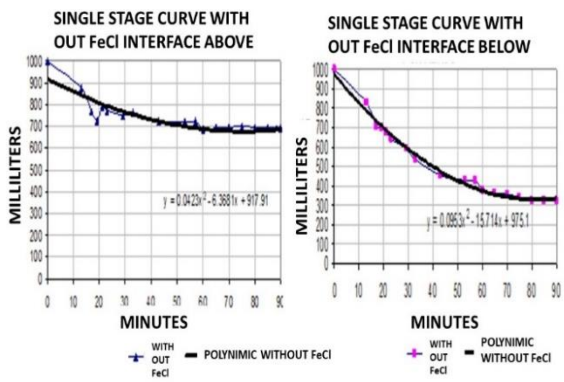

Figure 7 Fitted curves of the sedimentation process of the substrate CODIGESTION MONOETAPE without $FeCl_3$ addition of all the trials of the experiment over time

Substrate CODIGESTION MONOETAPA with addition of $FeCl_3$

The average $FeCl_3$ demand in the CODIGESTION MONOETAPE substrate in the trials was 2.6 ml in 50 ml of sludge.

The $FeCl_3$ concentration required for the sedimentation of the CODIGESTION MONOETAPA substrate was 15000 mg/l.

Of the 14 sedimentation tests performed on the substrate CODIGESTION MONOETAPA with $FeCl_3$ addition, 14 tests showed double interphase (100%) and 1 test showed resuspension. 14 trials presented double interphase (100%), and 1 trial presented a resuspension of the substrate.

The sedimentation curve of the above interface of the MONOETAPE CODIGESTION substrate with FeCl3 addition can be fitted to a second-degree polynomial form, as shown in equation 5.

$$y = 0.0393x^2 - 5.196x + 977.79 \quad (5)$$

As can be seen in Figure 8, which has the shape of a parabola that descends rapidly and irregularly in the first 20 minutes, and then descends very smoothly, until finally remaining constant at the 80th minute with an interface of approximately 835 ml.

The sedimentation curve of the bottom interface of the substrate CODIGESTION MONOETAPE with FeCl3 addition can be fitted to a second-degree polynomial form, as shown in equation 6.

$$y = 0.838x^2 - 13.824x + 981.43 \quad (6)$$

As can be seen in Figure 8, which corresponds to the shape of the type 3 settling sedimentation model, presenting a parabolic shape that descends very rapidly in the first 20 minutes and irregularly, and then slowly smoothes out irregularly and finally remains constant at the 75th minute with an interface of approximately 400 ml.

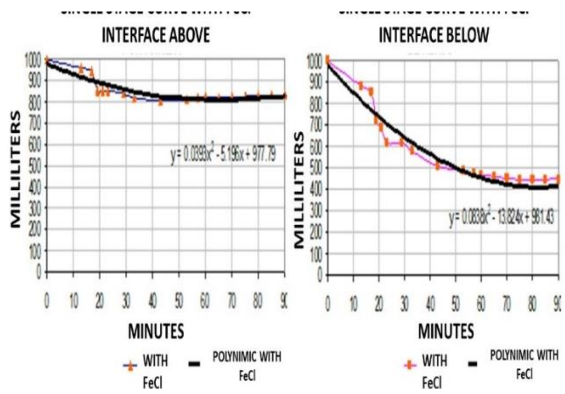

Figure 8 Fitted curves in the substrate sedimentation process CODIGESTION MONOETAPE with addition *of $FeCl_3$ from all tests of the experiment over time*

Figure 9 shows comparatively the 2 representative curves of the MONOETHAPE CODIGESTION substrate without $FeCl_3$ addition and with $FeCl_3$ addition.

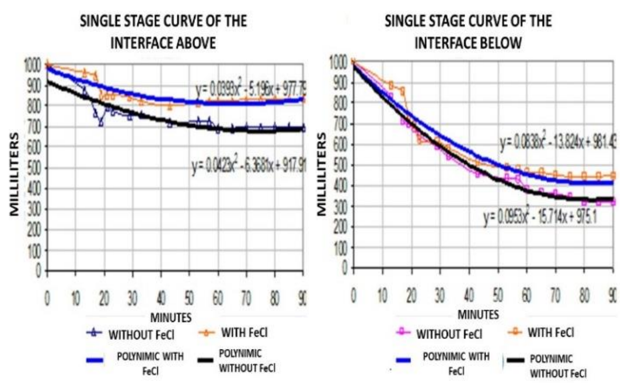

Figure 9 Integration of the representative curves of the substrate of MONOETAPE CODIGESTION with and without $FeCl_3$ addition

The quality of the clarified product with $FeCl_3$ addition is better than that without FeCl3 addition, as shown by the BOD and turbidity values in Table 2 and 3.

Sample Phases				
	DQO (mg/l)		Turbidity (NTU)	
Sample prom.	With FeCl	No FeCl	With FeCl	No FeCl
1	4028	5179	413	439
2	1687	2797	301	320
3	1690	4929	221	262
4	4864	11351	75	200
5	3862	6068	172	283

Table 2 COD and Turbidity values of the sample supernatant sample sedimentation process steps

Sample Monoetapa				
	DQO (mg/l)		Turbidez (NTU)	
Sample prom.	With FeCl	No FeCl	With FeCl	No FeCl
1	9784	12086	360	427
2	3916	6153	275	388
3	1690	5070	160	234
4	8108	18918	263	325
5	4965	6068	224	330

Table 3 COD and Turbidity values of the supernatant of the single-stage sample of the sedimentation process

So, we can make a comparison and comment on similarities and differences.

Regarding the interface from above.

1. The two representative curves behave very similarly, but in parallel, tending to an asymptotic value and an offset of about 100 ml between each one.

2. The representative curves are fitted to a polynomial equation of second degree.

3. The Monostage Codigestion substrate with $FeCl_3$ addition shows higher interphase flotation above than the Monostage Codigestion without $FeCl_3$ addition.

4. According to the results, the one with the highest effluent sludge flotation is the single-stage Codigestion substrate with the addition of $FeCl_3$.

Regarding the interface from below

1. The behavior at the first 50 minutes is practically identical, although from minute 60 onwards the curves slowly separate, the shape of the curve of the substrate Codigestion Monostage with $FeCl_3$ tends to become an asymptotic value of approximately 400 ml, while on the other hand the curve of the substrate Codigestion Monostage sn $FeCl_3$ tends to a value of approximately 300 ml, indicating a better compaction of the sludge.

2. The representative curves are fitted to a polynomial equation of second degree.

3. The substrate of single-stage co-digestion without $FeCl_3$ addition shows a higher compaction of the interface from below than the single-stage co-digestion without $FeCl_3$ addition.

4. According to the results, the one with the highest effluent clarification is the single-stage codigestion substrate with the addition of $FeCl_3$.

5. According to the results, the one with the highest compaction is the Phases Codigestion substrate without addition of $FeCl_3$.

6. With regard to the COD and turbidity results, the one with the best supernatant quality was that of the Phase Co-digestion substrate with the addition of $FeCl_3$.

Conclusions

Substrate CODIGESTION STAGES

Of the 14 sedimentation tests performed on the substrate Codigestion Phases, 12 tests showed double interphase (85.7%). Two trials presented a single interphase (14.3%), and one trial presented a resuspension (7.14%). However, the interface above was very scarce, so we conclude that in this type of substrate the interface presented by the interface above is negligible and easily eliminated.

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On the other hand, at the interface below it occurs in a similar way in the Phases Codigestion substrate without $FeCl_3$ as with $FeCl_3$ addition. Therefore, the addition of the coagulant has no influence.

As regards the clarification of the effluent, it turns out that it is higher with the addition of $FeCl_3$.

Of the 14 sedimentation tests performed on the substrate Codigestion Phases with addition of $FeCl_3$. 14 trials presented double interphase (100%).

Substrate CODIGESTIÓN MONOETAPA

Of the 14 trials that were carried out with the Codigestion Monostage substrate, 14 trials showed double interphase (100%) and 1 trial showed resuspension (7.14%).

With regard to the sedimentation of the substrate Codigestion Monostage, the two interfaces were present here, both from above and below, so that if the two interfaces are considered as a whole, then the following two interfaces are considered.

The sedimentation curve turns out to be better for the curve for the Mono-stage Codigestion substrate without $FeCl_3$.

Of the 14 sedimentation tests performed on the substrate Codigestion Monostage with FeCl3 addition, 14 tests showed double interphase (100%). 14 trials presented double interphase (100%).1 trial presented a resuspension (7.14%).

References

1. APHA, AWWWA, WPCF. (1995). Standar methods for the examination of water and wastewater. 15ª edición.

2. César V. E (2003) Ingeniería de los sistemas de tratamiento y disposición de aguas residuales. Fundación ICA, A.C. (Unidad I, II y III).

3. Collazos, C. J. Y Vega J. (2002) Tratabilidad de los lixiviados del relleno sanitario Doña Juana en un reactor UASB. Revista del Instituto de la Facultad de ingeniería. Departamento de ingeniería civil y agrícola. Bogotá Colombia 15 (4) pag. 70-78.

4. Consultoría Ambiental (2004), Tratamiento de Aguas, Instituto de Estudios Medioambientales. Fundación Universitaria Interamericana.

5. Degrémont (1979) Manual técnico del agua. Artes gráficas Grijelmo, S.A. 4ª edición española. pag. 427-439.

6. Gossett, James M.; McCarty, Perry L.; Wilson, Jerry C.; Evans, Don S. (1978) Anaerobic digestion of sludge from chemical treatment. Journal of Water Pollution Control Federation 50 (3) pag 533–542.

7. Güldner C., Hegemann, W., Peschen, N. and Sölter K. (1994) Use of lime for the upgranding of existing wastewater treatment systems. Water Sciencie and Technology 29 (12) pag 279-282.

8. Harleman, D. R. F. (1964) The significance of longitudinal disperson in the analysis of pollution in estuaries, Proceedings 2d international conference on water pollution research, Tokyo, Pergamon, New York.

9. Hernández M. A. (2001) Depuración de aguas residuales. Colegio de ingenieros de caminos y puertos. Quinta edición pag. 621-637

10. Hernández L. A. (2002) Manual de diseño de estaciones depuradoras de aguas residuales. Colegio de ingenieros de caminos y puertos quinta edición pag. 35 - 70.

11. Ma. Estela Montes Carmona: Estudio técnico económico de la digestión anaerobia conjunta de la fracción orgánica de los residuos sólidos urbanos y lodos de depuradora para la obtención de biogás (2010). Tesis Doctoral. Universidad Politécnica de Madrid.

ISSN-On line: 1390-9959

12. Manual de suministros de agua comunitaria (2002) Calidad y tratamiento del agua. editorial McGraw Hill, American Water Works Asociation. Capítulo 6 y 10 pag. 311,340,645.658.

13. McMichael, F. C., and J. E. McKee (1965) Waster Quality Criteria, 2d ed., California State Water Quality Control Board Publication 33.

14. Metacalf y Eddy (1996) "Ingeniería de Aguas Residuales". Tratamiento, Vertido y Reutilización". Ed Mc Graw Hill 3ª edición. Capítulo 11 pag. 392-393, 636-638,694-697.

15. N. Mahmoud, G. Zeeman, H. Gijzen, G. Lettinga (2003) Soilds removal in upflow anaerobic reactors, a review. Bioresource Technology 90, pag 1-9.

16. Ramalho R. S. (1993) Tratamientos de aguas residuales. Reverté S.A. pag.92-140, 533-541.

17. Vanderhasselt Alexis and Verstraete Willy (1999) Short-term effects of additives on sludge sedimentation characteristics. Water Research 33 No 2 pag. 381-390.

18. Wouter Ghyoot and Willy Verstraete (1997) Anaerobic digestión of primary sludge from chemical pre-precipitation. Water Science and Technology 36 No 6-7 pag 357-365. Desarrollo de Secciones y Apartados del Artículo con numeración subsecuente.