Rev. Int. Contam. Ambient. 23 (1) 17-24, 2007

REDUCTION OF SOLIDS AND ORGANIC LOAD CONCENTRATIONS IN TEQUILA VINASSES USING A POLYACRYLAMIDE (PAM) POLYMER FLOCCULANT

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(Recibido agosto 2006, aceptado febrero 2007)

Key words: tequila vinasses; solids separation; rotating screen; polycrylamide (PAM)

ABSTRACT

This study consisted of three experiments designed to evaluate the practicality of using a cationic polyacrylamide (PAM) polymer flocculant to reduce commonly used aquatic pollution indicators in tequila vinasses. A first experiment with a 2 x 2 factorial arrangement was used to observe the effects on vinasses of five different concentrations of PAM (20, 60, 100, 140 and 180 g/L) at two different temperatures, 25 and 90 °C. In a second experiment vinasses from different tequila factories were treated with 200 mg/L of PAM and the flocculated solids separated in a pilot-scale cylindrical rotating screen separator constructed of non-oxidized steel. In a third experiment the flocculation study was carried out in a small tequila factory using 4,500 liters of tequila vinasses treated with 200 mg/L of PAM discharged from three different pot stills. Recovered flocculated solids (g/L), settleable solids (SS, ml/L), total solids (TS, mg/L), total suspended solids (TSS, mg/L), total dissolved solids (TDS, mg/L) and chemical oxygen demand (COD, mg/L) concentrations were the evaluated answer parameters. The major effect in the PAM addition to vinasses samples in the two different temperature conditions, was reflected in the removal efficiency of SS and TSS. In SS concentration of treated vinasses there was a significant effect ($p<0.05$) due to temperature and PAM concentrations so as well as an interaction between both factors. TS removal efficiency was affected by the temperature and PAM concentration and there was no interaction among the temperature and coagulant concentration ($p<0.05$). COD concentration in vinasses samples, was affected only by the coagulant concentration, there was no interaction among temperature and coagulant concentration ($p<0.05$). Vinasse cooling and pH adjustment was not considered necessary for optimal polymer-amended vinasses solids separation. For vinasses with a SS of 400 mg/L or less an addition of 200 mg/L of PAM it is expected to have optimal removal values of SS and relatively acceptable values of TS, TSS and COD. Estimate costs associated with the level of PAM used in this study corresponded to 0.076 dollar per liter when the PAM cost was 3.8 dollar per kilogram.

Palabras clave: vinazas de tequila, separación de sólidos, filtro rotatorio, poliacrilamida

RESUMEN

El presente estudio se basó en tres tipos de experimentos para evaluar la aplicación de un floculante catiónico de un polímero de poliacrilamida (PAM), para reducir indicadores de contaminación acuática por vinazas de tequila. Se realizó un primer experimento con un arreglo factorial de 2 x 2 para observar los efectos sobre vinazas tequileras de cinco diferentes concentraciones de PAM (20, 60, 100, 140 y 180 g/L) a dos temperaturas diferentes 25 y 90 ºC. En un segundo experimento, vinazas tequileras de diferentes compañías fueron tratadas con 200 mg/L de PAM. El flóculo fue recuperado en un separador piloto cilíndrico rotatorio construido de acero inoxidable. En un tercer experimento, el estudio de la floculación fue realizado en una pequeña fábrica de tequila utilizando 4,500 litros de vinazas provenientes de tres diferentes alambiques de destilación con 200 mg/L de floculante. Los parámetros de respuesta que se utilizaron para la evaluación del floculante fueron: sólidos floculados recuperados (g/L), sólidos sedimentables (SS, ml/L), sólidos totales (ST, mg/L), sólidos suspendidos totales (SST, mg/L), sólidos disueltos totales (SDT, mg/L) y demanda química oxígeno (DQO, mg/L). El mayor efecto de la adición de PAM sobre las muestras de vinazas, en las dos diferentes condiciones de temperatura, fue reflejado por la eficiencia de remoción de SS y SST. En la concentración de SS en las vinazas tratadas, hubo un efecto significativo ($p<0.05$) debido a la temperatura y a las concentraciones de PAM, así como a la interrelación de ambos factores. La eficiencia de remoción de ST fue afectada por la temperatura y la concentración de PAM aunque hubo interacción de la temperatura y la concentración del coagulante ($p<0.05$). La concentración de DQO de las muestras de vinazas, fue afectada solamente por la concentración del coagulante y no por la interrelación de la temperatura y la concentración del coagulante ($p<0.05$). No se consideró necesario el enfriamiento de las vinazas ni el ajuste de pH para una separación óptima de los sólidos de las vinazas por acción del polímero. Para las vinazas con 400 mg/l de SS ó menos, se espera que la adición de 200 mg/L de PAM genere valores óptimos de remoción de SS y valores relativamente aceptables de ST, SST y DQO. Se estima que los costos asociados con las concentraciones de PAM utilizadas en este estudio, corresponden a 0.076 de dólar por litro de vinazas cuando el PAM cuesta 3.8 dólares por kilogramo.

INTRODUCTION

Tequila is a distilled beverage classically associated with Mexico. In addition to an alcoholic beverage, the tequila industry generates two byproducts: (a) lignocellulosic material called agave bagasse (1,200 g/L of tequila, wet basis) and (b) distillery wastewater generally known as vinasses. In a typical tequila distillery, 7 to 10 L vinasses are produced per liter of tequila at 100 proof (Cedeño 1995). In 2005, Mexico produced 177.4 millions liters of tequila (40% Alc. Vol.) (Consejo Regulador del Tequila, CRT 2005). 59.3 millions from sugars of agave plant and 118.1 millions from a minimum of 51% agave sugars mixed with up to 49% other sweeteners (white sugar, brown sugar, glucose, fructose, molasses, etc). Tequila vinasses are the distillation residual product of the fermented wort, once richly alcoholic products (tequila) were separated by means of heat and pressure. Tequila vinasses are a highly recalcitrant waste hardly decomposed by the usual biological processes such as activated sludge since it is highly coloured due probably to the presence of melanoidins. Melanoidins are present in spent wash from molasses distilleries (Sirianuntapiboon *et al.* 1988). These are brown polymers formed by the Maillar amino-carbonyl reactions (Wedzicha and Kaputo 1992). They have antioxidant properties and are often toxic to microorganisms used in waste treatment (Kitts *et al.* 1993). Besides, tequila vinasses have a low pH (3.5) and high temperature. Vinasses is a potential water pollutant in two ways. First, because it is highly coloured, it would block out light from rivers and streams thereby preventing oxygenation by photosynthesis an hence would be detrimental to aquatic life. Second, vinasses themselves have a high pollution load having a total nitrogen, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in the order of 52,628 and 24,575 mg/L, respectively. Vinasses are also a potential soil pollutant. If disposed on land without any control, they reduce the alkalinity of the soil and crops may be destroyed. Vinasses have also been shown to inhibit seed germination (Nalleli 2004). The treatment of this waste therefore remains a problem, that is why tequila producers are seeking alternative treatments to reduce excessive organic loading.

Currently, vinasses are disposed on land, by lagooning in ponds and/or by discharge into natural aquatic systems. A proper approach to tequila vinasses treatment must necessarily involve effective treatments that are both economically feasible to sustain the tequila production business and also beneficial for the ecosystem.

As the practice of tequila production increases, there is an urgent need for efficient and affordable treatment alternatives for handling excess contaminants and associated problems such as deterioration of water quality and nuisance odors.

It is obvious that, in order to significantly improve tequila vinasses management, we need technologies that can achieve effective separation of solids from liquids.

Vinasses solids contain solid agave particles consisting mainly of cellulose and pectin, and yeast cells, in addition to proteins, mineral salts, and some organic acids (Cedeño 1995). Solids separation is a common primary wastewater treatment. One such technology is ionic transfer using polymers where fine particulates typical of vinasses could be coagulated and flocculated.

Coagulation is a process of gathering solids that are suspended in a liquid into a mass to form particles that can settle. Flocculation is a process that connects coagulated particles into large, rapidly settling masses, also called flocks.

Solids separation may yield a value-added bioresource that may be used as fodder feed (Íñiguez *et al.* 1996, 2000). Therefore along with the solids, there is a significant capture of organic nutrients and oxygen-demanding compounds associated with the clumping of the small suspended particles that usually escape through screens or clog sand filters.

Also coupling solid-liquid separation with composting of solids and sprinkler irrigation of the liquid component of vinasses may be an acceptable disposal strategy. Íñiguez *et al.* (2005) composted agave bagasse with vinasses (including solids) and the compost product had no adverse effects on seedling emergence, relative growth, *in vitro* germination and root elongation of cucumber seeds. Polyacrylamide (PAM) polymer has been used as primary coagulant to promote the formation of aggregates in liquid swine manure. Walker and Kelly (2003) for instance, evaluated the efficiency of a polyacrylamide (PAM) flocculate-aided solids separation treatment to reduce pollution indicator concentrations in raw (untreated) swine waste slurry.

Results indicated that polymer amendments at concentrations of 62.5-750 mg/L improved slurry solids separation efficiency and significantly reduced concentrations of other associated aquatic pollution indicators in a majority of analyses conducted.

Martinez-Almeda J. and Barrera (2005), using polymer technology (PAM) reached high recovery solids (90 %) in liquid swine manure. Vanotti *et al.* (2005), using also PAM in liquid swine manure, reported efficiency removal of 98 and 84 % of total suspended solids (TSS) and COD respectively.

The goal of this work was to demonstrate the efficacy of PAM to remove organic compounds from tequila vinasses samples especially those compounds causing sedimentation problems and facilitate further vinasses treatment and/or utilization in sprinkler irrigation.

MATERIALS AND METHODS

This project consisted of three experiments designed to evaluate the practicality of using a cationic polyacrylamide (PAM) polymer flocculant (SNF Floerger®, France; the PAM bulk viscosity was 1140 cps, the UL viscosity was 4.6 cps, and the non volatile solids was 48.7 %) to remove organic compounds from tequila vinasses samples.

The tequila vinasses samples chosen for analysis represented vinasses generated from small tequila factories up to highly technified tequila factories. In a first experiment using a jar test methodology a factorial design of two factors with 10 treatments and three replicates for each treatment was used to observe the effects of PAM on some constituents of vinasses. One factor was the polymer flocculant at five levels of concentration (20, 60, 100, 140, and 180 mg/L) and the other factor was temperature at two levels 25 and 90 °C.

Settleable solids (SS), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD) and recovered flocculated solids were the evaluated parameters. COD was chosen to measure organic load rather than BOD due to high temperatures of discharged vinasses (90 °C) to affect BOD results.

Vinasses sub-samples of 500 mL were dispensed into 1000 mL glass beakers and mixed with appropriate amounts of PAM.

Mixing with a Hach® six-paddle, adjustable speed jar test apparatus (Hach Company®; Loveland, CO) was initiated at approximately 30 revolutions per minute (rpm) and maintained for 10 min to accomplish thorough mixing and to allow particle coagulation and flocculant (flock) formation (flocculation). During this 10 min appropriate amounts of PAM were added to reach the desired final concentration.

In a second experiment vinasses from different tequila factories were treated with 200 mg/L of PAM and the flocculated solids separated in a pilot-scale cylindrical rotating screen separator constructed of oxidized steel (63 cm diameter, 1.22 m length) with 2 mm openings. (**Fig. 1**).

Fig. 1. View of pilot-scale cylindrical rotating screen for separation of vinasses flocculated solids

The screen rotated on rollers attached to parallel drive shafts. Power to the two shafts was provided by a 0.5 hp gear reduction motor assembly. In a third experiment a flocculation study was carried out in a small tequila factory using 4.500 liters of tequila vinasses treated with 200 mg/L of PAM discharged from three different pot stills (1,500 litters each).

The flocculant was added in the moment of vinasses discharge. Treated vinasses were discharged into a holding pit were supernatant was removed by pumping and the flocculated solids separated in the same pilot-scale cylindrical rotating screen used in the second study.

Chemical analysis

Settleable solids (SS, mL/L), total solids (TS, mg/L), total suspended solids (TSS, mg/L), total dissolved solids (TDS, mg/L) and chemical oxygen demand (COD, mg/L) concentrations were determined for both raw and PAM-amended tequila vinasses according to APHA (1992). Vinasses pH values were determined using a HANNA pH meter, model 211 (HANNA Instruments, Portugal) in standard 0 to 14 pH scale units. Adjustment of pH was not considered to be necessary for optimal PAM flocculation efficiency by the manufacturer. Removal efficiency of TS, TSS, TDS and COD were calculated based on the concentration of the contaminants in samples of completely mixed vinasses without polymer flocculant in comparison to the concentration in the supernatant of treated samples after allowing the vinasses to settle for 45 minutes.

For settleable solids, the removal efficiency was calculated based on the concentration in samples of completely mixed vinasses without polymer flocculant in comparison to the concentration after the flocculated solids removal.

Statistical analyses

Results were subjected to analysis of variance for a completely randomized two factor factorial design followed by the LSD test at $p < 0.05$ (Montgomery 1991).

RESULTS AND DISCUSSIONS

Table I shows the average treatment performance of solid-liquid separation process using five PAM concentrations (20, 60, 100, 140 and 180 mg/L) at two different temperatures (25 and 90 ^{o}C). The non PAM treated vinasses sample had a SS content of 150 ml/L, and a TS, TSS, TDS and COD concentrations of 26,267, 5,280, 20,987 and 43,228 mg/L, respectively. In SS concentration of treated vinasses there was a significant effect ($p<0.05$) due to temperature and PAM concentrations, as well as an interaction between both factors.

At 25 and 90 °C, the SS removal efficiency was about 90 % or more for PAM concentrations of 60, 100, 140 and 180 mg/L. At 25 °C for the PAM concentration of 20 mg/L the SS removal efficiency was about 52.5 % while at 90 °C the SS removal efficiency was about 81.3%.

At 90 °C, an SS removal efficiency of about 97.9 % or more was reached for PAM concentrations of 60, 100, 140 and 180 mg/L.

TS concentration in vinasses samples were affected by the temperature and PAM concentrations. For higher PAM concentrations, higher values of TS removal efficiency ($p<0.05$).

TS removal efficiency was influenced by the temperature and PAM concentration and there was no interaction between the temperature and coagulant concentration ($p<0.05$) were seen.

TSS removal efficiency of about 76 % or more were reached at 90 °C and 100, 140 and 180 mg/L of coagulant concentration. COD concentration in

TABLE I. AVERAGE TREATMENT PERFORMANCE OF SOLID-LIQUID SEPARATION PROCESS USING FIVE PAM CONCENTRATIONS (20, 60, 100, 140 AND 180 g/L) AT TWO DIFFERENT TEMPERATURES (25 AND 90 °C)

Analyses	PAM concentrations (mg/L)					
	0	20	60	100	140	180
At 25 °C						
Settleable solids (SS, ml/L)	150[a]	71.3(52.5)[1b]	8.6(94.2)[cd]	9.7(93.5)[acd]	15(90)[c]	6.6(95.6)[d]
Total solids (TS, mg/L)	26,267[a]	24,683(6.0)[b]	23,700(9.7)[c]	22,925(12.7)[d]	22,716(13.5)[e]	21,908(16.6)[f]
Total suspended solids (TSS, mg/L)	5,280[a]	3,600(31.8)[b]	2,266(57.1)[c]	2,011(61.9)[cd]	1,978(62.5)[cd]	1,555(70.5)[d]
Total dissolved solids (TDS, mg/L)[2]	20,987	21,083	21,434	20,914	20,739	20,353
Chemical oxygen demand (COD, mg/L)	43,228[a]	39,338(9.0)[b]	36,785(14.9)[c]	36,146(16.4)[c]	33,421(22.7)[c]	32,881(23.9)[c]
At 90 °C						
Settleable solids (SS, ml/L)	150[a]	28(81.3)[b]	3.1(97.9)[cd]	1.6(98.9)[acd]	0(100)[c]	0.2(99.8)[c]
Total solids (TS, mg/L)	26,267[a]	25,450(3.1)[b]	24,500(6.7)[c]	23,808(9.3)[d]	22,700(13.6)[e]	21,858(16.8)[f]
Total suspended solids (TSS, mg/L)	5,280[a]	2,644(49.5)[b]	1,555(70.5)[c]	1,222(76.8)[cd]	1,222(76.8)[cd]	955(81.9)[d]
Total dissolved solids (TDS, mg/L)	20,987	22,806	22,945	22,586	21,478	20,903
Chemical oxygen demand (COD, mg/L)	43,228[a]	36,528(15.5)[b]	35,855(17.0)[c]	33,422(22.7)[c]	33,504(22.5)[c]	33,837(21.7)[c]

[1]Removal efficiency(%)

[2]TDS were calculated by difference of TS and TSS.

[a, b, c, d, e, f]Values followed by the same letter in a given row do not differ at $p \leq 0.05$ by LSD test

vinasses samples, was affected only by the coagulant concentration, there was no interaction among temperature and coagulant concentration ($P<0.05$). At 25 °C, COD removal efficiency was between 9.0 and 23.9 % and at 90 °C between 15.5 and 21.7 %, depending on PAM concentrations, higher PAM concentration imply higher COD removal.

In summary it can be seen, that the major effect in the PAM addition to vinasses samples in the two different temperature conditions, was reflected in the removal efficiency of SS and TSS, due to this, TDS concentrations were almost the same.

Table II shows the treatment performance of solid-liquid separation process using vinasses from 5 different tequila factories. 300 liters of vinasses were treated with 200 mg/L of PAM except for vinasses from "Leyros" tequila factory, that received 400 mg/L of PAM (two times, 200 mg/L each one) due to high solids concentration.

In vinasses treated with 200 mg/L of PAM the SS removal efficiency was between 95.1 % ("La Rojeña") and 100 % ("Cascahuin"), TS removal efficiency between 10.6 % ("Cascahuin") and 25.6 % ("La Noria"), TSS removal efficiency between 64.8 % ("La Rojeña") and 93.4 % ("Evolución 501") and COD removal efficiency between 12.7 % (Cascahuin) and 38.6 % ("La Noria").

As expected, recovered flocculated solids were higher for vinasses with higher SS concentration. In "La Noria" tequila factory with a vinasses SS concentration of 400 mL/L, 37.6 kg of flocculated solids with a dry matter content of 5% were recovered, while in vinasses form "Cascahuin" tequila factory with a vinasses SS concentration of 72 mL/L, only 11.2 kg of flocculated solids with a dry matter content of 10.4% were recovered.

It is not easy to take a representative sample of vinasses mainly by its high temperature (90 °C) and because at the end of the distillation process the vinasses solids settle in the bottom of the pot stills.

Different vinasses solids concentration and COD for the five different tequila factories sampled was due to that and also to different technological development used to produce tequila.

The high solids content and COD of vinasses form "Leyros" tequila factory was noticed, because samples were taken from a vinasses deposit and not from pot stills.

A first dose of 200 mg/L of PAM to vinasses of "Leyros" tequila factory reduced the concentrations of SS, TS, TSS and COD in 72.2, 28.5, 46.1 and 18.8 %, respectively.

A second dose also of 200 mg/L reduced the concentrations of SS, TS, TSS and COD in 99.3, 49.5, 90.2 and 52 %, respectively.

Based on results generated by this study, for vinasses with a SS of 400 mg/L or less an addition of 200 mg/L of PAM, should have optimal removal values of SS and relatively acceptable values of TS, TSS and COD.

TABLE II. VINASSES SOLIDS AND COD CONCENTRATION REDUCTION TREATMENT EFFICIENCY WITH 200 mg/L PAM ADDITION OF DIFFERENT TEQUILA FACTORIES. PILOT STUDIES

Analyses	Tequila factory										
	"La Noria"		"La Rojeña"		"Leyros"			"Cascahuin"		"Evolución 501"	
	before treatment[a]	after treatment	before treatment[b]	after treatment	before treatment[c]	after treatment	after treatment[1]	before treatment[d]	after treatment	before treatment[e]	after treatment
pH	3.6	3,6	3.6	3.6	3.5	3.5	3.5	3.9	3.9	3.5	3.5
Settleable solids (SS, ml/L)	400	5(98.7)[2]	350	17(95.1)	900	250(72.2)	6(99.3)	72	0(100)	200	0.5(99.7)
Total solids (TS, mg/L)	21,883	16,283(25.6)	29,300	22,216(24.1)	56,900	40,700(28.5)	28,700(49.5)	41,578	37,144(10.6)	28,431	21,394(24.7)
Total suspended solids (TSS, mg/L)	6,400	1,133(82.3)	10,266	3,616(64.8)	26,666	14,000(46.1)	2,600(90.2)	8,950	2,750(69.3)	6,400	421(93.4)
Total dissolved solids (TDS, mg/L)	15,483	15,150(2.1)	19,034	18,600(2.3)	30,234	26,700(11.7)	26,100(13.7)	32,628	34,394	22,031	20,973(4.8)
Chemical oxygen demand (COD, mg/L)	43,541	26,704(38.6)	48,230	39,857(17,3)	74,414	60,452(18.8)	35,700(52.0)	73,692	64,340(12.7)	44,116	32,351(26.6)
Recovered flocculated solids (kg)[3]		37.6 (5 % DM)		30.6 (7.5 % DM)		39.6 (9.2 % DM)	49.1 (12.0 % DM)		11.2 (10.4 % DM)		12.1 (9.3 % DM)

[a]25 ºC, [b]48 ºC, [c]35 ºC, [d]70 ºC, [e]75 ºC, respectively
[1]With 500 mg/L PAM adition
[2]Removal efficiency(%)
[3]In 300 treated liters

An excess in the addition of PAM can contribute to form a sticky flock difficult to handle in the separation process. However, as in the case of "Leyros" tequila factory where we had a high solid vinasses concentration, it can contribute to an inefficient solids removal for lack of PAM, that means, for each tequila factory, it will be necessary to adjust the optimum PAM addition to achieve the maximum removal of solids and COD.

Table III shows the average treatment performance of solid-liquid separation process in a small tequila factory using 200 mg/L of PAM concentration to treat 4,500 liters of vinasses. This amount of vinasses were discharged every two hours from three pot stills distilling fermented wort. Removal efficiency of SS, TS, TSS and COD was 100, 19.1, 94 and 15.7 % respectively. Total dissolved solids increased from 25,999 to 35,313 mainly due to SS and TSS removal where PAM has its principal effect. From this tequila factory were recovered 357 kg of flocculated solids were recovered with a water content of 83.4%, which corresponds to 79.3 g of flocculated solids per liter of vinasses. Estimate costs associated with the level of PAM used in this study corresponded to 0.076 dollar per liter when the PAM cost was 3.8 dollar per kilogram. Vinasses separated solids may yield a value-added bioresource that may be used as fodder feed or composting amendment due to its retained nutrient content and reduced water content.

Nowadays the tequila production process is not the same in all tequila factories. It can vary from 100 % agave tequila production to 49 % by weight of other sources of sugars. Also, the process can vary in the way of hydrolyzing inulin (agave sugar) into free sugars. Some factories use brick ovens or autoclaves for cooking the agave heads. Others tear uncooked agave heads first, using a knife cutter, and place the resulting pieces, mixed with water, into autoclaves to be cooked. Finally others tear uncooked agave heads into small pieces to extract the inulin with hot water. The extracted inulin is then hydrolyzed in autoclaves. For those reasons, vinasses chemical characteristics, mainly settleable solids and total solids content, will depend on the tequila production process. To establish a standard flocculant dose to be used for treatment of all vinasses resulting from different production processes, constitutes an incalculable risk.

The results of this research intend to serve as a guide for establishing a flocculant dose geared at a specific tequila factory vinasses treatment. Based on these results each tequila factory will have to establish its own specific dose for the vinasses treatment according to chemical analysis and desired solids removal efficiency. Lack of flocculant can result in an inefficient solids separation and an excess can give a sticky flock difficult to recuperate.

In the second and third experiments 200 mg/L of PAM were used to make sure that the efficiency of separation, mainly of settleable solids, would not be affected by a lack of flocculant as in the experiment with Leyros tequila vinasses, where the addition of 300 mg/L of PAM was required to remove 99.3 % of settleable solids and 49.5 % of total solids in comparison to 72.2 % of settleable solids and 28.5 % of total solids when 200 mg/L of PAM were used.

TABLE III. VINASSES SOLIDS AND COD CONCENTRATION REDUCTION TREATMENT EFFICIENCY WITH 200 mg/L PAM ADDITION OF "CASCAHUIN" TEQUILA FACTORY. SMALL COMMERCIAL SCALE

Analyses	"Cascahuin" Tequila factory before treatment[a]	after treatment
pH	3.9	3.9
Settleable solids (SS, ml/L)	284	0.0(100)
Total solids (TS, mg/L)	45,037	36,445(19.1)
Total suspended solids (TSS, mg/L)	19,038	1,132(94.0)
Total dissolved solids (TDS, mg/L)[2]	25,999	35,313
Chemical oxygen demand (COD, mg/L)	38,215	32,047(15.7)
Recovered flocculated solids (kg)[3]		357 (16.6% DM)

[a] 90 °C

CONCLUSIONS

In the first experiment using jar-test methodology, at 25 and 90 °C, the SS removal efficiency was about 90 % or more for PAM concentrations of 60, 100, 140 and 180 mg/L. TS removal efficiency was affected by temperature and PAM concentrations. TS removal efficiency increased with PAM concentration. At 90 °C and with PAM concentrations of 20 and 180 mg/L, ST removal efficiency was 3.1 and 16.8 %, respectively. At 25 °C, COD removal efficiency was between 9.0 and 23.9 % and at 90 °C between 15.5 and 21.7 %, depending of PAM concentrations, COD removal also increased with PAM concentration.

In vinasses from different tequila factories treated with 200 mg/L of PAM, the SS removal efficiency was between 95.1 % ("La Rojeña") and 100 %

("Cascahuin"), TS removal efficiency between 10.6 % ("Cascahuin") and 25.6 % ("La Noria"), and COD removal efficiency between 12.7 % ("Cascahuin") and 38.6 % ("La Noria").

The flocculated solids were successfully separated in a pilot-scale cylindrical rotating screen with 0.2 mm openings.

Estimated costs associated with the level of PAM used in this study correspond to 0.076 dollar per liter for a PAM cost of 3.8 dollar per kilogram.

The results obtained support the hypothesis that solids separation from tequila vinasses can be enhanced by use of a chemical polymer (PAM) flocculation treatment. Vinasse cooling and pH adjustment was not considered necessary for optimal polymer amended vinasses solids separation. However, results suggest that PAM-aided solids separation facilitates further effluent treatment and may therefore reduce the risk of environmental degradation following solids composting.

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