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Anaerobically Treated Wastewater in Agricultural Irrigation as an Alternative for Posttreatment in Water-Demanding Zones

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Abstract

Agroindustries usually produce high amounts of wastewaters and are frequently located close to agricultural activities. Agricultural use of treated wastewaters therefore represents a unique opportunity to solve the problem of water supply for irrigation and disposal of treated water at the same time. This article is the result of collaborative work with the biggest Chilean pisco- (a distillated drink prepared from Muscatel wine) producing company at present. Experiments were conducted to establish anaerobic treatability of wastewaters and also irrigation properties of treated water. With the purpose of confirming laboratory results, a full-scale anaerobic plant was built, and treated water is being used to irrigate 3000 eucalypti. The results showed, at both laboratory and full scale, that anaerobic treatment is suitable for the treatment of pisco wastewater, and that nutrient content of treated water can be beneficial for plant growth, reducing the need for fertilizers.

Index Entries: Pisco; anaerobic digestion; vinasses; irrigation; fertilization.

Introduction

The water supply problem represents an important and unfinished task for developing countries, which should be solved in the near future. Several challenges as well as opportunities to solve them are at hand. Problems such as adequate treatment and disposal of agroindustrial wastewaters and search for water sources for irrigation can, with the selection of the right technology, be related and confronted at the same time. In the search for this technology, anaerobic digestion appears as an interesting alternative, since it has proven to offer a suitable treatment for a wide

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spectrum of industrial wastes *(1,2)*. In addition, anaerobically treated wastewaters can be used for irrigation purposes, because they generally contain an important amount of nutrients (such as phosphorus and nitrogen), which can be profitable for agriculture. Thus, anaerobic treatment of agroindustrial wastewaters and their utilization for irrigation can solve different types of problems. For example,

1. An adequate treatment of wastewater is provided, reducing the environmental impact of pollutants.
2. Posttreatment is not necessary since the presence of nutrients is in fact desired. Nutrient content in treated wastewater reduces fertilizer requirements.
3. Problems related to correct disposition of treated water are solved.
4. The necessary amount of water is available for irrigation, at no cost.

Usually a high amount of water is required for agroindustries. Washing operations are common and produce an important amount of wastewater. Additionally, they are quite often located close to agricultural activities. This represents a potential opportunity for irrigation using treated waters.

Many of these considerations are applied to the Chilean pisco industry. Chilean pisco is an aged drink, prepared by distillation of wine made mainly from Muscatel grapes. As in any distillation process, it produces high concentrated wastewaters: vinasses originated as a residue from distillation operation. Residual process waters from cleaning operations of maceration, sedimentation, and fermentation tanks are also generated.

By analyzing the Chilean pisco industry's characteristics, it is quite clear that this activity offers a great opportunity for taking advantage of almost all positive properties of anaerobic digestion for wastewater treatment: biogas can be used in steam production, which is required for distillation; sludge can be employed for soil improvement for agricultural purposes; treated waters can be used for agricultural irrigation. This last point is extremely important in the case of Chilean pisco since water availability is low in the region where pisco is produced. Finally, the ability of anaerobic digestion to be stopped for long periods of time is also valuable since the pisco industry has almost no activity or waste generation for 3–5 mo/yr.

The present study deals with the application of anaerobic digestion processes for treatment of wastewater from the Chilean pisco industry, focusing on benefits related to the reuse of treated water for irrigation purposes. We present a 3-yr summary of collaborative work with the currently main Chilean pisco-producing company. Since wastewater characteristics of the pisco industry are special, the results of this investigation cannot be directly extended to other agroindustries, but they do reveal an important field of application where research can be conducted in the near future.

Table 1
Laboratory Reactor Dimensions

	UASB	EGSB
Volume (L)	4.5	4.7
Diameter (cm)	10	6
Height (cm)	60	160
Height/diameter relation	6	27

Table 2
Characterization of Vinasses

Parameter	Value
Total COD	37,800 mg/L
Soluble COD	34,400 mg/L
Biochemical oxygen demand	13,500 mg/L
Total solids	25,226 mg/L
Volatile solids	20,588 mg/L
Total suspended solids	1526 mg/L
Volatile suspended solids	1495 mg/L
Acidity	1719 mg $CaCO_3$/L
pH	3.0

Materials and Methods

Operation of Laboratory Reactors

Two 5-L laboratory reactors, an upflow anaerobic sludge bed (UASB) and an expanded granular sludge bed (EGSB), were used to study the anaerobic treatability of the wastewater. The reactors' dimensions are listed in Table 1. EGSB and UASB reactors were operated at superficial liquid velocities of 7 and 0.8 m/h, respectively. These values were obtained applying different levels of recirculation rates. Both reactors were fed with wine vinasses, obtained periodically from the pisco industry. The vinasses were kept refrigerated at 4°C until used to feed the reactors. Table 2 presents the characterization of wine vinasses. Both digesters were seeded with anaerobic granular sludge from a full-scale UASB treating brewery wastewater. pH was controlled by the addition of sodium bicarbonate, at a concentration of 2.5 g/L. The reactors were operated at 30°C for 8 mo. All analyses were made according to standard methods *(3)*.

Agricultural Utilization of Treated Wastewater

Several experiments were performed to analyze irrigation properties of treated wastewater. Lemon nursery plants were used as a standard cultivation. Several irrigation regimes and fertilization degrees were tested, using water, wastewater, and anaerobically treated wastewater. Irrigation

Table 3
Experimental Conditions of Irrigation Experiments
in Which Fertilization Was Applied
for Each Type of Water and Level of Irrigation

	Irrigation (class A pan evaporation percentage)			
Type of water	100%	200%	300%	400%
Treated wastewater	No fertilization	No fertilization	No fertilization	No fertilization
	50	50	50	50
	100	100	100	100
	150	150	150	150
Untreated wastewater	100			
Normal water	100			

was determined as a class A pan evaporation percentage *(4)*. Fertilization was performed every 2 d through the irrigation water and weekly by foliar applications. It was determined as a percentage in relation to the standard requirements of a nursery plant. Table 3 presents the experimental conditions (levels of irrigation and fertilization) for the irrigation experiments. Four replicas of each condition were performed.

Supplementary experiments were carried out using different levels of dilution of treated wastewater (25, 50, 75, and 100%), in order to evaluate the effect of its salt content. An irrigation of 400% was used in these experiments.

The parameters obtained during plant growth were the following: growth of apical shut and diameter of stem at 20 cm height, in reference to the moment in which the plant is ready to be grafted (commercial factor); amount, pH, and electrical conductivity of water percolation; and class A pan evaporation (millimeters/day) to program daily irrigation.

The experiments were conducted for a period of 4 mo, and started 4 mo after the startup of the reactors in order to accumulate enough treated water. Treated water was maintained refrigerated until its utilization.

Full-Scale Implementation

Based on a complete wastewater characterization performed during grape harvest in 1998, a 60-m^3 UASB digester was designed and built in the smallest production plant of the pisco company. This reactor is considered full scale for this production plant because it was conceived to treat all wastewater generated, and also as a pilot installation for the company, since positive results can signify the application of this treatment technology for the rest of production installations.

The reactor was started up with sludge obtained from a full-scale UASB digester, treating brewery wastewater. During the startup period, the reactor was fed only with vinasses. Afterward it began to treat all waste-

Table 4
Average Operational Conditions
of Laboratory-Scale Reactors During Operation

	UASB	EGSB
OLR (g COD/[L·d])	20	20
COD removal rate (%)	93	89
Hydraulic retention time (d)	1.8	1.8
pH	6.7–7.0	6.7–7.0
Biogas production (mL/g removed COD)	490	490
Methane concentration in biogas (%)	65	65

water generated in the production plant. pH was controlled online by the addition of NaOH.

To study the use of treated water for agricultural applications, 3000 eucalypti were planted in a terrain beside the production plant. Corn was also planted with the purpose of serving as support for growing trees. The growth of this tree plantation is being followed to confirm results obtained in laboratory experiments.

Results and Discussion

Operation of Laboratory Reactors

Operation of laboratory anaerobic reactors showed applicability of anaerobic digestion processes for the treatment of the Chilean pisco industry's wastewater. After a 5-wk period of startup, the reactors were able to treat an organic loading rate (OLR) of 20 g of chemical oxygen demand (COD)/(L·d), which was maintained during the study. Table 4 shows the main operational conditions for both reactors over its operation. High biogas production was observed in both reactors, being close to 500 mL/g of removed COD. Considering that methane concentration in biogas was 65%, this means that about 90% of the inlet COD was transformed into methane.

Growth of acidogenic biomass over EGSB digester granules generated problems during the reactor operation: granules became less dense, producing a continuous sludge washout. This can be appreciated in Fig. 1, which shows the solid content of granules from both reactors after 120 d of operation. Granules from the EGSB reactor present a lower solid content in comparison with UASB granules. This phenomenon seems to be related to the content of nonacidified organic matter, and it can seriously affect operation of EGSB reactors *(5–7)*. To maintain a constant sludge concentration in the EGSB reactor, seed sludge was continuously added during its operation. The UASB reactor presented a much more stable operation. As a result of this, as well as lower investments and operational costs, the UASB digester was chosen as the most appropriate treatment technology.

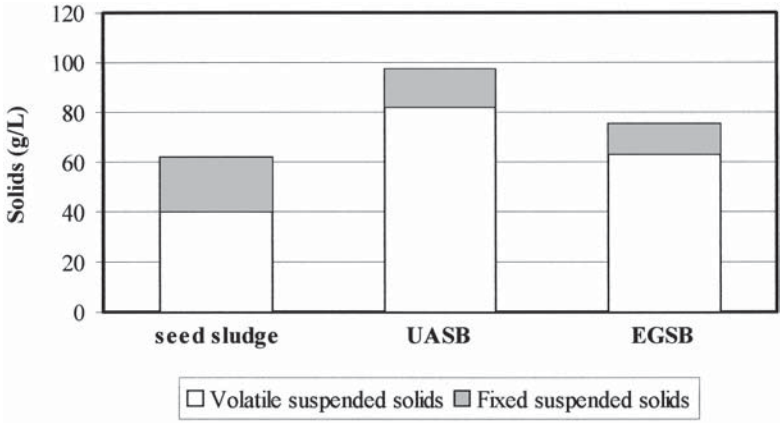

Fig. 1. Solids content of seed sludge and laboratory reactor sludge after 120 d of operation.

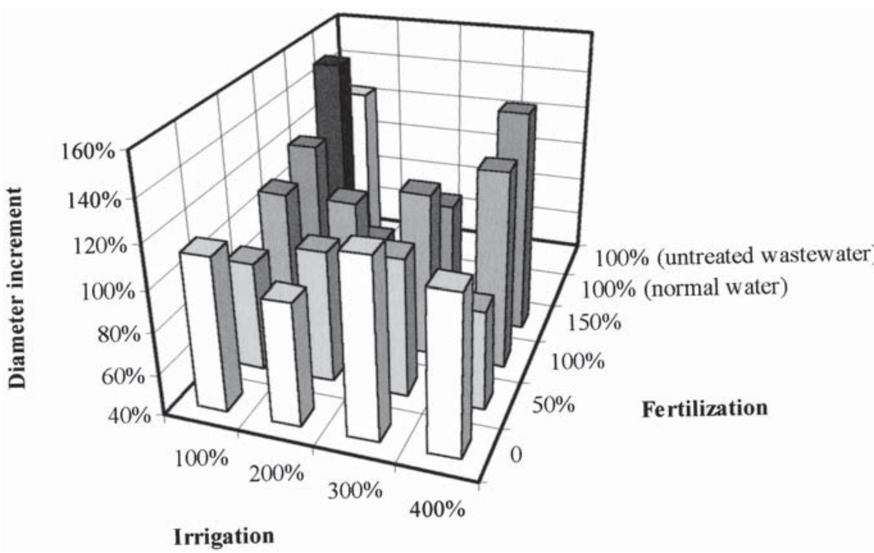

Fig. 2. Influence of percentage of irrigation and fertilization on increment in stem diameter of nursery plants.

Agricultural Utilization of Treated Wastewater

Experiments conducted to establish the possibility of using treated water for agricultural purposes showed good results. Figures 2 and 3 present the influence of irrigation regimes and fertilization levels on the nursery's plant growth, expressed as the percentage of increment in the diameter and height of the plants throughout the experiment, respectively.

Analysis of the measurements suggests that there is an effect of irrigation level on the diameter and height of the plants. The diameter of the plant shows a tendency to greater increments in those treatments that have a

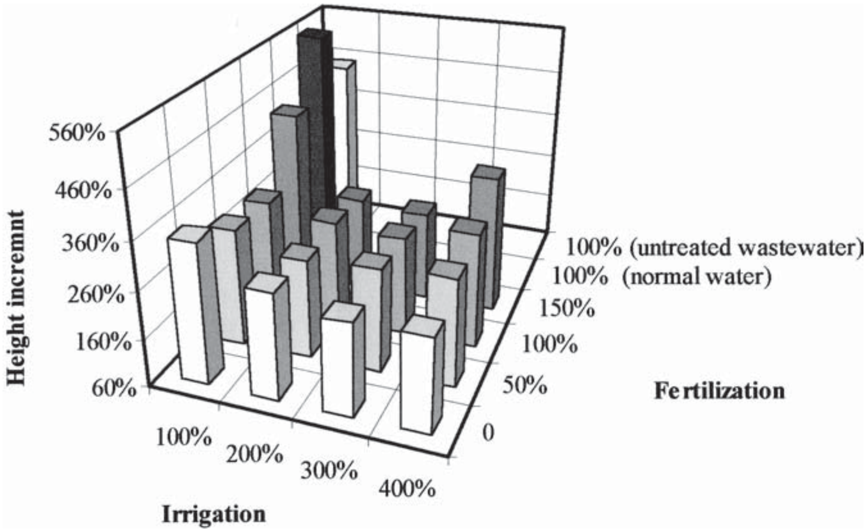

Fig. 3. Influence of percentage of irrigation and fertilization on increment in height of nursery plants.

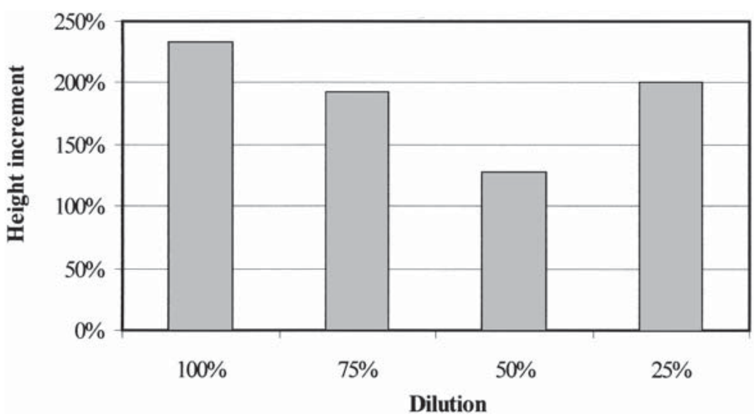

Fig. 4. Effect of treated wastewater dilution on plant height (a dilution of 100% corresponds to normal water).

100 and 150% complement of fertilization and in the endowment of water with 100 and 400% of pan evaporation (see Fig. 2).

Even though a tendency to increase the height of the plant as the water applied increases could be expected, a higher accumulation of sodium is also produced, which counterchecks this tendency (see Fig. 4). A high concentration of this ion is known to produce a notorious damage to the plant leaves, a phenomenon that was observed in the experiments. This observation is supported by the fact that the treated water presented an important content of sodium owing to pH control.

Dilution of treated water did not show a clear effect on plant height (Fig. 4). However, it is clear that dilution had an effect on the diameter of

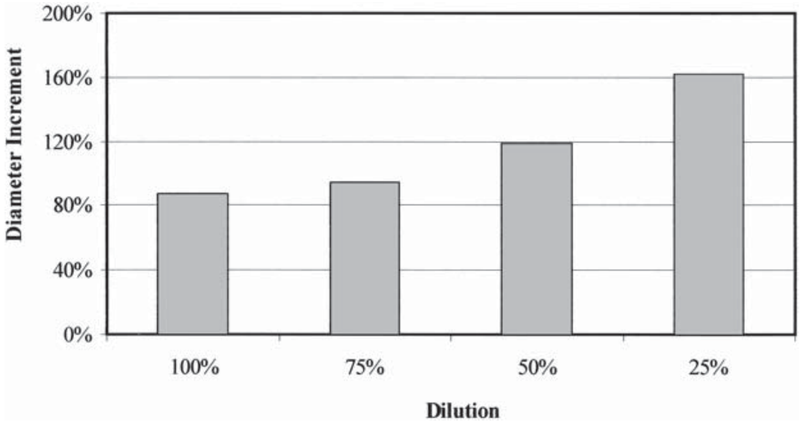

Fig. 5. Effect of treated wastewater dilution on plant diameter (a dilution of 100% corresponds to normal water).

Table 5
Characterization
of Anaerobic Granular Sludge

Parameter	Value
Nitrogen	5.29%
Phosphorus	1.45%
Potassium	0.32%
Calcium	4.5%
Magnesium	0.42%
Zinc	293 ppm
Manganese	182 ppm
Iron	13,031 ppm
Copper	365 ppm
Boron	8.16 ppm

plants (Fig. 5). There was a tendency to an increment of the diameter as treated water increased in proportion. This clearly means that a greater diameter was obtained as a result of higher levels of final salinity in the irrigation water. This is an important factor for nurseries because the aim is to obtain the maximum diameter as soon as possible in order to graft the plants earlier. This result can be related to a contribution in micronutrients of treated water.

The results show that agricultural use of anaerobically treated wastewater is possible, by putting its nutrient content to good use (nitrogen, phosphorus). Therefore, nitrogen can remain associated to life forms, also reducing utilization of foreign fertilizers and avoiding the need for post-treatment steps (nitrification-denitrification).

Table 5 presents the characterization of anaerobic granular sludge. Its composition provides an important nutritional content (N, P, Ca, Mg),

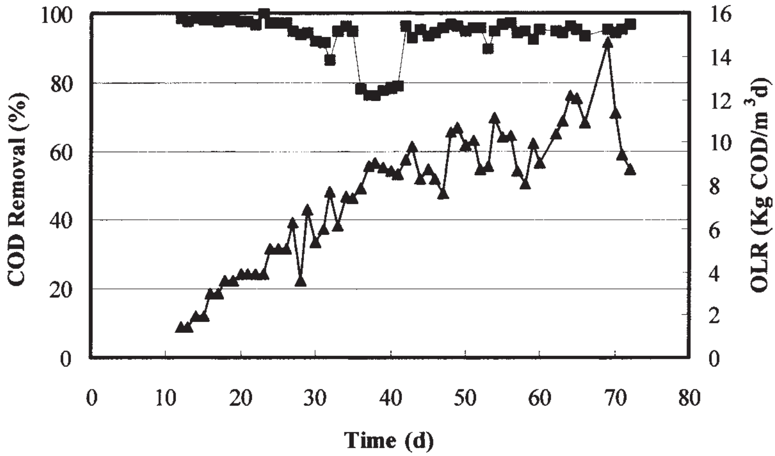

Fig. 6. OLR (▲) and COD removal rate (■) during startup of UASB reactor.

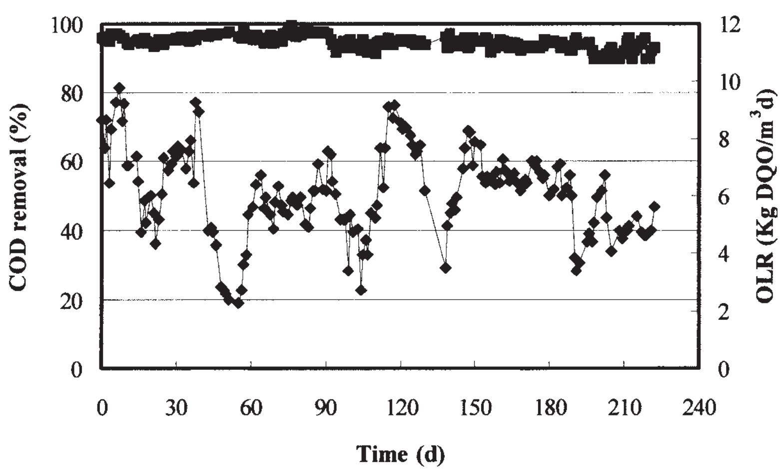

Fig. 7. OLR (◆) and COD removal rate (■) during operation of UASB reactor.

indicating that it could be used for soil improvement. Preliminary results (not shown) of an investigation that is being carried out in the agronomy faculty verify that hypothesis.

Full-Scale Implementation of UASB Reactor

The construction of the UASB reactor was finished in November 2000. The startup procedure took place for approx 75 d. Figure 6 presents the OLR and the COD removal during the startup of the UASB reactor. From day 36 to 41 there was a decrease in the COD removal owing to the discharge of slurry from sedimentation operation. It produced an increment (not measured) in the total solids content, changing the characteristics of the wastewater. Once this discharge was finished the COD removal recovered. Figure 7 presents the reactor operation for the following 8 mo.

High levels of COD removal were attained during this entire period (close to 95%).

During the first weeks after plantation of trees, some problems were detected on the leaves. This problem was related to the high sodium content of the treated water, resulting from the use of NaOH for pH control, a situation that was also detected during laboratory experiments. The utilization of sodium hydroxide was close to 2 g/L, during the first weeks of startup. At OLRs >6 kg of COD/(m^3·d), biogas production was great enough to provide an important level of alkalinity by CO_2 dissolution, and, therefore, the use of NaOH was considerably reduced (to less than 20% of its original value). Exposure of plants to high levels of sodium occurred for a short period of time and did not cause permanent damage to the trees. Nevertheless, this is a problem that should be seriously considered, especially during the digester startup period, or during operation at low values of OLRs.

Development of trees was completely normal. Rate of growth was the expected for a plantation in normal conditions. This is considered a good result; no fertilizer of any kind was used, and soil conditions were not adequate because the terrain of the tree plantation had been used for several years to dispose of wastewater by soil infiltration.

Conclusion

Anaerobic digestion is a suitable technology for treatment of wastewater generated during Chilean pisco production. This industry offers an opportunity to exploit all advantages of anaerobic digestion by wastewater treatment. Use of anaerobically treated wastewater for agricultural purposes is not only feasible, but also convenient because nutrient content of the treated wastewater can improve plant growth. This is of great importance for agroindustrial activities such as pisco production, because they generate high amounts of wastewater and are usually located close to agricultural activities. Anaerobic sludge also showed good nutritional levels, which means that it could be used for soil improvement. A negative effect of sodium on leaves was observed. This aspect should be taken into consideration in the alkalinity control system of anaerobic digesters.

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