Use of Anaerobic-Aerobic Treatment Systems for Maize Processing Installations: Applied Microbiology in Action

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Anaerobic and aerobic systems can be used to treat wastewater from the maize processes to obtain *tortillas*, and the byproducts derived from them can be further used giving an added value. For cornmeal industries (2500 m^3 per day or more), the anaerobic and the aerobic ones are compact and easy to operate. The savings in water by its recycling and in energy consumption by the use of the methane-rich biogas, wastewater disposal costs, and sale of biomass for fish protein-rich feedlots, make the treatment and recovery process economically feasible. The turnover rate is 1.5 years. For *nixtamal* mills, due to its size, it is not so economical to install an anaerobic-aerobic process for treating its wastewaters (between 500 L to 50 m^3 per day). An aerobic system is then used for these small establishments. In this case, partially treated wastewaters are sent to the municipal sewer system.

Keywords Maize wastewaters; anaerobic; aerobic; biofilm systems

Se pueden usar sistemas anaerobios y aerobios para tratar las aguas residuales de plantas que procesan maíz para producir *tortillas*, aprovechando los subproductos que se obtienen de ellos para darle un valor agregado a estos procesos. Para fábricas de harina de maíz *nixtamalizado* (2500 m^3 por día o más), los sistemas anaerobios-aerobios son compactos y fáciles de operar. Los ahorros por concepto de reciclado del agua y de consumos energéticos por el uso del biogas rico en metano así como por pagos de disposición de aguas residuales, así como por la venta de biomasa para dietas para peces ricas en proteína, hacen del proceso de tratamiento y recuperación un sistema económicamente viable. La tasa interna de retorno es de 1.5 años. Para los molinos de *nixtamal*, debido a su tamaño, no resulta económico instalar un proceso anaerobio-aerobio para tratar sus aguas residuales (de 500 L a 50 m^3 por día). Puede usarse un sistema aerobio para estos pequeños establecimientos y, en este caso, las aguas parcialmente tratadas se envían a la red municipal.

Palabras clave Aguas residuales de maíz; anaerobio; aerobio; sistemas de biopelícula o biofilm

1. Introduction

Corn or maize (*Zea mays*), an indigenous plant from Mexico, after the finding of the American continent by the Spaniards in the Fifteenth Century, spread all over the world and became a staple food for many human groups. Due to the globalization phenomena, one of the Mexican traditional maize products, "tortillas", are now an extremely popular food that can be found in most countries of the world. "Tortillas" are a sort of unleavened bread of circular form that, due to its mild flavor, can be combined

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with vegetables, meats, pulses, etc. They are the equivalent bread to "chapattis" for the people from India, "falafel" for the people of the Middle East, etc. The traditional production of "tortillas" involves a Precolumbian technique, known as "*nixtamalization*", from the Aztec words *nextli*=lime ashes and *tamalli*=cooked corn dough (Figures 1a,b). This ancient process, almost as old as the corn domestication and cultivation, is a time, water, and energy consuming technique (Figure 2).

Fig. 1a *Tortilla* prepared in the pre-Columbian manner using *metate* and *metlalpili* (grinding stones) and *comal* (cooking surface) [16].

Fig. 1b *Tortilla* machine to form and cook alkaline prepared maize dough [3].

Modernization of the traditional process to produce cornmeals instead of doughs to lengthen its shelf life as well as some other changes for mass production have been introduced in the last 50 years. However, as these changes affect the sensory characteristics of "tortillas", mainly "rollability", "sturdibility", and softness, it has been a common practice among big scale producers to introduce some chemical additives to make the new "supermarket tortillas" desirable from the sensory point of view. Unfortunately, from the nutritional point of view, it has not yet been proved that these additives are not affecting the health of the consumers. Some innovative processes that maintain these nutritional and sensory desirable characteristics, reducing at the same time, energy and water consumption, and most importantly, processing time, have also been developed and started to be used in some industries [1-4].

OPERATING CONDITIONS	*NIXTAMALIZATION*	
	Traditional	Modern
Processing Time, h	20	8
Water Consumption, Grain:Water Ratio	1:6	1:3
Wastewaters	5:1 (high BOD_5)	2:1 (extremely high BOD_5)
Energy Consumption	1 (Basis)	0.75

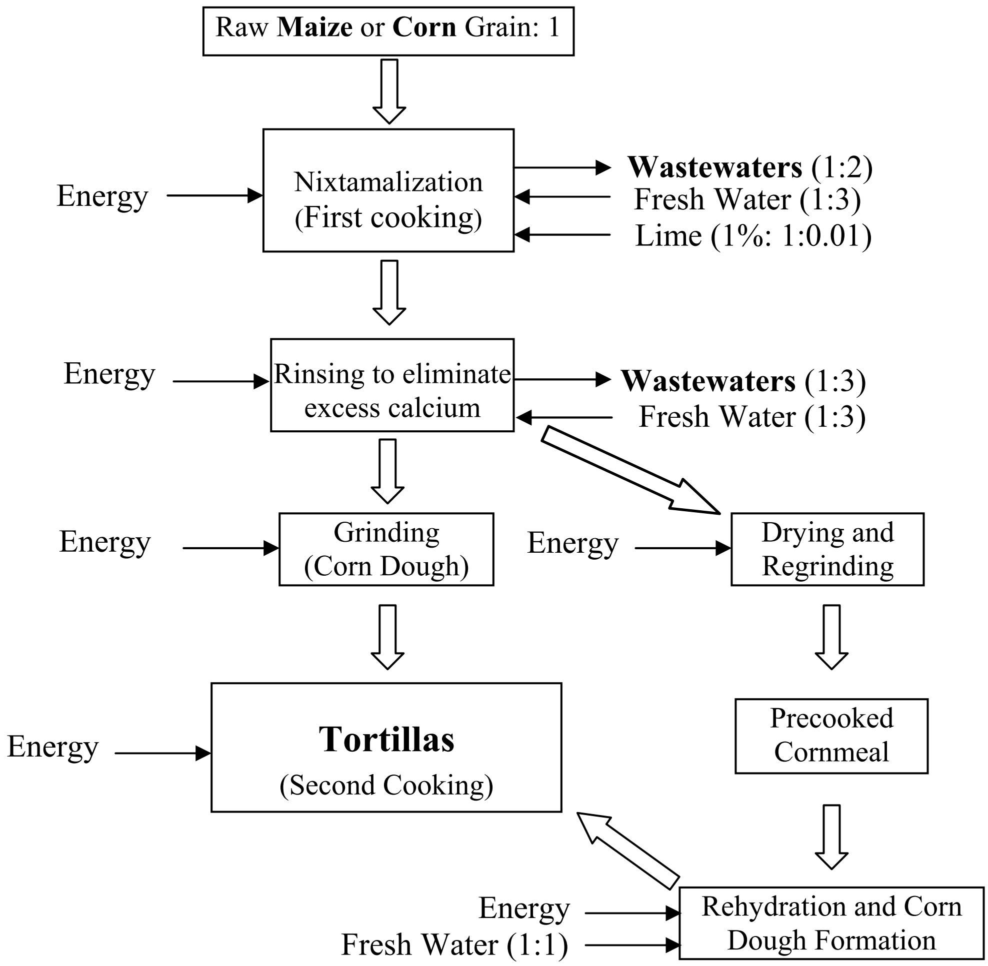

Fig. 2 Diagram for the traditional nixtamalización process [1].

However, as the traditional plants (more than 100,000 small scale and 25 large scale in Mexico) are still in operation, methods to treat and stabilize the wastewaters generated in the traditional process (socalled "*nixtamal*" mills that process around 0.5 to 4 metric tons maize per day) or in its industrial modifications (socalled precooked cornmeal or *masa-harina* factories, that process between 100 to 1,000 metric tons maize per day), that contain appreciable amounts of soluble and insoluble organic matter (Table 1) have also been developed. These methods are based in anaerobic and aerobic systems, and the interesting issue is that byproducts derived from the treatment can be further used, giving an added value to these treatment processes.

Research has been conducted to use anaerobic and aerobic systems, and the interesting issue is that byproducts derived from these treatment processes can be further used, giving an added value to these wastewater treatment systems.

Table 1 Maize lime-cooking (*Nixtamalization*) Wastewater Average Composition [5].

Characteristics	Average values	UE Normativity* for surface water
Suspended solids, kg/m^3	2.4-4.6	0.025 (25 mg/L)
Dissolved organic carbon, kg/m^3	3.0-5.0	-
Biochemical oxygen demand (5 days, 20°C), kg/m^3	1.5-3.0	<0.007 (7 mg/L)
Chemical oxygen demand (dissolved), kg/m^3	7.5-11.0	0.030 (30 mg/L)
Nitrogen (Kjeldahl), mg N/L as NO_3^-	80-270	1
Phosphates, mg PO_4^{-3}/L	7-18	0.4
pH Value	10-14	5.5-9.0
Color	Dark yellow	Colorless

*European Community: 16/6/75 (After physical and chemical treatment including disinfection)

2. Biological processes

Before studying the biological degradation of these wastewaters, primary settling tests to recover broken maize pieces and peelings were carried out [5,6]. The biological processes developed for clarified *nejayote* (the name given to these wastewaters, from the *Nahuatl* or Aztec language, meaning lime ashes broth), were screened out after testing at laboratory level [5].

These studied processes were those commonly used in wastewaters biological treatment. For the aerobic phase, these were activated sludge reactors, aerated lagoons, facultative lagoons, packed bed aerobic reactors, and rotating biological or biodiscs reactors. Once the different aerobic systems were tested, experiments were carried out with packed bed and biodiscs reactors at bench scale [6,7]. For the anaerobic phase, low and high rate anaerobic reactors as well as packed bed reactors, all at bench scale, were tested [6,7].

From the results obtained at laboratory or bench scale [6], a process was proposed and implemented at pilot or demonstration scale in a real cornmeal factory in Guadalajara, Mexico [7,8]. The first ones were performed with reactors from 200 mL up to 50 liters, and the demonstration scale was made with reactors up to 3000 liters.

A pre-factibility economical analysis was carried out to define the feasibility of the overall process [9,10].

3. Results and discussion

After primary settling tests to recover broken maize pieces and peelings, the anaerobic process was carried out to transform most of the biodegradable dissolved matter present in the wastewaters into methane-rich biogas. This process was followed by the aerobic one, that polishes the treatment and removes the traces of sulfide and other undesirable compounds in treated water and converts the remaining biodegradable matter into protein-rich biomass. A tertiary treatment using activated carbon or any organic adsorbent or polymeric membranes rendered recyclable water for the process. Results from the experiments in both laboratory and bench scales were corroborated with the prototype plant. The developed method for treating the wastewaters from maize alkaline processing to produce "tortillas" is shown in Figure 3. This process includes a physical separation of solid corn by-products (especially broken grains, pericarps, and other maize byproducts that have a nutritional added value.

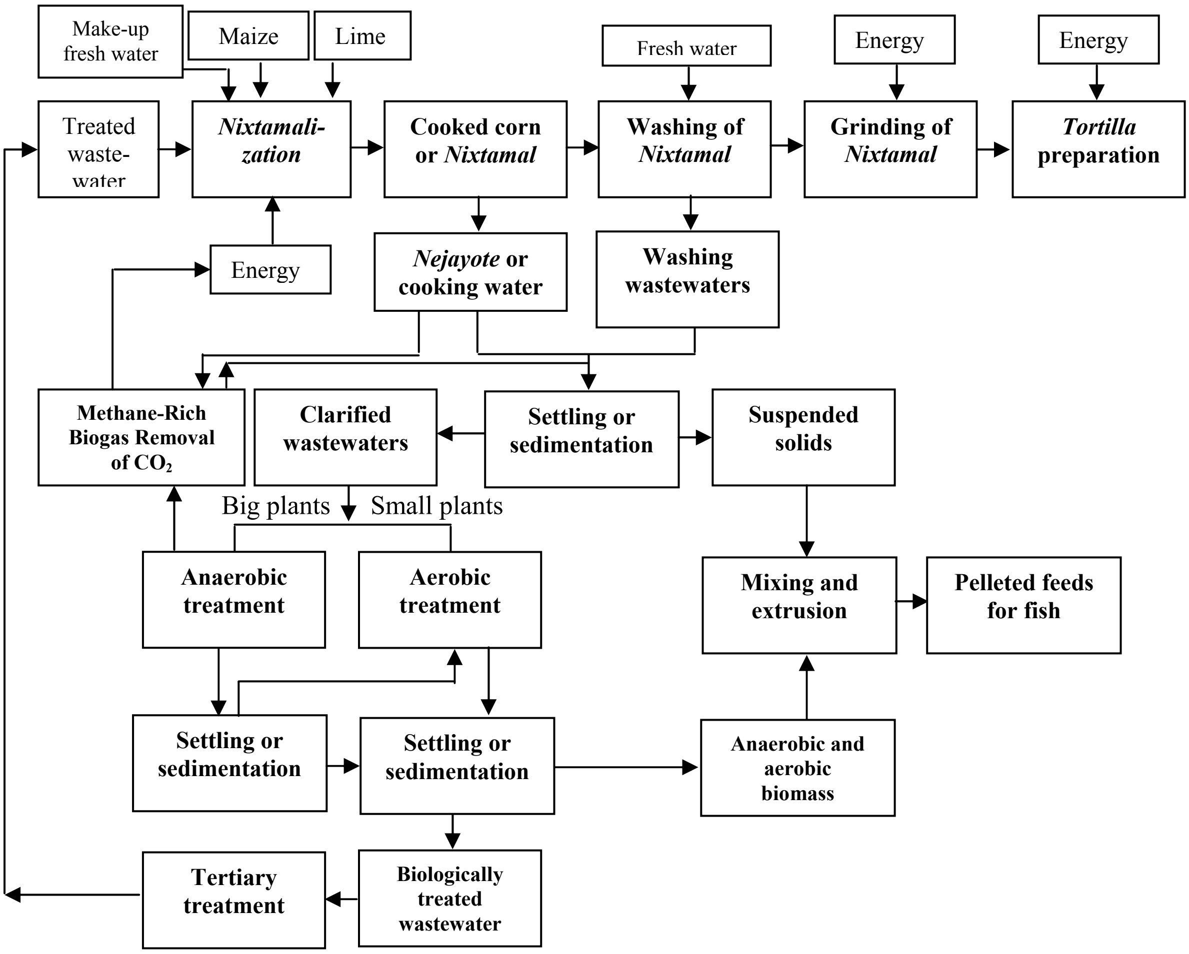

Fig. 3 Proposed process to recycle maize processing wastewaters using anaerobic-aerobic treatment for big nixtamalized cornmeal factories and aerobic treatment for small corn dough plants.

3.1 Big cornmeal processing plants

Particularly for those factories that process considerable amounts of corn (more than 500 tons per day) and generating important amounts of wastewaters (2500 m^3 per day), the anaerobic phase is very important to save energy. Thus, in these plants, an anaerobic treatment in high rate reactors, either packed bed type or upflow anaerobic sludge blanket reactors, depending upon the availability of granular anaerobic biomass is considered. Results indicated that the amount of methane from biogas obtained from the anaerobic treatment of the wastewaters is 9.6-16.8m^3 per metric ton of maize processed (considering 5 m^3 of wastewaters coming out per metric ton maize with a conversion of 80% of the dissolved biodegradable matter into biogas) [8,9].

For the anaerobic step, the packed bed anaerobic reactors or the upflow anaerobic sludge blanket reactors are the ones that render the highest conversion into methane-rich biogas at the lowest hydraulic residence times, between 24 and 48 hours. Effluent from the anaerobic phase is clarified to eliminate excess anaerobic biomass to be further used. If the biogas obtained roughly contains 80% methane, as occurred in these experiments both at bench and demonstration scales, the yield of this energy-rich gas is 7.7-13.48 m^3 methane per metric ton of maize processed [8,9]. This methane-rich biogas may be washed using the nejayote (that contains lime residues) producing a suspended solid of $CaCO_3$, eliminating the CO_2, and the remaining high purity CH_4 is compressed to be used as a secondary source of energy during the lime-cooking of corn grains (*nixtamalization*).

Clarified anaerobic effluent is sent to the aerobic treatment. For the aerobic step, the rotating biological or biodiscs reactors are excellent to transform the soluble remaining biodegradable dissolved and colloidal organics into aerobic biomass. The energy consumption for the rotational speed needed is very low since organics inflow is much lower than with untreated wastewaters and the area occupied by the reactors is also very low. This type of reactor produced protein-rich biomass that settled without problems in spite of the poor C:N ratio in the wastewaters thanks to the formation of a stable biofilm. The most suitable reactors to be used for this type of carbonaceous wastewater are those that develop active biofilms, particularly because the biomass formed tend to show more cohesion, and separate more easily from the liquid phase by sedimentation [8,9].

The recycling of the by-products generated is shown in Figure 3 too. The anaerobic and aerobic biomass and the maize byproducts suspended solids obtained can be processed with an extruder to form pellets or flakes for fish feedstuffs. Considering the mass balances from the aerobic and anaerobic processes these amounts are 23 kg suspended solids and 10.6 kg biomass per metric ton of maize cooked (dry basis). These solids, biomass and suspended solids, pellets or flakes proved to be comparable to mixtures of commercial feedlots for carps and other edible fish [9,10]. Figure 4 shows the results for carps fed with these pellets as protein partial supplement of their diet, particularly at a 50% addition.

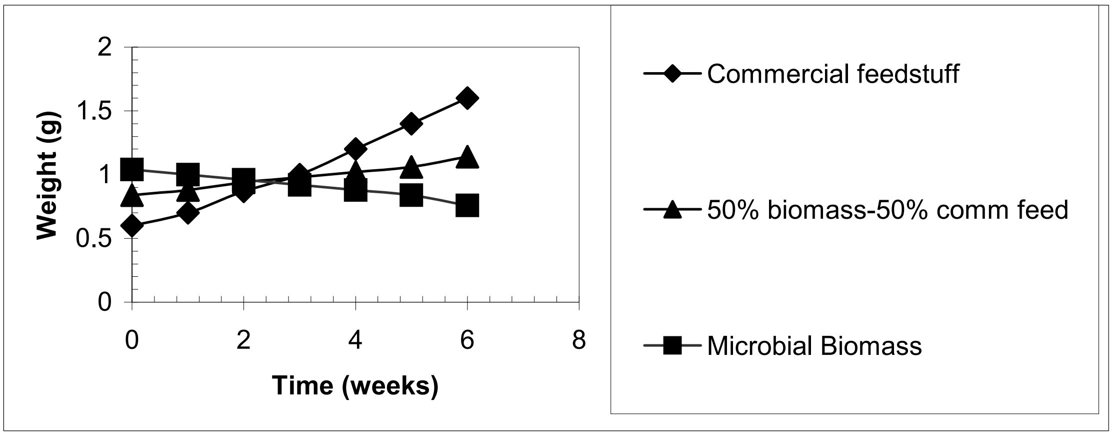

Fig. 4. Fish experiments using extruded by-products from nejayote biological wastewater treatment [10].

From the economical analysis carried out, the turnover rate is 1.5 years. That is, the invested money in the wastewater treatment plant together with the accessories to recover biogas and biomass and to reuse them is recovered in 18 months [9,11].

Figure 5 shows the system to be used in cornmeal factories. Both systems, in a cascade mode, the anaerobic reactors followed by the aerobic ones are compact and easy to operate. The savings in water and energy consumption, through the use of the methane-rich biogas as non conventional source of energy, wastewater disposal costs, and the sale of biomass for fish protein-rich feedlots, make the treatment and recovery process economically feasible.

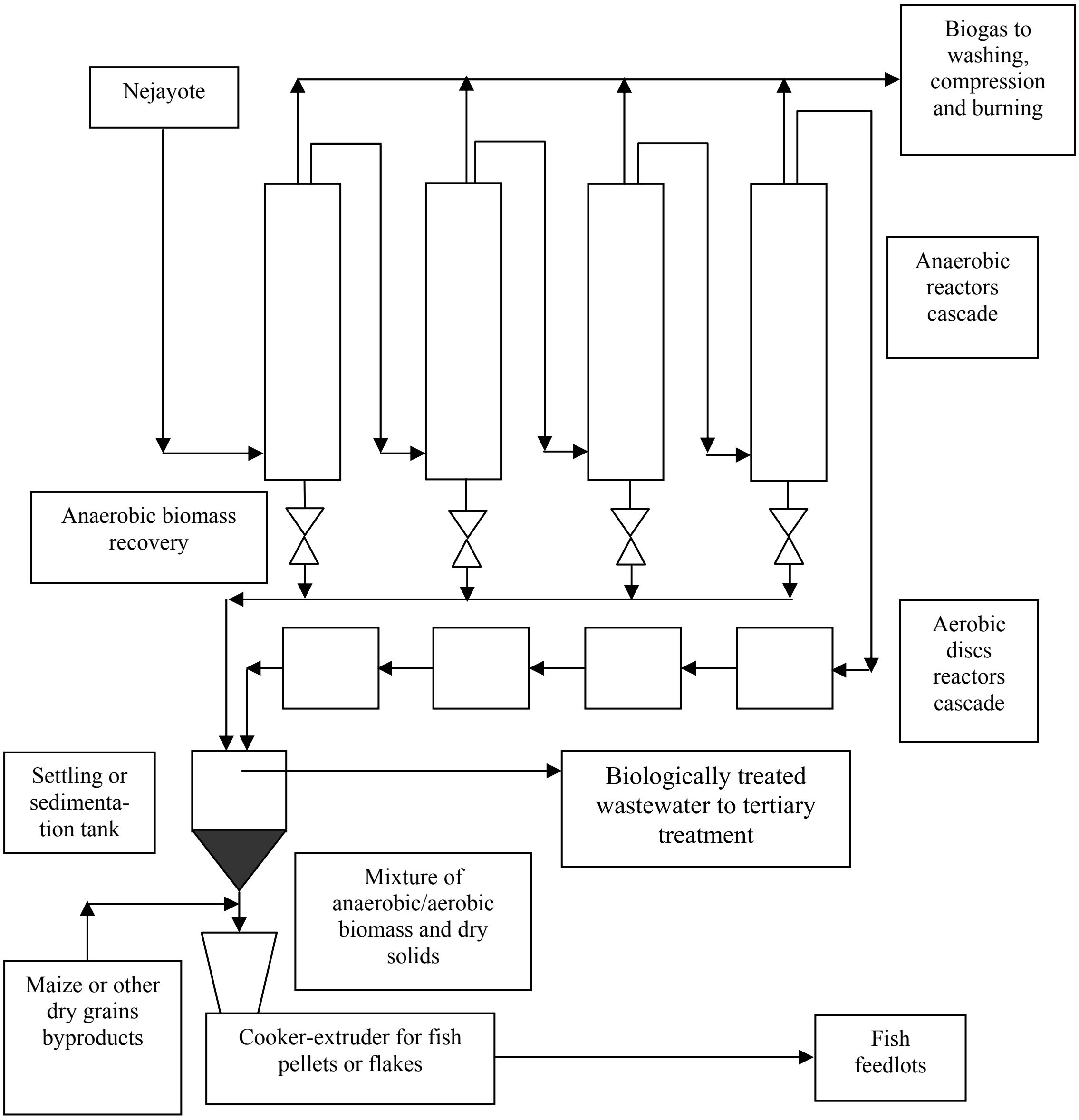

Fig. 5 Block and flow diagram for the cornmeal factories wastewaters recycling [7].

3.2 Small processing plants: Nixtamal mills

For *nixtamal* mills, due to its size (they process between 100 and 10 000 kg per day), it is not so economical to install an anaerobic-aerobic process for treating its wastewaters (between 500 L to 50 m^3 per day). Thus, only aerobic systems were being recommended to be used in these small establishments.

Figure 6 shows the installation carried out in a *nixtamal* mill located in Mexico City to partially treat their wastewaters before sending them to the municipal sewer. Wastewaters from the cooking tanks are sent to a settling tank where suspended solids from the bottom are sent to a filter press.

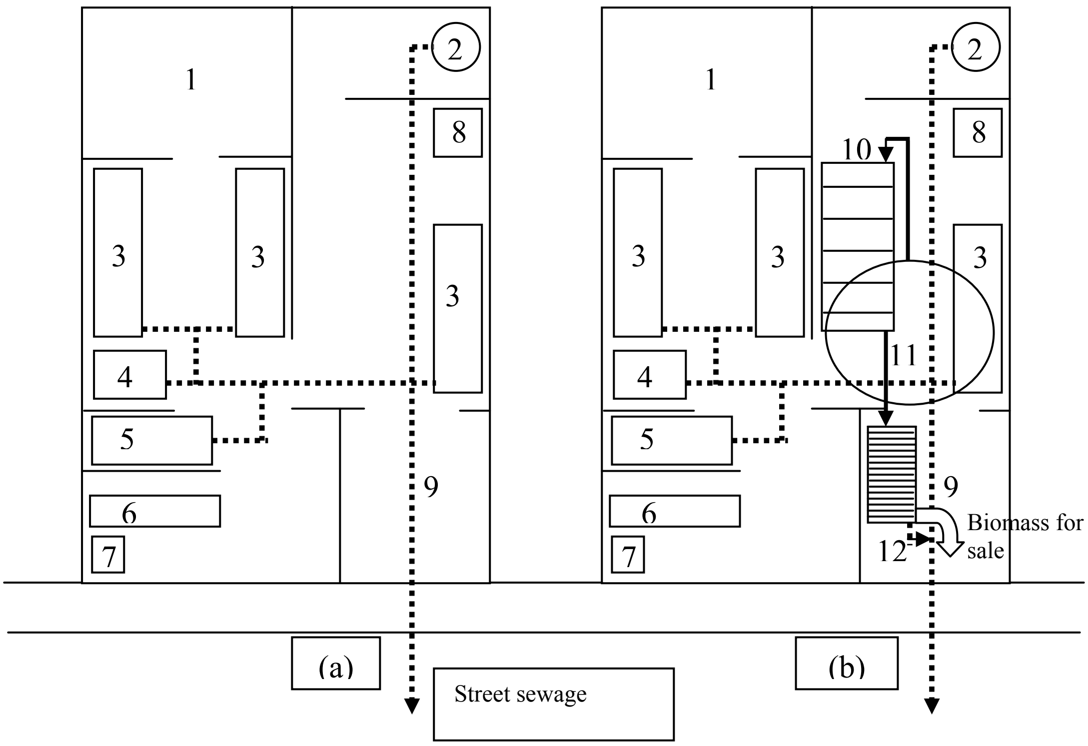

Fig. 6 *Nixtamal* mill (a) before and (b) after installing an aerobic wastewater treatment (biodiscs reactor): (1) Grain storage room, (2) Boiler, (3) *Nixtamalization* tanks, (4) Washing water storage tank, (5) Stone *nixtamal* mill, (6) Sales shelf, (7) Scales for weighing corndough, (8)Water reservoir, (9) Fresh maize grains, lime or calcium hydroxide, and corn solid wastes storage room, (10) Biodiscs or rotating biological reactor with feeding chamber, four discs stages and biomass collecting chamber, (11) Settling or sedimentation tank (underground) coupled with two small pumps, one to send bottom solids to a filter press, and the other one to send clarified wastewaters to biodiscs reactor, and (12) Filter press to recover maize solids and biomass for its sale (mixed with dry solids from fresh maize grains cleaning), and to send treated wastewaters to sewage [9].

Clarified wastewaters are treated in a four-stage biodiscs reactor, that has an antechamber where a pulley moved by the liquid reduces energy consumption for the gyratory movement of the discs, and a postchamber to collect the suspended biomass to send it to the filterpress. The solid material from the filter press (both primary treatment solids and aerobic microbial biomass) are being sold directly to owners of small fish farms since microbial protein cannot be directly assimilated by the other animals, such as chicken, pigs, etc., that eat it but do not gain weight [10]. Partially treated wastewaters sent to the municipal sewer system have a composition similar to households in terms of chemical and biochemical oxygen demand [9].

Economical feasibility for a slightly bigger *nixtamal* mill, considering a 10 ton per day maize processed, and using an anaerobic-aerobic combined system, gives a turnover ratio of 500%, recovering the capital invested in less than two years [11].

Finally, it should be mentioned that these systems, the combined anaerobic-aerobic for big *nixtamalized* cornmeal plants, and the aerobic process for small *nixtamal* mills, may become applicable to other wastewaters from the food industry sectors, particularly to those that contain substances of carbonaceous nature. They have been already tested with wastewaters of sugarcane mills, both in Mexico and in India, where successful operations for recycling anaerobically-aerobically treated wastewaters within their processes have been done [12-15].

When proteinaceous wastewaters are to be degraded, the wastewaters may be anaerobically treated, but the gases must be washed to remove the sulfur compounds separated from the protein matrices before using the biogas as a combustion or fuel source. Hydrogen sulfide is extremely corrosive and toxic, but once dissolved in water as sulfates it may be used by aerobic organisms to be reconverted into biomass protein.

4. Conclusions

For cornmeal industries, the anaerobic and the aerobic reactors and complementary equipments are compact and easy to operate. The savings in water and energy consumption, the reduction of wastewater disposal costs, and the sale of biomass for fish protein-rich feedlots, make the treatment and recovery process economically feasible. The turnover rate is 1.5 years, that is, the invested money in the wastewater treatment plant together with the accessories to recover biogas and biomass and to reuse them is recovered in 18 months. For nixtamal mills, due to its size, it is not so economical to install an anaerobic-aerobic process for treating its wastewaters (between 2.5 to 20 m^3). An aerobic system is then used for these small establishments. The solid material collected from the filter press can be directly fed to small fish farms. In this case, partially treated wastewaters are sent to the municipal sewer system.

Microbiology, when applied to solve real problems, not only supports the formation of new generations of professional and excellently trained personnel but also generates new knowledge that can be applicable to solve similar or even completely different problems, since it gives the insight of a methodological approach to use microbial consortia in normal every day life conditions to obtain a useful result.

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