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Present and perspectives of anaerobic treatment of domestic sewage

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ABSTRACT

The paper is a general overview of anaerobic processes applied to domestic sewage treatment. After comparing decanter-digester (septic tank) and anaerobic technologies, the organic matter flows in aerobic and aerobic systems are presented. For UASB technology the influence of key operational parameters as temperature, sludge age and hydraulic retention time is discussed and quantified. After discussing some sustainability parameters, technical characteristics of the new plant of Ciudad Sandino (Nicaragua) are presented. The future of anaerobic treatment is related to the new decentralized sanitation and reuse concepts.

Keywords: Anaerobic digestion; Domestic sewage; Sanitation; Reuse

1. Introduction

1.1. Historical background

The first application of anaerobic processes for domestic wastewater can be found in 1890 with the development and implementation of the "septic tank" concept by Mouras. This was followed by different technologies keeping identical concept. The best known, even in our days, is the Imhoff tank. These decanter-digester technologies can be considered primary treatment systems. Fig. 1 shows a septic tank with two chambers and an Imhoff tank [1,2].

Both technologies present a clear limitation. The influent has a very poor contact with the microorganisms, so the efficiency removing soluble matter is very limited. The system works as a good settler but as a poor biological reactor.

Taking into account this biological constraint, anaerobic reactors try to facilitate the contact between microorganisms and wastewater in order to improve the biological process efficiency. The most popular anaerobic technology with several hundred of plants running in moderate climates is the upflow anaerobic sludge bed (UASB) reactor. Fig. 2 shows a clear comparison between septic tanks and UASB reactor. The UASB reactor was developed in the Netherlands [3]. The most characteristic "internals" are: i) the gas-liquid-solid separator and ii) the influent distribution system. A nice advantage of the system is the formation of granular sludge with excellent settling characteristics.

1.2. Why anaerobic?

Figs. 3a, 3b and 3c show the organic matter flow in a conventional activated sludge process. The figures clearly indicate that the technology bottle neck is production and treatment of sludge. To convert organic matter in CO_2 and secondary sludge a huge amount of energy is needed (<1 kW/kg $COD_{removed}$). This situation derives from the intrinsic characteristics of the aerobic process: high secondary sludge production and high energy consumption.

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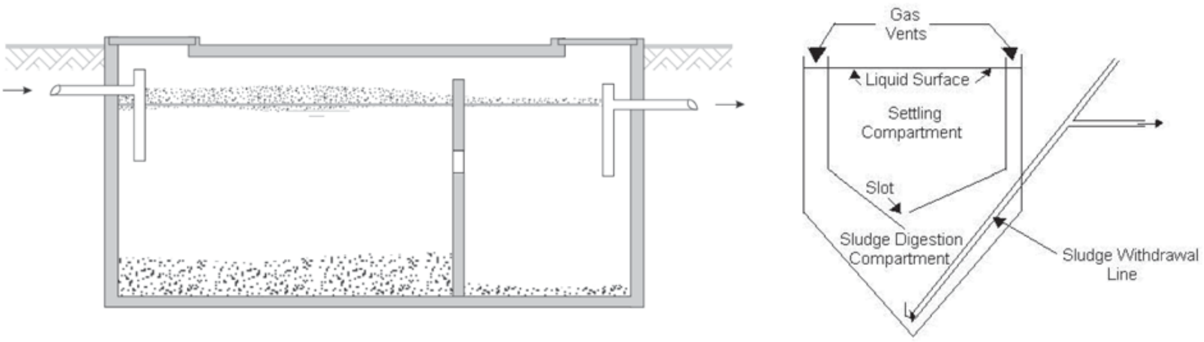

Fig. 1. Schematic representation of a two chambers decanter–digester and an Imhoff tank.

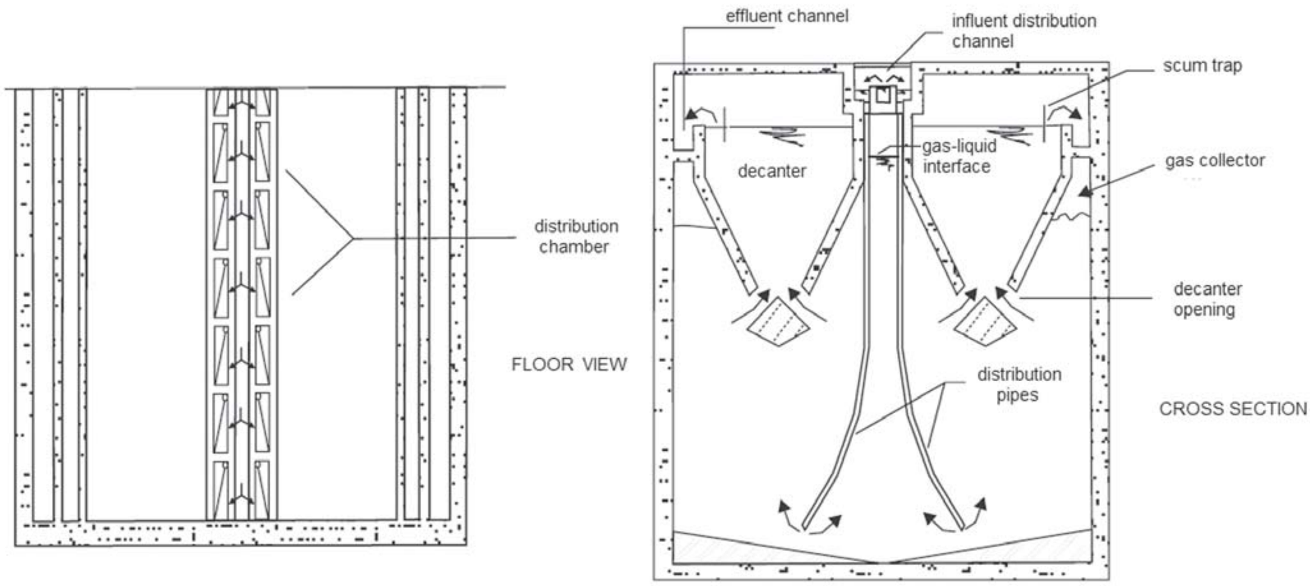

Fig. 2. Schematic representation of a rectangular USB reactor.

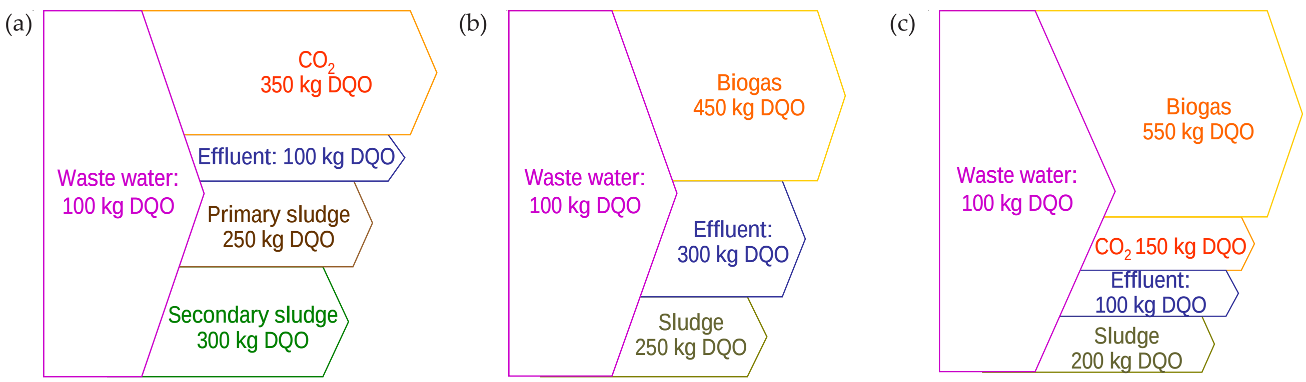

Fig. 3. Organic matter flow for (a) a conventional activated sludge (aerobic/anaerobic) process; (b) an anaerobic process; (c) an anaerobic/aerobic process.

Table 1
Benefits and drawbacks of anaerobic treatment of domestic sewage [4]

Benefits	Drawbacks
Efficient in the removal of organic material.	Long start-up period when seed sludge is not available.
Low construction cost and small land requirements.	Low pathogen removal.
Low operation and maintenance costs (low energy consumption and little equipment needed).	Requirement for post-treatment to reach the effluent standards, depending on the requirements.
Lower sludge production as compared to aerobic and physical-chemical processes.	Low removal efficiency of particulate organic material at low temperatures.
Biogas production (energy generation).	Risk of odour nuisance form the reduction of sulphate to sulphide.

The anaerobic process takes advantage of two intrinsic characteristics: no energy consumption for aeration and very low sludge production. The organic matter flow is shown in Fig. 3b.

A summary of benefits and drawbacks of anaerobic treatment are shown in Table 1.

1.3. Anaerobic is treatment or pre-treatment?

Depending on the quality desired for the final effluent, the anaerobic process can be considered as a global treatment or only as an intensive pre-treatment that must be followed by an aerobic polish section. Typical configurations for both possibilities are shown in Fig. 4. Fig. 4c shows the organic matter flow for an anaerobic/aerobic process.

2. Anaerobic treatment in practice

Anaerobic treatment is a well established technology mainly applied in tropical or subtropical areas. Table 2 summarizes data for five full scale plants operating at moderate temperatures [4]. These data indicate that for 25°C average temperature, COD removal ranges between 60 and 80%.

2.1. Temperature effect

The main limitation of the anaerobic process is related to temperature. Working in the mesophilic range (optimum 35°C), removal efficiency decreases at low temperature. In anaerobic systems treating sewage the rate limiting step of the overall process is the hydrolysis rate of particulate matter. To maintain the efficiency at low degradation rates it is necessary to increase the solid residence time. Relationship between temperature and solid residence time is proposed by van Haandel and van der Lubbe (2007) [5].

$$R_{su} = (15)\,(1{,}067)^{(T-25)} \quad (15°C < T < 35°C) \qquad (1)$$

where R_{su} is is the anaerobic sludge age in an UASB reactor expressed in days.

2.2. Hydraulic retention time (θ)

In fact it is the main design parameter. From operational results of five full scale UASB reactors (Bucaramanga, Cali, Cetesb, Pedegral and Kampur), all of them operating in the range 20–25°C, Chernicharo (1999) [6], proposes two equations to calculate COD removal (η_{COD}) and expected SST concentration in the effluent.

Table 2
Summary of recent results for treatment of sewage under tropical conditions (>20ºC) in pilot and full scale systems [4]

Volume (m³)	Temperature (ºC)	HRT (h)	Influent COD_t (m/h)	Removal (%)	
				COD_t	SS
64	24–26	4–6	267	65	70–85
686	20–25	4.5	455	11–60	27–58
120	—	4.7–9	315–265	50–70	56–79
1200	20–30	6	74	74	75
6600	25	5.2	60–80	60–80	—

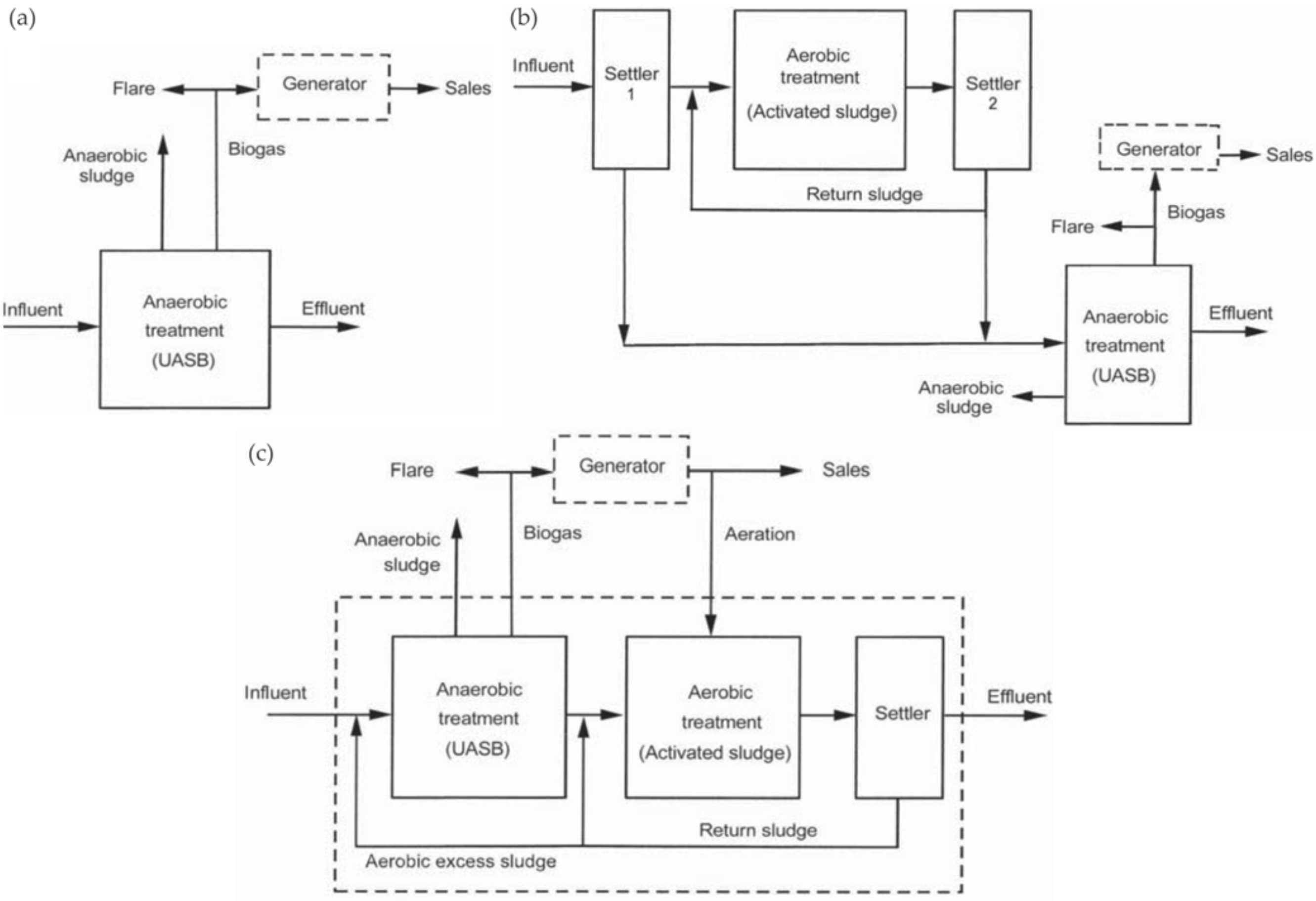

Fig. 4. Typical configurations for anaerobic technology: (a) anaerobic process, (b) activated sludge + sludge anaerobic digestion, (c) integrated anaerobic/aerobic process.

$$\left.\begin{aligned}\eta_{COD} &= 100\left(1-0.68\,\theta^{-0.35}\right)\\ \eta_{SST} &= (250)/(\theta+10)\end{aligned}\right\}\ \theta = \text{hours} \qquad (2)$$

2.3. Sludge age

In systems operated without intentional excess sludge discharge, looking for the maximum sludge mass that could be retained, the design and efficiency of the gas-liquid-solid phase separator is a key factor. Fig. 5 shows experimental behaviour of two UASB reactors operating at 25°C [5].

3. Anaerobic treatment and sustainability

The sustainability concept is a useful tool to check the suitability of a process and compare processes.

Fdz-Polanco et al. [7] compared from a sustainability point of view two standard conventional facilities for the treatment of domestic wastewater under warm weather conditions (24°C): aerobic and combined anaerobic + aerobic.

The indicators taken into account, according to the ICheme method, were environmental, energetic, economic and social [8,9].

The *environmental indicators* selected show the land footprint, the amount of sludge produced, and the CO_2 emissions. As can be observed in Fig. 6, the aerobic alternative generates as much as three times more sludge, and could represent near a half of the land footprint needed in the anaerobic option. CO_2 emissions are close one to the other in both cases.

The *energetic indicators* reflects the plant consumption and the reuse of biogas generated. Fig. 6 shows that the aerobic treatment systems needs almost twice the electricity needed in the combined one, and the biogas production is higher in the anaerobic alternative.

The *economic indicators* show that variable, capital and total cost are higher in the aerobic treatment than in the anaerobic alternative.

The indicator selected to measure de *social impact* was the generation of employment, which is less in anaerobic systems.

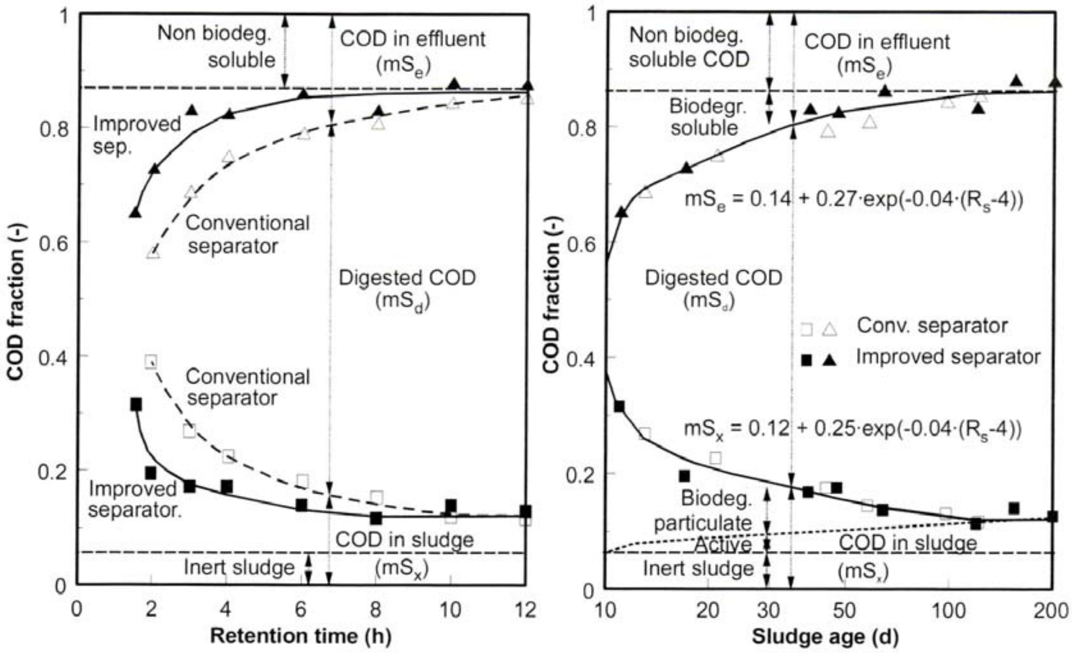

Fig. 5. COD fractions in effluent, digested and sludge as a function of retention time and sludge age [5].

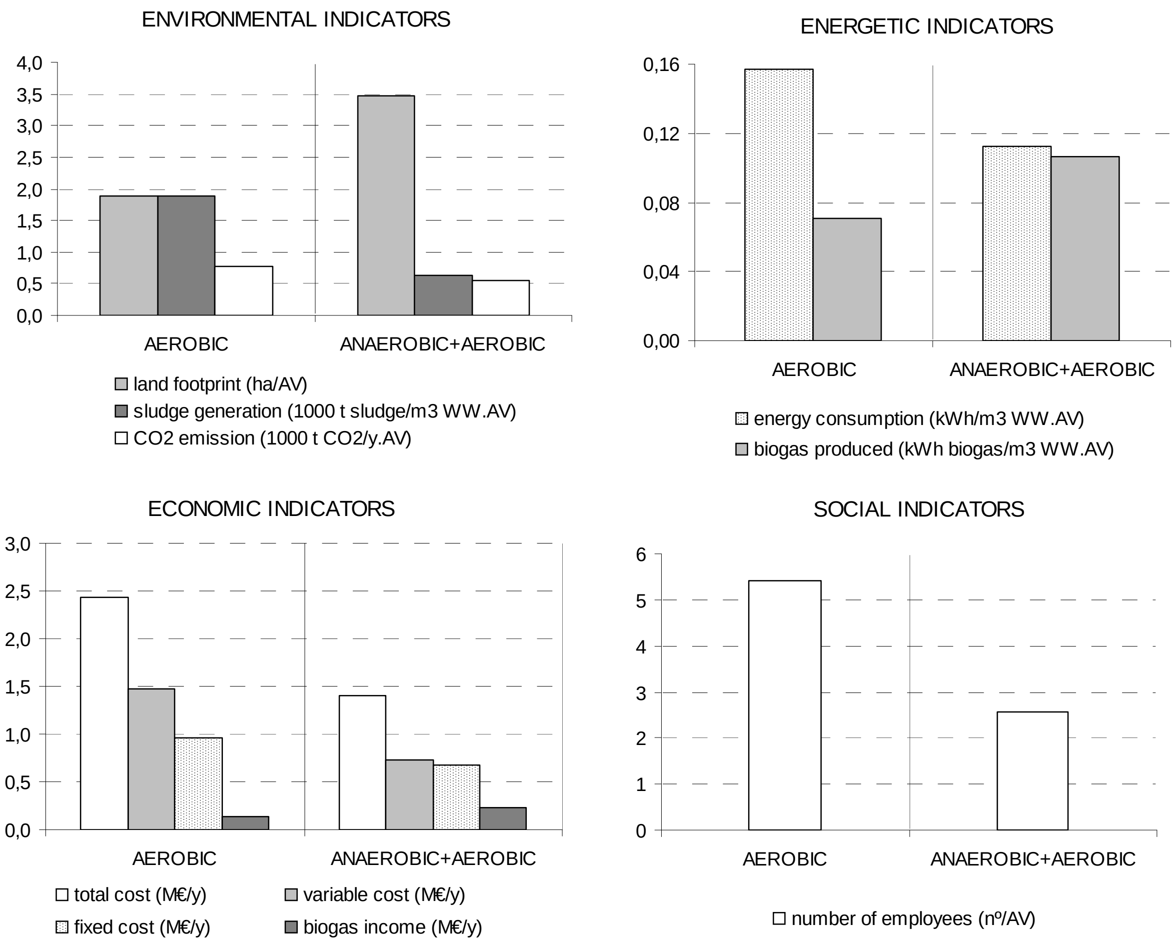

Fig. 6. MWW indicators.

4. A practical example of anaerobic technology

Recently, under the UE sponsorship (program Promaper/UE) a new sewage treatment plant has been built in Cuidad Sandino (Nicaragua). The UASB process engineering was developed by the Environmental Technology Group of the University of Valladolid (Spain), while design, detail engineering and project were developed by BEFESA Construcción y Tecnología Ambiental S.A. (Sevilla, Spain).

The plant was designed to treat 6000 m^3/d, covering a population of 47,500 inhabitants, with temperature ranging between 25 and 28°C. The daily contaminant charges are: BOD_5 = 1,938 kg/d; COD = 3,876 kg/d; TSS = 1,820 kg/d. Design effluent characteristics are: BOD_5 = 90 mg/L; COD = 180 mg/L; TSS = 80 mg/L, settleable solids = 1 mg/L; grease and oil = 10 mg/L; Blue methylene active substances = 3; pH = 6 – 9). The required removal efficiencies are as high as: BOD_5 = 75%; COD = 72% and TSS = 73%. These quite high values fit to well designed and operated UASB reactors.

The main equipment and operations in the plant are: coarse screen and by-pass, feed pumps, compact aerated system for sand and grease removal, rotary drum fine screen, distribution box, UASB reactor, disinfection, sludge drying bed.

Fig. 7 shows the flow diagram of the UASB section. It has 4 modular units, (dimensions 15×9×6 m), each module is equipped with influent gravity distribution system, solid–liquid–gas phase separator and effluent outlet.

5. Anaerobic treatment and decentralized sanitation and reuse

The traditional sanitation concept is "end of pipe" technology. Some elements to be considered are:

i) Most of soluble nutrients are found in urine
ii) The health danger of wastewater comes almost exclusively from faecal matter
iii) Wastewater that is not mixed with human waste (urine and faeces) is a great resource for high quality reuse water
iv) Source control should include evaluating all products that end up in the water
v) Rainwater run-off is one of the reasons for building sewerage systems [10].

Some developments in this area are separation toilets and vacuum toilets. The concept separation toilets is suitable for rural settlements, the aim is to provide a low cost, low maintenance system with potential of full re-

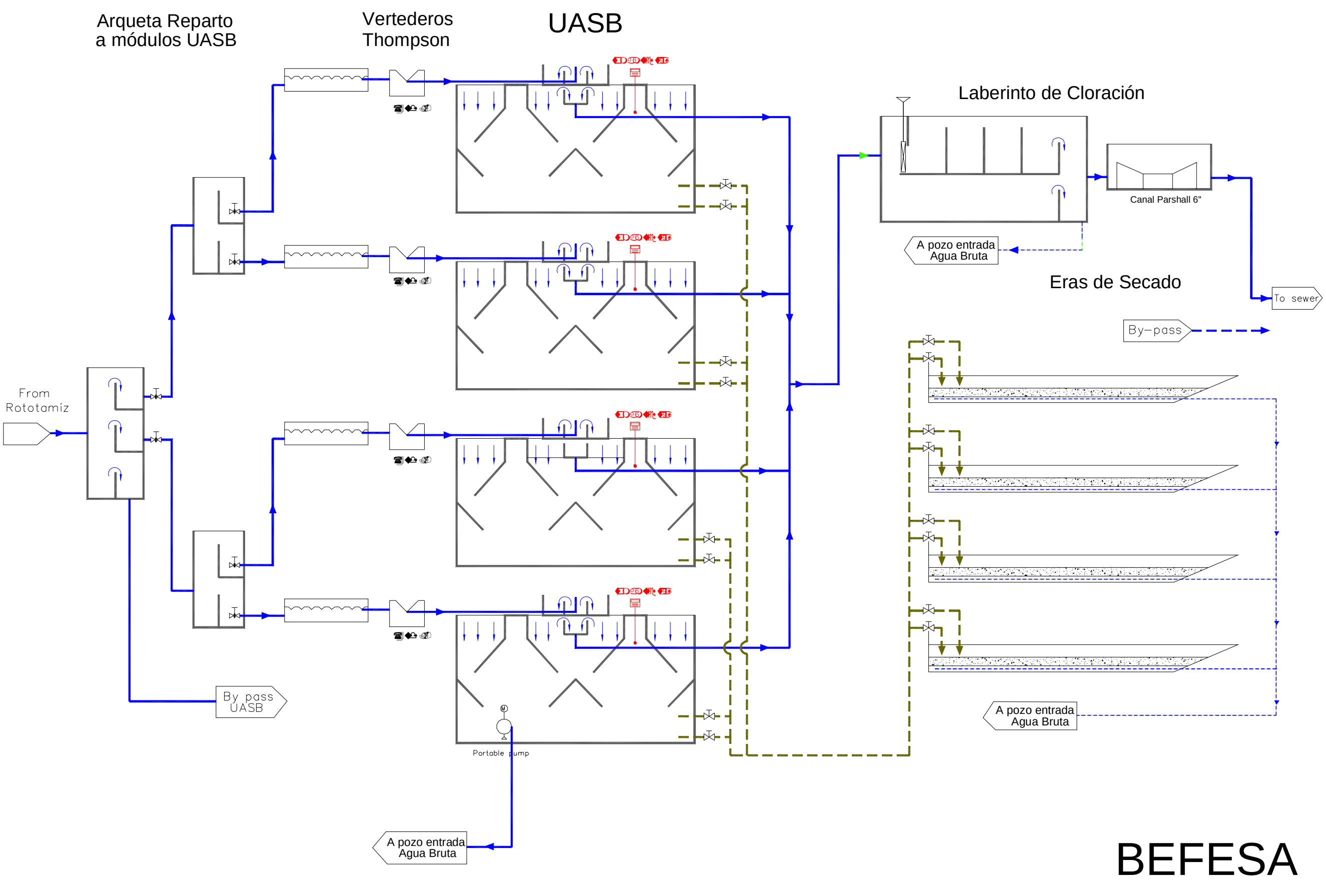

Fig. 7. UASB section flow diagram (Ciudad Sandino, Nicaragua).

sources recovery. Urine (yellow water) is collected through a separate pipe and stored for agricultural purposes. Faeces (brown water) are flushed with four to six litters of water to a composting tank or an anaerobic reactor. Vacuum toilets only need one litre of water. In both cases the high concentration of organic matter favours the application of anaerobic systems.

6. Conclusions

- UASB reactors are widely used in tropical and subtropical areas, providing as average COD removal efficiencies ranging between 50–75%.
- To achieve higher efficiencies it is necessary to treat the anaerobic effluent in an aerobic reactor.
- Compared with a conventional aerobic/anaerobic (activated sludge + anaerobic sludge digestion) system, the anaerobic/aerobic approach is more sustainable. For identical removal efficiency the system consumes less energy and produces less stabilised sludge.
- The main operational constraint is temperature.
- The new decentralised sanitation approach opens new possibilities for the implementation of anaerobic technology.

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