ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.140

Wastewater treatment of a municipal slaughterhouse in the city of Tacna-Peru using an Upflow Anaerobic Sludge Blanket Reactor

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Abstract. The present research study was carried out at the Mario Eyzaguirre municipal slaughterhouse in the city of Tacna, Peru where the design, construction, and evaluation of a water treatment system comprising catchment units, a desander, a settling tank, a grease trap, and an Upflow Anaerobic Sludge Blanket (UASB) was proposed. The initial and final values of BOD_5, COD, ammoniacal nitrogen, oils and fats, pH, total dissolved solids, and total dissolved solids were used as indicators of treatment efficiency. The results show a percentage of removal at a temperature of 20°C of 36 % of COD and 35 % of BOD, and the results for temperature values at 35°C showed improvements in the removal of organic pollutants with an average value of 54 % for BOD_5 and 45 % for COD. To improve the study proposal, units such as coagulation, flocculation, filtration, and disinfection were complemented and installed after the UASB, where the results indicate improvements in water quality up to 70.84 % for BOD_5 and 70.69 % for COD. The present study demonstrates that applying a UASB in a municipal animal feedlot can considerably reduce the pollution of its effluents.

Keywords-- Upflow Anaerobic Sludge Blanket, COD, BOD_5, slaughterhouse, wastewater.

I. Introduction

Slaughterhouses are strategically located to avoid damaging the surrounding environment [1]. However, with population growth in Tacna, Peru, this is often becoming increasingly difficult as people tend to live near these slaughterhouses. Most of these agro-industries do not have any treatment system [2], and effluents, represent a severe problem for public health [3] as these slaughterhouses can produce a large amount of waste, which can be [4] and wastewater loaded with proteins, fats and meat pieces, which could lead to a non-point source of contamination [5]. In addition, these waters are considered a hot spot for antibiotic-resistant bacteria and antimicrobial residues [6]. Therefore, it is necessary to propose alternatives to use or reuse waste and water to reduce the negative impact of these companies on the environment [7]. The Mario Eyzaguirre Yáñez municipal slaughterhouse is located in the district of Pocollay, province, and region of Tacna, Peru. (-17.9990295,-70.228373) at an altitude of 713 m.a.s.l., which currently has a pretreatment system for its effluents consisting of a screening operation to separate solids, a sand trap, a grease trap, and three interconnected retention tanks to store wastewater, with deficiencies in the design of operations and unit processes. The wastewater is then pumped into a tanker truck that discharges the effluent to a different point in the municipal slaughterhouse area (Figure 1-B). Untreated wastewater is discharged into the municipal sewer system, causing a high degree of contamination due to its high organic load, with BOD5 and COD values well above the Maximum Allowable Value stipulated by Peruvian law, likewise, by Article 24 of the Ley N° 28611 de Ley General del Ambiente de Perú [8].

The company notes that all human activity involving construction, works, services, and other activities that are likely to cause significant environmental impacts are subject to Sistema Nacional de Evaluación de Impacto Ambiental. In addition, this company processes cattle, pigs, sheep, and goats, generating many of contaminated effluents that are discharged to the primary treatment plant; however, as shown in Figure 1-A, this process collapsed, generating contamination and an unhealthy environment. Therefore, nowadays there are different alternatives to reduce the environmental impact of slaughterhouses [9], [10], [11], [12], [13], [14] highlighting the traditional Upflow Anaerobic Sludge Blanket (UASB) [15], despite being a known technology, it is not taken into account for its implementation in the Tacna region.

II. Materials and Methods

A. *Determination of the effluent flow*

For the determination of the flow rate, ten daily measurements were taken during five days from Monday to Friday, considering the work schedule, which is from 7:00 am to 15:00 pm, applying the volumetric gauging method, which consists of measuring the flow rate directly a container of known volume and controlling the filling time.

B. *Characterization of industrial wastewater*

For the physicochemical characterization of the wastewater, parameters such as temperature, pH, and electrical conductivity were measured in the field. Then a sample of raw water was taken at the outlet of the processing plant, applying procedures according to the Protocol for sampling the quality of effluents from the Ministerio de Vivienda Construcción y Saneamiento [16]. Physicochemical analyses of Biochemical

Fig. 1 Treatment system at the Mario Eyzaguirre Yáñez municipal slaughterhouse, Tacna, Peru. A) Deficient treatment and B) Pumping of untreated wastewater for disposal into the sewage system.

Oxygen Demand (BOD_5, mg/L), Chemical Oxygen Demand (COD, mg/L), Total Suspended Solids (TSS, mg/L), Ammonia Nitrogen (AN, mg/L), and Oils and Fats (OF, mg/L) of raw and treated wastewater samples have been sent to the CERPER Laboratory for analysis.

C. Dimensioning, design, and construction

The sizing, design, and construction of the wastewater flow conveyance channel were carried out using the Manual of Design Criteria for hydraulic works for the formulation of hydraulic projects of the Autoridad Nacional del Agua (ANA) of Perú [17] based on Manning's equation having the following expression:

$$Q = \left(\frac{1}{n}\right) \times AR^{2/3} \times S^{1/2} \tag{1}$$

Where "Q" is the flow rate in (m^3/s), "n" corresponds to roughness, "A" is the area in m^2 and "R" is the hydraulic radius that corresponds to the ratio of wetted section area to the wetted perimeter, "S" is the slope in mm.

Subsequently, the Hcanales 3.0 software was applied for the hydraulic design where a square section of 0.30 x 0.30 meters was considered for the conduction channel with a slope of 0.5 % and a velocity of 0.0001 m/s, which does not produce sedimentation problems, considering a minimum flow of 120 cm^3/min. Based on this hydraulic design, we considered the construction at the pilot plant level of the catchment units, sand trap, sediment trap, and grease trap, considering as the optimum design parameter the feed flow rate applied in the construction and preparation of the land to start up the UASB, as shown in Figure 2.

D. Upflow Anaerobic Reactor Design

The following was taken into account for the design of the UASB (Figure 2). The following formula was used to calculate the reactor volume:

$$V = \pi \times r^2 \times h \tag{2}$$

Where "V" is the volume in liters, "π" corresponds to 3.1416, "r" is the radius, and "h" is the height in meters. The following formula was used for calculating the flow rate.

$$Q = V_r \times T_r \tag{3}$$

Where, "Q" corresponds to the flow rate in L/s, "V_r" is the retention volume in liters, and "T_r" is the retention time in seconds. On the other hand, the calculation of the effective height of the reactor was calculated using the following formula:

$$h = \frac{4 \times V_r}{\pi \times d^2} \tag{4}$$

Finally, the hydraulic retention time calculation was determined with the following formula

$$T_r = \frac{V_r}{Q} \tag{5}$$

The sizing parameters of the UASB were as follows; the inlet flow rate of "Q" was 120 cm^3/min for a volume of 101.3 L and a height of 2 m. Subsequently, based on these data, the cylindrical reactor was built with rigid plastic polyvinyl chloride, which was installed in the facilities of the Mario Eyzaguirre Yáñez municipal slaughterhouse in Tacna (Figure 3).

E. Treatment System applied in an Upflow Anaerobic Sludge Blanket

The dimensions of the anaerobic reactor are 0.245 m in diameter and 2.0 m high, with a capacity of 101.3 L, installed inside a wooden house 3 m long by 2 m wide and 2.40 m high, which was thermally insulated with 2-inch thick Technopor sheets to maintain a constant temperature. For the start-up of the anaerobic reactor, the inoculum of anaerobic microorganisms was prepared based on bovine rumen combined with a portion of the residual effluent and left to stand for 45 days; the inoculum was then loaded into the reactor in a volume of 20 L, which is less than 20 % of the effective volume of the reactor and left to stand for 24 hours.

The anaerobic digestion process was carried out at a temperature of 20 and 35 °C, at a flow rate of 120 ml/min. The reactor was fed continuously and uninterruptedly for 90 days to ensure the formation of an active and effective sludge blanket, installing a leveling tank of 180 L capacity, which is

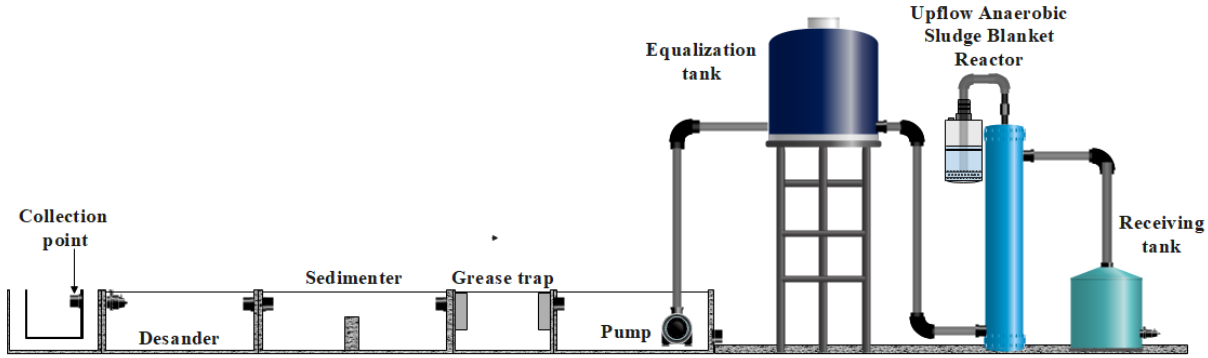

Fig. 2 Design of the wastewater treatment system from the municipal slaughterhouse of Tacna applied to an Upflow Anaerobic Sludge Blanket.

fed by an electric pump that is located at the outlet of the grease trap and at the height of 2.25 m, which allows managing a continuous flow rate and then by the action of gravity the wastewater was dosed into the reactor through a previously graduated inlet valve. Subsequently, after this time, the efficiency of organic load removal began to be evaluated by sampling the wastewater at the inlet and outlet of the reactor at 1, 2, 3, 4, and 5 weeks.

Fig. 3 Upflow Anaerobic Sludge Blanket of rigid plastic polyvinyl chloride installed in the facilities of the Mario Eyzaguirre Yáñez municipal slaughterhouse in Tacna.

Therefore, the present study aims to implement the use of a UASB as a viable and low-cost technical alternative for primary treatment to remove the high organic load that characterizes the effluents of municipal slaughterhouses, which in addition to its high efficiency have low operating and maintenance costs. In addition, they allow obtaining methane gas that can be reused, as well as lower sludge production. Therefore, a wastewater treatment system was designed, built, and evaluated at the Mario Eyzaguirre Yáñez municipal slaughterhouse, consisting of collection units, a sand trap, a settling tank, a grease trap, and UASB at the pilot level.

III. RESULTS AND DISCUSSION

A. *Daily average effluent flow rate gauging*

The effluent flow from the processing area was determined for five days, considering that the processing work is carried out from Monday to Friday, with higher effluent volumes on Mondays and Fridays due to the intensified slaughtering and slaughtering of animals on those days (see Table I).

TABLE I
AVERAGE EFFLUENT FLOW RATE FROM THE BENEFICIATION AREA

Day	Flow rate (L/s)
Monday	1.08
Tuesday	0.80
Wednesday	0.73
Thursday	0.77
Friday	1.07

B. *Removal efficiency of BOD_5 and COD at 20 °C and 35 °C*

Based on the results of the physicochemical analysis of wastewater samples taken at the inlet and outlet of the UASB, COD, and BOD_5 were determined as critical control parameters as quality indicators to evaluate the percentage of organic matter removal in the reactor. Table II shows the analysis results of these two parameters over five weeks.

TABLE II
REMOVAL PERCENTAGE (%R) OF BOD_5 AND COD AT 20 °C FROM INFLUENT AND EFFLUENT OF THE UPFLOW ANAEROBIC SLUDGE BLANKET.

Week	BOD_5 (mg/L)			COD (mg/L)		
	Input	Output	%R	Input	Output	%R
1	5185	3936	24.09	8530	6572	22.95
2	6118	4018	34.32	9377	5849	37.62
3	7673	5166	32.67	9205	6038	34.41
4	6317	3686	41.65	8798	5277	40.02
5	4346	2445	43.74	6250	3509	43.86

Table III shows the COD and BOD_5 analysis results at a temperature of 35 °C. Figure 4 shows graphically the removal of BOD_5 at a temperature of 20 °C, with average values of 35 % removal, and for COD, average values of 36 % removal were reached about the organic load contained in the industrial wastewater effluent.

TABLE III
REMOVAL PERCENTAGE (*%R*) OF BOD_5 AND COD AT 35 °C FROM INFLUENT AND EFFLUENT OF THE UPFLOW ANAEROBIC SLUDGE BLANKET.

Week	BOD_5 (mg/L)			COD (mg/L)		
	Input	Output	*%R*	Input	Output	*%R*
1	6370	3681	42.21	8092	4213	47.94
2	5428	2043	62.36	7935	4335	45.37
3	6239	2526	59.51	8851	5689	35.72
4	8297	5080	38.77	10720	6506	39.31
5	4197	1350	67.83	5359	1876	64.99

For the wastewater treatment applied in the UASB at a temperature of 35 °C, average removal values of 54 % for BOD_5 and 45 % for COD were achieved. Without oxygen, the treatment system develops a sludge stabilization at a temperature of 35 °C; likewise [18] refers that the organic matter removal efficiency is evaluated by the COD and BOD_5 test.

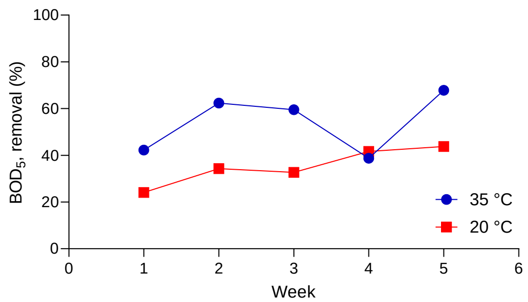

Fig. 4 Removal of BOD_5 and COD at 20 °C from influent and effluent of the Upflow Anaerobic Sludge Blanket.

Therefore, the 25 to 35 °C reactors show better reaction rates and provide stable treatments and the results show that the system studied shows a high removal efficiency [19]. Therefore, different studies are carried out where the purpose of anaerobic treatment is to remove COD components from wastewater (Joubert O., 2005) and these can operate satisfactorily at temperatures ranging from 25 to 38 °C [18].

To improve the study proposal, units such as coagulation, flocculation, filtration, and disinfection were complemented and installed after the UASB, where the results showed an improvement in water quality up to 70.84 % for BOD_5 and 70.69 % for COD (Figure 5).

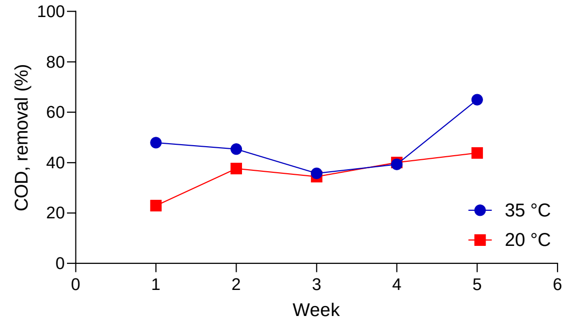

Fig. 5 Removal of BOD_5 and COD at 35 °C from influent and effluent of the Upflow Anaerobic Sludge Blanket.

The characterization of the influents and effluents of the wastewater treatment applied to the UASB, gave as a result of the BOD_5 parameter a concentration in the influent of 4630 mg/L and in the effluent of 1350 mg/L, in the COD parameter 6400 mg/L and 1876 mg/L; where it can be seen that there is a similarity in the results obtained by [20]. For the parameters of TSS 2136 mg/L and 358 mg/L, Oils and Fats 1797 mg/L and 13.8 mg/L, and ammoniacal nitrogen 9825 mg/L and 252 mg/L; from where the results indicate that only the Maximum Allowable Values are met for the parameters of total suspended solids which was 358 mg/L and for oils and fats 13.8 mg OF/L (Figure 6), similar results to those obtained by [21] where the amount of TSS decreases. Likewise, the results indicate that it does not comply with BOD_5, COD, and ammonia nitrogen regulations because the organic matter produced in the processing activities is high, reaching concentrations greater than 100 % of the treatment design flow. Therefore, the removal efficiency of TSS is below the data reported by [20].

Other studies have demonstrated the effectiveness of UASBs for wastewater treatment (Table IV), such as the study of Nacheva *et al.* [22] where we worked at a temperature between 20.9 and 25.2 °C for the treatment of a slaughterhouse with a volume of 15 L of the reactor, achieving the removal of 90 % of the COD. On the other hand, Olarte *et al.* [21] carried out a similar study where the treatment of wastewater from a slaughterhouse in Huancavelica, Peru, achieved a maximum COD removal of 42.14 % at a temperature range of 9 to 21 °C in a 29 L reactor.

Musa *et al.* [23] in a 14 L rector were able to remove more than 90 % of the COD from a slaughterhouse at an average temperature of 35 °C, likewise, Amin *et al.* [24] were able to remove 94.6 % of the DOC at the same average temperature in a 30 L reactor. At a similar temperature Rajakumar *et al.* [25] were able to remove 78 % of COD from slaughterhouse wastewater in a 4 L reactor.

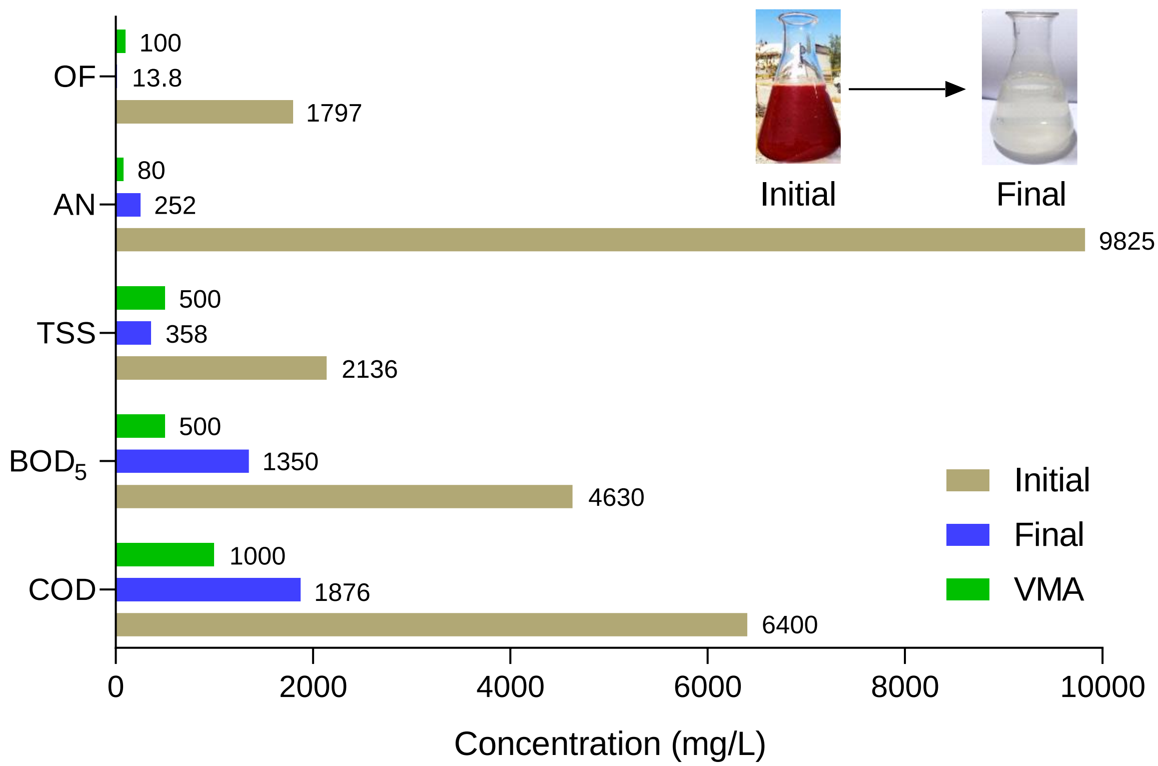

Fig. 6 Treatment efficiency comparing initial and final study concentrations with maximum allowable values (MAV)

Finally, Saghir *et al.* [26] were able to remove 97.31 % of COD from slaughterhouse wastewater in a 33.4 L reactor at an average temperature of 30 °C. These results could explain the results since in the present investigation it has been demonstrated that temperature plays an important role in the removal of COD in a UASB, increasing the removal from 36 to 45 % by increasing the temperature from 20 to 35 °C.

TABLE IV
OVERVIEW OF COD REMOVAL FROM SLAUGHTERHOUSE WASTEWATER USING UASB.

Temperature (°C)	Reactor volume (L)	COD in wastewater (mg/L)	COD removal (%)	Reference
20.9 - 25.2	15	3437	90	[22]
9-21	29	1063	42.14	[21]
34 - 36	14	32000	> 90	[23]
34.5 – 35.5	30	1222.2	94.6	[24]
29-35	4	4800	78	[25]
28-32	33.4	5350.01	97.31	[26]
20-35 °C	180	6400	36 - 45	This research

IV. CONCLUSIONS

It was demonstrated that with the implementation of UASB, it is possible to remove COD and BOD_5 in the effluent of the municipal slaughterhouse of Tacna. It was determined that a temperature of 35°C achieves the highest COD and BOD_5 removal efficiency. The UASB is a good alternative for primary treatment because of its small footprint, low installation, operation, and maintenance costs, and high organic load removal efficiency. To optimize the wastewater treatment applied to a UASB, units such as coagulation, flocculation, filtration, and disinfection were implemented and installed after the UASB.

The results showed an improvement in water quality reaching an organic load removal rate of 70.84 % for BOD_5 and 70.69 % for COD. From the results of the effluent and treated effluent characterization, it was determined that only the parameters of total suspended solids and oils and fats comply with the VMA for wastewater effluents; however, the VMA for the parameters BOD_5 (1350 mg/L), COD (1876 mg/L), TSS (358 mg/L) and ammonia nitrogen (252 mg/L) are not complied.

The wastewater after treatment can be subjected to other complementary treatments; thus, it could be reused in the processes within a slaughterhouse or other industries that generate large amounts of wastewater.

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