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Theoretical Calculation of the Potential of Production of Biogas in the Wastewater Treatment Plant of Alba Rancho in Cochabamba, Bolivia

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Abstract: Anaerobic wastewater treatment in UASB type reactors generates biogas that can be an alternative source of energy through the use of methane (CH4) gas. This potential source of bioenergy obtained in a Wastewater Treatment Plant, can make it self-sustainable, at least in terms of energy consumption. This paper considers a hypothetical situation with the use of UASB type reactors in the current Alba Rancho WWTP in the city of Cochabamba (Bolivia) and its theoretical potential for the generation of methane gas. For this, and through a calculation procedure established by CHERNICHARO [1], methane flows of 5,138 m^3/d have been obtained for an average wastewater flow of 655 l/s (year 2009); 8,839 m^3/d for an average wastewater flow of 800 l/s (year 2015) and 14,800 m^3/d for an average waste water flow of 1,200 l/s (year 2,025). This work was presented at the XV Bolivarian Congress of Sanitary and Environmental Engineering of AIDIS in Cochabamba (Bolivia).

Key words: biogas, wastewater treatment Plant, UASB, Cochabamba, Alba Rancho

1. Introduction

As in the great majority of the big cities of Latin America, in Cochabamba (Bolivia) there are also huge problems with wastewater management in general and with its treatment and reuse in particular. Since 1986, a Wastewater Treatment Plant (WWTP) has been in operation, consisting of a set of optional stabilization ponds. The system consists of 4 modules of 2 primary lagoons and a secondary lagoon. This PTAR to date and after 27 years of continuous operation, has not undergone any type of improvement or expansion, despite the fact that the city has practically doubled its population since the time it was put into operation.

There are several reasons why the PTAT of Alba Rancho is currently completely collapsed; from the increase of the hydraulic load and the organic load that enters the lagoon system to the geometric design itself and constructive aspects of it, apart from not having been subject to any of the extensions that were planned in the original project. The area occupied by the WWTP is approximately 40 Ha, subtracting about 17 Ha for any type of expansion that is intended to be implemented. At present, and according to reports from the Municipal Company of Potable Water and Sewerage of Cochabamba (SEMAPA), there is an approximate average flow of 650 l/s (year 2009) of raw water entering the system and it is known that a future expansion in its treatment capacity of 800 l/s (year 2015) and up to 1,200 l/s (year 2025) is intended.

The present work intends to show the theoretical calculation of the potential of biogas (methane gas) that could be obtained with an expansion project that uses the technology of anaerobic upflow reactors or UASB type reactors. On the other hand, the probable treatment through this technology would also generate a flow of

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treated water for agricultural reuse on land in the Metropolitan Region of Cochabamba, as well as the possibilities of generating bioenergy through the use of methane gas to be produced. With this technology. Finally, the environmental benefits considerations that the productive use of biogas obtained from its anaerobic treatment are presented.

2. Material and Methods

Initially, the parameters of water quality monitoring that enter the Alba Rancho WWTP that SEMAPA performs were analyzed; this analysis also included the amount or the average monthly flow that enters for its treatment. From this evaluation, it was decided to work with the parameter of the COD (Chemical Oxygen Demand) total in its monthly average, corresponding to the 2009 management. Likewise, the average monthly flow of the raw or tributary wastewater was considered, corresponding also to the 2009 management. Based on these data and using the equations established by Chernicharo (2007) [1], the theoretical calculation of biogas and methane gas production was carried out, assuming that the treatment will be carried out in anaerobic UASB reactors. The calculation methodology considers as a basic parameter the COD of domestic wastewater and a sequence of 16 stages of simple arithmetic operations.

Once the volume of biogas and methane gas calculated by the Alba Rancho WWTP was calculated; The bio-energy potential of the same was calculated, based on the calorific potential of this type of resource. Subsequently, and knowing the production of calories to which methane gas production is equivalent, the different energy transformation potentials were inferred. Finally, evaluations of the environmental, social, technological, economic and energetic aspects were carried out, which involve the treatment of domestic wastewater by implementing anaerobic biological treatment through UASB reactors, in an environment such as Cochabamba (Bolivia).

2.1 Obtaining Dara on the Quantity and Quality of Wastewater

One of the main tasks developed is to obtain the values of the parameters of the physical, chemical and microbiological self-monitoring carried out by the Alba Rancho SEMAPA WWTP. For this purpose, the corresponding authorities were carried out beforehand, having obtained the values of the monitoring carried out in 2009. These values are inferred to be lower than those of 2013, since the flow rates of the raw wastewater have increased and also the Organic charges that enter the WWTP, which to date has not been subject to any type of extension or improvement in its treatment process.

Among the different qualitative characterization parameters of raw wastewater entering the Alba Rancho WWTP, are the Biochemical Oxygen Demand (BOD) and the Chemical Oxygen Demand (COD), which serve to measure the amount of organic matter that can rust. In relation to the characteristics of anaerobic treatment of domestic or municipal wastewater from the city of Cochabamba, which also contain industrial effluents, it has been determined to use the COD parameter as directly responsible for the measurement of oxidation (degradation) not only of biodegradable organic matter but also of other compounds of difficult degradation by biological route and which are only oxidized by the presence of chemical compounds. On the other hand, the measured data of the raw wastewater flow corresponding to the 2009 management were used, as well as the data regarding the quality of the water to be treated in the WWTP and that were delivered to the author in 2010 [2](SEMAPA, 2010).

Consequently, in Table 1, the values used of both the BOD and the COD of the raw wastewater entering the WWTP of Alba Rancho, measured for 2009 management, are presented.

Likewise, the report was received from SEMAPA (2010) regarding the flows of entry to the PTAR of Alba Rancho, which are recorded in Table 2.

Table 1 Monthly average concentrations of total BOD5 and total COD of management 2009 [2].

Parameter	Jan	Feb	Sea	Apr	may	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
BOD5 total	-----	-----	510.06	198.55	-----	-----	----	342.34	----------	-------	-------	------	**350.32 mg/l of O_2**
COD total	509.16	-------	1,003.74	516.03	581.29	399.25	337.43	619.07	770.19	402.69	625.94	488.55	**568.48 mg/l of O_2**

Table 2 Monthly average flows (l/s) of the crude tributary to the WWTP Alba Rancho, 2009 management [2].

Jan	Feb	Sea	Apr	may	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average (l/s)
734,660	794,399	703.406	803,024	730,189	620,943	639,297	551,373	574,279	607,112	544,399	558,946	**655.17**

2.2 WWTP Design Parameters

Considering that the treatment of domestic wastewater is carried out in a set of anaerobic UASB reactors, the data in Tables 1 and 2 were used and the parameters referring to the design and operation of the supposed UASB reactors were adopted from the bibliographic reference.

2.2.1 Current Situation (Year 2009)

Basic calculation parameters:

- Population served (P): 360,000 inhabitants
- Flow of raw wastewater or tributary (medium Q): 655 l/s or 56,592 m^3/do **2,358 m^3/h**
- Maximum daily tributary flow (Qmax-d): It is considered 20% more than the average flow, therefore it is: 1.2 X 56.592 = 67.910 m^3/do **2.829 m^3/h**
- Maximum hourly tributary flow (Qmax-h): It is considered 80% more than the average flow, therefore it is: 1.8 × 56.592 = 101.865 m^3/do **4.244 m^3/h**
- Average concentration of BOD from the tributary to the reactor: 350 mg/l
- Average COD concentration of the tributary to the reactor: 568 mg/l (S0)
- Average temperature of the raw wastewater of the coldest months (T) = 17°C
- Solids production coefficient (Y): 0.19 kg STS/kg APQ applied (adopted value)
- Solids production coefficient in terms of COD: 0.22 kg COD/kg COD applied (value adopted)
- Expected concentration for the sludge to be discarded: Clodo = 5% (adopted value)
- Mud density: γ = 1020 kg SST/m^3 (adopted value)

NOTE: The values adopted are taken from the specialized literature [1].

2.2.2 Medium-term Situation (Year 2015)

Basic calculation parameters:

- Average wastewater flow (Qmedio): 800 l/s 0 69,120 m^3/d 0 2,880 m^3/h
- COD removal efficiency (EDQO) = **Efficiency = 65%**
- Average COD concentration of the tributary to the reactor: **800 mg/l** (S0)
- COD concentration in treated effluent (S): S = S0 **-** (E × S0)/100
- SUASB-COD = 800 **-** (65 × 800)/100 = 280 mg COD/l (kg COD/ m^3)
- Solids production coefficient in terms of COD: 0.22 kg COD/kg CO applied (value adopted)
- Average temperature of the raw wastewater of the coldest months (T) = 17°C
- 70% of biogas is Methane Gas

2.2.3 Long-term Situation (Year 2025)

Basic calculation parameters:

- Average wastewater flow (Qmedio): 1,200 l/s 0 103,680 m^3/d 0 4,320 m^3/h
- COD removal efficiency (EDQO) = **Efficiency = 70%**
- Average COD concentration of the tributary to the reactor: **800 mg/l** (S0)

- COD concentration in treated effluent (S):
  $S = S0 - (E \times S0)/100$
- SUASB-COD = 800 - (70 × 800)/100 = 240 mg COD/l (kg COD/m^3)
- Solids production coefficient in terms of COD: 0.22 kg COD/kg CO applied (value adopted)
- Average temperature of the raw wastewater of the coldest months (T) = 17°C
- 70% of biogas is Methane Gas

3. Results and Discussion

3.1 Calculation Procedure for the Current Situation (Year 2009)

3.1.1 Biogas Calculation Process

1) Calculation of the average tributary load of the COD (L0-UASB-COD):

L0-UASB-COD = S0-UASB-COD × Medium Q

0.568 kg/m^3 × 56.592 m^3/d = 32.144 kg COD/d

2) Hydraulic retention time adopted according to the temperature of the wastewater (t):

t = 10 h

3) Determination of the total volume of the UASB reactors (V):

V = Qmedium × t

V = 2,358 m^3/h × 10 h

V = 23,560 m^3

4) Number of UASB reactors adopted (Nr):

The specialized bibliography recommends that the volume of each unit should not exceed 2,500 m^3, then:

Nr = 23,560 m^3/2,500 m^3

Nr = 9.42

Nr = 10 units of UASB reactors

5) Volume of each reactor (Vr):

Vr = V/Nr

Vr = 23,560 m^3/10

Vr = 2,356 m^3

6) Height of the reactor type (H):

The specialized bibliography recommends a height of 4 to 5 m, then:

H = 5 m

7) Determination of the area occupied by each of the type reactors (Ar):

Ar = Vr/H

Ar = 2,356 m^3/5 m

Ar = 471.2 m^2

Rectangular reactors of dimensions are adopted: 28 m × 17 m = 476 m^2

8) Verification of the corrected area, volume and hydraulic retention time:

Total corrected area:

At = Nr × Ar = 10 × 476 m^2 = 4,760 m^2

Total corrected volume: Vt = At × H = 4,760 m^2 × 5 m = 23,800 m^3

Corrected hydraulic retention time: t = Vt/Qmedium = 23,800 m^3/2,358 m^3/h = 10 h

9) Verification of the applied loads:

Volumetric hydraulic load (CHV):

CHV = Qmedio/Vt

CHV = 56,592 m^3/d ÷ 23,800 m^3 CHV = 2.38 m^3/m^3×d < 5.0 m^3/m^3xd OK!

Volumetric organic load (Cv):

Cv = Qmedio × S0/Vt

CV = 56,592 m^3/d × 0.568 kg COD/m^3 ÷ 23,800 m^3

Cv = 1.35 kg COD/m^3xd < 3.5 kg COD/m^3xd OK!

10) Verification of the superficial velocities of the residual water inside the reactors or ascending speeds (v):

For Qmedio: v = Qmedio / At

v = 2,358 m^3/h ÷ 4,760 m^2 v = 0.5 m/h < 0.7 m/h OK!

For Qmax-d: v = Qmax-d/At

v = 2,829 m^3/h ÷ 4,760 m^2 v = 0.59 m/h < 0.7 m/h OK!

For Qmax-h: Qmax-h/At

v = 4,244 m^3/h ÷ 4,760 m^2 v = 0.89 m/h < 1.1 m/h OK!

11) Raw wastewater distribution system within UASB reactors

NOTE: The distribution system will be for vertical tubes inside the reactor and the criterion is adopted that each tube will have an area of influence or distribution (Ad) of 2.25 m^2, then the number of tubes (Nd) will be:

Nd = At/Ad

Nd = 4,760 m^2/2.25 m^2 = 2,115.56 = 2,116 tubes

In each of the 10 UASB reactors, there will be:

2.116/10 = 211.6 Nd = 212 tubes that must be distributed symmetrically within the reactor whose cross section is: 28 m × 17 m

NOTE: Due to the rectangular geometry of the reactor they will be placed in the direction of the length greater than 28 m, 22 tubes and in the sense of the length less than 17 m, 10 tubes, with which in reality each reactor will have 220 distributor tubes, thus improving the entry of raw wastewater. In this way the area of influence in each reactor will be:

Ad = 476 m^2/220 tubes,

Ad = 2.16 m^2

12) Estimation of the efficiency in the removal of the COD from the system (EDQO):

EDQO = 100 × (1 - 0.68×t-0.35)

EDQO = 100 × (1 - 0.68×10e-0.35) = 69.6% Efficiency = 65%

13) Estimation of the efficiency in the removal of the BOD from the system (EDBO):

EDBO = 100 × (1 - 0.70 × t-0.50)

EDQO = 100 × (1 - 0.70 × 10e-0.50) = 77.86% Efficiency = 75%

14) Estimation of COD and BOD concentrations in the treated effluent:

S = S0 - (E × S0)/100

SUASB-COD = 568 - (65 × 568)/100 = 198.8 mg COD/l (kg COD/m^3)

SUASB-BOD = 350 - (75 × 350)/100 = 87.5 mg DBO/l (kg DBO/m^3)

15) Evaluation of the production of Methane Gas:

DQOCH4 = Qmedio × (S0-UASB-COD - SUASB-COD) – Yobs × Qmedio × S0-UASB-COD

COD4 = 56,592 m^3/dx (0.568 - 0.1988 kg COD/m^3) - 0.22 kg COD/kg kg APPLY × 56.592 m^3/dx 0.568 kg COD/m^3

COD4 = 13,822.03 COD4 = 13,822 kg COD/d

f(T) = (P × KDQO)/[R × (273 + T)]

f(T) = (1 atm × 64 g COD/mol)/[0.08206 atm l/mol K × (273 + 17°C)]

f(T) = 2.69 kg COD/m^3

QCH4 = COD4/f(T)

QCH4 = 13,822 kg COD/d ÷ 2.69 kg COD/m^3 **= 5,138 m^3/d**

16) Evaluation of Biogas Production

The percentage of methane in biogas is considered to vary between 70% to 80%; and considering a moderate production of 70%, the theoretical production of biogas is:

Qbiogás = QCH4/CCH4

Qbiogás = 5,138 m^3/d ÷ 0.70 **= 7,340 m^3/d**

3.2 Medium-term Situation (Year 2015)

Evaluation of methane gas production:

DQOCH4 = Qmedio × (S0-UASB-COD - SUASB-COD) – Yobs × Qmedio × S0-UASB-COD

COD4 = 69,120 m^3/dx (0.800 - 0.280 kg COD/m^3) - 0.22 kg COD/kg kg APPLY × 69,120 m^3/dx 0.800 kg COD/m^3

COD4 = 23,777.28 COD4 = 23,777 kg COD/d

f(T) = (P × KDQO)/[R × (273 + T)]

f(T) = (1 atm × 64 g COD/mol)/[0.08206 atm l/mol K × (273 + 17°C)]

f(T) = 2.69 kg COD/m^3

QCH4 = COD4/f (T)

QCH4 = 23,777 kg COD/d ÷ 2.69 kg COD/m^3 **= 8,839 m^3/d**

Qbiogas = 8.839 m^3/d ÷ 0.70 **= 12.627 m^3/d**

3.3 Long-term Situation (Year 2025)

Evaluation of methane gas production:

DQOCH4 = Qmedio × (S0-UASB-COD - SUASB-COD) – Yobs × Qmedio × S0-UASB-COD

COD4 = 103,680 m^3/dx (0.800 - 0.240 kg COD/m^3) - 0.22 kg COD/kg kg APPLY × 103.680 m^3/dx 0.800 kg COD/m^3

COD4 = 39.813.12 COD4 = 39.813 kg COD/d

f(T) = (P × KDQO)/[R × (273 + T)]

f(T) = (1 atm × 64 g COD/mol)/[0.08206 atm l/mol K × (273 + 17°C)]

f(T) = 2.69 kg COD/m^3

QCH4 = COD4/f (T)

QCH4 = 39,813 kg COD/d ÷ 2.69 kg COD/m^3 = **14,800 m^3/d**

Qbiogás = 14,800 m^3/d ÷ 0.70 **= 21,143 m^3/d**

3.4 Results Obtained

Depending on the application of the equations established in CHERNICHARO (2007) and the characteristics of quantity (raw wastewater flows) and quality of the raw tributary (in terms of the COD); The results presented in Table 3 were obtained.

Table 3 Volumes of biogas and methane gas possible to be generated at the Alba Rancho WWTP.

PTAR horizon (UASB type reactors)	Methane Gas Volume (m^3/d) 70% of Biogas	Biogas volume (m^3/d)
Year 2009 (considered current)	5,138	7,340
Year 2015 (medium term)	8,839	12,627
Year 2025 (long term)	14,800	21,143

4. Conclusion

Due to the conditions of hydraulic overload and organic overload, the Alba Rancho WWTP is completely collapsed and due to social problems in its environment, it is necessary to implement a new treatment technology, which allows an acceptance of the neighboring population and its consequent social viability for an extension of said plant

The procedure of calculation and design of anaerobic reactors type UASB is simple, likewise the calculation of biogas and methane gas, using the equations established in the bibliographic reference.

The area occupied by UASB type reactors for the treatment of raw wastewater is much smaller than with the current stabilization lagoon treatment system, an important aspect in the region of the Cochabamba Metropolitan region, lacking spaces and areas for future extensions of the Alba Rancho PTAR

The volumes of biogas in general and of Methane Gas in particular, allow the possibility of a bioenergetic transformation useful for the region, either as bioelectricity or as vehicular biogas.

The use of anaerobic wastewater treatment technology in the Alba Rancho WWTP through UASB type reactors, would allow the generation of 3 sub-products with added value: treated water for reuse in agricultural irrigation, biogas for energy purposes and stabilized sludge for use in agriculture

References

[1] C. A. L. Chernicharo, *Reatores Anaerobios* (2nd ed.), DESA/UFMG, Belo Horizonte, Brazil, 2007.

[2] SEMAPA, Monthly monitoring tables of the physical-chemical and biological quality of the 2009 management, carried out in the laboratory of the PTAR Alba Rancho, Cochabamba, Bolivia, 2010.