24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-0617
DIMENSIONING OF A MOBILE ANAEROBIC BIORREATOR - FOR FIELD BIOMASS ANALYSIS

Julio Damyan Imbriaco Silveira
Carlos H. Lagemann
Universidade do Vale do Taquari - Univates
chlagemann@univates.br

Guilherme Leite Lago
Universidade do Vale do Taquari - Univates
gui_llago@hotmail.com

Odorico Konrad
Universidade do Vale do Taquari - Univates, R: Avelino Talini, 171. CEP 95914-014 – Bairro Universitário Lajeado/ RS- Brazil
okonrad@univates.br

Rafael Farias Garcia
Universidade Federal do Rio Grande do Sul
rafafg1985@gmail.com

Rafael Crespo Izquierdo
Universidade Federal do Rio Grande do Sul, R: Sarmento Leite, 425 - 2º Andar. CEP: 90.050-170 – Porto Alegre, RS – Brazil
rcrespo9@hotmail.com

***Abstract**. Bioreactors are static equipment responsible for the process of anaerobic biodigestion (fermentation without the presence of air), through which biogas is generated. The objective of this work is to present a proposal for the design of a mobile bioreactor that allows to perform experiments in different types of environments, providing reliable information about the biogas production potential of the biomass (organic matter) tested, being necessary to take to the laboratory only the biogas generated, for analysis. Taking in consideration the mobility requirements, the concepts discussed in this work are: constructive characteristics of a bioreactor; Dimensioning of structural components; Thermal requirements and computational simulation. This study shows that it is feasible to implement these systems, thus generating technical bases on biogas*
***Keywords:** Bioreactor; Biomass; ASME VIII**.*

1. INTRODUCTION

Biomass as a source of energy (biogas) has potential for growth in the coming years. To determine the energy potential of biomass, it is necessary to generate and analyze it in laboratory, which demands great logistics and costs, since the biomass must be collected for test, and soon after discarded correctly. A bioreactor is a closed and controlled environment in which organic matter undergoes a process of decomposition due to the action of microorganisms. There are several studies in literature that address the design of bioreactors, such as Oliveira (2006), but although, they are considered important concepts in the process of biogas formation, they dimension static bioreactors (installed in laboratories), which require that the biomass be tested, and send to them.

For Thomasi (2010), the bioreactor provides the necessary conditions to promote the metabolic production of interest, allowing the control of parameters that influence the development of the anaerobic process (temperature, homogeneity, pH, among others). In the case of a static bioreactor, the accessories used to control the parameters mentioned previously are decentralized, so that its components are allocated accordingly to the characteristics of each laboratory. In this case, with the purpose of making this mobile structure, the present work proposes the dimensioning of a bioreactor, its components and parts in order to achieve the desired mobility.

The proposal becomes more relevant if we consider that the anaerobic process, which is responsible for the generation of biogas in bioreactors, can be performed in two ways: in the continuous system, in which the equipment is fed daily with small amounts of biomass, maintaining the generation of permanent biogas; and in the discontinuous system, also called batch, where once the capacity of the equipment is fed and the biogas is generated the reaction of this amount of biomass allows (OLIVEIRA, 2009). In both systems, but especially in the continuous, the biomass logistics values are relevant in the total cost of the process, a fact that highlights the importance of mobility of bioreactors.

Through the design of a "mobile bioreactor" equipment, is a gain in agility and economy since only the biogas will be transported to the laboratory.

2. METHODOLOGY

In order to present a proposal for the design of a mobile bioreactor, the following steps are proposed:

1) Definition of the variables of the anaerobic biodigestion process:
   1.1) Anaerobic biodigestion occurs in the absence of oxygen, therefore, the system must be isolated.
   1.2) The internal temperature of the bioreactor must be stable and operate in one of the existing ranges (0 to 20 ° C, 20 to 45 ° C or 45 to 70 ° C).
   1.3) The homogeneous substrate avoids the formation of a superficial shell, allowing the biogas to exit.
2) Structural dimensioning, thermal and other considerations:
   2.1) The ASME VIII standard presents a mathematical procedure for the structural dimensioning of the bioreactor (pressure vessel).
   2.2) The selected material must meet the structural requirements, of mobility and corrosive nature of the biogas. Due to its characteristics, the material selected is AISI 304 austenitic stainless steel.
   2.3) Dimensioning a thermal insulation system is necessary to reduce loss of energy. In Incropera (2011), are presented the procedures for the selection of insulation material and thermal balance calculations.
   2.4) The proposed equipment aims to analyze biomass on a pilot (non-laboratory) scale in field. It is estimated that the total storage capacity of 1.25 m³ (1 m³ substrate and 0.25 m³ biogas).

3) Proposed components and its fundamental operation:
   The main proposed components for the mobile bioreactor are shown in Fig. 1.

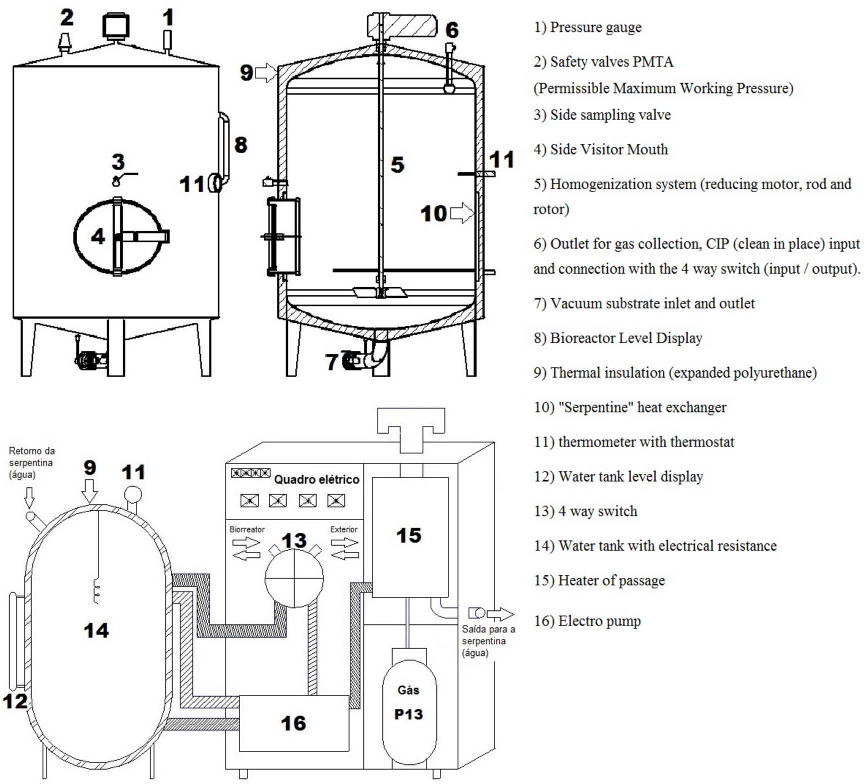

Figure 1: Mobile bioreactor outline and its peripherals.

Figure 1 illustrates the arrangement of the proposed components, and their operation is as follows:

a) Start the pump to start the suction of the substrate into the bioreactor.

b) Switch on the thermostat and the homogenization system. The thermostat activates the electric pump, which connects the heating system of the bioreactor. When the system reaches appropriate internal temperature, the thermostat will shut off the pump, thus shutting off the water flow and, consequently, the passage heater.

c) Checking and collecting data (temperature, pressure and PH) should be periodic, so the operator should inspect the Bioreactor daily. It is also necessary to collect biogas for laboratory analysis.

3. DIMENSIONING, RESULTS AND DISCUSSION

3.1 Dimensioning

In this work, the design of the mobile bioreactor comprises the following steps:

Step 1) Internal volume.

The internal volume of a pressure vessel is determined by the sum of the volumetric capacities of the central cylinder (side), with the internal volumes of the two tops ASME 6 (lower and upper) that make up the pressure vessel. The final result is an internal volume of approximately 1.25 m³, which will be occupied by 1 m³ of substrate, leaving 0.25 m² for biogas storage.

Step 2) Biogas pressure

Biogas is a mixture of various gases, therefore, to determine the pressure exerted by this composite gas one must consider the percentage that each of the gases occupies in the mixture. Applying the Eq. (1), (2), (3) e (4), the pressure generated by the biogas sample is obtained:

Equation (1) allows to determine the gas constant, R´, from the ideal gas constant R.

$$R' = \frac{R}{M} \tag{1}$$

Equation (2) allow us to determine the mass of the sample volume (0,25 m²).

$$m = Vgás \,.\, m\, esp \tag{2}$$

Equation (3) allows determining the number of mass, from the mass of the biogas sample.

$$n = \frac{m}{M} \tag{3}$$

The general gas equation, Eq. (4), makes it possible to find the pressure generated by the mixture.

$$P.V = n.R.T \tag{4}$$

According to Telles (2013) the standard suggests to use a pressure of at least 1.0 kg / cm² (~ 98 KPa), even if the vessel operates with zero or lower pressure, as in this case.

Step 3) Thermal balance
For purposes of calculation, the present work assumes:

- ❖ Disregard thermal losses occurring in small areas without insulation (other couplings of bioreactor accessories); Disregard heat transfer by radiation.

- Divide the bioreactor in three parts, as show in Fig. 2, tops, cylinders "coil" and the cylinder.

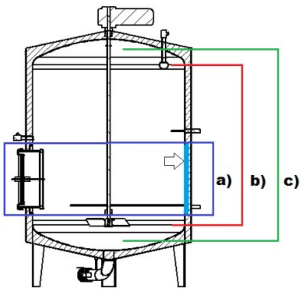

Figure 2: Division into three parts of the bioreactor.

Considering the Eq. (5), (6), (7) e (8), the thermal resistance values are obtained in each of the proposed divisions of the Bioreactor in Fig. 2 and, consequently their summation will result in the total thermal resistance of the equipment.
Equations (5) and (6), allow to determine the thermal resistance by conduction and by convection in flat walls.

$$R_{t\,cond} = \frac{L}{k\,A} \quad (5)$$

$$R_{t\,conv} = \frac{1}{h\,A} \quad (6)$$

Equations (07) and (08) allow to determine the thermal resistance by conduction and by convection in cylindrical walls.

$$R_{t\,cond} = \frac{\ln(\frac{R}{r})}{2\,\pi\,k\,L} \quad (7)$$

$$R_{t\,conv} = \frac{1}{h\,2\,\pi\,r\,L} \quad (8)$$

Considering that the bioreactor proposed is divided in three parts (top, cylinder and serpentine cylinder) Figs. 3 and 4 illustrate the views of the composite wall layers and the thermal resistances of each case.

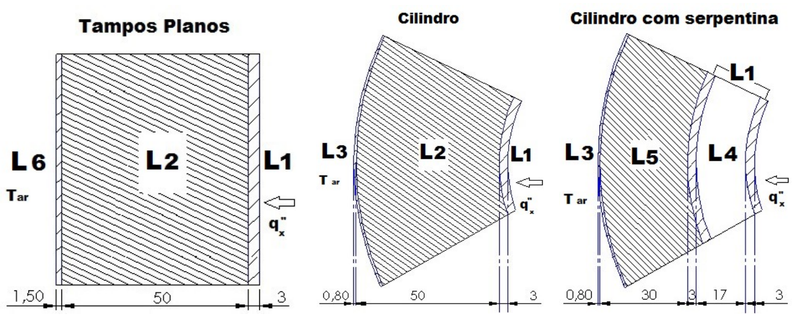

Figure 2: Thermal flow through the different layers.

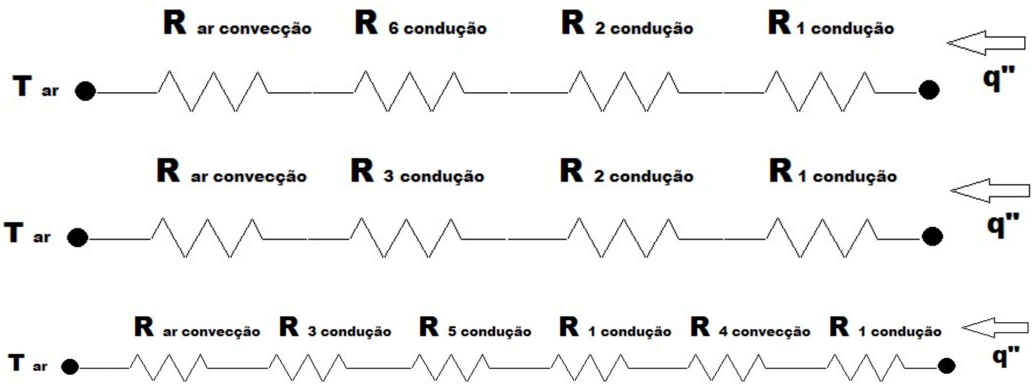

Figure 4: Thermal Circuits in the layers of the Tops, cylinder and cylinder with serpentine, respectively.

Total thermal resistance of the system is a result of the sum of the aforementioned resistors.

Step 4) Cap and side

For the dimensioning of the plate thicknesses to be used in the tops and sides of the proposed equipment, the present work follows the mathematical procedures indicated in the ASME VIII standard.

Side

The standard explains that there are two groups of pressure vessels, those of great thickness and those of small thickness. In order for a pressure vessel to be considered of great thickness, it must meet one of the requirements below, otherwise it is small cylinders.

$$e > \frac{1}{2} R \quad (9)$$

or

$$P > 0{,}385\ SE \quad (10)$$

In view of the above requirement and taking into account the working pressure of 98 KPa, it is concluded that the proposed pressure vessel is of small thickness. Through Eq. (11), (12) and (13), the thickness of the plate and the maximum allowable working pressure (PMTA) are obtained, to the side of the pressure vessel, necessary to withstand the project specifications.

The result of the equation (11) allows the dimensioning of the thickness considering the circumferential stresses.

$$e = \frac{PR}{SE - 0{,}6P} + C \quad (11)$$

The result of equation (12) allows the dimensioning of the thickness considering the longitudinal tensions.

$$e = \frac{PR}{2ES + 0{,}4P} + C \quad (12)$$

The result of equation (13) that allows the dimensioning of the maximum allowable working pressure.

$$PMTA = \frac{SEe}{R+0,6e} \quad (13)$$

Cap (ASME 6)

The following equations size the maximum admissible working pressure (PMTA) required to ensure the resistance of the torriespheres to the ASME 6 standard.

Equation that allows the dimensioning of the thickness of the top sheet.

$$e = \frac{0,885PL}{SE-0,1P} + C \quad (14)$$

Equation that allows the sizing of the maximum working pressure allowed in the bioreactor tops.

$$PMTA = \frac{SEe}{0,885L+0,1e} \quad (15)$$

As already mentioned, it is usual to use plate of the same thickness for tops and sides, even if the vessel is oversized, since it facilitates the manufacturing process, according to Telles (2013). The outer plate has a merely aesthetic, non-structural function, so that its dimensioning is not necessary.

The data generated in the sizing step allow the final sketch of the project proposed in this work, according to Fig. 5.

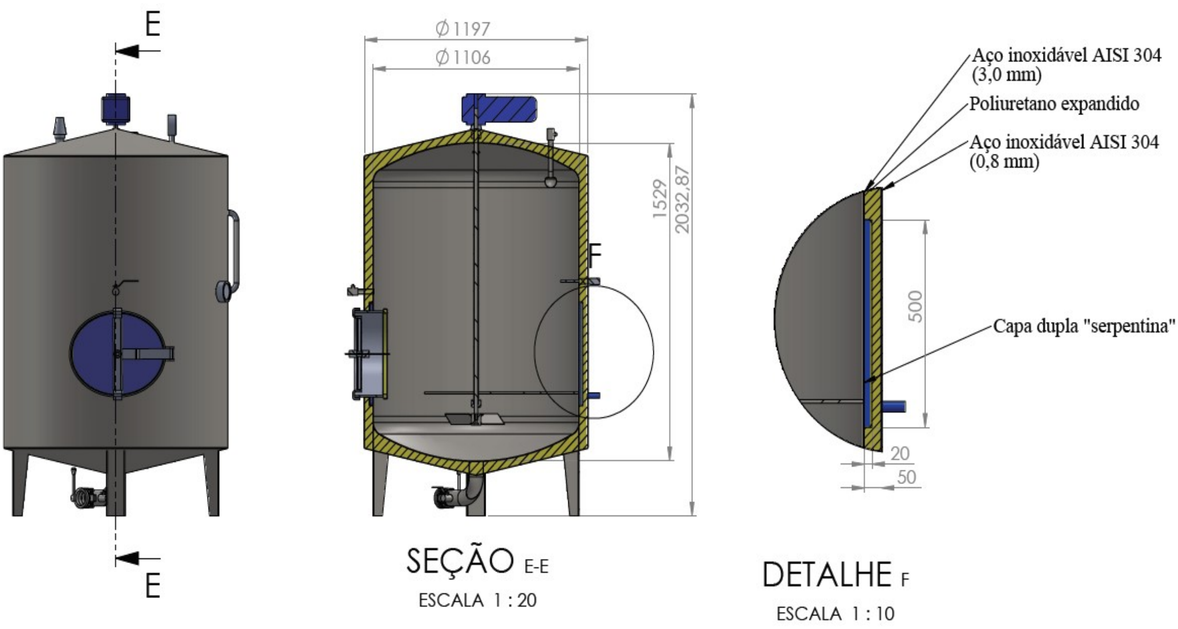

Figure 5: Bioreactor

3.2 Simulation

The following thermal simulation was performed considering the working temperature in the thermophilic range (temperature of 318 K to approximately 343 K) because it is the condition of greater severity at which the bioreactor will be exposed. The entire interior volume of the bioreactor is considered to be at the same temperature. For the thermal simulation, the internal temperature was set at 343 K and the thermal flow rate q" was 6.63 W/m².

The analysis was performed in Solidworks® software, obtaining the results represented in Fig. 6.

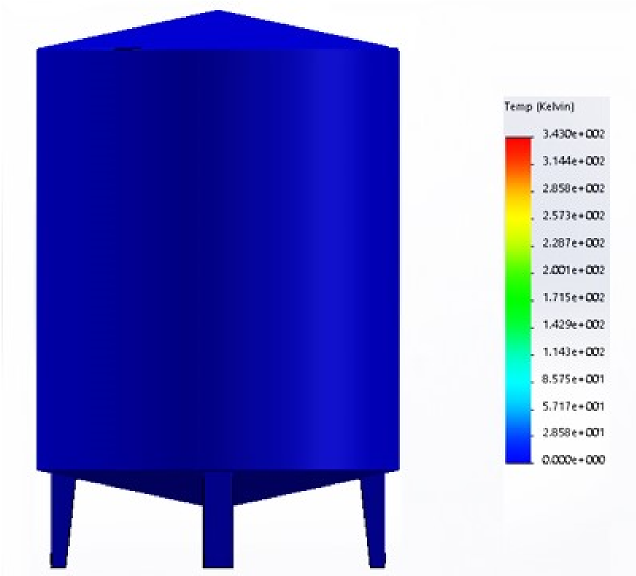

Figure 6: Simulation of the heat flow from the interior to the exterior of the Bioreactor.

The mesh used for the thermal simulation is mixed containing 55657 nodes and 28399 elements.

Analyzing the results obtained in Fig. 6, it is verified that the dimensioned insulation provides a thermally stable environment.

The simulations associated with the bioreactor structure and the internal pressure are presented in Figs. 7 and 8, respectively.

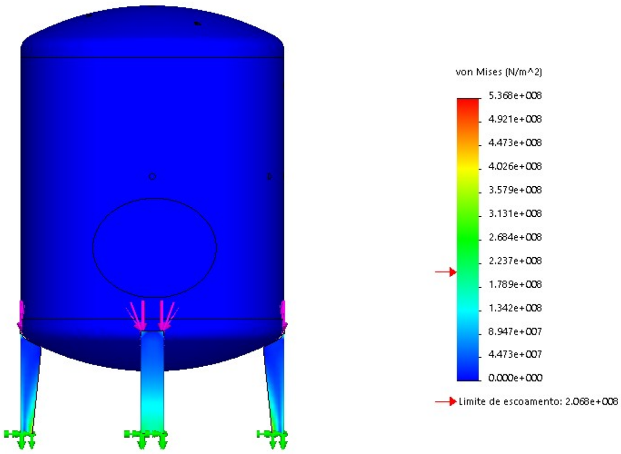

Figure 7: Structural Static Simulation.

The structural simulation of the bioreactor occurs taking into account the load generated by the sum of the masses of the biomass and the material that constitutes the equipment.

The base of support was fixed and the sum of the masses divided equally in the four feet of support of the bioreactor. The mesh used is mixed, containing 57438 nodes and 28940 elements.

To simulate the internal pressure, using the calculated pressure, were distributed force vectors in all directions, inside the bioreactor, inside of the bioreactor.

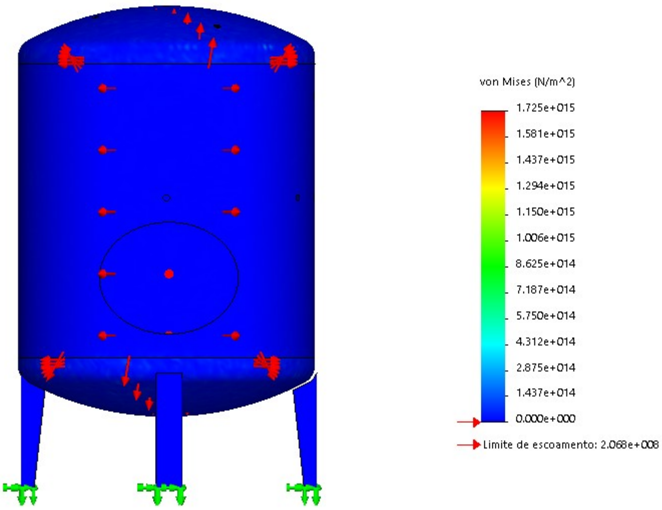

Figure 8: Simulation Static internal pressure.

By analyzing the results it is possible to verify that the structure meets the failure criteria of Von Mises and, therefore, it is considered a safe pressure vessel.

Figure 9 outlines the final assembly of the mobile bioreactor where it can be mounted under an automotive trailer.

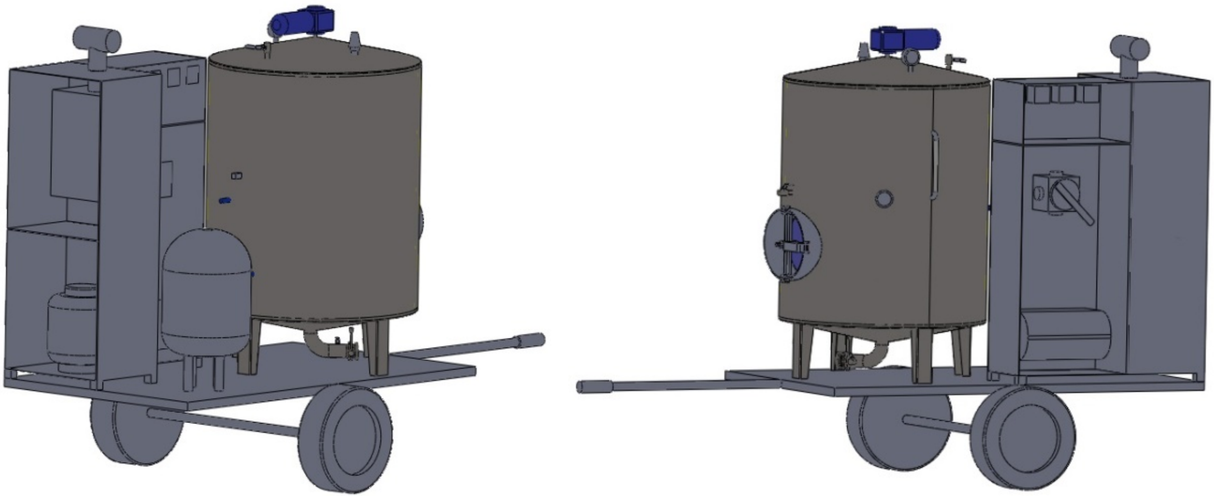

Figure 9: Mobile Bioreactor.

4. CONCLUSIONS

After scaling, it was concluded that the executed study shows that it is feasible to implement the proposed systems. The "mobile bioreactor" will be of great help in the development of studies of the biomass potential, as well as in the generation of biogas.

5. REFERENCES

Incropera, F. P. et al., 2011. *Fundamentos de Transferência de Calor e de Massa*. Rio de Janeiro: LTC, 6th edition.

Oliveira, P. A. V., 2006. "Projeto de biodigestor para produção de biogás em sistema de produção de suínos". 15 May 2016 <http://www.cnpsa.embrapa.br/sgc/sgc_publicacoes/publicacao_l4l77t4r.PDF>

Oliveira, Rafael D.E., 2009. "Generation of electric energy from the biogas produced by the anaerobic fermentation of waste in slaughterhouse and the possibilities in the carbon market". 03 May 2016 < file:///C:/Users/Jorge/Downloads/Oliveira_Rafael_Deleo_e.pdf>.

Telles, Pedro C. da S., 2013. *Vasos de Pressão*. Rio de Janeiro: LTC, 2nd edition.

Thomasi, Sérgio S., 2010. “Evaluation of performance parameters of three models of bench pneumatic bioreactors”. 14 May 2016. < http://www.bdtd.ufscar.br/htdocs/tedeSimplificado//tde_busca/arquivo.php?codArquivo=3282>

6. RESPONSIBILITY NOTICE