ORIGINAL ARTICLE

Analysis of Von Mises Stress in Anaerobic Biodigesters Type Rigid Dome

Análisis de tensiones Von Mises en biodigestores anerobios de cúpula rígida

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ABSTRACT. The work shows an analysis of Von Mises stresses of biodigesters of rigid dome (Chinese type), which are the most extended under Cuba conditions. For the above-mentioned, a professional software of design CAD was used. These investigations were executed based on Attended Design for Computers (CAD) as well as on the use of the physical simulation to small scale in plastic biodigesters and taking mensurations to real scale. The objective of the work was to compare the correspondence between the results obtained in the variable pressure of biogas obtained to laboratory scale and the values reported by other authors to pilot scale against the pattern on-line used. By means of the on-line pattern, the most dangerous sections in the different constructive elements that conform the biodigesters of this constructive type could be determined. It was possible to determine that the stresses that cause the interior pressure of biogas generated in these biodigesters of rigid dome (Chinese type), do not constitute dangerous stresses affecting the structures of walls, dome and neck of this biodigestor type.

Keywords: von Mises stress, biodigesters, computer simulation.

RESUMEN. El trabajo realiza un analisis de tensiones Von Mises de los biodigestores de cúpula rígida (tipo chino), los cuales son los más extendidos en las condiciones cubanas. Para lo anterior, se procedió al empleo de un software profesional de diseño CAD.Basadas en técnicas de Diseño Asistido por Computadoras (CAD), así como a la utilización de la simulación física a pequeña escala en biodigestores plásticos y la toma de mediciones a escala real, se ejecutó esta investigación. El objetivo del trabajo estuvo dirigido a comparar la correspondencia entre los resultados obtenidos en la variable presión de biogás obtenido a escala de laboratorio y los valores reportados por otros autores a escala piloto contra el modelo computarizado empleado. Mediante el empleo del modelo computarizado se pudo determinar las secciones más peligrosas en los diferentes elementos constructivos que conforman los biodigestores de esta tipología constructiva, además de los límites de rigidez que pueden soportar este tipo de biodigestor, en dependencia de sus dimensiones y el material de construcción utilizado. Como conclusiones se llegó a determinar que las tensiones que provocan la presión interior de biogás generado en estos biodigestores de cúpula rígida (tipo chino), no constituyen tensiones peligrosas que puedan afectar las estructuras de las paredes, cúpula y cuello de este tipo de biodigestor.

Palabras clave: tensiones von Mises, biodigestores, simulación por computación.

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INTRODUCTION

According to Asociación Cubana de Producción Animal (ACPA) (2007), biodigesters Chinese type (rigid dome), model NL-7, built of bricks with different volumes: 19.20 m^3, 19.58 m^3 and 24.00 m^3, ended up supporting a maximum interior pressure of biogas of 1070 mm w.c (water column) on their internal walls and dome (volume = 24.00 m^3). On the other hand, Cuban biodigesters of different capacities (volume = 12, 24, 32, 47 and 90 m^3), designed by them and introduced in the production in Villa Clara Province, were built using bricks or blocks by means of similar technologies to the ones used by Asociación Cubana de Producción Animal (ACPA), (2007). They have reached maximum inner biogas pressures of 1650 mm w. c. (volume = 24.00 $m^{3)}$. As Guardado (2007) refers, an essential requirement in a biogas plant is that it should be waterproof, the deposit of gas should not have escape and for this reasons they should keep in mind calculations that avoid fissures. The author above mentioned outlines that there are internal and external forces that act on the structure of a biogas plant, among them the gas pressure in the walls and dome of the biodigester. For such a reason, internal forces can be diminished, if an appropriate form of construction is selected. Because of that, the use of structures conformed by curved planes (vaults, domes, cylinders etc), in which more uniform distribution of the external and internal forces is achieved, diminishes the concentration of stresses and their "peaks" in the diagrams. According to Moreno (2011), in the Chinese type biodigesters (rigid dome), gas meter does not exist, and the biogas is stored inside the system. As the pressure of the gas stored in the dome of the biodigester increases, its pressure increases, forcing the liquid, in the inlet and outlet tubes to ascend and reaching pressures of up to 1000 mm w.c. In these, between 0.15 and 0.20 volumes of gas per digester/day volume are generated. As consequence of the pressure variation, the one that increases when the gas is generated and diminishes when it is consumed; decreases the efficiency in high consuming equipment. In accordance with Sánchez *et al.* (2005), in biodigesters of rigid dome built in Matanzas Province, Cuba, the pressures obtained have oscillated between 1000-1400 mm w. c. (volume = 24.00 m^3). As Pérez (2010) refers, in biodigesters of fixed dome, the gas produced during the digestion is stored under the dome with pressures between 1000 and 1500 mm of w.c. On the other hand, ANÓNIMO (2004) recognizes, that in the Chinese type biodigesters, internal pressures of biogas of more than 1000 mm w.c. are reached. Before these variations of biogas interior pressure in similar biodigesters which use pig manure, caw manure or mixtures of both as biomass, it was decided to carry out a study of this variable using simulation for computer and physical simulation to small scale. It was done to see if these stresses, created by the biogas pressure, could be considered dangerous for the walls and domes of these biodigesters. For that, Computer Assistant Design (CAD) tools, broadly well-known and used to global scale were utilized and by means of them different variables, to which new projects will be subjected, can be simulated. By means of these techniques, it is possible to study the different elements or parts that build any type of engineering installation. In the Cuban case, the most utilized professional softwares are the AutoCAD, Mechanical Desktop, Inventor and others. In this case, a 3 D design software, titled Solidworks Office Premium, 2014 (Solidworks, 2014).

METHODS

Reduced models of biodigesters of rigid dome were built by using 5 L bottles of water. Holes of 8mm diameter were practiced in their respective covers. Different devices were placed to allow the exit of the gas toward two branches or different conduits. A branch is connected toward a gasometer in test tube form, where biogas production is monitored daily. The other branch is connected toward a micro manometer model Schragrohrmanometer Fabr.Nr.898192

(Schragrohrmanometer, 2014), to monitor the interior pressure of generated biogas. In Figure 1 details of the reduced models are shown.

FIGURE 1. Biodigester (reduced model) and micro gauge utilized.

The biomass introduced in the models to reduced scale was composed by 36 g of ground corn (flour), 358 g of pig manure and 1576 mL of water, dissolved in relationship water-excretes of 4:1. The bioreactors were placed under field conditions, being monitored during a hydraulic retention time (HRT) of 35 days. The climate variables evaluated were atmospheric pressure and environmental temperature, while in the micro gauge the displacement of the manometric closing liquid utilized (water) was observed. Ethylic alcohol, mercury or water can be used indistinctly as manometric liquid. In this case, water was used like manometric liquid.

The professional software (Solidworks, 2014), was used for the simulation for computer in the reduced model and in the model to real scale, based on the work developed by Guardado (2007), using the constructive data and materials used for the construction of the model to lab scale, as well as of the biodigesters that are used to real scale. The study for simulation supported by the software (Solidworks, 2014), was carried out. For that purpose, the obtained data to lab scale, and the ones to real scale offered by Sánchez *et al.* (2005) were utilized.

In the real model, for the determination of biogas pressures generated in the interior, expression (1) was used according to Nekrasov (1986).

$$Pest = \delta o\ liquid \cdot g \cdot \Delta L \quad (1)$$

Where:

Pest- pressure (Pa);

δo liquid- density of the manometric liquid (Water) (kg/m^3);

g- gravity (9.8 m/s^2).

ΔL – static height of the manometric liquid (m);

In the case of the biogas pressures generated inside the model to lab scale the expression 2 was used, which is defined for:

$$P = cp \cdot \Delta L \cdot [o + 0{,}0009\ (To - Tm)] \quad (2)$$

Where:

P- pressure (Pa);

cp- constant for the pressure, depends on the inclination grade of the closing liquid column. For inclination similar to 90^0; (cp = 0.1962);
ΔL – reading of the manometric liquid (mm);
δo – density of the manometric liquid in the moment of measuring (g/cm^3);
To- environmental temperature in the moment of measuring (^0C);
Tm- temperature of the micro gauge (^0C).

The investigation was made under field conditions. Then To and Tm have the same value, reason why they are annulled. Being the expression 2 similar to:

$$P = cp \cdot \Delta L \cdot o \quad (3)$$

In accordance with Perry (1967), the density of the manometric liquid (water) is selected with the temperature in the moment of the mensuration. For the mensuration's to real scale, the data offered was used in Asociación Cubana de Producción Animal (ACPA) (2007). The monitoring of the pressure was made to the exit of the biogas (neck or gas meter). In the Figure 2 an outline of the biodigester of rigid dome is shown where the bench mark of static height is appreciated (Aest); value that determines the pressure of maximum biogas that can be reached in this biodigesters type from the constructive point of view.

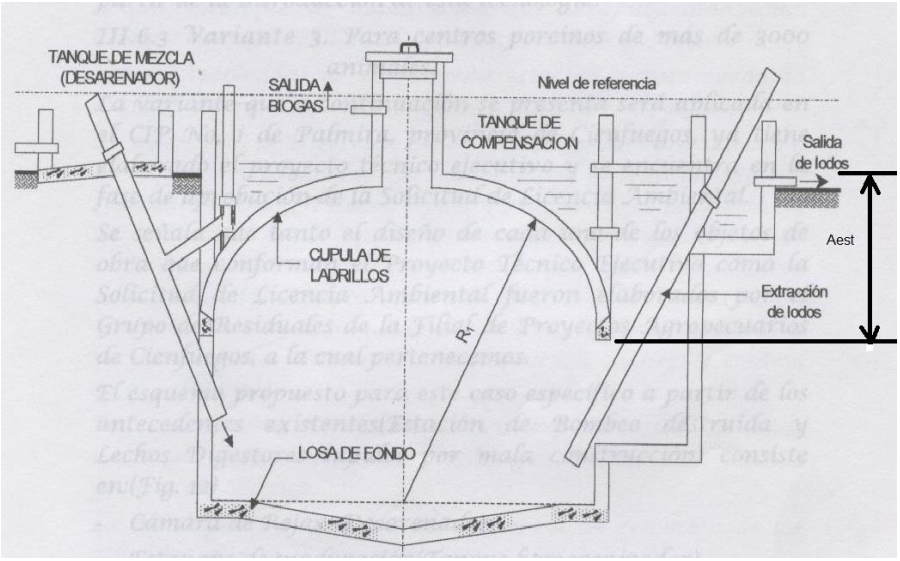

FIGURE 2. Sketch of the biodigester of rigid dome to real scale. Search: Guardado (2007).

Once determined the calculation expressions for each case, they were evaluated following the methodologies explained previously. For that, mensuration results to lab and real scale were considered and the effect these interior pressures of biogas could cause in the design of the biodigesters was simulated. The study of von Mises stresses in the walls and dome of this biodigester type was also carried out.

RESULTS AND DISCUSSION:

The values of interior biogas pressure obtained during the analyzed cycle (35 days) in the models to lab scale are shown in Table 1.

For the analysis of stresses Von Miles, the maximum value of pressure obtained to lab scale (39.66 Pa) was introduced in the software Solidworks (2014) and the graphics obtained are shown in the following Figures.

TABLE 1. Pressures Obtained in Different Days of Monitoring the Lab Scale Model

Days	Temperature (ºC)	Water Density (g/cm^3)	Reading of the Manometric Liquid (mm)	Pressure (Pa)
8	35	0.99	205	39.59
13	35	0.99	123	23.74
14	33	0.99	120	23.17
15	34	0.99	62	11.97
16	33	0.99	68	13.13
17	34	0.99	65	12.55
18	36	0.99	68	13.12
19	36	0.99	70	13.51
21	28	0.99	205	**39.66**
32	34	0.99	125	24.14

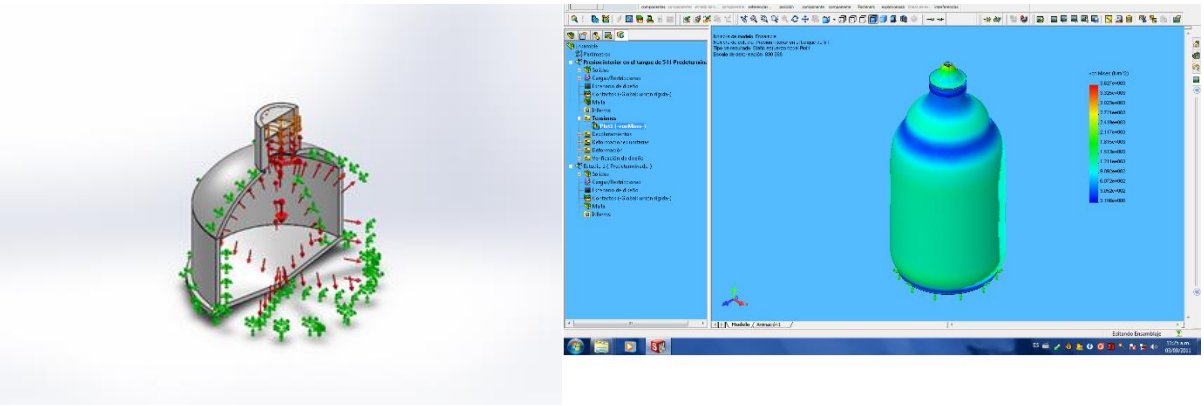

FIGURE 3. Analysis von Mises in Biodigester to Reduced Scale

The study of stresses von Mises realized in Figure 3 revealed that dangerous stresses do not exist. That allows affirming that all interior sections of the tank resist favorably the stresses caused by biogas pressure generated in the models to lab scale. It is remarkable that as simulation material to reduced scale plasticized PVC was used.

In the case of the biodigestores to real scale, with the measuring data obtained, introducing the maximum pressure value obtained (16 180.97 Pa) (biodigester of rigid dome) and using the software (Solidworks, 2014), the following graphics were obtained.

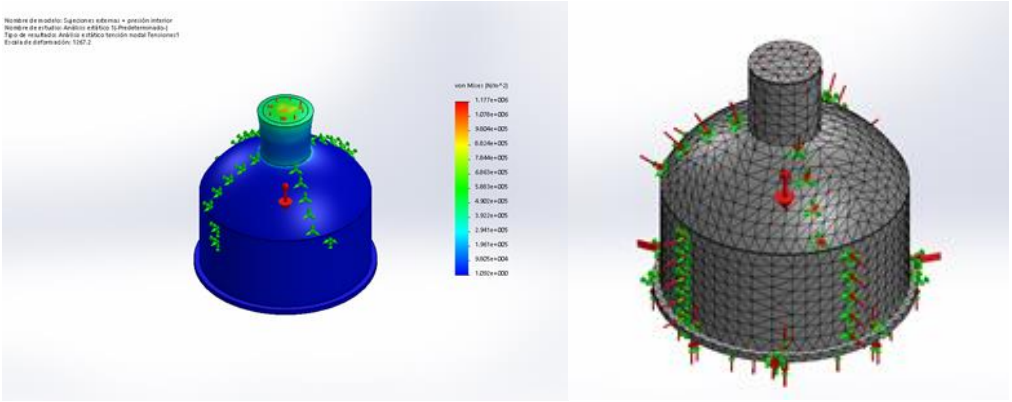

FIGURE 4. Analysis of von Miles in biodigester to real scale.

In Figure 4, the study of von Mises stresses realized is shown. It is possible to appreciate that for this case there are not points of dangerous stresses, which confirms that the biodigester resists appropriately the interior pressures of the generated biogas and hence these pressures can be considered like lower pressures (16 180.97 Pa). Ceramic porcelain was used as simulation material, since the software (Solidworks, 2014), does not have bricks or construction blocks in its database as simulation materials. This could bring some small variations in the results, but it is believed by authors that they would not be significant, since the utilized material is quite similar. On the other hand, it is well-known that in any simulation, it is not possible to imitate the reality100%.

Very little information is available in the literature regarding the variable studied in this work. However, according to Martínez *et al.* (2007), in the utilized analyzers of gas at laboratory level, it is common to determine variables such as: methane content (CH_4), content of carbon dioxide (CO_2), oxygen content (O_2), content of hydrogen sulfide (H_2S) and atmospheric pressure in the moment of mensuration. Nevertheless, it is not common to determine the interior pressure of generated biogas. The above-mentioned does not mean that analyzers of gases able to carry out it, just as Ansyco (2000) describes, do not exist. However, they are expensive and for this work, there were any available.

Therefore, in accordance with the results of these investigations, it is possible to state that in both, in the models to lab scale and in the models to real scale, the stresses caused by the generation of interiors biogas pressures in the body and dome of these biodigesters (walls, dome and neck), are not dangerous. That confirms the mechanical rigidity of these biodigesters, as well as a sure work and without danger regarding this variable, if the constructive technical requirements referred by Guardado (2007) are fulfilled.

CONCLUSIONS

- Physical simulation to laboratory scale and by means of professional software guarantees a valuation of anaerobic biodigesters of this type without high expenses in materials and labor and constructive forces.
- Von Miles stresses caused by the generation of interior biogas pressures in biodigesters models to lab and real scale, on their body, dome and neck, are not dangerous.

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