Design of Digester Biogas Tank Part 4: The Stress Analysis Of Digester Biogas Tank

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Summary. This paper presents the application of Autodesk Inventor 2014 program for numerical simulation of stress distribution in a pressure vessel.The stress analysis was performed for a digester biogas tank. The distribution of loads and meshing were analyzed. The results of analysis were discussed.
Key words: biogas, stress analysis, finite element method.

INTRODUCIOTN

One of the ways to prevent the effects of global warming is the evelopment of renewable energy sources. According to the data presented by PSE S.A. on 31 Jan 2013, the Polish renewable energy sources are responsible for 9,6% of all the energy produced in the country. One of possibilities for increasing the share of renewable energy could be the agricultural biogas. In practice, biogas is most frequently used in cogeneration when creating heat and electric energy. It is becoming more popular as a source of biomethane [7]. Valuable nutrients obtained in the process of fermentation may be re-used as substitutes for mineral fertilisers. This process results in the lowering of CO_2 emissions, allows for conserving fossil fuels and decreasing costs [10].

The process of biogas creation may utilize highly varied technologies [8, 12]. There is a wide spectrum of ways in which the components and technical equipment may be connected. The technical elements of a biogas installation are selected to match the substrates used to produce the gas. The size of individual generators and tank volumes depend on the quantity of the input material.

Modern agricultural biogas plants utilize different fermentation chambers. Their construction is mostly dependent on the utilized technology of biogas production.

Currently, the most prevalent material for production of such chambers is ferro-concrete. It is the material of choice in both Germany and Poland [2]. Its main advantage is the production cost [4].

Steel tanks, used in biogas plants as reactors for methane fermentation are usually of similar volumes as the ones made of ferro-concrete and are considered a good alternative as the latter type is prone to gas or substrate leaks and releasing of smells [4]. Steel fermentation chambers are usually placed on concrete foundations. The walls of a steel tank are made of sheet metal bands that are connected by welding or screws [2]. The types of steel used are stainless, acid-resistant, galvanized or enamelled. Stainless steel tanks are characterized by resistance to corrosion by hydrogen sulphide and ammonia. Fermentation chambers may also be created from non-alloy steel, however in such a case a plastic cover must be used to protect the walls of the tank against chemical corrosion. Such solution is cheap but requires diligence when creating seals, openings and when attaching the plastic to the walls of the tank [2]. The thickness of the sheet metal is usually lower than 5 mm [4]. A definitive advantage of a steel tank is that it starts its operation very quickly, as it can be easily heated after being filled with substrate [2]. With ferro-concrete tanks it is impossible to quickly heat the substrate as the contractor usually defines limits for the maximal increase of temperature within the tank [2]. A significant advantage is also the short construction period as finished components, such as sheet metal bands, are delivered to the construction site. Steel fermentation chambers are usually built from top to bottom (Fig. 1).

All screw joints are specially sealed. As with ferro-concrete chambers, in the steel tanks the roof may be created as a biogas tank using membranes [13]. The tank may be covered by a single membrane or two membranes. In a roof consisting of two membranes, the top membrane separates the biogas storage (internal membrane) from the weather conditions.

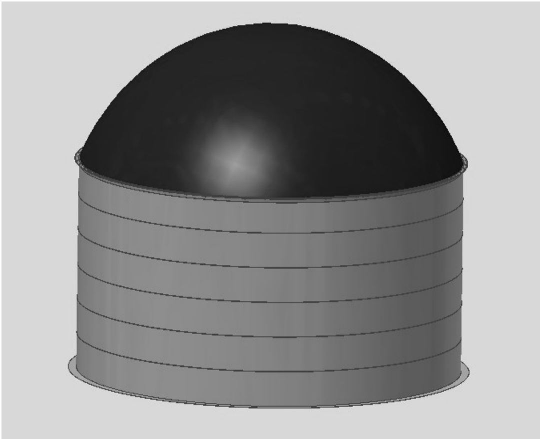

Fig. 1. Steel fermentation chamber [own elaboration]

The roof of such chambers may also be made of steel but in such a case an additional spherical two-membrane biogas storage tank is built [13].

ANALYSIS OF STRESSES OF BIOGAS TANK'S RINGS WITH CONSIDERATION OF THE INTERNAL PRESSURE OF THE LIQUID AND THE WEIGHT OF THE INDIVIDUAL ELEMENTS OF THE SHELL

According to the Pascal's law, a liquid exerts hydrostatic pressure on the tank that is dependent on the liquid column level and the specific weight of the liquid. Pressure distribution in a tank filled with liquid was presented in Figure 2 [3].

The average pressure value for a given ring ($ts_1 - t_{s6}$) was calculated taking into consideration hydrostatic pressure at different heights of the liquid-filled tank according to equation (1) and was given in Table 1.

$$p_h = qgh, \tag{1}$$

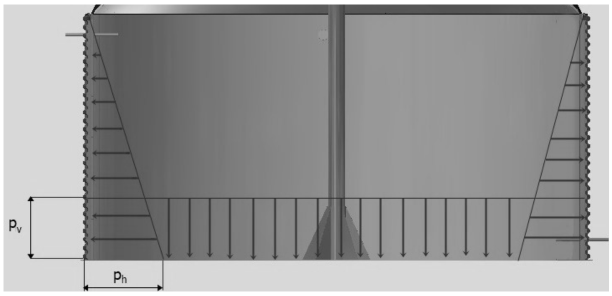

Fig. 2. Hydrostatic pressure distribution in a liquid-filled tank [own elaboration]

where:
p_h – hydrostatic pressure [MPa];
q – liquid's density[kg/m³], assumed q = 1000 [kg/m³];
h – liquid column level equal to depth [m].

Average pressure distribution on a given ring is given in Figure 3.

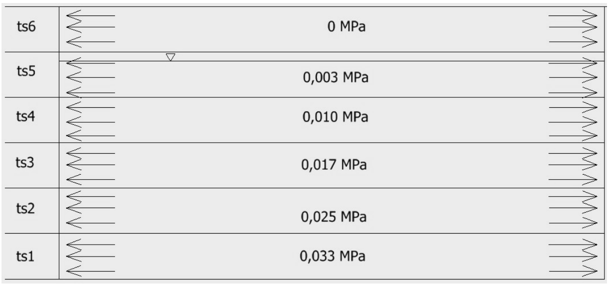

Fig. 3. Distribution of average pressure on a ring [own elaboration]

The top surface of the rings was loaded with the weight of the construction elements [14, 16]. Table 2 presents the load distribution of own weight for individual shell rings.

In order to determine stresses in a ring caused by water pressure and load from other construction elements (due to their weight), the stress analysis module was applied

Table 1. Average hydrostatic pressure at levels of individual rings [own elaboration]

Ring number	Level measured from the upper surface of the tank h [m]	Level measured from the liquid level [m]	Liquid pressure p_h = p_v [MPa]	Average pressure p_v for a ring [MPa]
ts6	4,64	-	0,000	0,000
	3,87	-	0,000	
ts5	3,87	-	0,000	0,003
liquid level	**3,71**	**0,00**	**0,000**	
	3,09	0,62	0,006	
ts4	3,09	0,62	0,006	0,010
	2,32	1,39	0,014	
ts3	2,32	1,39	0,014	0,017
	1,55	2,16	0,021	
ts2	1,55	2,16	0,021	0,025
	0,78	2,93	0,029	
ts1	0,78	2,93	0,029	0,033
	0,00	3,71	0,036	

Table 2. Load due to weight of elements, exerted on top edges of individual rings [own elaboration]

Construction element	Thickness [mm]	Height [mm]	Internal diameter of the ring [mm]	Element's volume [m3]	Element's mass [kg]	Element's weight [N]	**Meridional force on construction element [N]**
ts6	5	772	9268	0,056	442	4332	**2155**
ts5	5	772	9268	0,056	442	4332	**6486**
ts4	6	772	9268	0,067	530	5199	**10818**
ts3	6	772	9268	0,067	530	5199	**16017**
ts2	6	772	9268	0,067	530	5199	**21215**
ts1	6	772	9268	0,067	530	5199	**26414**
ring holding down membranes	80	7	9290	0,008	64	633	not analyzed
top angle section	7	100	9278	0,020	155	1522	not analyzed

from the "Environment" tab of the Autodesk Inventor software. The analysed ring was ts$_1$, which was produced from a welded band of sheet metal. The model omits the top bevelling and does not include holes for pipes used to remove the processed substrate from the tank [1, 9]. The upper edge of the ring is under force of about 26414 N, due to own weight of chamber's elements above that ring and the average pressure at this level of the tank – 0.033 MPa. In order to perform stress analysis, the first step was selecting the material the construction element is made from [11, 15]. From the program's material library the non-alloy steel was selected. The second step was to select the linkage between the model's elements [5]. The ring was linked with two immobile links placed on its top and bottom base (Fig. 4).

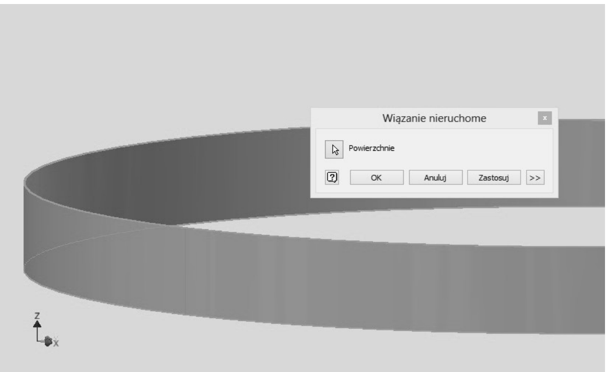

Fig. 4. Creation of immobile links in the model [own elaboration]

Next the loads were established: pressure 0.033 MPa (Fig. 5) exerted on the internal surface of the tank and the load of 26414 N (Fig. 6) exerted on the top edge of the ring.

The software was used to generate a mesh of 35591 finished elements, which covered the surface of the ring. The mesh was automatically concentrated on the weld of the ring (Fig. 7).

After the simulation was launched, the program generated results for, among others, reduced stresses (MPa), displacements (mm) and the safety factor. The results were available in the browser's window under the branch entitled

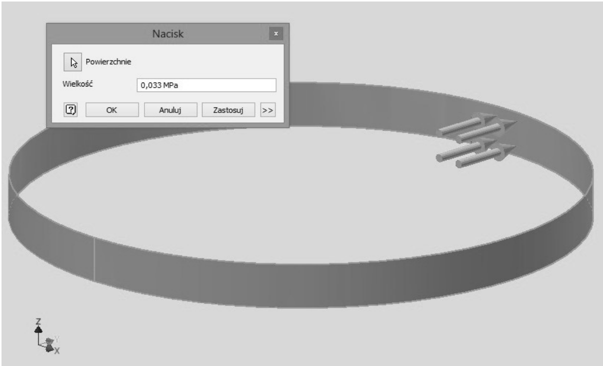

Fig. 5. Defining of load due to the pressure exerted on the ring [own elaboration]

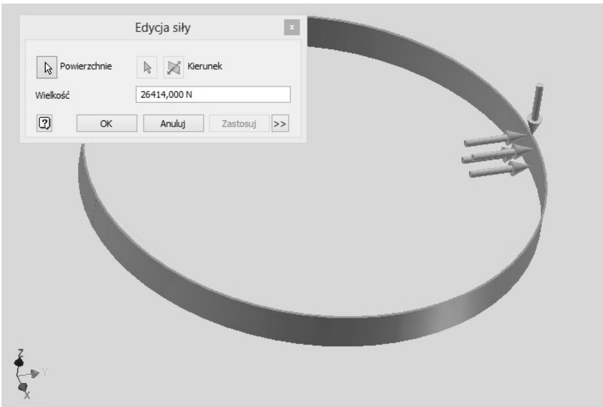

Fig. 6. Defining of load due to the weight of construction elements [own elaboration]

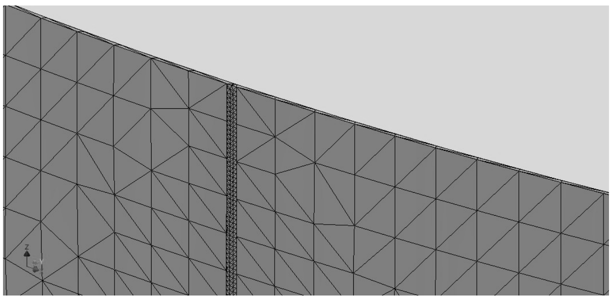

Fig. 7. Mesh of finished elements covering ring t_{s1} with visible concentration on elements in the weld area [own elaboration]

"Results". The results were displayed with "contour shadows" on that allows presentation of results without translations between colours. Figures 8, 9 and 10 present the areas characterized by maximal and minimal Von Mises stresses.

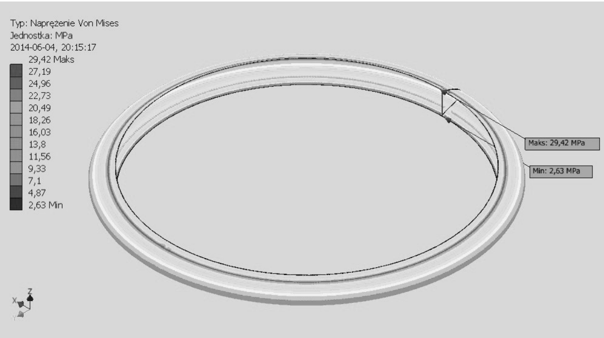

Fig. 8. Von Mises stresses [own elaboration]

Maximal Von Mises stresses are marked in red (about 27.42 MPa). They are present in the area of the weld at both the top and bottom edge of the ring (Fig. 9).

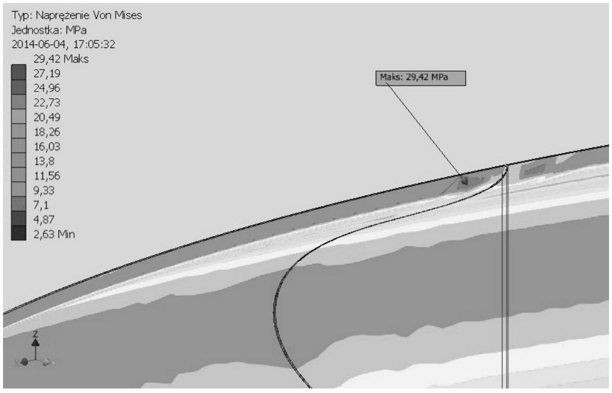

Fig. 9. Maximal Von Mises stresses – view from the internal side of the ring [own elaboration]

Minimal Von Mises stresses were recorded at the middle of the top and bottom base of the ring and are 2.63 MPa (Fig. 10).

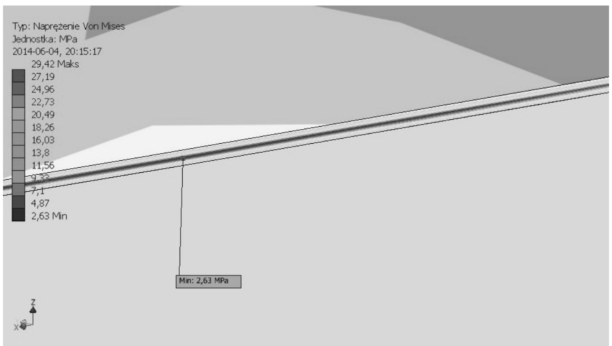

Fig. 10. Maximal Von Mises stresses [own elaboration]

Next, the displacements were analysed in mm. The largest displacements were observed in the middle part of the ring (Fig. 11) and the smallest in the lower part of the ring's wall (Fig. 12).

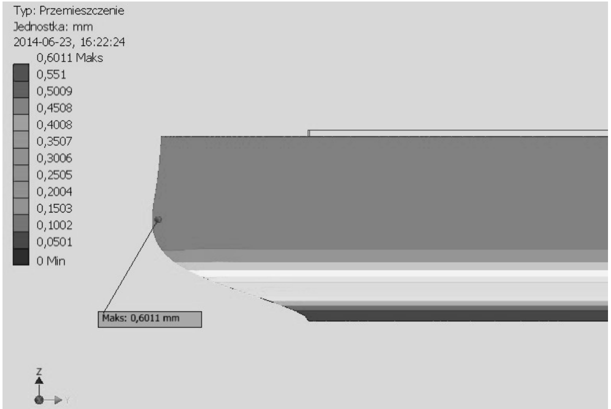

Fig. 11. Maximal displacement in mm [own elaboration]

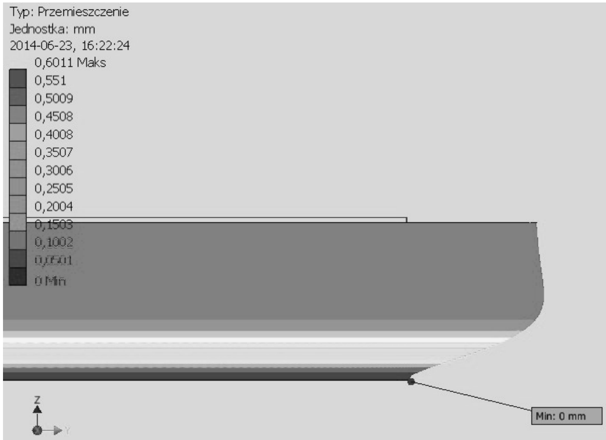

Fig. 12. Minimal displacement in mm [own elaboration]

At the next stage the safety factor needed to be established, which is an absolute amount, resultant from the quotient of the Von Mises stress and the yield point of a given material. The safety factor should not be below 1.0 [6]. Below the results are presented of the safety factor for the tested ring (Fig. 13). These values are between 7.04 and 15ul.

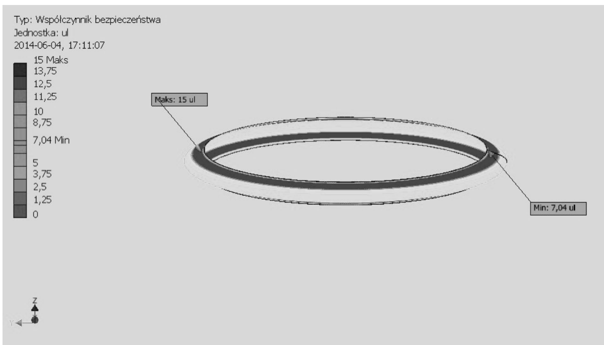

Fig. 13. Safety factor [own elaboration]

CONCLUSIONS

Tools included in the Autodesk Inventor 2014 program allow for the designing of a steel fermentation chamber. On the basis of the realized stress analysis of ring $t_{s1,}$ it can be stated that the element will bear the stresses it is going to be subjected to. In order to optimize the construction costs it is possible to change the thickness of the element or consider changing the material. The calculations may be burdened with errors as the method of strength calculation is an approximation (division into finished elements of a certain size results in simplification of calculations). During the stress analysis using the Autodesk Inventor 2014 program it was established that the calculation options are limited and that there is no possibility to perform complex calculations, therefore the authors recommend using different calculation package (e.g. Anasys) in order to calculate the key elements of the installation, such as the fermentation chamber .

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PROJEKTOWANIE ZBIORNIKA KOMORY BIOGAZOWEJ CZ. 4.: ANALIZA STANU NAPRĘŻEŃ PIERŚCIENIA ZBIORNIKA BIOGAZU

Streszczenie. W pracy przedstawiono zastosowanie programu Autodesk Inventor 2014 do symulacji numerycznej rozkładu naprężeń w zbiorniku ciśnieniowym. Przeprowadzono analizę wytrzymałości pierścienia zbiornika biogazu. Przeanalizowano rozkład obciążeń w zbiorniku i sposób generowania siatki elementów skończonych. Omówiono uzyskane wyniki obliczeń.
Słowa kluczowe: biogaz, obliczenia wytrzymałościowe, metoda elementów skończonych