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ABOUT THE DESIGN AND BEHAVIOUR IN TIME OF TANKS USED FOR ANAEROBIC FERMENTATION OF SLUDGE BY–PRODUCTS RESULTED FROM WASTEWATER TREATMENT PLANTS

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Abstract: The following article aims to point out the complex connection between the concept, design and construction requirements and behaviour in time of one of the key objects used in the biological treatment stage of wastewater, the tanks used for anaerobic sludge fermentation. The objective is to draw attention on a series of factors related to time behaviour within the required parameters and under the criterion mentioned in the current paper. The practical examples analysed for the present study show, through visual characterisation, different visual defects that lead to misfunctioning of the mentioned structures in time. The in–situ investigation was correlated with mathematical models of calculation based on the Wrinkler model, which serves as the primary framework for assessing how the structure responds to stresses and deformations caused by loads encountered during the operation of this type of analysis.

Keywords: anaerobic fermentation, sludge, biogas, water treatment, plant

INTRODUCTION

The long–lasting development of a society requires a constant and reliable water flow, which reaches the necessary water demand per capital in both urban and rural areas, as well as covers the water flow required by the utility services and industrial operations in the area.

Water drawn from surface sources such as rivers, reservoirs or from groundwater sources must be treated to satisfy certain quality parameters to ensure the safety and health of the population and the necessary comfort of the municipality. [1] This is especially important because regulatory compliance is evolving and they permanently need full-time monitoring and improved management. [2]

Wastewater from urban and industrial processes represent a massive negative impact on these water surfaces but also to the climate and energy producing. [3] They need to be purified to the acceptable quality level to ensure ecological preservation of the: soil, groundwaters, rivers, etc.

The treatment of water with respect to its potability, as well as the purification of wastewater is defined as a biochemical process that evolves in time due to the diversity and increase in the pollution. [4] This represents a particularly complex issue which requires large investments of resources and mainly energy consumption. To ensure the effective use of the resources invested, both practical and economic, research must be conducted in multidisciplinary fields, including a high–level engineering design, operating personnel and maintenance of the facility after being put in service. At the same time, the environmental risk and high cost for disposal of the substances used for water treatment represents in general about 30-50% of the total treatment expense. [5]

Romania has a rich history in designing and executing projects of this nature (an example can be seen in Figure1.), with water treatments and purification plants currently operating in some of its largest cities: Iaşi, Cluj, Târgu–Mureş, Timişoara, Arad, Oradea, Constanța, Bucureşti, etc. However, it must be mentioned that there is still a lack in operating water supply and sewage systems in rural areas.

It should also be pointed out that a vast majority of the water purification stations have only two–stages treatment, the first being mechanical and the second one being biological. The new European Directives in the field impose very stern guidelines, including tertiary and quaternary purification stages. Therefore, large efforts and funds are necessary to raise the operational standard of the existing plants to the required criterion.

Figure 1. The Bucharest Municipality Water Purification Center

According to the literature in the field of anaerobic digestion, researchers and engineers are encouraged to study the recycling of the substances used in this process and the correlation with energy. [1], [6], [7].

The fundamental requirements which determine the technological and structural conception of the anaerobic fermentation tanks can be grouped two categories.

The first category is based on functional requirements which determine the technological process and equipment type: hydraulic, mechanic and biological.

The second category focuses on structural requirements such as strength, stability, water tightness and durability, which ensures suitable structural integrity over the course of at least 50 years. [8] This represents the sludge process, still considered the most popular type of biotechnology nowadays, that is composed by a mixture of different compounds among which organic matter, nutrients and substances for fermentation are encountered that have the property to remove pollution from the wastewater.[9] Fermentation takes part of the de-pollution process having the property of changing organic waste into organic compounds. [10], [11], [12].

Concurrently, the efficiency of the fermentation tanks from the technological standpoint is determined by the following requirements:

- ensuring that the stored sludge is at a constant temperature of +35°C all year round. This temperature is specific to the propagation of mesophilic fermentation.
- ensuring the constant mixing and homogenization of the sludge to encourage fermentation and to prevent lithification and sedimentation.
- heating of fresh sludge and ensuring the recycling of the sludge in the context of a constant exploitation at the reservoir level.
- storage of the gases resulted from the fermentation process and design of equipment for the heating of the fresh sludge, as well as to produce electrical energy from burning biogas.
- sludge dehydration and concentration equipment together with the fermented sludge.

Provided that the essential requirements mentioned above are satisfied, then the main scope of the anaerobic fermentation tanks is assured and the mineralization of the sludge via the removal of organic substances and other type of treatments can be fulfilled. [13]

The result of fermentation is the production of biogas that can ensure the energy independence of this treatment stage by creating a cogeneration plant. This is achievable because under normal operating conditions, a fermentation tank would produce a volume of biogas per day equal to the volume of sludge stored in the tank.

The operational safety of the structure of the fermentation tanks, as well as an adequate durability, cannot be ensured without satisfying the fundamental structural requirements: strength, stability, tightness. Meanwhile, the design and shape of the structures of this nature must first and foremost fulfil the functional requirements mentioned above.

Keeping in mind the functional requirements, the structural shape taken by the tank must have axial symmetry, made up of flat and curved plates, for which the ratio between the inner diameter (D_i) and the height (H) of the tank to be between the interval: $1,00 \leq H/D_i \leq 1,50$.

MATERIALS AND METHODS

The most appropriate material for the construction of such a structure is reinforced concrete and prestressed reinforced concrete.

While studying this type of structures in Romania, fermentations tanks with volumes of 1000 m^3, 2000 m^3, 3000 m^3, 4000 m^3 have been built and designed in the form of a truncated cone, composed of a reinforced concrete slab in the form of a circular or truncated conical slab, a curved cylindrical plate made of prestressed reinforced concrete, with ring prestressing and in the direction of the generator and a truncated conical roof plate in the upper part, made of reinforced concrete.

The largest fermentation tanks made in Romania with a capacity of 5 x 8000 m^3 were constructed in an ovoid shape, made up of curved toroidal, conical and cylindrical slabs made of prestressed reinforced concrete applied along two directions, annular and meridian. The dimensions of this type of tank can be observed in Figure 2, together with the shape and the distances from one point to another.

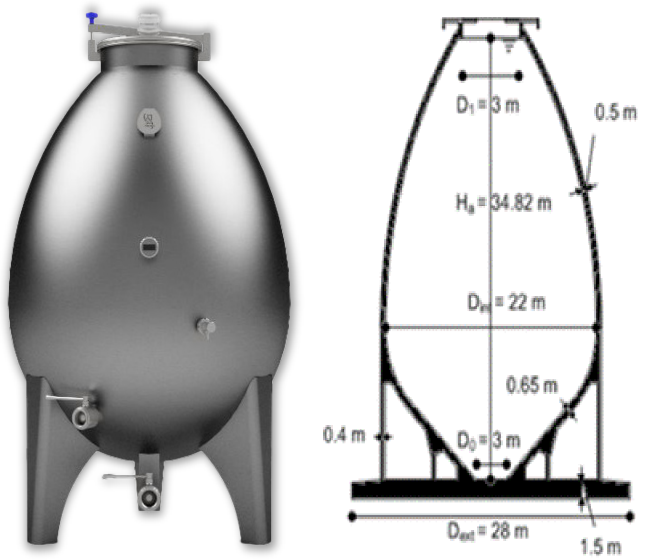

Figure 2. Ovoid shaped fermentation tanks with a capacity of 5 x 8000 m^3

The symmetrical axial shape for fermentation tanks internationally used for this type of structures [4], [8], [14] offers the following advantages: the shape responds very well to functional requirements and from a structural point of view, it ensures an advantageous and safe response in stresses and deformations, especially in the case of prestressed structures in two directions.

Nowadays, modern approaches also allow a different concept for the fermentation tanks (the shape is a cylinder–spherical one) as the solution of getting together both the sludge reservoir and the bio–gas reservoir in the same construction proved to be sustainable in the context of fulfilling almost all the fundamental structural exigencies and those related to electricity supply using fermentation gas. [12]

Figure 3. Fermentation tanks: the sludge reservoir is coupled with the gas reservoir in the same construction

Behaviour of the fermentation tanks over time. A series of factors influence behaviour in time of fermentation tanks, among which one can point out:

- high level of stress of the structures, with the development of a state of spatial stresses, characterized by axial and sliding forces in the median surface of the curved plates, associated with bending moments, shear forces and torsional moments developed in two directions.
- quality of projects and quality assurance during the construction works.
- quality of building materials and implementation of corrosion–proof materials on the inner surface of the tanks.
- corresponding thermal insulation on the outside of the tanks to reduce the efforts induced by the temperature variations.
- proper maintenance of the tank structure, equipment.

Brief overview of the state of stresses and strains in the fermentation tank structure

For the fermentation tank, the determination of the stress and strain state is performed in the elastic linear domain using the analytical method as the solutions of the synthesis equations in the case of bending or circular plates acted upon in their plane are known, respectively the solutions in the bending and membrane theory in the case of cylindrical curved plates. [14], [15].

The soil–structure interaction modelling taken into account for the considerations in this paper is the Wrinkler model for non–cohesive [16] soils and the Pasternak model for cohesive soils, both leading to satisfactory results.

The analytical method of calculation used for the fermentation tanks is applied using the Winkler model and the solutions of the synthesis equations that define the state of stresses and deformations in the bending theory in the case of cylindrical curved plates, as well as the solutions for the circular plates resting on elastic medium using the Winkler model. [16], [17].

From the study of cylindrical curved plates and circular plates elastically supported using the Winkler model, it was possible to define the behaviour indexes of two types of structural elements, whose importance is essential in the actual calculations [3].

The behaviour index (λ_c) of the symmetrically axially stressed cylindrical curved plates was defined with the following expression:

$$\lambda_c = l_c \cdot \frac{\sqrt[4]{3\cdot(1-\mu^2)}}{\sqrt{a\cdot h_c}} \qquad (1)$$

where: **a** is the radius of the median surface of the cylindrical curved plate; **h$_c$** is the thickness of the cylindrical curved plate.

Depending on the value (□c), cylindrical curved plates may fall within two categories:

- long cylindrical curved plates having $\lambda_c > 5$ in which the bending effects on one contour are quickly damped and no longer have an influence on the opposite contour;
- short cylindrical curved plates if $\lambda_c \leq 5$ in which the effects on one contour also have an influence on the opposite contour.

The behavior index (λ_c) of circular flat plates resting on an elastic medium has the expression:

$$\lambda_r = a \cdot \sqrt[4]{K/B} \qquad (2)$$

where:

≡ a is the outer radius of the circular plate.
≡ K is the coefficient of soil reaction;
≡ $B_r = \frac{E\cdot h_r^3}{12\cdot(1-\mu^2)}$ is the stiffness of the circular plate in bending
≡ h_r is the thickness of the circular plate.

Depending on the value (λ_r) circular plates resting on elastic media can fall within three categories of behaviour, namely:

≡ rigid plates if $\lambda_r \leq 0{,}75$;
≡ semi–rigid plates if $0{,}75 \leq \lambda_r \leq 3$;
≡ flexible tiles if $\lambda_r > 3$.

Considering the fact that the cylindrical curved plate has a long cylinder behaviour, and the particular solution of the synthesis equation in the bending theory coincides with the solution of the synthesis equation in the membrane theory and also using the principle of superposition of effects, the calculations were performed using the calculation models presented below.

The calculation model (basic system, Figure 4) was obtained by suppressing the continuity link between the cylindrical curved plate and the circular flat plate of the slab and highlighting the unknown equal and opposite moment (x_1) and shear forces (x_2) on the joint contour.

At the same time, in the case studied, at the level of the connection between the wall and the slab plate, there must be equal deformations on both elements at the level of the common contour (Figure 5.b):

- the radial displacement **w** of the cylindrical plate in the lower contour section is equal to the horizontal displacement **u** of the slab plate in the outer contour section;
- the rotation □c of the cylindrical plate in the lower contour section is equal to the rotation □r of the slab plate in the outer contour section.

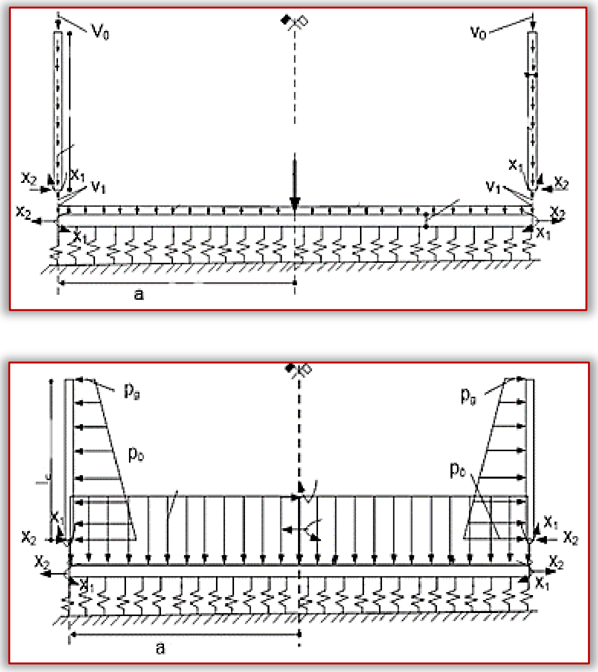

Figure 4. Calculation model of the fermentation tank in the hypothesis of action a) own weight, respectively b) hydrostatic pressure and internal gas pressure

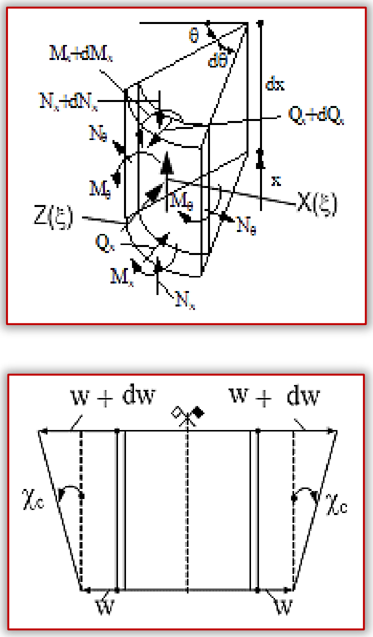

Figure 5. Stress and strain condition in cylindrical curved plate in the convention of positive signs

The synthesis equation of the cylindrical plates subjected to the action of the systems of forces normally applied on the surface of the plate:

$$\frac{d^4 w(\xi)}{d\xi^4} + 4\lambda_c^4 w(\xi) = \frac{Z(\xi)\cdot l_c^4}{B_c} \qquad (3)$$

with ξ=x/l$_c$, Z(ξ) the component of the external loads in the radial direction, respectively the bending stiffness of the cylindrical plate $B_c =$

$\frac{E\cdot h_c^3}{12\cdot(1-\mu^2)}$ with E being the longitudinal modulus of elasticity, respectively the Poisson coefficient of the material from which the plate is made.

DISCUSSIONS

While making on–site analysis of fermentation tanks with a service life of 35 to 40 years, some of the following observations were made.

The prestressed concrete structural elements in the form of cylindrical curved slabs in the composition of the cylindro–conical shaped tanks have behaved well over time, with no cracks or other failures.

The reinforced concrete structural elements: truncated cone–shaped slabs and roofs (Figure6.) have registered cracks whose opening have increased over time, above the permissible limit, in the case of these types of works with the dimensions of 0.2 mm.

Figure 6. Cylindrical–conical fermentation tanks with cracked roof dome

The occurrence of cracking (Figure 7) can sometimes be influenced by the quality of the thermal insulation materials, which promote the development of additional stresses from temperature changes. The cracking can also be favoured by the inadequate maintenance of such works.

At the same time, due to inadequate maintenance, the sludge was deposited and cemented in the lower area of the tanks.

Figure 7. Cracking of reinforced concrete elements of fermentation tank

At the vast majority of the tanks, the acid–sulphatic chemical attack (Figure 8) was found due to the fermentation gases and humidity in the upper part of the truncated conical roof tiles, a phenomenon accentuated by the poorer quality of the anti–corrosion protection materials.

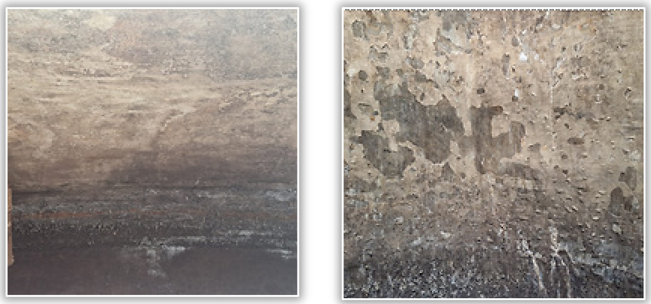

Figure 8. Chemical attack on the inner surface

CONCLUSIONS

From the analysis of the behaviour over time of the existing fermentation tanks with an age in operation of 35–40 years, the following recommendations can be deduced for the future:

- the structural shape of future tanks must be axially symmetrical to allow the introduction of prestressing in one direction or in two directions throughout the structure.
- thermal insulation materials must be efficient, to improve both the thermal balance in operation, but also to reduce the effects of temperature variations.
- the corrosion proof protection materials must have high–performance characteristics, both in terms of resistance to chemical attack of the acid–sulphatic type, but also in terms of adhesion to the concrete surface.

Structures with an age in operation of more than 30 years must be rehabilitated by: removal of damaged protections on the entire interior surface; revealing cracks and injecting them; application of new protection materials with high performance both in terms of corrosion proof resistance and physical–mechanical resistances.

Another recommendation is concerning the concept and design of the structures chosen for the fermentation tanks that must be differently chosen according to wastewater content: domestic wastewater mixed with rainwater, industrial wastewater or wastewater from livestock farms and storage capacities.

Depending on the technical condition found in situ and the degree of damage of the reinforced concrete elements (truncated conical roof dome), possible rehabilitation and consolidation solutions can be analysed using carbon fibre fabrics, additive mortars and special resins with resistance to corrosive actions of the acid–sulphatic type.

However, the rehabilitation–consolidation solutions adopted must not significantly modify the thickness of the element so as not to produce additional stresses from temperature variations, given that they are proportional to both the value of temperature variations and the value of axial stiffness and bending stiffness.

The adhesion of the reinforcing materials to the existing concrete structure must also be ensured where the unit adhesion force must be greater than 2000 kN/m² [3]. At the same time, the cleaning of the existing concrete surface must be carried out with pressurized water.

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