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IMPROVEMENT OF THERMAL CHARACTERISTICS OF HOUSEHOLD BIOREACTOR

Rational form of reservoir was set and the typical number of household biogas plants was presented. The analysis of different types of thermal insulation to reduce the heat loading on the heating system of bioreactor was carried out. The amount of thermal energy flowing into the tank from the solar radiation was defined. The results are presented in graphic and empirical form.

Key words: biogas plant, bioreactor, reservoir, biogas, methane-tank.

Запропоновано раціональну форму резервуара та представлено типовий ряд побутових біогазових установок. Здійснено аналіз різних типів теплової ізоляції для зменшення теплового навантаження на систему підігріву біореактора. Визначено кількість теплової енергії, що надходить в резервуар від сонячного випромінювання. Результати досліджень подано у графічному та емпіричному вигляді.

Ключові слова: біогазова установка, біореактор, резервуар, біогаз, метантенк.

The topicality

One way to supplement and partially replace exhaustible kinds of fuel is the use of biogas.

The process of utilization by anaerobic fermentation is complicated by the necessity of temperature observance and high power consumption.

A very important factor of the process of fermentation is temperature of mass which ferment. The formation phase of methane begins at a temperature 6°C and becomes more intensive during its growth to 55° C. However, at keeping up high temperature of fermentation substrate thermal energy consumption is quite high. At low temperature of environment and insufficient insulation of tank heating costs can be so high that the biogas which is produced will not be enough to heat fermentation mass.

Thus, the solution of the problem of the efficient heat supply of the reservoir of household biogas plants with regard to reducing the cost of fundamental and operational costs is an urgent task.

Aims and objectives of research

Identification methods for improving thermal characteristics of household bioreactor.

Analytical studies and its analysis

The improvement of thermal characteristics of household biogas plant is achieved by several methods:

1. The choice of optimal overall shapes and sizes of reservoir.
2. The use of optimal, efficient insulation.
3. The use of alternative energy sources.

An important aspect of energy efficiency design of biogas plant is the choice of the form and overall sizes of the tank as from these factors depend energy savings of the whole complex.

In terms of the choice of geometric shapes, the most effective form is a sphere because it has the smallest surface area among all bodies that close this volume, and the largest closed volume for a given surface area.

To improve the thermal characteristics of the biogas plant reservoir in the cold season design is additionally equipped with thermal insulating material that increases the thermal resistance of the surface in several times.

Another important factor in energy efficiency of biogas plant design is the ability of surface reservoir to take sunlight effectively, as the angle of sunlight changes throughout the day.

The most effective surface in terms of the perception of sunlight is the plane that is normal to the sun.

After analyzing the existing geometric shapes [2] methane-tanks of household biogas plants, bioreactor is proposed (Fig. 1) of cylindrical shape with truncated cones to the top and bottom, which takes into account energy-saving characteristics and peculiarities of the technologic process.
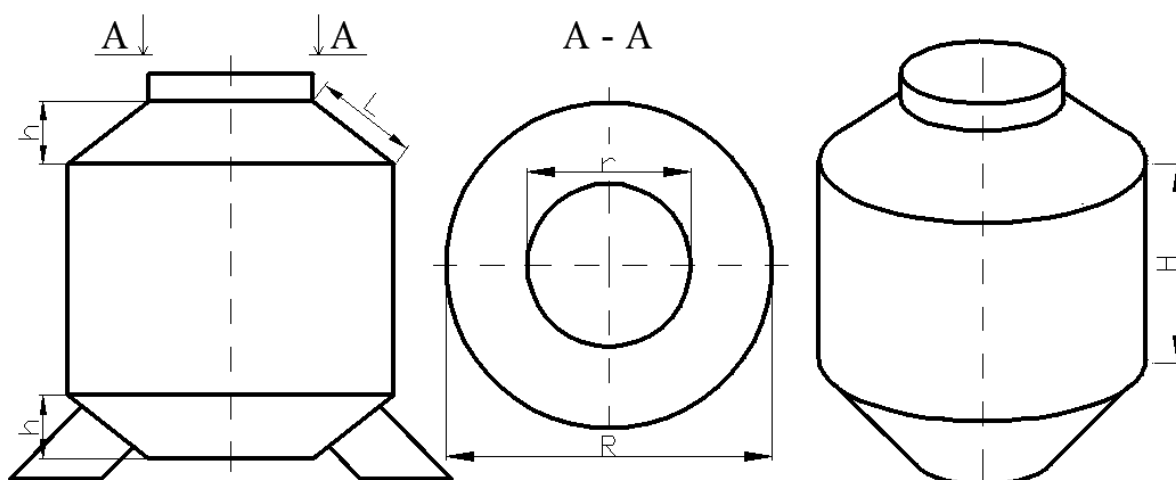

Fig. 1. The structural view of the reservoir of the household biogas plant:
a – side view; b – top view; c – axonometric view; H – height of the cylindrical part;
h – height of the conical part; L – generating line; R – radius of the cylinder; r – radius of the truncated cone

This biogas tank design allows the use of a continuous cycle of biogas production. Owing to rational size the minimum size of outer space protection is reached which would guarantee the reduction of heat loss in the cold season.

For series bioreactors volume of 1 m3 to 5m3 were defined geometrical dimensions of household, the results are given in table 1. When these recommended amounts are provided with minimum area of outside protection.

Table 1

Recommended overall sizes of household biogas plants

V_t, m^3	The cylindrical part of the reservoir			The conical part of the reservoir			
	H, m	R, m	S_{cl}, m^2	h, m	r, m	L, m	S_c, m^2
1	0,90	0,50	4,37	0,33	0,25	0,35	0,83
2	1,20	0,63	7,25	0,34	0,32	0,38	1,12
3	1,40	0,72	9,65	0,37	0,36	0,41	1,39
4	1,60	0,79	11,77	0,40	0,39	0,44	1,64
5	1,80	0,83	13,72	0,44	0,42	0,48	1,89

V_t – tank volume, m^3; S_{cl} – area of the cylindrical surface of the tank, m^2; S_c – surface area of the conical tank, m^2.

The effect of thermal insulation is both energy saving and economic, and depends on many factors, starting with climate where the plant is, tank shape, type and thickness of the insulation.

The use of an insulation material should be considered as providing of equivalent thermal conditions, i.e. identical linear thermal resistance.

The calculation of thermal insulation for different materials was carried out:

foam plastic; – polyurethane; – mineral wool; – eurobatex; – pearlite

The optimum thickness of the thermal insulation:

$$\delta_{onm} = \left(\frac{Q_{onm}}{2l\pi(t_6 - t_3)} - r\alpha_1 \right) \cdot \frac{2r\alpha_2 + \lambda_{i3}}{\lambda_{i3} \cdot \alpha_2} - r \text{ , m} \tag{1}$$

where α_2 - heat transfer coefficient inside of the tank, W /(m²°C); α_1 – heat transfer coefficient of the outer surface of reservoir, W / (m² ° C); r,l – respectively the radius and the height of the reactor, m; λ_{i3} – coefficient of thermal conductivity of insulation W/ m² ; Q_{onm} – thickness of the insulation material, W; t_3,°C – external temperature of the environment; t_6,°C –the temperature of biomass.

Operating results of analytical studies [3], nomogram was obtained (Fig. 2), which can significantly simplify the calculations when determining the thickness of thermal insulation for a variety of its species and temperature regimes.
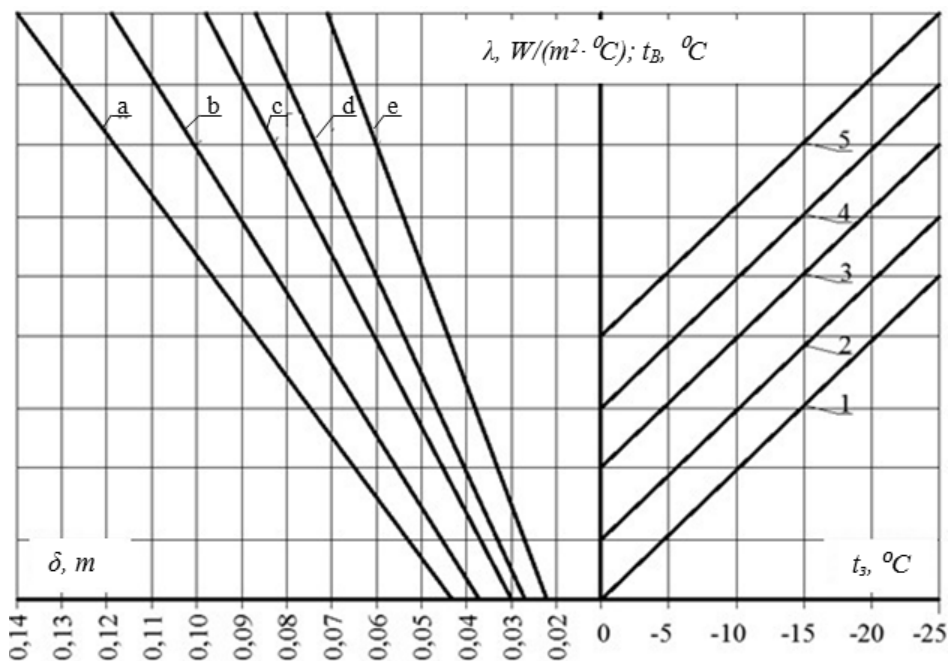

Fig. 2. Nomogram of thickness determination of thermal insulation δ_{onm} , m depending on the outside temperature t_3 ,°C , temperature of biomass t_6 ,° C , coefficient of thermal conductivity of insulation λ_{i3} , W /(m · °C). polyurethane $\lambda = 0,027W$ /(m · °C) ; b – eurobatex $\lambda = 0,033W$ /(m · °C) ; c – foam plastic $\lambda = 0,037W$ /(m · °C) ; d – mineral wool $\lambda = 0,045W$ /(m · °C) ; e – pearlite $\lambda = 0,057W$ /(m · °C) ; 1 – $t_6 = 20°C$; 2 – $t_6 = 25°C$; 3 – $t_6 = 30°C$; 4 – $t_6 = 35°C$; 5 – $t_6 = 40°C$;

The results of approximation are presented in formulas:

$$\delta = 0,004 + 0,708 \cdot \lambda + (0,0001 - 0,024 \cdot \lambda) \cdot (-29,52 + 1,464 \cdot t_â - 1,44 \cdot t_ç) \text{ , m.} \tag{2}$$

Significant energy savings on heating can be obtained through usage of solar energy.

There are different methods of absorption of solar energy, such as the use of solar power plants, solar photo panel, different types of heating and electric battery, that give good index of heating supply. However, their use for heating household bioreactors is inappropriate as system of biogas plant rise in

price. Therefore, for heating supply of the tank the scheme of heating supply was proposed according to which sunlight directly heats the surface of the bioreactor.

The amount of heat is determined that gets into the household bioreactor from solar radiation. According to the proposed heating supply scheme sunlight directly heats the reservoir of the biogas plant through thermal conductivity heating of raw materials is happened inside of the methane-tank. As this scheme does not require additional equipment, therefore does not require additional fundamental costs.

Research was conducted for domestic bioreactor (Fig. 1) volume of 1 m3 with the temperature of the internal environment t = 40 ° C. Bioreactor is made of steel and painted in black. For the for the warm period of the year increasing heat transmission of thermal insulation was dismantled.

The thermal process was maintained with the help of solar radiation which was absorbed by the surface of the reservoir.

Heat flow into the bioreactor from solar radiation through the vertical surface, W:

$$Q_C = q_0 + \beta \cdot A_q \tag{3}$$

where q_0, W – average daily flow heat from solar radiation; A_q, W – amplitude of heat flow fluctuations.

$$q_0 = \frac{F}{R_0}(t_в^{ум} - t_в) \tag{4}$$

F – area of the vertical surface of bioreactor, m^2; R_0 – thermal resistance of the walls of the reservoir, m^2 K/W; $t_в^{ум}$ – notional average daily outside temperature, °C;

The amplitude fluctuations of heat flow A_q, W is defined by:

$$A_q = \alpha_в \cdot F \cdot A_{тв} \tag{5}$$

$A_{тв}$ – amplitude of the temperature fluctuations inside of the reservoir wall, °C;

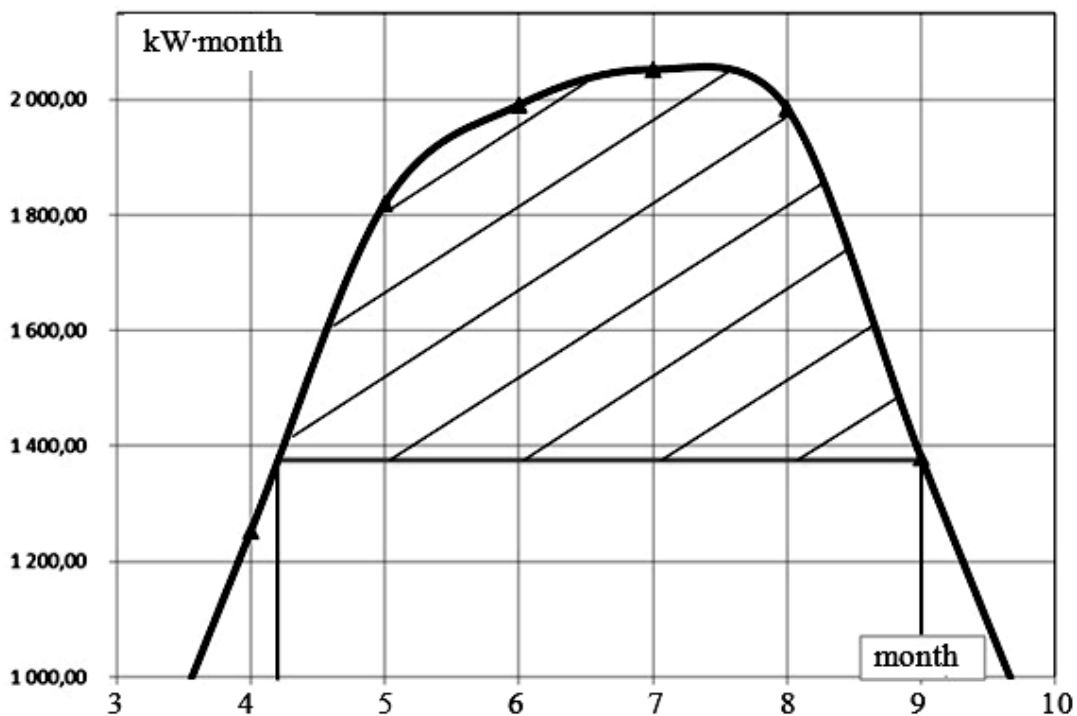$\alpha_в$ – heat transfer coefficient on the inner surface of the wall bioreactor, W/ m^2 K.

Fig. 3. Admission of heat from solar radiation in the household bioreactor during the warm period of the year.
3 – March; 4 –April; 5 – May; 6 – June; 7 – July; 8 – August; 9 – September; 10 – October

The graph shows that the peak heat admission is reached in July, the lowest amount of solar heat that gets into the bioreactor during the warm period of the year is observed in September. We provide admission limit for heat 1380 kW per month, that is below this limit the use of the sun's energy is not efficient.

Conclusion

Efficient overall shapes and sizes of household bioreactors were defined. Recommended sizes of methane –tanks were given that provide minimum areas of outside protection. Different types of thermal insulation were analyzed in order to use it in a biogas plant to reduce heat loss of bioreactor, optimal thermal insulation is mineral wool with a thickness of 0.13 m. A range of efficient use of solar energy for heating raw materials reservoir of household biogas plant was determined. Suggested design of the bioreactor allows maximum use of solar radiation during the day.

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