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THERMOPHYSICAL CALCULATIONS THE PROCESS SEDIMENTATION BEESWAX

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Summaru **- the article is devoted to improving the efficiency of cleaning wax from contaminants by reducing heat energy losses, the rate of temperature reduction; a method for the thermal calculation of compact heat-insulated tank is proposed on the example of reducing energy losses during the deposition of contaminants from wax in a molten state. Primary wax contains many polluting components, such as bee bread, merva, more than 15 different organic compounds and scrapings of frames and so on. The most common method of wax cleaning is its long settling in the molten form, followed by crystallization and removal (cutting) of the settled layer of contaminants. The aim of the study is to establish the possibility of improving the energy efficiency of the deposition of contaminants from wax in a molten state by reducing energy consumption to maintain its temperature, installing heat insulation, determining the optimal location and calculation of the boiler to compensate for heat losses. To create rational temperature conditions under which it is possible to clean the wax from contaminants, it is necessary to take into account the thermophysical properties of the wax, as well as data on its basic physical and mechanical properties. The calculation of the amount of heat for the deposition of contaminants from the wax, which is in the molten state, in a tank of complex shape is performed on the basis of a joint solution of the heat balance and heat transfer equation. The amount of heat required for heating water, wax, steel tank and heat insulation, melting and overheating of wax is determined. The layout of the elements of the installation for cleaning wax is proposed. The heat losses of all sections of a thermally insulated tank of complex shape for the deposition of contaminants from wax, insulated with basalt wool mats were determined. The surface temperatures of the**

outer layer of thermal insulation are determined for different arrangement of elements. The proposed methodology for calculating heat loss can be used in the design of thermal insulation of complex containers for the deposition of contaminants from wax.

***Key words*: energy saving, thermal insulation, energy loss, compact containers of complex shape, deposition, pollution, wax cleaning.**

Formulation of the problem. Wax is extremely important for the national economy. Wax is used in food, cosmetic, electrical and many other industries, it is a valuable commodity for export. More than 40 industries use wax as a raw material [1]. In the context of energy saving and environmental safety, the requirements for the cleaning process of wax raw materials are increasing and its improvement is currently a very urgent problem [2].

Analysis of recent studies. Primary waxes contain many polluting components, such as bee bread, merva, more than 15 different organic compounds, scrapings of frames, and so on [3,4]. The most common method of wax cleaning is its long settling in the molten form, followed by crystallization and removal (cutting) of the settled layer of contaminants [5]. A significant role in solving the problem of saving thermal energy belongs to highly efficient thermal insulation [6,7,8]. Thermal insulation of a complex-shaped tank provides a reduction in energy consumption for the sedimentation of contaminants from wax. However, the operating conditions of thermal insulation impose special requirements [9,10,11,12]. Therefore, the search for ways to increase the efficiency of its use [13,14,15,16,17,18,19, 20] plays an important role, because it allows for a long time to reduce heat loss.

Formulation of the problem. The aim of the study is to establish the possibility of improving the energy efficiency of the sedimentation of contaminants from wax in a molten state by reducing energy consumption to maintain its temperature, installing heat insulation, determining the optimal location and calculation of the boiler to compensate for heat losses.

To achieve this goal, the following tasks:

1. To propose a methodology for calculating the cost of thermal energy for cleaning wax and heat loss, taking into account the location of thermal insulation.
2. Check the compliance of theoretical calculations with the actual surface temperature of the outer layer of thermal insulation. Research technique is based on a modified method for studying process of heat loss.

Main part. To create rational temperature conditions under which it is possible to clean the wax from contaminants, it is necessary to take into account the thermophysical properties of the wax, as well as data on its basic physical and mechanical properties. The calculation of the amount of heat for the sedimentation of contaminants from the wax, which is in the molten state, in a tank of complex shape is performed on the basis of a joint solution of the heat balance and heat transfer equation [6]. Heat balance equation takes form:

$$Q_{heatig} = Q_{w.} + Q_{wax} + Q_{t.\&sh.} + Q_{h.in.} + Q_{e.loss.}, \qquad (1)$$

where $Q_{heating}$ - the amount of heat received by the heater, kJ, Q_w - the amount of heat for heating water, kJ, Q_{wax} - the amount of heat for heating and melting the wax, kJ, $Q_{t.\&sh.}$ - the amount of heat for heating the tank and shirt, kJ, $Q_{h.in.}$. - the amount of heat to heat the insulation, kJ, $Q_{e,loss.}$. - heat energy loss, kJ.

The heat transfer equation [6] determined by the formula (2):

$$Q_{e.loss} = k_{\tan k} \cdot F_{\tan k} \cdot (t_h - t_c) \cdot \tau \text{, kJ,} \qquad (2)$$

where k_{tank} - the heat transfer coefficient of the container enclosure, W/(m^2·K), F_{tank} - the surface area of the tank, m^2, t_h and t_c - the temperature of the hot medium and cold environment, ^{o}C, τ - the operating time of the installation, s.

The amount of heat Q_w for heating water is determined by the formula (3):

$$Q_w = c_w \cdot m_w \cdot (t_{w.fin.} - t_{w.in.}) \text{, kJ,} \qquad (3)$$

where c_w - the heat capacity of water, kJ / (kg · K), m_w - the mass of water added to the capacity, kg, $t_{w \cdot fin}$ - final water temperature, ^{o}C, $t_{w.in.}$ - initial water temperature, ^{o}C. To determine the amount of heat for heating water, it is necessary to determine the mass of water m_w added to the tank. According to the technology, softened water is poured into the tank up to 5% of the tank volume.

$$m_w = V_{\tan k} \cdot \rho_w \cdot f_w \text{, kg,} \qquad (4)$$

where V_{tank} - tank volume, m^3, ρ_w - density of water added to the tank, kg / m^3, f_w - tank filling factor with water, we take 0.05.

Scheme of tank for sedimentation of contaminants from wax is shown in Fig.1.

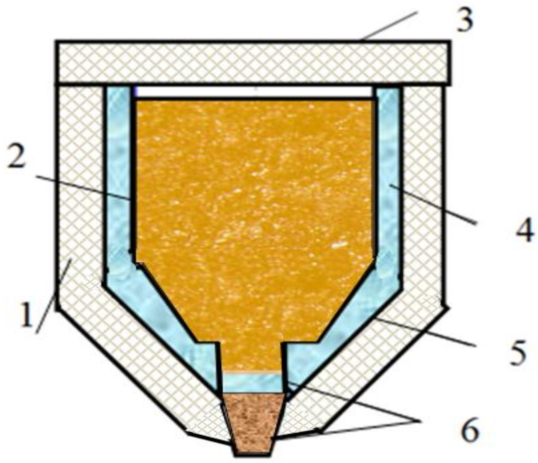

Fig. 1. Scheme of the tank for the sedimentation of contaminants from wax: 1 - thermal insulation of the tank, 2 - cylindrical part of the tank, 3 - cover, 4 - heating shirt, 5 - conical part of the tank, 6 - sedimentation tank to remove dirt

Amount of heat for heating and melting the wax Q_{wax} consists of 3 components: amount of heat for heating the wax to the melting point Q_{wax1}, the amount of heat for melting the wax $Q_{wax\ melt.}$ and for overheating the wax Q_{wax2}.

$$Q_{wax} = Q_{wax1} + Q_{wax.melt.} + Q_{wax.2}\text{, kJ.} \quad (5)$$

The amount of heat Q_{wax1} for heating the wax to the melting temperature is determined by the formula (6):

$$Q_{wax.1} = c_{wax} \cdot m_{wax} \cdot (t_{wax.fin.} - t_{wax.in.})\text{, kJ,} \quad (6)$$

where c_{wax} - the heat capacity of the wax, kJ / (kg · K), m_{wax} - the mass of the wax loaded into the tank, kg, $t_{wax.in.}$ - initial wax temperature, ^oC, $t_{wax\cdot fin}$ - the final temperature of the wax, ^oC.

To determine the amount of heat for heating the wax to the melting temperature, it is necessary to determine the mass of wax loaded into the tank. Wax loading, by the technology, is up to 95% of the tank volume.

$$m_{wax} = V_{\tan k.} \cdot \rho_{wax} \cdot f_{wax}\text{, kg,} \quad (7)$$

where V_{tank} - tank volume, m^3, ρ_{wax} - density of wax loaded into the tank, kg / m^3, f_{wax} - filling factor of the wax, we take 0.95. Wax density: 950-970 kg / m^3.

The melting point of wax is 62 ... 68 ^oC. We accept the initial temperature of the wax + 10 ^oC. Wax heat capacity: c_{wax} = 2,930 kJ / (kg · K).

The amount of heat $Q_{wax.melt}$ for melting wax is determined by the formula (8):

$$Q_{wax.melt.} = m_{wax} \cdot \lambda_{wax}\text{, kJ,} \qquad (8)$$

where λ_{wax} - the specific heat of melting of the wax, kJ / kg. We accept the specific heat of melting of the wax: λ_{wax} = 176 kJ / kg.

The amount of heat Q_{wax2} for heating the wax from the melting point to a temperature of 95 ^{o}C is determined by the formula (9):

$$Q_{wax.2} = c_{wax} \cdot m_{wax} \cdot (t_{wax.fin.} - t_{wax.in.})\text{, kJ.} \qquad (9)$$

Amount of heat $Q_{t.\&sh.}$. for heating tank and heating shirt from an initial temperature of +10 ^{o}C to a temperature of +95 ^{o}C determined by the formula (10):

$$Q_{t.\&sh.} = c_{\tan k} \cdot m_{\tan k} \cdot (t_{\tan k.fin} - t_{\tan k.in.})\text{, kJ,} \qquad (10)$$

where c_{tank} - the specific heat of steel, c_{tank} = 0.460 kJ / (kg · K), $t_{tank.in.}$. - initial temperature of the tank, ^{o}C, $t_{tank.fin}$.- the final temperature of the tank, ^{o}C.

The amount of heat $Q_{h \cdot i}$. for heating the thermal insulation of the tank, which is made of basalt wool mats, the specific heat capacity of the mats is $c_{h.i.}$. = 0.84 kJ / (kg ·°C) is determined by the formula (11):

$$Q_{h.i.} = c_{h.i.} \cdot m_{h.i.} \cdot (t_{h.i..fin.} - t_{h.i.in.})\text{, kJ,} \qquad (11)$$

where $Q_{h.i}$. - the amount of heat for heating the insulation, kJ, $c_{h.i.}$ - the heat capacity of the insulation, kJ / (kg · K), $m_{h.i.}$. - mass of thermal insulation, kg, $t_{h.i.in.}$. and $t_{h.i.fin.}$ - initial and final thermal insulation temperature, ^{o}C.

To determine the amount of heat for heating the insulation, it is necessary to determine the mass of the insulation tank.

$$m_{h.i.} = V_{h.i.} \cdot \rho_{h.i.} = F_{h.i.} \cdot \delta_{h.i.} \cdot \rho_{h.i.}\text{,} \qquad (12)$$

where $m_{h.i.}$ - mass of thermal insulation, kg; $V_{h.i.}$ - volume of thermal insulation, m^3, $\rho_{h.i}$.– thermal insulation density, 200 kg/m^3; $F_{h.i}$. - thermal insulation area, $\delta_{h.i.}$. - thermal insulation thickness of 0.100 m.

The results of determining the amount of heat required for heating water, wax, steel tanks with a heating shirt and thermal insulation and melting of wax are presented in table 1.

Table 1. - The results of determining the amount of heat required for heating water, wax, steel tanks and heat insulation and melting wax

№	Value, designation and units of measurement	Value
1	Amount of heat ensures wax is heated to melting point, $Q_{wax\ 1}$, MJ.	144,3
2	The amount of heat that provides melting of the wax, $Q_{wax.melt}$ MJ.	176
3	Amount of heat ensures wax is heated to 95 °C, Q_{wax2}, MJ.	88,2
4	Total amount of heat for wax processing, $Q_{wax.}$, MJ.	408,5
5	The amount of heat providing water heating, $Q_{w\cdot}$, MJ.	20,4
6	The amount of heat that provides heating of the steel tank and the shirt to a temperature of 95 ^{o}C, $Q_{tank\&sh.}$, MJ.	97,8
7	Amount of heat that provides heat insulation to 95 ^{o}C, $Q_{h.i\cdot}$, MJ.	44,3

The dependence of the temperature of the wax during its heating and melting on the amount of heat input is presented in Fig. 2.

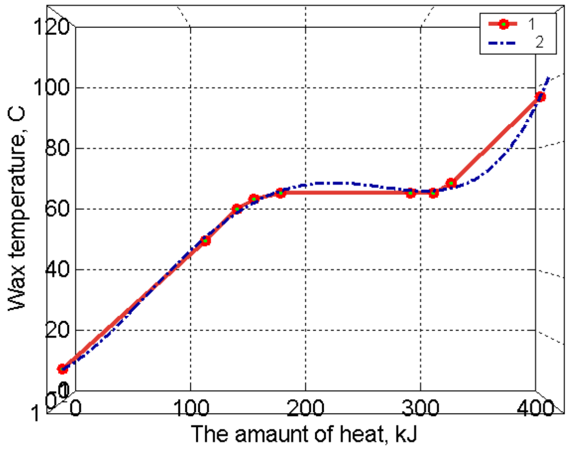

Fig. 2. Dependence of the temperature of the wax when it is heated and melted on the amount of heat supplied: 1 - curve of melting wax, 2 - empirical dependence

The dependence of the temperature of the wax during its heating and melting on the amount of heat input can be described by equation (13):

$$T = 9.9 + 0.19 \cdot Q + 0.01 \cdot Q^2 - 2 \cdot 10^{-5} Q^3 + 3.1 \cdot 10^{-8} \cdot Q^4, \quad (13)$$

where T - the temperature of the wax during heat treatment, ^oC, Q is the amount of heat supplied to the wax, kJ / kg,

Let us determine the loss of thermal energy to maintain the temperature above the melting temperature for several days (depending on the quality of the wax) for the implementation of the settling process, with thermal insulation of a 100 mm thick basalt wool tank. Loss of thermal energy into the environment goes through the surface of the insulation [6]. To determine the temperature of the outer shell of the tank, we will solve the heat transfer equation (2) from the water in the heating shirt and then to the outside air through three layers of material:

- the first layer is the outer skin of the shirt made of steel with a thickness of $\delta_{h.i.}$ = 5 mm; - the second layer is the heat-insulating material of mats made of basalt wool thick $\delta_{h.i.}$ = 100 mm; - the third layer is the outer metal lining of steel with a thickness of $\delta_{h.i.}$ = 0.5 mm.

Determine the heat transfer coefficient k_{tank} [6] of the multilayer fence, W / (m^2 · K), according to the formula (14):

$$k_{\tan k.} = \frac{1}{\frac{1}{a_{out.}} + \sum_{i=1}^{n} \frac{\delta i}{\lambda i} + \frac{1}{a_{in.}}}, \qquad (14)$$

where $\alpha_{out.}$, $\alpha_{in.}$- heat transfer coefficients from the outside of the shirt and the inside of the fence, W / (m2 · K); δ_i - the thickness of the structural layers of steel and thermal insulation, m; λ_i - the thermal conductivity coefficients of steel and thermal insulation, W / (m · K). The initial data for the calculation of the heat transfer coefficient are written in table 2.

Table 2 - The initial data for the calculation of the heat transfer coefficient

№	Value, designation and units of measurement	Value
1	Heat transfer coefficient α_B from hot water to the outer skin	2500
2	The thickness of the inside layer of steel, $\delta_{in.}$, m	0,005
3	The thickness of the heat insulating layer, $\delta_{h.i.}$, m	0,100
4	Thermal conductivity coefficient of basalt wool, λ_{mat}, W/(m · K)	0,035
5	The thickness of the outer layer of steel, $\delta_{out.}$, m	0,0005
6	Heat transfer coefficient from the outside fence, $\alpha_{out.}$, W/(m^2·K)	57
7	Coefficient of thermal conductivity stainless steel, λ_{st}, W/(m · K)	58,0

Substituting the values in the formula (14), we obtain:

K_{tank} = 1/(1/2500+ 0,005/58+0,100/0,035 +0,0005/58+1/57) = 0,3478 W/(m^2·K).

Define the thermal resistance of thermal insulation $R_{h.i.}$ multi-layer fencing capacity, (m2 · K) / W, according to the formula (15):

$$R_{h.i.} = 1/k_{tank.} = 1/0,3478 = 2,875182\ (m^2 \cdot K)/W. \quad (15)$$

Determine density of heat flux through the three-layer wall by the formula (16):

$$q_{thr.wall.} = k_{\tan k.} \cdot (t_{in.} - t_{out.})\ . \quad (16)$$

$$q_{thr.woll.} = 0,3478 *(95-10) = 29,56\ W / m^2.$$

Determine temperatures on contacting surfaces by formulas (17), (18), (19), (20):

$$t_{in.woll.1.} = t_{out.} - \frac{q}{\alpha_1} = 95 - 29,56/2500 = 94,98\ ^0C; \quad (17)$$

$$t_{in.woll.2.} = t_{in.woll.1.} - \frac{q \cdot \delta_{woll.}}{\lambda_{st.}} = 94,98-29,56*0,005/58 = 94,83\ ^0C; \quad (18)$$

$$t_{h.in.} = t_{in.woll.2.} - \frac{q \cdot \delta_{h.in.}}{\lambda_{h.in.}} = 94,83 - 29,56*0,100/0,035 = 14,94\ ^0C; \quad (19)$$

$$t_{out.} = t_{h.in.} - \frac{q \cdot \delta_{st.}}{\lambda_{st.}} = 15 - 29,56*0,0005/58 = 14,9\ ^0C. \quad (20)$$

The temperature of the outer surface of the insulation at a coolant temperature of 95 ^oC and an average outdoor temperature of + 10 ^oC will be +14.9 ^oC.

The amount of heat required to heat the outer skin is ($6.48 \cdot 10^{-3}$) % of the amount of heat spent on heating the wax, that is, it is negligible and can be ignored in further calculations.

We determine the loss of thermal energy into the environment through the surface of the insulation, taking the operating time equal to 1 second according to the formula (2):

$$Q_{loss.\sec.} = k_{\tan k} \cdot F_{\tan k} \cdot (t_{h.} - t_{c.}) \cdot \tau = 0,3478 *30*(95-10) = 886,89\ W.$$

We determine the loss of thermal energy into the environment through the surface of the insulation, taking the operating time equal to 12 hours:

$$Q_{loss.} = Q_{loss.sec.} *12*60*60 = 886,89*12*60*60 = 40 \text{ MJ}$$

Let us determine the amount of heat, which takes into account the heating of water, wax, a steel tank with a volume of 10 m^3 and thermal insulation to a temperature of 95 °C and maintaining this temperature until the wax completely goes into liquid state plus losses to the environment for boiler calculation.

$$Q_{boil.\ calc.} = 4275,7 + 40 = 4315,7, \text{ MJ.}$$

We determine the peak power of the boiler for melting wax in a tank during 12 hours:

$$Q_{boil.\ peak.} = Q_{boil.\ calc.} /\tau = 4315,7*1000/(12*60*60) = 100 \text{ kW.}$$

We determine the boiler power for long-term maintenance of the wax in the molten state at a temperature that ensures the sedimentation of impurities, taking into account heat losses to the environment:

$$Q_{boil.\ long.} = Q_{loss.}/\tau = 40*1000/(12*60*60) = 40000/(12*60*60) = 0,9259 \text{ kW.}$$

It is recommended to use a hot water boiler with a temperature of 95 °C to melt the wax for 12 hours, and then use it in a production heating system. Boiler capacity for space heating with a total area of 3800 m^2.

$$N_{boil.\ heat.} = F_{пом.}*\varphi = 3800*0,125 = 475 \text{ kW.}$$

It is better to install 2 boilers of 0.75 ... 80% power (according to the standard for safety when one of them fails in the cold), then:

$$N_{boil.\ heat.0,5} = N_{boil.\ heat.} * 0,75 = 356 \text{ kW.}$$

Conclusions. The proposed method of thermophysical calculation to improve the efficiency of cleaning wax from contaminants by reducing heat energy losses and the rate of temperature decrease during the sedimentation of contaminants from wax in a molten state.

The heat losses of all sections of a thermally insulated container of complex shape for the sedimentation of contaminants from wax, insulated with basalt wool mats were determined.

The surface temperatures of the outer layer of thermal insulation are determined for a different arrangement of elements.

The proposed methodology for the heat calculation of wax cleaning, taking into account the phase transition and calculation of heat loss during the sedimentation of contaminants, can be used in the design of thermal insulation tanks of complex shape [21,22,23,24,25] for the sedimentation of contaminants from wax and the selection of boiler equipment.

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ТЕПЛОФИЗИЧЕСКИЕ РАСЧЕТЫ ПРОЦЕССА СЕДИМЕНТАЦИИ ПЧЕЛИНОГО ВОСКА

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Борохов И. В., Ковалёв А. В.

Аннотация

Статья посвящена повышению эффективности очистки воска от загрязнений, путем снижения потерь тепловой энергии, темпа снижения температуры, предложена методика теплового расчета компактных теплоизолированных ёмкостей на примере

уменьшения потерь энергии в процессе осаждения загрязнений из воска, находящегося в расплавленном состоянии.

Воск первичной перетопки содержит множество загрязняющих его компонентов, таких как перга, мерва, более 15 различных органических соединений, соскобы рамок и так далее. Наиболее распространенным методом очистки воска является его длительное отстаивание в расплавленном виде с последующей кристаллизацией и удалением (срезанием) осевшего слоя загрязнений. Целью исследования является установление возможности повышения энергоэффективности осаждения загрязнений из воска, находящегося в расплавленном состоянии путем снижения энергозатрат на поддержание его температуры, установкой теплоизоляции, определения оптимального расположения и расчета котла для компенсации тепловых потерь.

Для создания рациональных температурных условий, при которых возможно проводить очистку воска от загрязнений необходимо учитывать теплофизические свойства воска, а также данные его основных физико-механических свойств. Расчёт количества теплоты для осаждения загрязнений из воска, находящегося в расплавленном состоянии, в ёмкости сложной формы выполним на основе совместного решения уравнения теплового баланса и теплопередачи. Определено количество теплоты, необходимой для нагрева воды, воска, стальной ёмкости и теплоизоляции, плавления и перегрева воска. Предложена схема расположения элементов установки для очистки воска. Определены тепловые потери всех участков теплоизолированной ёмкости сложной формы для осаждения загрязнений из воска, утепленной покрытием матами из базальтовой ваты. Определены температуры поверхности наружного слоя теплоизоляции при различном расположении элементов. Предложенная методика расчета тепловых потерь может быть использована при проектировании теплоизоляции ёмкости сложной формы для осаждения загрязнений из воска.

ТЕПЛОФІЗИЧНІ РОЗРАХУНКИ ПРОЦЕСУ СЕДИМЕНТАЦІЇ БДЖОЛИНОГО ВОСКУ

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Анотація

Стаття присвячена підвищенню ефективності очищення воску від забруднень, шляхом зниження втрат теплової енергії,

темпу зниження температури, запропонована методика теплового розрахунку компактних теплоізольованих ємностей на прикладі зменшення втрат енергії в процесі осадження забруднень з воску, що знаходиться в розплавленому стані.

Віск первинної перетоплювання містить безліч забруднюючих його компонентів, таких як перга, мерва, більше 15 різних органічних сполук, зіскрібки рамок і так далі. Найбільш поширеним методом очищення воску є його тривале відстоювання в розплавленому вигляді з подальшою кристалізацією і видаленням (зрізанням) шару забруднень. Метою дослідження є встановлення можливості підвищення енергоефективності осадження забруднень з воску, що знаходиться в розплавленому стані шляхом зниження енерговитрат на підтримку його температури, установкою теплоізоляції, визначення оптимального розташування та розрахунку котла для компенсації теплових втрат.

Для створення раціональних температурних умов, при яких можливо проводити очистку воску від забруднень необхідно враховувати теплофізичні властивості воску, а також дані його основних фізико-механічних властивостей. Розрахунок кількості теплоти для осадження забруднень з воску, що знаходиться в розплавленому стані, в ємності складної форми виконаємо на основі спільного рішення рівняння теплового балансу і теплопередачі. Визначено кількість теплоти, необхідної для нагрівання води, воску, сталевої ємності і теплоізоляції, плавлення і перегріву воску. Запропоновано схему розташування елементів установки для очищення воску.

Визначено теплові втрати всіх ділянок теплоізольованої ємності складної форми для осадження забруднень з воску, утепленій покриттям матами з базальтової вати. Визначено температури поверхні зовнішнього шару теплоізоляції при різному розташуванні елементів. Запропонована методика розрахунку теплових втрат може бути використана при проектуванні теплоізоляції ємності складної форми для осадження забруднень з воску.