Optimization of technology for processing liquid waste from meat processing plants

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Abstract. The existing treatment facilities of many meat processing plants are not able to provide modern requirements for the liquid waste quality. There was an urgent need for modernization and reconstruction of wastewater treatment plants, in such a way that they made it possible to achieve regulatory requirements. In the process of research, particular attention was drawn to the study of very simple technologies and facilities, which fully take into account the specific characteristics of the wastewater from meat processing plants, the actual working conditions and operation of treatment facilities. To purify wastewater from suspended substances, fat, as well as to reduce the total biological oxygen demand and chemical oxygen consumption, it is recommended to use a fundamentally new combined installation - an aerobic clearing reactor (FLOTEX - AERO) or an anaerobic clearing reactor (FLOTEX - ARO). During the design development of them the main advantages and disadvantages of the used grease skimming tanks, dirt collectors, floaters and aeration clarification units designed for incomplete biological cleaning, as well as special the specific features of the wastewater from meat processing plants were taken into account. The paper describes the dependencies for calculating the main parameters of the treatment plants.

1. Introduction

The meat industry is one of the largest pollutants in the food industry. The meat processing plant and the meat industry is one of the strategic sectors of the economy, set up to ensure a sustainable supply of the population with the necessary high-quality food products.

As for the environmental components, the meat processing plant has the most intense impact on water resources. Along with this, the enterprise also damages the soil and atmosphere (emits solid, liquid and gaseous substances). In terms of water consumption per unit of output, the meat-packing plant occupies one of the first places among the enterprises of the food industry [1-3].

About 200 thousand tons of polluting substances are formed annually at an average-capacity enterprise, and only about 50% of them undergo purification. Existing treatment facilities do not provide the necessary degree of treatment, and outdated technological equipment makes it difficult to implement measures to prevent the formation of pollution.

Wastewater is generated as a result of separate technological processes: hydrotransportation, sorting of raw materials on the assembly line, washing of raw materials and semi-finished products, their portioning, heat treatment, etc.
Wastes from the meat processing industry contain a large number of organic compounds, which makes their disposal rather difficult [1-5].

According to [6], an environmental assessment of meat processing enterprises was given in terms of four types of environmental impact: waste management and wastewater discharge, energy use and water use.

For a long time, meat processing waste was used by farmers for soil fertility. Modern research in the field of agriculture and livestock has revealed shortcomings in the direct use of waste from meat processing plants without appropriate treatment: the spread of soil pathogens and the transmission of diseases to animals, water pollution, and greenhouse gas emissions. Therefore, it is important to find new environmentally friendly waste processing methods. One of them is the method of waste disposal in malnourished animal feed. However, in some countries, regulations prohibit the use of meat processing waste for feed production [7].

The publications [8–10] present the results of the use of meat waste as a component for a compost mixture. Such wastes made it possible to increase the activity of the process, to improve the physicochemical characteristics and maturity of the resulting compost without affecting the salt content, pH, and phytotoxicity. However, this technology is unprofitable for large meat-packing plants with a large volume of waste; therefore, it cannot solve the problems of their utilization.

According to [11–13], the results of studies of wastewater treatment in the meat industry by the method of electrochemical purification are presented, and in [14], biological wastewater treatment of slaughterhouse associated with the generation of electricity and nitrogen reduction in a hybrid microbial fuel cell system with aerobic and anoxic bioreactors.

The scientific works of many modern scientists have noted the high efficiency of utilization of liquid wastes of the meat industry by producing biogas [15-19].

Assessing the effectiveness and real possibilities of implementing the methods used for the treatment of wastewater from meat processing plants highly concentrated in fats, nitrogen, phosphorus, and potassium, it should be noted that these methods either cannot provide modern requirements for the quality of treated wastewater, or they are very complicated and expensive. The results of research on biological wastewater treatment of meat and other industries show that in modern conditions and in the foreseeable future, the optimal solution to the problem of pre-treatment of wastewater in meat processing plants is the use of biological methods [20-24]. These methods, like no other, provide an effective reduction in the biochemical oxygen consumption (BOD) of wastewater - an indicator that is currently quite strictly regulated for wastewater discharged into the city sewer network. At the same time, biological methods have high technical, economic and operational indicators [25-30].

Most of the technologies for treating wastewater concentrated by biogenic elements include a two-stage anaerobic-aerobic process for removing contaminants [31; 32]. As a result of the anaerobic process, biogas is formed, consisting of methane (60-90%), carbon dioxide (10-40%) and biomass of a new composition. A comparison of anaerobic and aerobic processes using glucose oxidation as an example allows one to conclude that anaerobic reaction releases 7 times less energy than in an aerobic process: 404 kJ compared to 2844 kJ. The yield of excess biomass in an anaerobic reactor is much less than in an aerobic one.

The concentration of pollutants largely depends on the quality of raw materials received for processing, type of technological equipment and other factors. In particular, the amount of waste generated during canning ranges from 12 to 35% by weight of the raw materials. Of these, from 20 to 50% fall into the sewer network along with wastewater.

They are rich in organic, easily degradable substances. The main reason for this is the presence of carbohydrates, especially sugars, the concentration of which reaches 12-290 mg/L. Therefore, wastewater must be cleaned fresh. The temperature of the wastewater can range from 19 to 39°C.

Considering that the existing facilities of many meat processing plants are not able to meet modern requirements for the quality of wastewater treatment, there is an urgent need for the modernization and
reconstruction of treatment facilities, so that they make it possible to achieve these requirements, so the relevance of the research topic is beyond doubt.

The main task of preliminary treatment of highly concentrated liquid waste from meat processing plants - wastewater is the removal of suspended solids, fats, organic and other contaminants with a decrease in the degree of pollution of wastewater to the level established for their discharge into the city sewers of a specific settlement.

The aim of the work is to optimize the technology for processing liquid waste from meat plants with a wastewater flow rate of up to 300 m³/h.

2. Theoretical part

An analysis of the specific situation prevailing at meat processing plants, as well as modern scientific and technical achievements in the field of wastewater treatment of meat processing plants and other similar enterprises according to literature and patent sources, made it possible to make a decision that is considering to be optimal.

In the research process, special attention was paid to very simple technologies and facilities, to the fullest extent possible, taking into account the specific characteristics of the wastewater of meat processing plants, the actual working conditions and operation of treatment facilities [33].

The studied technology of flotation-biological wastewater treatment can provide not only the required degree of pollution removal, but also utilize a significant part of the organic products contained in wastewater (fat, protein and organic substances of plant origin, etc.). The basis of the project for the reconstruction of treatment facilities can be fundamentally new, developed in Russia by the ECOS Company, combined facilities: FLOTEX-AERO; FLOTEX-ARO [23-25].

The first step in wastewater treatment should be the removal of large wastes, sand and other large and heavy impurities, the ground mass of suspended substances and fat. From the structure of existing facilities, it is necessary to use only grids installed in the receiving tank of the pumping station.

To remove sand and other impurities, it is advisable to use tangential sand catchers - compact and efficiently operating structures.

To purify wastewater from suspended solids, fat, as well as to reduce the total biochemical oxygen consumption, it is recommended to use a fundamentally new combined installation - an aerobic clarifier reactor (FLOTEX - AERO) or an anaerobic clarifier reactor (FLOTEX - ARO) During the design development of them the main advantages and disadvantages of the used grease skimming tanks, dirt collectors, floaters and aeration clarification units designed for incomplete biological cleaning, as well as special the specific features of the wastewater from meat processing plants were taken into account.

The proposed aerobic technological scheme for wastewater treatment with a flow rate of 300 m³/h includes an additional screen with manual cleaning to remove large waste, two tangential sand catchers with a diameter of 1.3 m for separating mineral impurities, two FLOTEX-AERO which includes a dirt collector with a diameter 6 m, a floater with a diameter of 8 m to remove the bulk of suspended solids and fat from wastewater, the aeration tank is a sedimentation tank with a diameter of 16 m, which provides oxidation of the remaining organic pollutants and thereby reduces the biochemical oxygen consumption and chemical oxygen consumption fat concentrations and other indicators to the established level (Figure 1) [34].

Large debris trapped by the screen and sediment removed from the sand catchers are transported to designated areas.

Sludge from sedimentation tanks - floaters together with excess activated sludge formed during biological wastewater treatment after dehydration in a centrifuge is transported to disposal sites. After the reconstructed treatment facilities are put into continuous operation and the sediment composition established, it can be considered as an additive to dry animal feed, the production of which should be established at a meat-packing plant.

The floating fat mass from the sedimentation tanks-floaters is removed. For biological wastewater treatment, aeration tanks with jet aeration and built-in vertical secondary sedimentation tanks are used.
For aeration of the sludge mixture in aeration tanks, jet aerators are used, developed by the authors of the recommendations and successfully used at many treatment plants of the meat and dairy industry and populated areas. The principle of operation of jet aerators is based on the involvement of atmospheric air in a sludge mixture with jets of working fluid moving at high speed. The sludge mixture taken from the aeration zone is used as the working fluid. Simultaneously with aeration of the contents of the aeration tanks, activated sludge is recycled.

**Figure 1.** Technological scheme of aerobic treatment: 1-pump station; 2-suction chamber; 3-screen; 4-tangential sand catcher; 5-distribution chamber; 6-aerobic combined installation; 7-impounding basin for fat mass; 8-intermediate tank; 9-air; 10-pressure tank; 11-pump; 12-flotation sludge compactor; 13-reservoir tank; 14-tank flow regulator; 15-centrifuge; 16-dehydrated sludge; 17-centrifuge effluent; 18-floating sludge; 19-sediment; 20-recirculating working fluid; 21-excess aerobic sludge; 22-sludge mixture; 23-jet aerators; 24-silt water; 25-to the processing line; 26-treated wastewater.

Excess activated sludge generated during biological wastewater treatment is mixed with the centrifuge formed by centrifuging the sludge from sedimentation tanks - floaters, and the resulting mixture is fed into two flotation sludge compactors with a diameter of 3 m. Flotation sludge from flotation sludge compactors is fed to a centrifuge, and sludge water from them flows into the distribution chamber before the combined installation, recirculated liquid is taken from the intermediate tank located after the combined installation, which is supplied after it is saturated with air to the settling tanks - floaters and flotation tanks silt compactors [35].
Existing grease traps and floaters are not used in the recommended technological scheme for wastewater treatment. After shutting down these facilities from work, the resulting free space in the existing building will be used to place jet aeration pumps, flotation sludge compactors and other equipment on it [33-35].

Concentrations of pollutants in the treated wastewater discharged into the city sewer are taken with regard to the maximum permissible discharges (MPD) established for the meat plant, mg/l: suspended solids - 250; BOD - 220; COD - 350, fats - 50; ammonium nitrogen - 5.8; phosphates - 3.5; chlorides - 600; sulfates-150; pH-7.0-7.5.

3. Practical part

Due to insufficient information for the design of a combined installation-aerobic clarifier reactor, this work presents its calculation.

The estimated duration of wastewater sludging at a maximum flow rate is assumed to be 0.5 hours.

The diameter of the sludging zone is

\[ D_{zs} = \left( \frac{Q}{0.785 \times h_p} \right)^{0.5} \]  \hspace{1cm} (1)

where \( h_p \) - the working height of the sludging zone, m; \( n \) - the number of collectors-floaters, pcs; \( Q \) - the maximum estimated wastewater flow rate, m\(^3\)/day.

The indicated settling time is sufficient for the separation of coarse and heavy impurities from wastewater, constituting approximately 35% of the total amount of suspended solids contained in wastewater.

The diameter of the flotation zone is taken equal to 8.0 m. The estimated hydraulic load of the flotation zone is determined by the formula:

\[ q_{zf} = \frac{Q \left(1 - k_p\right)}{0.785 \times D_{zf}^2 \times n} \]  \hspace{1cm} (2)

where \( k_p \) - coefficient of recirculation of the working fluid; \( n \) - the number of sedimentation tanks-floaters, pcs; \( Q \) - maximum estimated wastewater flow rate, m\(^3\)/day.

The resulting hydraulic load is less than the recommended 6.0 m\(^3\)/(m\(^2\)*h), which will ensure effective separation of grease and suspended solids from wastewater.

To supply the working fluid to the sumps and flotation sludge compactors, the working and reserve pumps of brand SM 200-5006/4 are used with a feed characteristic of 200 m\(^3\)/h, pressure of 50 m, and an electric motor power of 110 kW.

To saturate the working fluid with air (the amount of air supplied per 1 m\(^3\) of liquid is 0.05-0.06 m\(^3\)), two compressors are used, one working and one reserve of brand U-43102 with a characteristic of 30 m\(^3\)/h, pressure 0.7 MPa, power 4.2 kW.

To saturate the working fluid with air, pressure tanks with a capacity of at least 5.0 m\(^3\) are used, which will ensure that the working fluid remains in it for 4 minutes. Pressure tanks are equipped with special pumps (working and reserve) for mixing the air-water mixture in the tanks.

The dry solids mass of the sediment trapped in the sludge zone of the flotation sumps with the estimated retention effect of suspended solids of 35% and fat of 30% will be:

\[ M_{dls} = \frac{C_s E_s + C_f E_f}{10^6} Q_d \]  \hspace{1cm} (3)

where \( C_s \) and \( C_f \) - concentration of suspended solids and fat, respectively, in untreated wastewater, g/m\(^3\); \( E_s \) and \( E_f \) - the effects of the retention of suspended solids and fat, respectively, during sedimentation; \( Q_d \) - estimated wastewatter flow rate, m\(^3\)/day.

When sludge is dehydrated in an OGS type centrifuge, its moisture content should not exceed 77%. With this humidity, the volume of sediment removed from the sedimentation tanks-floaters will be equal to:

\[ W_s = \frac{M_{dls} \times 100}{100 - 77} \]  \hspace{1cm} (4)

The dry solids mass of the emerged fat mass removed from the sedimentation tanks-floaters will be equal to:
where $C_s$ and $C_f$ - concentration of suspended solids and fat, respectively, in untreated wastewater, g/m$^3$; $E_s$ and $E_f$ - the effects of the retention of suspended solids and fat, respectively, during sedimentation; $C'_s$ and $C'_f$ - concentration of suspended solids and fat, respectively, in untreated wastewater, g/m$^3$.

When the moisture content of the fat mass is 85%, its volume will be equal to:

$$W_f = \frac{M_f \times 100}{100 - 85}$$  \hspace{1cm} (6)

The grease under gravity pressure enters the storage tank, from where it enters the existing line for processing grease.

The grease in the aerated tank subjected to gravity pressure enters the sedimentation tank, from where it enters the existing line for processing grease.

The estimated total biochemical oxygen consumption of the wastewater entering the aeration tanks should take into account the oxygen demand for the oxidation of not only dissolved and colloidal, organic, but also organoleptic contaminants in coarse and emulsified wastewater. Therefore, the estimated BOD of wastewater entering the aeration tanks is taken to be:

$$L_a = L_0 + (q_2 \cdot (a \cdot C'_s + C'_f))$$  \hspace{1cm} (7)

where $C'_s$ and $C'_f$ - concentration of suspended solids and fat, respectively, in the wastewater entering the aeration tanks, g/m$^3$; $L_0$ - BOD of wastewater (clarified sample) entering the treatment plant, g/m$^3$; 
a - the fraction of organic impurities in the composition of suspended solids; $Q_2$ - the specific oxygen consumption for biochemical oxidation of coarse organic impurities and fat.

The required volume of aeration tanks is equal, m$^3$:

$$W_a = \frac{(L_a - L_t) \cdot Q_d}{D_s \cdot (1 - S) \cdot V_{ox}}$$  \hspace{1cm} (8)

where $L_a$, $L_t$ - BOD of wastewater, respectively, before and after treatment in aeration tanks, mg/l; $Q_d$ - wastewater flow rate calculated for aerotanks (average wastewater flow rate for the aeration period), m$^3$/h; $D_s$ - the dose of sludge in aerotanks, g/l; $S$ - ash content of sludge, fraction of a unit; $V_{ox}$ - the specific oxidation rate, mg/(g $\cdot$ h).

The maximum speed of the upward movement of treated wastewater in the secondary sedimentation tank will be:

$$V_{w.t.} = \frac{Q \cdot (1 + k_p)}{0.785 \cdot D_{ss} \cdot n \cdot 3.6}$$  \hspace{1cm} (9)

where $Q$ - the maximum flow rate of wastewater, m$^3$/hour; $D_{ss}$ - diameter of the secondary sedimentation tank, m; $n$ - the number of secondary sedimentation tanks, pcs.

The performance of the pumps supplying the sludge mixture to the aeration tanks jet aerators should be equal to:

$$Q_p = \frac{(L_a - L_t) \cdot Q_d}{24 \cdot 61}$$  \hspace{1cm} (10)

where $L_a$, $L_t$ - BOD of wastewater, respectively, before and after treatment in aeration tanks, mg/l; $Q_d$ - estimated wastewater flow rate, m$^3$/hour; 61 - a parameter characterizing the oxidizing ability of the aerator.

To supply the sludge mixture to jet aerators, it is necessary to use two working and one reserve pumps of the brand D2500 - 17 with the characteristic: feed 1500m$^3$/h, pressure 15 m, rotation speed 735 r/min, and pump power 125 kW.

Eventually, take the overall dimensions of the designed installation of a diameter of 16 m a height of 11 m.

The anaerobic wastewater treatment process includes an additional screen with manual treatment to remove large waste, two tangential sand catchers with a diameter of 1.3 m for separating mineral impurities, two FLOTEX- ARO which includes a sediment catcher with a diameter of 6 m, a floater with a diameter of 8 m to remove the main mass of suspended solids and fat from wastewater, a attenuation zone with a diameter of 16 m, which provides oxidation of the remaining organic
pollutants and thereby reduces to established levels of BOD, COD, fat concentrations and other indicators.

The required volume of the attenuation zone with the duration of the wastewater in it during the day is:

\[ W_{a.z.} = \frac{Q_d}{n} \]  

(11)

where \( Q_d \) - daily wastewater flow rate, \( m^3/\text{day} \); \( n \) - the number of reactors, pcs.

When annular velocity of wastewater in the clarification zone is 1.0 mm/s, its diameter is:

\[ D_{c.z.} = \frac{Q \cdot (1+k)}{0.785 \cdot n \cdot 3.6 \cdot V_a} \]  

(12)

where \( Q \) - the maximum flow rate of wastewater, \( m^3/\text{hour} \); \( k \) - the recirculation coefficient, 0.5; \( n \) - the number of reactors, 2 pcs.

The scheme of the FLOTEX - ARO installation is shown in Figure 2 [35].

![Combined anaerobic plant](image)

**Figure 2.** Combined anaerobic plant.

Thus, the combined installation for pre-treatment of highly concentrated wastewater from meat processing plants, and not only them, have elements of the best available technologies, namely, combining flotation and aerobic oxidation processes in one module. The water purified in the combined installation is treated in existing biological treatment facilities.
4. Conclusions
There are currently no unified methods for processing liquid waste from meat processing plants that have elements of the best available technology. It is necessary to take into account the specifics of each meat plant and, first of all, to take into account the costs of liquid waste.

In order to optimize the technology for processing liquid waste at all meat processing plants, it is advisable to pre-treat wastewater in the combined installations of FLOTEX-AERO and FLOTEX-ARO.

The optimal operating parameters of the plants, providing the greatest efficiency of liquid waste treatment, can be calculated according to the relationships given in the article.

Wastewater treated in a combined installation can be pre-treated efficiently at existing biological treatment plants of enterprises without reconstruction.

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