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ULTRAFILTRATION METHODS IMPLEMENTATION FOR LIQUID WASTE REUSE TECHNOLOGIES

Introduction

Liquid waste is the main part of industrial waste. The main goal of such waste processing is to prevent their harmful effects on human health and the natural environment. All industrial waste must be collected, transported, destroyed and disposed of in compliance with all sanitary requirements and regulatory acts[1].

The main organizational activities are aimed to the prevention of discharge of wastewater into reservoirs without their treatment. Modern technical events involve wastewater treatment using various methods. This creates a scientific and technical basis for the reuse of wastewater – the closed water use systems creation. The implementation of innovative methods in the technological reuse processes at enterprises allows reducing the pollutants inflow into the wastewater and developing energy-saving closed water circulating[2].

1 Shtefan Ye., & Pashchenko B. (2022) .The liquid waste disposal innovative technologies of printing enterprises. Modern scientific strategies of development : collective monograph. Compiled by V. Shpak; Chairman of the Editorial Board S. Tabachnikov. Sherman Oaks (pp.290-298). California : GS Publishing Services, 349 p.

2 Shtefan, Ye., & Serogin, O. (2022). Energy-saving technologies for disposal of waste with printing design elements. Theoretical and practical aspects of modern scientific research : collective monograph. Compiled by V. Shpak; Chairman of the Editorial Board S. Tabachnikov. Sherman Oaks (pp. 91–103). California : GS Publishing Services, 256 p.

Thus, according to the hierarchy that proposed by the Waste Framework Directive (2008/98/EC), reuse processes are the most perspective among existing technologies of liquid waste processing (Fig. 1).

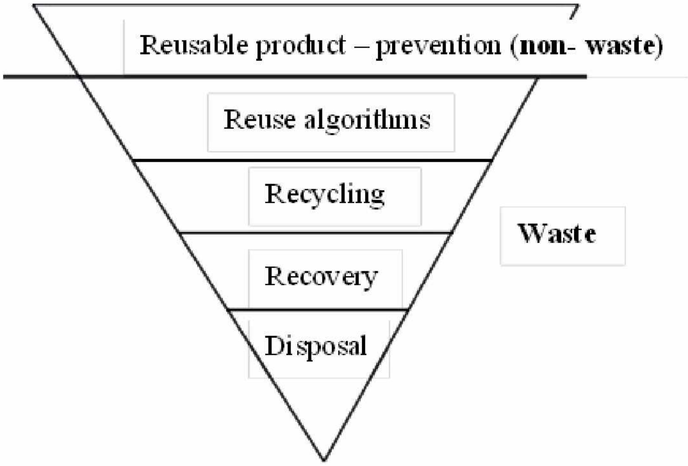

Fig 1. Waste hierarchy according to the Waste Framework Directive (2008/98/EC)

There are several methods of wastewater treatment at enterprises, which can be tentatively classified into mechanical, physical, chemical, and biological. The choice of a water treatment scheme depends on the type and amount of pollution and the required degree of purification.

In present report, ultrafiltration is considered – a membrane process for the distribution of solutions with low osmotic pressure[3]. This technological operation is used to purify wastewater from high molecular weight substances, suspended particles and colloids.

Modern ultrafiltration technologies have become widespread in many industries, first of all, where separation of multicomponent mixtures and dispersed systems is required. This is due to a number of advantages, in particular, low energy consumption and high efficiency of membrane separation. The main feature of the ultrafiltration process is the presence of a semipermeable membrane.

Ultrafiltration technologies is widely used in water treatment systems, for concentration and fractionation of solutions, for desalination of salt water, purification of various industrial liquid wastes, sterilization and clarification of all types of drinks and obtaining ultrapure water. These processes can be carried out at any temperature, even at low temperatures[3]. However, the mechanism of membrane processes is not yet fully understood, and it should be considered for each process separately.

3 Bacchin, P., & Aimar, P. (2005). Critical fouling conditions induced by colloidal surface interaction: from causes to con sequences. Desalination, 175(1), 21–27.

The main working element for the implementation of membrane separation is a membrane – a thin layer of a certain material that separates two liquid phases with different properties and composition[4]. The membrane material differs from these phases in terms of physical and chemical characteristics and has a selective (selective) permeability relative to various components of these phases[5].

The practical use of membrane technologies depends on the physical and chemical characteristics of the contained substance and the processed solution, in particular, pH, ionic strength of the solution, etc.[6] The main task of filtration equipment designing is the selection of membrane filter elements selective layer with a certain porosity and thickness. Such elements make it possible to provide the main technological parameters of the filtration process, pressure and temperature in the membrane module, the time of productivity reduction. Thus, for the effective implementation of the ultrafiltration process in industrial enterprises, it is necessary to carry out appropriate design calculations of the filtration equipment main parameters.

Research Methodology

An experimental unit was developed to conduct a study to determine the characteristics of the dispersion system filtration process and perform optimization calculations of the filtration equipment main parameters. The main working element was used the ceramic ultrafiltration membrane from Inopor Rauschert Distribution GmbH, Germany, the technical parameters of which are presened in Table 1.

Table 1

Technical parameters of Inopor ultra ceramic membrane

Properties	Значення
Material	α-Al_2O_3
The number of pores per unit volume	5-10
Separation boundary	7500 D
Porosity	30-55%
Thermal conductivity, W/(m·K)	31,0
Specific heat capacity, J/kg·K s	795
Working temperature, ^0C	-100/1000
Membrane working area, m^2	0.0058

4 Pashchenko, B. (2020). Regularities of the of membrane separation of dispersed systems with concideration for structural and mechanical parameters of filter elements and sediment. (Dis. Cand. Sc. (Mechanical Engineering, PhD). National University of Food Technologies, Kyiv.

5 Shtefan, E., Pashchenko, B., Blagenko, S., & Yastreba, S. (2018). Constitutive Equation for Numerical Simulation of Elastic-Viscous-Plastic Disperse Materials Deformation Process. In Design, Simulation, Manufacturing: The Innovation Exchange (pp. 356–363). Springer, Cham.

6 Milić, J. K., Petrinić, I., Goršek, A., & Simonič, M. (2014). Ultrafiltration of oil-in-water emulsion by using ceramic membrane: Taguchi experimental design approach. Central European Journal of Chemistry, 12(2), 242–249.

The experimental unit that contain the filter module (Fig. 2) consists of a collection container 7, with a mechanism for regulating and changing the pressure in the system; centrifugal pump 3, which ensures the movement of the test substance through the filtration elements; thermostat 8, which ensures a constant operating temperature of the filtering process; rotameter 5, which measures the flow rate of the substance; heat exchanger 6 for heating the liquid solution; membrane module with ceramic filter element 4; manometer 1 and compressor 9, which provides the specified working pressure in the system. With the help of the shut-off valve 2, the flow of the substance is regulated and a bypass loop is created, as well as the removal of the purified substance and waste from the installation.

The compressor 9 is connected to the collection container 7 by means of a connecting pipe, which is fixed with a clamp. The collection container is connected to the system using a pipe. The thermostat 8 is connected to the heat exchanger 6 similarly to the connection of the compressor 9 with the container 7. The difference is that not one, but two connecting pipes are used for this.

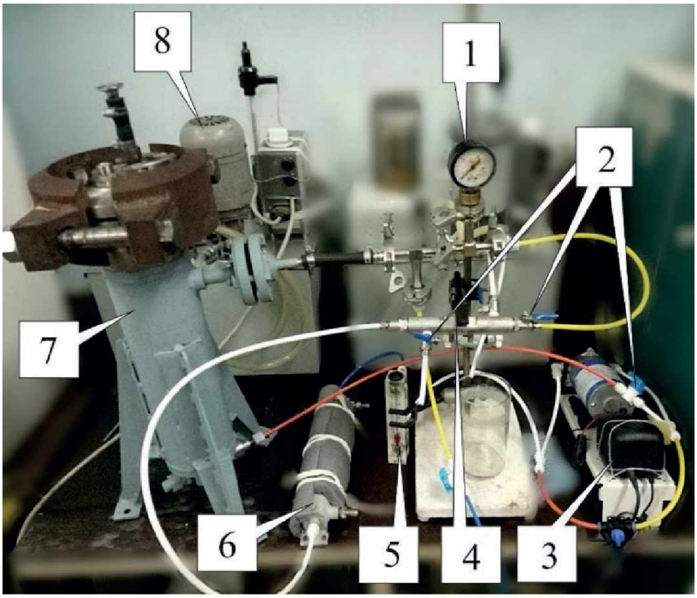

Fig. 2. General view of the experimental setup: 1 – manometer; 2 – shut-off valve; 3 – centrifugal pump; 4 – membrane module with a ceramic element; 5 – rotameter; 6 – heat exchanger; 7 – collection container for the pressure creating; 8 – thermostat

The membrane element 2 is placed in the corrosion-resistant metal housing 1 of the filter cell (Fig. 3). Due to the increase in the temperature of the processing liquid by heating through the water jacket of the heat exchanger 6, the filtering process is intensified, which increases the rate of circulation of the substance. Its value is determined with the help of a rotameter 5. Shut-off valve 1 is intended for the removal of purified liquid in the system, water and washing solution is also used as an element of regulation in the bypass device.

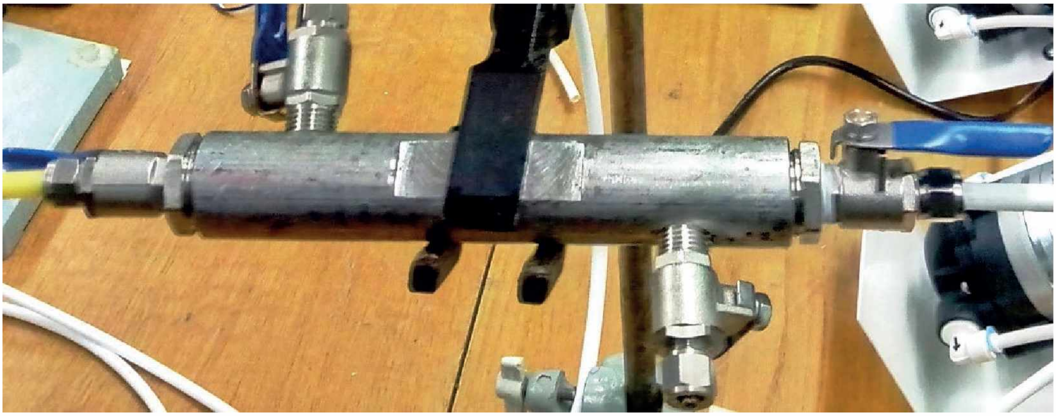

Fig. 3. Photo of the filter cell of the experimental unit

This device (bypass) is installed on the inlet and outlet channels of the centrifugal pump and ensures uninterrupted operation of the pipelines at the time of a sudden shutdown of the equipment and makes it possible to control fluid flows, as well as ensures a smooth increase in pressure. In addition, the bypass is a simple safety measure that protects the membrane element from pressure drops that can cause water hammer.

Such a design of the filter unit is technically reasonable from the point of view of installation and connection to the water treatment, water treatment or wastewater treatment system due to the simplicity of the design and easy replacement of individual elements and equipment units. The next stages of design are the calculation of the equipment analyzed parameters.

One of the important characteristics of ultrafiltration equipment is hydraulic efficiency coefficient. It characterizes the degree of liquid use in the ultrafiltration process in the so-called tangential filtration mode with subsequent filter regeneration by backwashing. This coefficient is defined as the ratio of the filtrate flow to the water (washing solution) flow which supplied during regeneration:

$$C_e = \frac{\left(V_{ф}^{'} \cdot t_{ф} - V_{з}^{'} \cdot t_{з}\right)}{\left(V_{ф}^{'} \cdot t_{ф} - V_{п}^{'} \cdot t_{п}\right)} \cdot 100\%, \quad (1)$$

where C_e is hydraulic efficiency, %; $V'_{ф}$ V - filtrate consumption, m^3/h; $V_{з}$ - water consumption for backwashing, m^3/h; V'_{n} – water consumption for direct washing, m^3/h; $t_{ф}$, $t_{з}$, t_{n} – time (duration) of filtration of reverse and direct washing, respectively, h.

If direct flushing is not performed for the installation, the equation is simplified:

$$C_e = \frac{\left(V'_{ф} \cdot t_{ф} - V'_{з} \cdot t_{з}\right)}{\left(V'_{ф} \cdot t_{ф}\right)} \cdot 100\% \qquad (2)$$

For example, the hydraulic efficiency of ultrafiltration units for filtering relatively clean water is up to 95%, for low-quality water due to the need for frequent washing, it drops to 70-80%.

At the same time, the useful power of the N_u pump is:

$$N_u = Q \cdot \Delta P_s \qquad (3)$$

where Q is pump productivity, m^3/s; ΔP_s - pressure losses necessary for pumping liquid through the membrane module, pipelines and fittings.

To ensure the unit reliability and maintainability it is advisable the parallel arrange the membrane elements in filtration module.

With parallel arrangement of membrane elements we may obtain:

$$\Delta P_s = \Delta P_{ò} + \Delta P_{ì}, \qquad (4)$$

where $\Delta P_т$ – pressure loss in pipes and fittings (installation circuit), Pa; $\Delta P_м$ – pressure loss in the membrane module, Pa.

The initial rate of concentrate flow in the filter element channel:

$$Q_0 = \pi r^2 u \cdot n, \qquad (5)$$

where n is the number of parallel elements in the module ($n = 2$); u – liquid flow rate passing through the walls of the filter element (filtrate); r is the radius of the internal channel of the membrane.

The value of $\Delta P_т$ is determined by the formula:

$$\Delta P_{ò} = \left(\lambda \frac{x}{2r} + \xi\right) \cdot \rho \frac{u^2}{2}, \qquad (6)$$

where λ is the coefficient of hydraulic friction; ξ is the tortuosity coefficient of the porous medium; x is the length of the membrane element.

Equation (3) with (4-6) can be written in the following form:

$$N_u = \pi r^2 \cdot u \cdot n \cdot (\Delta P_{ò} + \Delta P_{i}). \qquad (7)$$

The module productivity Q_p:

$$Q_p = n \cdot q_{ð}, \qquad (8)$$

where q_p is the liquid volume flow: $q_{ð} = \pi r^2 \cdot u$.

For the laminar process regime:

$$N_u = \pi r_0^2 \cdot U_0 \cdot n \cdot [\Delta P_{ò} + P_0(1 - e^{-b\lambda}\}, \qquad (9)$$

$$Q_p = n \cdot q_0 (1 - e^{-b\lambda}). \quad (10)$$

where b is a structural parameter that depends on the permeability coefficient.

Since membrane permeability also depends on fluid temperature (which is a consequence of fluid viscosity changing with temperature), this parameter can be normalized by the temperature correction factor. Normalized permeability ($m^3/m^2 \cdot h \cdot Pa$) is calculated as follows:

$$k_{20} = \frac{k}{k_t}, \quad (11)$$

where k_{20} is the permeability normalized at 20°C, k is the permeability at the current temperature, k_t is the temperature correction factor.

The main reason for the temperature change in permeability is the change in the viscosity of the system when the temperature rises. Since the flow of liquid through the pores of the filter element is subject to the Hagen-Poiseuille dependence, the temperature correction factor can be written as:

$$k_t = \frac{\eta(20^0 C)}{\eta(t)}, \quad (12)$$

where η(20°C) is the dynamic viscosity at 20 °C, and η(t) is the dynamic viscosity at temperature t (determined empirically), t is the temperature in degrees Celsius.

On the basis of the developed pilot plant and the performed design calculations, it is proposed to use a membrane filtration plant at the stage of wastewater treatment in the existing wastewater treatment scheme of the meat processing industry (Fig. 4). It consists of a line of physico-chemical wastewater treatment, flotation treatment, coarse filters, membrane UV unit (Fig. 4). Wastewater treatment methods used in this scheme: mechanical treatment; physico-chemical cleaning by flotation method; settling; rough cleaning with sand filters; further purification by ultrafiltration.

Captured pollution is unloaded into a special container. From the fat catcher the wastewater directed to a settling tank with a thin-layer module 3 and than to the flotation column 6. The flotation cleaning process consists in the formation of «particle-bubble» complexes. The size, number and even distribution of air bubbles in the treated wastewater are of great importance during flotation.

Results and Discussion

The equations (8-10) made it possible to calculate the module productivity in the laminar mode of liquid flow depending on permeability coefficient (Table 2). On its basis, it can be concluded that with an increase in the permeability coefficient, the equipment productivity is also increases.

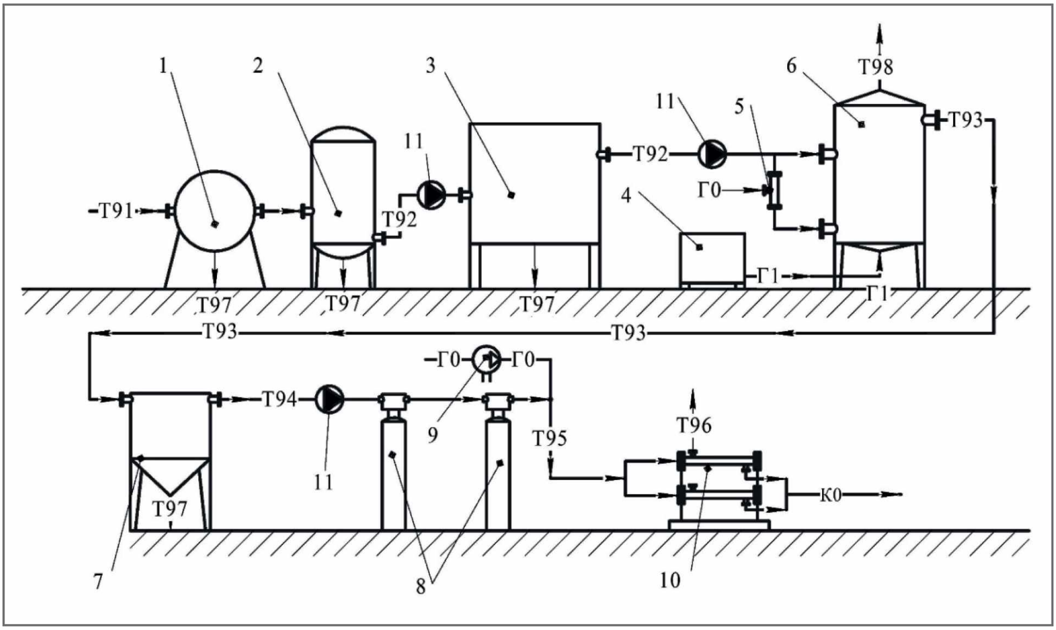

Fig. 4. Equipment-technological diagram of wastewater treatment of meat processing production using a membrane ultrafiltration unit:
1 – drum sieve; 2 – grease trap; 3 – thin-layer clarifier; 4 – oxygen concentrator; 5 – ejector; 6 – flotation column; 7 – sump; 8 – sand filters; 9 – compressor; 10 – ultrafiltration unit; 11 – pumps.
Flows: G0 – air; H1 – oxygen; T91 – sewage; T92 – effluents after mechanical cleaning; T93 – effluents cleaned by flotation; T94 – settled water; T95 – filtrate water; T96 – water treated with UV and re-sent to production; T97 - cake and other impurities; T98 - flotation foam; K0 - water discharged into the sewage network

Table 2

Productivity depending on the permeability coefficient

The coefficient of permeability, м^3/(м^2·s·Pa)	1,94	1,32	0,49	0,24	0,17	0,10	0,08	0,04
Productivity, L/(м^2·h)	27,590	20,669	8,691	4,438	3,296	1,878	1,489	0,842

According (2) we may calculate the hydraulic efficiency for the experimental unit:

$$C_e = \frac{(57 \cdot 1595 - 53 \cdot 300)}{(57 \cdot 1595)} \cdot 100\% = 62{,}5\%.$$

Since the model solution used in the physical simulation is a two-phase dispersed system with various colloidal impurities, the pores of the membrane element become contaminated rather quickly. Therefore, backwashing was carried out regularly after each work cycle. As a result, the hydraulic efficiency is not high.

Key indicators identified the degree of purification of wastewater from pollution: chemical oxygen consumption (COC), color (characterizes the intensity of water color, which is caused by the content of colored organic substances), turbidity (characterizes the natural property of water, caused by the presence of suspended organic and inorganic substances in the water origin) and pH level (value showing the degree of activity of H+ hydrogen ions in the solution, i.e. the degree of acidity or alkalinity of this solution). These indicators of wastewater, which were obtained using the proposed additional treatment scheme, were compared with similar ones obtained during the traditional treatment scheme (Table 3).

Table 3

Indicators of wastewater treatment of a meat processing enterprise

Indicator of degree of purification	Indicator Suggested cleaning scheme	Indicator Traditional cleaning scheme
COC, mg/l	136	150
Color, degrees	71	80
Turbidity, (mg/dm^3)	66	75

As can be seen from the analysis of Table 3, the use of proposed membrane filtration unit at the stage of wastewater treatment in the existing wastewater treatment schemes allows to increase the degree of wastewater treatment by 10-15%.

Conclusions

1. The design parameters of the ultrafiltration equipment, which take into account the peculiarities of the production processes of a particular enterprise have been determined.
2. It has been proven that the use of the specified equipment and technological scheme in combination with design calculations allows to increase the degree of wastewater treatment of a meat processing enterprise by 10% and obtain a significant economic effect due to the return of part of the purified waste to the technological process and, as a result, a reduction in the costs of auxiliary material flows.
3. The specified solutions to increase the level of environmental safety of the enterprise due to the creation of closed water circulation schemes and the reuse of purified water.

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