Technological Audit of Wastewater Treatment at the Production of Crude Oils

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3 authors:

Maria Kameristaya
National Research University Higher School of Economics

Alena Basamykina
Peoples' Friendship University of Russia

Ekaterina Kurkina
Peoples' Friendship University of Russia

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Maria Kameristaya, Alena Basamykina and Ekaterina Kurkina

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Maria Kameristaya[a)], Alena Basamykina[b)] and Ekaterina Kurkina[c)]

Peoples' Friendship University of Russia (RUDN University), 6, Miklukho-Maklaya st, Moscow, 117198, Russian Federation

[a)] Corresponding author: mkameristaya@bk.ru
[b)] alena.basamykina@gmail.com
[c)] katkur04@gmail.com

Abstract. The article presents a general characteristic of the fat-containing effluents of an oil and fat enterprise, taking into account the composition of the raw materials, the industrial chemicals used for their processing, and the technological scheme of production. It has been revealed that most oil and fats enterprises, due to the specific nature and high pollution of their wastewaters, require a process audit of their treatment plants to optimize water use, effectively reduce operating costs, and improve effluent treatment efficiency, etc. The main steps of a process audit are presented. Frequent shortcomings in the existing process and irregularities in the operation of the wastewater treatment plants are identified. Recommendations have been developed to modernize the wastewater treatment plants of the oil and fats enterprises to increase their efficiency and minimize the possible negative impact on the environment: equipment replacement containing defects and addition of a technological scheme with biological treatment step, as well as a post-treatment stage for the use of treated water in production. The study developed a modernized and most appropriate wastewater treatment process for this food industry segment, including automation and recovery systems. It is concluded that the proposed technological scheme improves the wastewater treatment plant's efficiency and minimizes the possible negative impact on the environment.

INTRODUCTION

Oil and fats manufacturing is an integral part of the food industry. It includes the production of oilseeds, oil refining for various consumption areas, and the supply of waste products to the feed industry.

The increased demand for edible oil worldwide has resulted in vast quantities of wastewater, generated mainly during processing operations and equipment washing [1]. Effluent from the oil and fat industry has a high nutrient content consisting of oil crop husk and shell particles, high biological oxygen demand (BOD) and chemical oxygen demand (COD), oil products, organic and inorganic content, and is characterized by an unpleasant odour when condensed (Table 1) [2, 3]. Such high values can cause the death of aquatic flora and fauna and make fertile soils unfit for cultivation [2]. Consequently, it is necessary to predict the wastewater quality that enters the wastewater treatment plant, conduct process audits, and modernize the wastewater treatment plant in the oil and fat food industry, selecting effective treatment options, recycling, and reuse methods for the wastewater.

It is worth noting that wastewater treatment plants in the oil and fat manufacturing are a specific segment of the industry, with highly irregular wastewater flows and composition, often a lack of reliable baseline information, a shortage of efficient solutions (with a large market), staffing issues of plant operation and high unit costs [3].

Through periodic process audits of both the whole oil and fat enterprise and its process units, more efficient water and wastewater management, optimization of water use, improved water accounting systems (water loss detection and water-saving potential), reduced wastewater generation, effective reduction of energy costs (pumping), increased efficiency of wastewater treatment, etc. [4].

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TABLE 1. Characteristics of wastewater generated in an oil and fats plant [2, 3].

Parameter	Minimum	Maximum
pH	3.5	6.7
COD (mg/L)	7000	9700
BOD_5 (mg/L)	1900	7000
TSS (mg/L)	1520	2000
TKN (mg/L)	500	625
NH_3 (mg/L)	18	51
Total P (mg/L)	50	420
Oil-grease products (mg/L)	550	760
Sulfate (mg/L)	10800	11750

MATERIALS AND METHODS

A technology audit of a wastewater treatment plant is a comprehensive technology audit of both existing and planned facilities to develop measures to improve technological and energy efficiency [4].

Depending on the purpose of the audit, the following tasks can be solved: collection and systematization of reliable data to assess the state of industrial safety and the current state of the equipment; drawing up the water balance of the enterprise; pre-project study of technological solutions; design of a preliminary solution for wastewater treatment; assessment of existing technological environment reserves; design of solutions to improve existing operating systems and reduce operating costs; search for directions of constructive and technological modernization of existing sewage treatment plants and optimal operating modes of sewage treatment plants with greater productivity and lower labour costs [4].

Based on the data and research results obtained, the specialist selects the most suitable physico-chemical solutions and tests in accredited laboratories to simulate physico-chemical and biological processes.

Thus, the auditor, when analyzing the raw data, follows the following plan:

1. Sampling of the process wastewater at the inlet and outlet of the wastewater treatment plant, including the following steps: sampling preparation, sampling, labelling of the sample container, preservation, filling in of the sampling report, transport to the laboratory, samples acceptance in the laboratory [2].
2. Performing a visual assessment of the plant's performance and modelling its operation:

- Performance analysis of the coarse filter: Whether the mesh size is appropriate for the effluent flowing through;
- Check the operating conditions and monitor the water in the averaging unit;
- At the flotation plant or sedimentation chambers, it is possible to influence the treatment plant's operation as much as possible, using the suitable reagents without causing any harm to the treatment process or the equipment. At this stage, it is necessary to carry out a laboratory selection of reagents, taking into account the equipment material: choosing the most effective pH reducing coagulant (inorganic based on aluminium or iron, organic - melamine, polyamine, etc.) and type of flocculant, selecting their optimum dosage and concentration. In case of high suspended solids content and turbidity in the effluent from the flotation plant, it is necessary to check the reagent input sequence (coagulant, neutralizer, flocculant), the pH of the effluent, reduce the hydraulic load for a longer chemical reaction time, increase or decrease the dosage of coagulant, flocculant, change the reagent dosing point (tubular flocculant) and check the compressor pressure (Table 2) [5, 6];
- Depending on wastewater contaminants, COD and fat levels, establish whether biological treatment is needed. It must be considered that it will be ineffective at elevated COD and BOD values. Therefore, it is essential to specify each treatment step's limiting values and consider common operational problems, especially at the first stage of biological treatment - anaerobic treatment [5, 6]. It is also essential to consider that the potential biological treatment scheme should be designed so that the highest possible biochemical process rates are realized, the amount of sludge is minimized, effective process control is developed, etc.;
- If the dewatering of flotation sludge/excess active sludge is problematic, the sludge can be mixed with excess active sludge if possible, the coagulant can be dosed, and additional reagents can be individually selected, or equipment (belt filter press, decanter, etc.) can be changed [7];

- Investigate the feasibility of additional treatment step with a disc, sand, or charcoal filter.

3. The study establishes which elements need to be refined and modernized and which need to be removed entirely from the existing technological process.

Thus, the reconstruction results in the design quality of the treated water at the design inlet wastewater parameters.

TABLE 2. Remedial measures for the chemical wastewater treatment phase [2, 5].

Possible causes of occurrence	Remedial action
Purified water (turbid, with flakes)	
Low coagulant dosage/ Extremely high coagulant dosage	Check reagents performance in the flocculator by sampling from the sampling taps after each reagent. Carry out a rapid test to establish the optimum coagulant and flocculant aid dosage. Increase coagulant dosage, and decrease flocculant dosage.
Wastewater has changed in terms of pollutants (start-up of an additional oil refinery)	Dosage adjustment.
Incorrect pH range	Calibrate the pH sensor.
Dirty flotation plant	Flush and clean the flotation device.
Too much water flow coming in for cleaning	Reduce the flow to the design values.
Low pressure in the saturation unit	Check the pressure. Increase the overpressure to 5-6 bar.
Pre-mixing station (incorrect operation)	
Manual mode enabled	Set the equipment to automatic mode.
Not enough powder in the hopper	Pour the flocculant aid into the hopper.
The flocculant solution has lumps, mucus	Drain the flocculant aid solution. Flush the pre-mixing

RESULTS

In the oil and fat industry, treatment plants have broadly similar problems due to the specific characteristics of the production segment [3].

The sewage pumping station (SPS) of fat-and-oil enterprises has structural deformations due to which moisture penetrates and, as a result, mould forms on the inner surface. When flowing through sewer networks, oils stick to the walls of the duct, sticking impurities together, causing a reduction in the flow cross-section. The following work needs to be done: eliminate water leaks from water pipes and fittings, and fix the drainage system [8].

The pumps run very loudly, creating extraneous noise, and the equipment overheats; staff have found that the pump sometimes short-circuits when started [8]. Also, due to the high initial pressure, overloading of the metering pumps has been diagnosed. Based on a negative experience, it is worth selecting and using new, better and upgraded pumps.

Mechanical treatment. The sewage treatment plant grate has gaps between the grate frames and operates with hydraulic overloading [9]. The causes are incorrect installation during installation. This stage is essential in protecting plant equipment from faults, especially pipes and pumps, which cause these elements to malfunction [4]. There is no automatic cleaning of the mechanical grid, making this stage challenging to operate. If this is the case, replace the grid with a new one and add a stage for the effluent to pass through the revolving screen.

Inefficient operation of the grease trap in concrete (collapsing from above) has been recorded. The possible reason is an incorrect calculation of the operating parameters for the existing effluent volume and its contamination's qualitative and quantitative characteristics.

Physico-chemical treatment. Excess primary sludge is not removed from the sedimentation tank and flotation tank in a timely and sufficient manner. In the flotation unit, the air is inefficiently bubbling; in addition to not being resistant to rust and mechanical damage, the combs do not remove the flotation foam sludge on the water surface entirely due to their positioning at a relationally high level relative to the flotation unit. The saturator pumps air weakly and clogs, failing to do its work (creating a water-breathing mixture), i.e. the COD and BOD are not reduced.

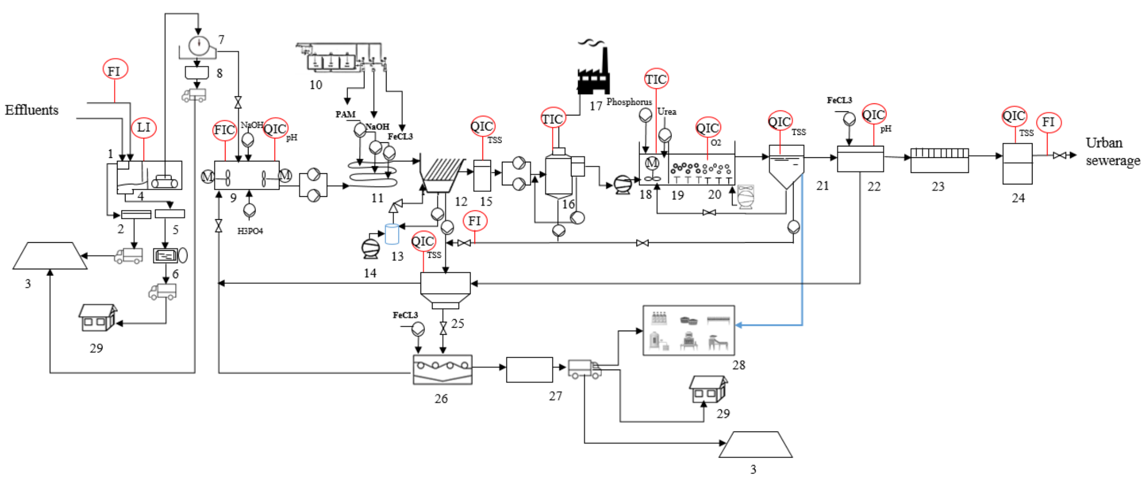
In addition, the wastewater contains organic acids and nitrogen-containing substances, which, once neutralized, decompose to form hydrogen sulphide from decomposing proteins and reducing sulphates. There is no frequency control device necessary because of the significant daily load variations in wastewater treatment equipment and which is economically feasible to use to control the pumps due to the lack of feasibility of any refurbishment and severe physical deterioration [9].

At the outlet of the flotation plant, the effluent is turbid, with flakes and lumps, and the outlet, after this stage, produces elevated COD and BOD.

Popular as wastewater treatment equipment for oil and fat industries, the microfiltration module is very often in a neglected state, a possible reason being strong concentration polarization, i.e. a dense sludge - a gel layer - formed on the membrane surface, which was predictable after analysis of the effluent and the mismatch between the capacity of the wastewater treatment plant and this effluent. Indeed, the module receives effluent that is highly polluted and has not been pre-treated to such a level that the module is not overloaded, can cope with the incoming contamination and is not clogged.

DISCUSSION

As a result of the analysis of oil-bearing raw materials, production technology (by compiling a material balance for each stage), used industrial reagents, the wastewater composition and based on the given recommendations, taking into account the use of instrumentation and automation to monitor the equipment performance, the technological scheme of wastewater treatment, including the stages of mechanical, physico-chemical and biological treatment was developed (fig. 1).



1 - protective grid; 2 - waste compactor (1); 3 - landfill; 4 - grease trap; 5 - container for free fat collection; 6 - centrifuge-separator; 7 - revolving screen; 8 - waste compactor (2); 9 - blender; 10 - reagent preparation equipment; 11 - flocculator; 12 - flotator; 13 - overflow tank; 14 - compressor; 15 – mixing tank; 16 - digester; 17 - boiler house; 18 - selector; 19 - anoxic zone; 20 - aerobic zone; 21 – secondary clarifier; 22 - phosphate removal tank; 23 - disc filter; 24 - disinfection unit; 25 - sludge thickener; 26 - belt filter press; 27 - container with dewatered sludge; 28 - production (workshops) of the audited enterprise; 29 – treated sludge for realization.

Sensors: LI - level indicator; FI - flow indicator; QIC_{ph} - pH indicator; FIC - flow controller with display; QIS_{tss} – SS (suspended solids) sensor; TIC - regulator with temperature indication; QIC_{O2} - O_2 sensor.

FIGURE 1. Technological scheme for wastewater treatment at an oil and fats plant.

Mechanical treatment stage. Wastewater from all workshops, including domestic sewage, is routed through a pressure pipe to the sewage treatment plant (a concrete basin divided into two parts). The intake compartment is equipped with a safety grid with automatically controlled flushing. This coarse mechanical cleaning aims to retain coarse debris that can put pumps and equipment out of operation in further stages. The "bulk" pollution captured on the grids is collected in compactors and then disposed of (taken to organized industrial waste landfills).

After passing through a protective grid, the water enters the grease trap, where part of the accessible fat in unemulsified form is mechanically separated. In dispersed aggregate state systems, grease waste discharged from grease traps is class IV waste (low-hazard) [10]. Waste treated fats are used as a raw material to produce laundry soap, oil paints, varnishes, technical lubricants, etc. The equipment used for fat separation is a centrifuge separator [2].

The water then overflows into a second compartment of the wastewater treatment plant with a submersible pumping station that receives the maximum calculated salvo discharge into the section where the wastewater is pumped to a trommel screen. Fine solids deposited on the filter drum are removed with a unique rotating knife, collected in a container, and then disposed of; their aggregate state is a mixture of fine solids (including fibres), hazard class IV [10].

The water then flows under gravity to a steel average tank (for concentration and flow averaging, equalizing peak discharges) in a closed design and 50-70% filling capacity, where a pH sensor is installed to balance hydraulic peaks, concentration, acidification (a process of organic acid formation that helps increase the performance of the next stage - biological treatment) and a flow controller with a display to control the water volume.

The mixing tank is equipped with two stirrers (the mixing process is continuous). There is also a reagent dosing (pre-treatment) for neutralization (as different production stages use reagents with varying pH values). The entire further treating process operates efficiently at a neutral range of values. Here, alkali neutralizing reagents (NaOH) (top) or phosphoric acid (H_3PO_4) (bottom) are dosed. A metering pump is installed for each neutralizer. Pumps do the transition of the waters to the next stage.

Physico-chemical treatment. The wastewater then undergoes flotation (removes only undissolved compounds - suspended solids and grease, 20-30% organics - from the wastewater) [11]. The water passes through a tube flocculator where the reagents are applied in the following sequence: coagulant, alkali, and flocculant. It is worth noting that the resulting high emulsified fat flotate must be disposed of at this stage (it cannot be used as raw material for other operations, such as fat separated by grease trap) because of the heavy metal in its composition. Still, if we do not use coagulant or use organic coagulant, the efficiency of this step is reduced, subsequently affecting the operating costs.

Iron chloride (sometimes acid is added if necessary) is used to break down the emulsion to introduce a metal charge (this coagulant lowers the pH to the acidic side). The subsequent flocculant works at a neutral value, so the automation has an alkaline feed (40% caustic solution) to correct the pH value again to remove suspended solids and fats (what is in the water in an undissolved form). Then a flocculant organic compound (polyacrylamide anion, -(CH_2-CH-($CONH_2$))n-) is used, and its consumption will be determined experimentally, based on the flocculate composition of the, which produces flocs.

The removal of fat ($\rho = 0.95$ g/cm³) mainly takes place at this stage, so it is better to lift this sludge upwards in the flotation machine: part of the water is taken after the flotation machine into a tank where compressed air is fed with a pressure of 5-6 atm, i.e. air to water dilution effect takes place [12, 13].

The resultant rather large amount of flotation sludge (dry solids content 5-7 %) is collected by a scraper, taken to a flotation hopper, and conveyed by a screw pump to a sludge collector dewatering. The water is sent to an averaging tank, where suspended solids are measured to control the quality of the previous stages. The effluent is then pumped to the biological treatment stage.

Biological treatment stage. The water is pumped into an intermediate tank. It is fed to the biological treatment using a methane digester, which has a circulation system with a pumping station and has a biogas extraction and combustion plant (which can be used for heat, steam, and electricity), removing 90% of organic pollutants, nitrates/nitrites and sulphates anaerobically without air access by methanogenic organisms to form biogas, but the water must be heated to a temperature of 33-38 degrees [14]. A temperature and flow indicator is fitted here.

The final stage is aerobic treatment (the water comes from the averaging tank). The remaining 10% is removed (consists of three chambers: 1 - selector equipped with a stirrer, also at this stage there are three dosing pumps to add nutrients (phosphorus, urea) with nitrogen and phosphorus compounds if it turns out during operation that these elements are not enough; 2 - denitrification, equipped with a stirrer to remove nitrogen; 3 - nitrification, where organic matter is removed, and nitrate formation from ammonium nitrogen occurs; all tanks have one water level) [15]. The optimum process temperature is 25 - 35 °C. In the aeration tank, equipped with sensors for measuring suspended solids and oxygen content, a blower station supplies air to support the aeration process. Then there is a clarifier (with a sensor for measuring sludge content) where the separated biomass can be fed back into the aerobic reactor in automatic mode. The excess activated sludge can be sent to the sludge thickener, like the separated float sludge in the physico-chemical treatment plant. After thickening, the volume of sludge will be reduced by a factor equal to the ratio of the thickened sludge to the concentration of the incoming sludge, on average, 26 g/dm^3: 5.2 g/dm^3 = 5 times [16].

The total sludge produced after wastewater treatment consists of all chemical and biological sludge collected from the bottom of the physical-chemical and biological treatment tanks. Part of the sludge is returned to biological treatment processes, while the excess sludge is sold as biofuel feedstock or taken to the landfill.

The chemical dewatering sludge of industrial wastewater has applicable reuse as a bio-energy resource. Solid biofuels can dry sand and minerals in special drying units in modern production plants and dry mixed feed, grain, and lumber. Furthermore, solid biofuels can be used for steam production, which, like drying, is very energy-intensive [17].

After the aerobic stage, the water is routed by gravity to a secondary clarifier, where the amount of suspended solids is measured [12]. The water that meets the prescribed discharge standards [18] then passes into the city's sewage plants.

Post-treatment of wastewater. The proposed stage is introduced to supply treated water for the plant's production needs (for the moisture-heating treatment of mint, oil treatment with water, aqueous solutions of electrolytes, sodium hydroxide, etc.). The following stages are water clarification; disc filters - due to their design, they do not allow suspended solids more extensive than the microfilter screen clearance; the washed sludge goes to a sludge collector (located in the filter housing), where it can be removed by gravity; the disinfection unit – the destruction of micro-organisms and viruses that cause infectious diseases.

The design technological scheme for wastewater treatment of an oil and fat enterprise brings water standards indicators of discharge into the city sewer, makes it possible to reuse treated water for the production needs of the enterprise, reduces energy and technological losses, operating costs, offers the use of the resulting waste for commercial purposes, ensures safety and reliability this treatment, which ultimately leads to a reduction in the harmful effects on the environment.

CONCLUSION

Thus, due to the technological audit of oil and fat production treatment plants, the most common shortcomings of the existing technological process and disruption of wastewater treatment plants were identified. Recommendations were developed to modernise oil and fat plant treatment facilities to increase efficiency and minimize the possible negative impact on the environment: replacement of equipment containing defects and the addition of a technological scheme with biological treatment and a post-treatment stage for the use of treated water in production. It is suggested that the waste produced to be used for commercial purposes.

REFERENCES

1. P. S. Shapovalova, *Problems and prospects of the fat-and-oil industry and justification of new principles of intra-company planning* (Vestnik Adygejskogo gosudarstvennogo universiteta, Adygeya, 2012).
2. Y. T. Hung and D. Kaya, *Treatment of vegetable oil refining wastes* (Lenox Institute Press, NY, 2020), pp. 5-13.
3. J. L. Lucas and J. M. Chardigny, *Food losses and waste in the French oil crops sector* (EDP Sciences, Paris, 2015).
4. R. C. Mishra and S. B. Srivastava, *Quality and Profitability improvement by Technical Audit* (International Journal of Engineering and Technology, UAE, 2009), pp. 12–17.
5. S. W. Ho, K. K. Cheung and W. C. Fung, *Sustainable wastewater treatment - Ways to achieve energy neutrality* (Transactions Hong Kong Institution of Engineers, Hong Kong, 2014).
6. M. R. Sello, *Wastewater fats oils and grease characterisation, removal and uses. A Review* (Environmental Science Journal, Hyderabad, 2021).
7. S. W. Hasan, *Recent improvements in oily wastewater treatment: Progress, challenges, and future opportunities* (Journal of Environmental Sciences, Beijing, 2015).
8. M. L. Leming and F. D. Reyes, *Mechanisms of Fat, Oil and Grease (FOG) deposit formation in sewer lines* (Journal of the International Water Association (IWA), London, 2013).
9. V. V. Berezutskiy, V.V. Gorbenko and I.A. Mezentseva, *On the possibility of sewage disposal fat-containing occurring on the enterprise's oil industry* (East European Journal of Advanced Technology, Kharkiv, 2012).
10. The Federal classification catalog of waste. Order of Rosprirodnadzor dated 05.22.2017 No. 242 (with amendments of October 4, 2021), URL: https://rpn.gov.ru/fkko/

11. B. S. Ksenofontov, A. S. Kozodaev, R. A. Taranov and M. S. Vinogradov, Purification of Wastewater from a Vegetable Oil Plant from Fats and Suspended Solids Using Reagents, Ecology and Industry of Russia **1816**, **0395,** 2413-6042 (2022).
12. V. I. Lorenz, *Wastewater treatment of food industry enterprises* (Builder, Ukraine, 1972), pp. 31–36.
13. A. O. Bystranova, S. Yu. Teplykh and E. A. Teplykh, *Cleaning of oil-containing wastewater* (Urban planning and architecture, Samara, 2018), pp. 24–28.
14. V. I. Kichigin, *Modeling of water purification processes* (ASVa, Moscow, 2017), pp. 357–361.
15. A. N. Basamykina, E. V. Kurkina and M. A. Kameristaya, Applicability of biological wastewater treatment for various industries, IOP Conf. Series: Earth and Environmental Science, **941,** 012001 (2021).
16. P. C. Osorio and P. A. Avila, *Comparison of Biodegradation of Fats and Oils by Activated Sludge on Experimental and Real Scales* (MDPI, Basel, 2019), pp. 2–7.
17. M. S. Jami, *Problems, Control, and Treatment of Fat, Oil, and Grease (FOG): A Review* (Journal of Oleo Science, Nagasaki, 2014).
18. Resolution of the Government of the Russian Federation of 07.29.2013 No. 644 "On approval of the Rules of cold water supply and sanitation and on Amendments to Certain Acts of the Government of the Russian Federation" Appendix No. 5 to the Rules of cold water supply and sanitation, URL: http://www.consultant.ru/document/cons_doc_LAW_150474/d4c6cb4e5630ac0fbc8c7ff7aba49e22c1cca718/