The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2025

Volume 33, Pages 148-154

IConTech 2025: International Conference on Technology

Classification of Industrial Wastewater Generated by Food and Beverage Industry

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Abstract: A classification of wastewater generated by food and beverage industry based on their various indicators: temperature, level of impurities, type of impurities, acidity, cyclicality of generation was made. Samples of industrial wastewater, taken immediately upon their receipt, were studied. Physical parameters - density, dynamic viscosity, content of non-volatile impurities, electrical conductivity, acidity and optical transmission of different types of wastewaters from canning, dairy, meat processing, brewing and aromatic industries in temperature range between 25 and 80 °C were obtained. The possibilities for recycling industrial wastewater using mechanical vapour recompression method are commented on. It has been found that a large part of industrial wastewater generated from food and beverage industry is suitable for recycling by mechanical vapour recompression method at low energy costs due to its high temperature and low content of dry organic matter. The resulting recycled water has the physical characteristics of pure distilled water.

Keywords: Wastewater treatment, Mechanical vapour recompression, Food and beverage industry

Introduction

Overview

Food industry enterprises use large amounts of fresh water in their production processes. These businesses have high energy costs associated with transporting and treating fresh water. At the same time, these same enterprises are generators of large amounts of wastewater, and they have to pay high costs for treatment and disposal. The separation of large quantities of wastewater in a given production means high costs for purification and landfilling. If wastewater has a high outlet temperature, it means that enterprise loses energy in form of heat, and this leads to increased production costs. The transition from an open to a closed water cycle of water use in production process is the main goal of energy managers in enterprises: in addition to reducing energy costs in the production process, the goals of a circular economy are also achieved (Stoyanova, 2011; Tabakov, 2004; Valchev & Nenov, 2014). The main methods for water treatment are as follows:

- mechanical methods: precipitation, separation of solid suspended particles with centrifuges andhydrocyclones, filtering (retain finely dispersed pollutants substances);
- physicochemical methods: coagulation and flocculation, flotation, sorption, ionic exchange, extraction, evaporation, evaporation, crystallization, electrolysis, membrane processes (electrodialysis, reverse osmosis, ultrafiltration) (Gertsen & Sonderby, 2009; Smith, 2005; Shrivastava et al., 2022; Semerdzhieva et al., 2024 Rilling, 2012; Ramalho, 1977).

Wastewater treatment using mechanical vapour recompression (MVR) heat pump system is method, which is applied to extraction of volatile organic pollutants from some wastewater - ammonia, phenols, anilines, amines

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

and others. The method consists in heating and boiling wastewater and as a result separation from impurities according to their different volatility (Russel, 2006; Ng, 2006). The wastewater generated by enterprises in food and beverage industry is characterized by different temperature, dynamic viscosity, level and type of impurities, electrical conductivity, acidity, optical transmission and cyclicality of generation. The values of parameters are discussed above determine possibility of wastewater treatment using method of mechanical vapour recompression.

Studying Indicators of Wastewater

Temperature of Wastewater

This parameter is important for energy characteristics of MVR heat pump system. In addition, temperatures of wastewater and used fresh water determine efficiency of recycling process according to proposed method. Certain technological operations in enterprises (e.g. rinsing, hydrotransport, washing with fresh water, etc.) using fresh water at ambient temperature and generated wastewater is at the same temperature levels. In others (e.g. cooling) consumed cold fresh water is heated to temperatures higher than ambient temperature, and in others (e.g. washing with hot water) used hot fresh water is also discarded as hot wastewater (Waldron, 2007). According to temperature wastewater can be classified into the following groups:

Group A1 – cold wastewater with ambient temperature (in range of 10-30°C).
Group A2 – warm wastewater with temperatures higher than ambient temperature (in range of 30-50°C).
Group A3 – hot wastewater with temperature up to 100 °C. The upper limit of this interval is determined by the fact that wastewater disposal is carried out in the environment at atmospheric pressure (in range 50-95°C).

Level of Impurities in Wastewater

The wastewater generated by enterprises in food and beverage industry are characterized by varying degrees of pollution. It could be expressed through different indicators- biologically required oxygen (BOD), chemically required oxygen (COD), content of dissolved or total dissolved and undissolved non-volatile impurities. For the purpose of the present study, most appropriate indicator of evaluation is total content of non-volatile impurities. The low content of non-volatile substances, as a rule, leads to a higher degree of regeneration of wastewater (Ghimpusan et al., 2017; Syed, 2006; Valchev et al., 2016). According to level of impurities wastewater can be classified into the following groups:

Group B1 – low-polluted wastewater with a content of non-volatile impurities up to 200 mg/dm^3;
Group B2 – moderately polluted wastewater with a content of non-volatile impurities from 200 to 600 mg/dm^3;
Group B3 – highly polluted wastewater with a content of non-volatile impurities over 600 mg/dm^3;

Type of Impurities in Wastewater

It is established that industrial wastewater, contains impurities of various origins (inorganic, vegetable, animal, chemical), chemical and physical composition and structural-mechanical properties. The type of impurities contained in a given wastewater determine properties related to boiling process in MVR heat pump system-density, dynamic and kinematic viscosity, surface tension, coefficient of thermal conductivity, specific heat capacity, physico-chemical temperature depression, etc. This properties determine intensity of heat exchange, the dynamics of scale formation on heat exchanger surfaces and the intensity of microorganism development in water (Muller & Marechal, 2008). According to type of impurities wastewater can be classified into the following groups:

Group C1 – volatile impurities. This includes water soluble and insoluble liquids (organic acids, etc.) with boiling temperatures lower than boiling temperature of distilled water at the same pressure and dissolved gases (air, ammonia, amines, decomposition products, etc.). When wastewater is boiled, impurities will be released together with evaporated water.

Group C2 – non-volatile impurities of inorganic natural origin. Water soluble and insoluble mineral particles such as soil, grains of sand, dust, salt, etc. are included here. They are characterized by great stability during storage and heat treatment, such as the evaporation process - lack of thermal decomposition and release of gases, reduced scale formation. Some of them can be separated from the water only by filtering. When wastewater is boiled, impurities will be completely released with concentrated sludge.

Group C3 – non-volatile impurities of organic plant origin. This includes insoluble dry matter in the form of macro particles such as fruit residues (pulp, seeds, bark), seeds, flowers, leaves, straws, roots, etc., residues of their derivatives (yeast, wort), paper particles, insoluble liquids such as vegetable fats, dissolved solids such as sugars (sucrose, glucose, fructose), starch, etc. Insoluble solids can be separated from wastewater by filtration. Chemically, these impurities are mainly carbohydrates - cellulose, fats, sugars, etc. As such, they are characterized by instability during longer storage and heat treatment. Processes of intensive development of microorganisms occur, leading to decomposition and release of gases, formation of scales, crystallization is observed.

Group C4 – non-volatile impurities of organic animal origin. Insoluble macro particles such as remains of animal tissues (muscles, skin, tendons, fur, feathers), bone particles, blood, fat, etc. are counted here. This type of impurities is characterized by a high content of proteins and fats. Macro particles can be separated from wastewater by filtration. Impurities from this subgroup are also characterized by instability during storage and heat treatment - intensive development of microorganisms with decomposition and release of gases, formation of scales, denaturation, saponification, etc.

Group C5 – non-volatile chemical impurities. Impurities such as bases (sodium, potassium), acids (nitric, citric), washing detergents, synthetic food additives and flavorings - dyes, preservatives, emulsifiers, anti-corrosion and oxygen-reducing inhibitors are included here. These impurities are relatively stable during storage and heat treatment.

Acidity of Wastewater

This indicator is directly related to composition of the impurities. Acidity of wastewater determines appropriate choice of construction materials and seals for equipment used in MVR heat pump system (Gurd et al., 2019; Valchev, 2014). According to acidity wastewater can be classified into the following groups:

Group D1 – neutral wastewater with an active pH value in range 6.5 – 7.5. They are obtained in absence of contact with fresh water with acidity-correcting substances. This wastewater is not aggressive compared to standard corrosion-resistant stainless-steel brands.

Group D2 – alkaline wastewater with a value of active reaction pH above 7.5. The presence of dissolved bases in wastewater is obtained (for example, from cleaning equipment). They are not aggressive to standard corrosion-resistant brands of stainless-steel brands.

Group D3 – acidic wastewater with a value of active reaction pH below 6.5. Acids dissolved in wastewater are present (for example, from cleaning equipment, from technological processes) and some of them are aggressive towards standard corrosion-resistant stainless-steel brands.

Cyclicality of Wastewater Generation

Observations on operating technological processes show that wastewater is released according to a different time schedule. This feature provides various possibilities of processing these waters within a day-simultaneously with their separation, with accumulation and processing through low electricity cost at night period, accumulation of clean condensate, etc. With this, cyclicality of wastewater separation affects energy costs incurred for their processing by MVR method (Brenan, 2006; Liang et al., 2013). According to cyclicality of wastewater generation wastewater can be classified into the following groups:

Group E1 – continuously generated wastewater. They are obtained from continuously operating technological processes and operations (evaporation, hydro transport, washing). Wastewater is characterized by a relatively constant mass flow over time for the entire working period of the enterprise.

Group E2 – periodically generated wastewater. They are obtained in periodic technological processes and operations (washing, rinsing). A certain mass flow of wastewater is released for a relatively short period compared to the entire working period of the enterprise.

Method

Samples of wastewater from various technological operations in production of: canned vegetables, beer, mayonnaise, baby food, oil, aromatic products, dairy products, meat preparations, were examined. A list of industrial wastewater samples studied is shown in Table 1. The density was determined by the weight method. A Gay-Lussac pycnometer with a capacity of 50 cm^3, vessel with heater and thermostat VEB MLW Labortechnik Ilmenau/ GDR type MLW-WB2, Ne = 250 W, 220 V was used. The mass of wastewater was measured using an electronic balance KERN – PCB 250-3 with a maximum working range of 250 g. Dynamic viscosity was measured according to Höpler method using a viscometer with a falling ball type BH2. Electrical conductivity was measured using a WTW Inolab COND7110 Tetracon 325 sensor. pH was measured using a pH meter WTW INOLAB pH7110 pH electrode WTW SenTix 6L, pH 0-14 (0-100 ºC) 3 kmol/l KCl. Optical transmission was measured using a Lovibond PFX880 V10 instrument.

Table 1. Studying industrial wastewater samples

Designation	Type
Sample 1	Wastewater from washing cucumbers /cold, fresh water/
Sample 2	Wastewater from washing pepper /cold, fresh water/
Sample 3	Wastewater from receiving tubs with pepper for transport and initial washing /cold, barometric water from evaporation system/
Sample 4	Wastewater from mayonnaise production /contains warm fresh water and degreaser/
Sample 5	Wastewater from rinsing PET bottles /contains 25-30 ppm peracetic acid and negligible impurities from expanded bottles/
Sample 6	Wastewater from poultry slaughterhouse /mix of wastewater for washing waterfowl birds with cold water 18 - 20 ºC and washing equipment, floors, walls and alkaline warm water 60 ºC, pH 13, wastewater contains fats, household waste, grit/
Sample 7	Wastewater from production of baby food (puree) /clean water 75 ºC with 2% nitric acid, temperature 68 ºC/
Sample 8	Wastewater from first step of "cleaning in place" (CIP) system in canning factory /pure water with 2% NaOH, temperature 87 ºC/
Sample 9	Wastewater from saponification of free fatty acids with NaOH (23%) in extraction unit / temperature about 80 ºC, wastewater contains soap, unreacted NaOH and organics.

Density and dynamic viscosity of wastewater were studied as a function of wastewater temperature. For this purpose, a classic one-factor experiment was used. All parameters were measured three times, and the obtained results are presented as an arithmetic mean value. In addition, the obtained values were evaluated statistically by determining variance and root mean square deviation of average result, as well as confidence error and dependence interval (Raichkov, 2001):

For mean score variance $S^2(\overline{x})$:

$$S^2(\overline{x}) = \frac{1}{m.(m-1)} \sum_{i=1}^{m} (x_i - \overline{x})^2$$

For root means square deviation of the mean score S $(\overline{x})$:

$$S(\overline{x}) = \sqrt{S^2}\,(\overline{x})$$

For confidence error ε $(\overline{x})$:

$$\varepsilon(\overline{x}) = t(p, m-1).S(\overline{x})$$

where t (p, m-1) is Student's criterion for accepted confidence probability p=0.95 and number of repeated measurements m - 1 = 2. A value of t (0.95, 2) = 4.303 is reported.
For confidence interval:

$$x = \overline{x} \pm \varepsilon(\overline{x})$$

Results

Wastewater density was studied for wastewater in its natural form as a function of temperature in range 25 °-80 °C. The temperature factor variation levels are four and include values 25 °C, 40 °C, 60 °C and 80 °C. The results of measurements are presented in Table 2.

Table 2. Density of wastewater depending on temperature

Designation	Density at 25°C, kg/m^3	Density at 40°C, kg/m^3	Density at 60°C, kg/m^3	Density at 80°C, kg/m^3
Sample 1	998.5±1.1	994.0±1.1	983.7±0.8	973.3±0.9
Sample 2	998.5±0.9	994.2±1.0	984.9±0.9	971.9±1.0
Sample 3	998.2±1.9	994.2±0.7	984.7±1.5	973.1±1.4
Sample 4	1003.3±1.0	998.4±1.8	985.3±1.8	977.4±0.9
Sample 5	998.8±1.1	994.9±1.4	986.5±1.5	976.5±1.4
Sample 6	999.5±0.8	994.5±0.9	983.7±1.8	973.3±1.1
Sample 7	998.3±0.8	997.6±0.5	982.3±0.6	978.3±0.9
Sample 8	998.1±1.5	991.5±1.1	984.1±0.9	972.1±0.5
Sample 9	1005.1±1.4	1001.5±1.1	990.7±1.0	981.8±1.5
Distilled water	998.1	993.3	984.3	972.8

Wastewater dynamic viscosity was studied for wastewater in its natural form as a function of temperature in range 25 - 60 °C. The temperature factor variation levels are three and include values 25 °C, 40 °C, 60°C. The results of the measurements are presented in Table 3.

Table 3. Dynamic viscosity of wastewater depending on temperature

Designation	Dynamic viscosity at 25°C, cP	Dynamic viscosity at 40°C, cP	Dynamic viscosity at 60°C, cP
Sample 1	0.929±0.028	0.835±0.025	0.837±0.019
Sample 2	0.883±0.027	0.801±0.018	0.743±0.033
Sample 3	0.929±0.027	0.759±0.033	0.684±0.012
Sample 4	6.811±0.178	4.317±0.201	3.466±0.163
Sample 5	0.891±0.031	0.797±0.019	0.746±0.028
Sample 6	0.866±0.039	0.730±0.033	0.650±0.033
Sample 7	1.256±0.028	1.095±0.038	0.901±0.088
Sample 8	1.234±0.035	1.108±0.098	0.944±0.045
Sample 9	1.971±0.099	0.923±0.065	0.740±0.042
Distilled water	0.879	0.671	0.616

Electrical conductivity, active reaction and optical transmission of wastewater were investigated in natural form. The results of the measurements are presented in Table 4.

Table 4. Electrical conductivity, active reaction and optical transmission of wastewater

Designation	Electrical conducti-vity, µS/ cm^2	Active reaction (pH)	Optical transmission %
Sample 1	962.0±12.6	6.81±0.01	34.98±0.95
Sample 2	779.3±11.5	7.50±0.03	-
Sample 3	888.0±20.3	7.44±0.02	54.95±1.26
Sample 4	10.6±0.3	4.61±0.02	0.00±0.0
Sample 5	56.5±0.8	5.86±0.02	43.74±0.53
Sample 6	1128.3±22.9	6.68±0.03	13.33±0.22
Sample 7	-	4.24±0.00	-
Sample 8	-	12.67±0.06	-
Sample 9	-	12.46±0.04	-
Distilled water	3.0±0.2	-	-
Fresh water	622.0±12.4	-	-

The investigated wastewater samples, distributed by groups, are presented in Table 5.

Table 5. Classification of industrial wastewater by groups

Designation	Tempe-rature, °C	Content of non-volatile impurities mg/dm^3	Cyclicality of wastewater generation	Group A	Group B	Group C	Group D	Group E
Sample 1	15 °C	0-200	continuously	A1	B1	C1	D1	E1
Sample 2	15 °C	0-200	continuously	A1	B1	C3	D1	E1
Sample 3	29 °C	0-200	continuously	A1	B1	C5	D1	E1
Sample 4	45 °C	>600	periodically	A2	B3	C5	D3	E2
Sample 5	42 °C	200-600	periodically	A2	B2	C5	D3	E2
Sample 6	43 °C	200-600	periodically	A2	B2	C4	D1	E2
Sample 7	75 °C	>600	periodically	A3	B3	C5	D3	E2
Sample 8	87 °C	>600	periodically	A3	B3	C5	D2	E2
Sample 9	80 °C	>600	periodically	A3	B3	C5	D2	E2

Conclusion

The obtained values for density and dynamic viscosity of wastewater show that for majority of samples values are higher than values of density and dynamic viscosity of distilled water for corresponding temperature. In general, due to low concentration of total dry matter in wastewater, these values are close to density and dynamic viscosity values of distilled water. Electrical conductivity values show that one group of wastewater has conductivity values close to the value of fresh water. Another group has an electrical conductivity value lower and third group has an electrical conductivity value higher than value of fresh water. than that of the drinking water due to the presence of organic substances in them. High values of electrical conductivity are dilated on presence of dissolved electrolytes - salts, acids and bases. Regarding to active reaction values, wastewater is divided into three groups – neutral (pH=7.0), with an acidic reaction (pH<7.0) and with a basic reaction (pH>7.0). Optical transmission values show that for wastewater with low dry matter concentration, optical transmittance values are high and vice versa. A classification system for industrial wastewater generated by enterprises of food and beverage industry in connection with their possibilities for recycling by evaporation method was created. On the basis, it can be concluded that a greater part of wastewater can be effectively purified and recycled with MVR heat pumps due to low values of dry matter in wastewater and close values of their thermophysical characteristics to values of distilled water.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

Funding

* This study received no external funding.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology (www.icontechno.net) held in Trabzon/Türkiye on May 01-04, 2025.

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To cite this article:

Valchev, S., & Nenov, N. (2025). Classification of industrial wastewater generated by food and beverage industry. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 33,* 148-154.