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LIFE CYCLE ASSESSMENT OF WASTEWATER FROM DAIRY INDUSTRY

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Abstract. *In this study, life cycle assessment (LCA) was used to investigated the environmental impacts associated with dairy wastewater treatment. The composition of dairy wastewater was investigated by applying various water quality methods. Indicators like pH, suspension, chemical oxygen demand (COD), biochemical oxygen demand (BOD), extractable substances, detergents, sulfates (SO_4^{2-}), nitrates (NO_3^-), nitrites (NO_2^-), N, P and others were determined. Also, the composition of treated water, at the exit of the treatment plant, was established. Monitoring of the effluent composition was performed for three years, the determinations being performed every month in triplicate. For the environmental inventory analysis, the average of the values obtained for quality indicators in 2015 was considered, the year in which the highest values for the quality indicators were registered. GaBi software was used for the environmental impact calculation. Results showed that treatment of dairy wastewater influences mostly the eutrophication potential. Other impact categories are mainly influenced by electricity production for consumption in the wastewater treatment process. It was observed that acidification potential has the highest value, followed by the global warming potential, the photochemical ozone formation potential, and human toxicity potential, respectively.*

Keywords: dairy, environmental impacts, life cycle, milk

1. Introduction

Dairy industry includes various processes, from raw milk pasteurization to production of different food products based on raw milk transformation (yoghurt, cheese, cream, butter, and various dessert types) [1, 2]. Annually, approximately 850 million tons of raw milk are produced globally [3], while, for example, in the EU in 2019, 158.2 million tons were produced, of which 1.122 million tons in Romania [4]. In milk processing, water is used in every step included in the technological process, and considerable water volumes are consumed in washing operations [5, 6]. It is estimated that for every liter of processed milk, between one and five liters of wastewater are generated [7]. But, other authors [8] have reported that for one liter of processed milk, between 0.2 and 10 L of wastewater are generated. The waters resulting from the dairy industry are characterized by a high content of organic matter, nutrient and extreme pH variations, and if these waters are not treated properly, serious environmental issues can occur [1, 9]. The discharge of this wastewater, without proper treatment or without being treated would lead to rapid depletion of dissolved oxygen from water bodies, due to high organic load leading to the destruction of aquatic life and environmental damage [1]. The environmental impacts associated with wastewater treatment can be determined by applying life cycle assessment (LCA). Widely used in the field of wastewater treatment [10, 11], this tool could provide useful information for: improvement of the wastewater plant operation, comparison of different alternative systems, development

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of new technologies or nutrient recycling [12 -14]. There are some recent studies based on assessment of dairy effluents from environmental point of view, for example: Stanchev et al. [6] evaluated the environmental performance of anaerobic treatment of dairy effluents; Elginoz et al. [15] investigated the environmental impacts associated with production of volatile fatty acids from dairy wastewater; Queiroz et al. [16] determined the environmental impacts associated with application of aquatic macrophytes for phytoremediation of dairy effluents.
The aim of this study was to investigate the environmental impacts associated with treatment of wastewater generated from a dairy factory in Romania.

2. Case study

The wastewater treatment plant, considered in this study, includes the following stages (Fig. 1): particle separation, standardization, flocculation and coagulation, primary and secondary decantation, biological phase, flotation and sludge collection. The dairy effluents composition is determined at the entrance to the station and at the exit. Wastewater quality indicators, maximum permitted concentrations according to [17] and analysis methods used in this study are presented in Table 1.

3. LCA methodology

3.1. Goal, system boundaries, functional unit

The goal of this study was to determine the environmental impacts of wastewater from dairy industry by applying LCA methodology, in accordance with [18, 19].
The specific objectives of this study are:
- performing an inventory analysis on the use of materials and resource consumption with wastewater treatment;
- identification of the environmental impacts of the researched system.

System boundaries: in general, in LCA studies the construction, operation and demolition phases are within the system limit, but this study is limited only to the operation phase.

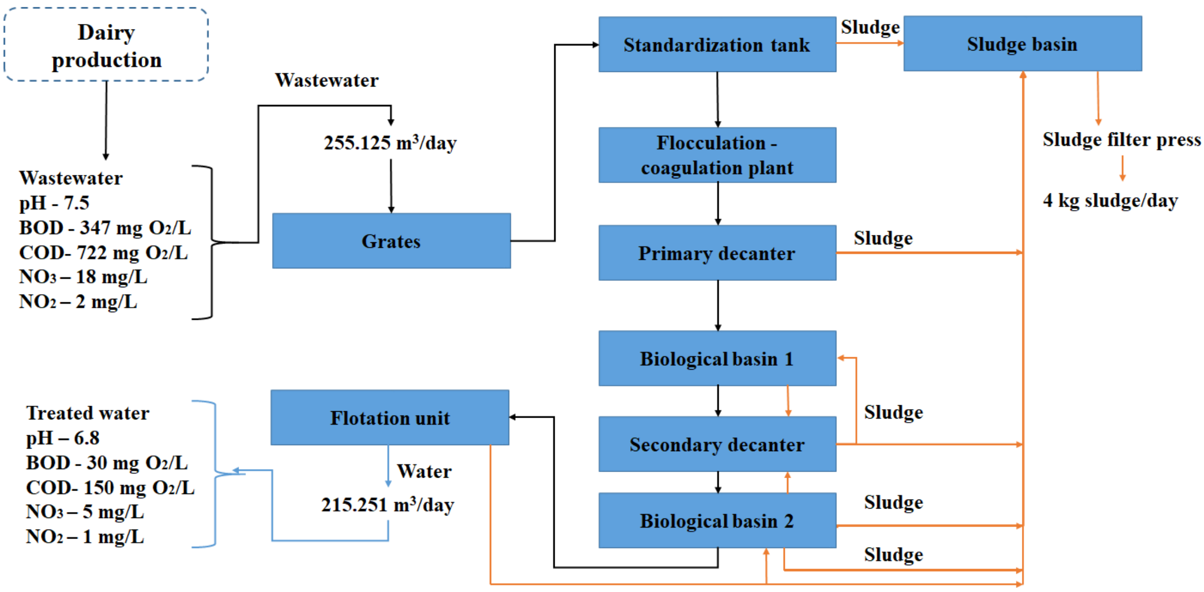


Fig. 1. The flow diagram of treatment processes

Table 1.

Wastewater quality indicators and analysis methods

No.	Quality indicators	Allowed values [17]	Methods of analysis used in this study
1	pH (pH unit)	6.5-8.5	SR ISO 10523: 2012. Water quality. Determination of pH
2	Suspension (mg/L)	60	SR EN 872: 2005 Water quality. Determination of suspended solids content. Filtration method on fiberglass filters
3	Chemical oxygen demand COD (mg O_2/L)	125	IS015705: 2002 (E). Water quality. Determination of chemical oxygen consumption
4	Biochemical oxygen demand BOD (mg O_2/L)	25	SR EN 1899-2 / 2002. Determination of biochemical oxygen consumption after n days (BODn). Part 2: Method for undiluted samples
5	Extractable substances (mg/L)	20	Method 1664 B. Determination of extractable substances
6	Detergents (mg/L)	0.5	SR EN 903/2003. Water quality. Determination of anionic surfactants by measuring the methylene blue index MBAS
7	Sulfates (SO_4^{2-}) (mg/L)	600	STAS 8601-70. Surface water and wastewater. Determination of sulfates
8	Ammonium (NH_4^+) (mg/L)	2	SR ISO 11905. Water quality. Determination of nitrogen
9	Total phosphorus (P) (mg/L)	2	SR EN ISO 6878/2005. Water quality. Determination of phosphorus. Ammonium molybdate spectrometric method.
10	Total nitrogen (N) (mg/L)	10	SR ISO 11905. Water quality. Determination of nitrogen
11	Filtered residue (mg/L)	2000	STAS 9187/84. Surface water, groundwater. Residue determination
12	Nitrates (NO_3^-) (mg/L)	25	SR ISO 7890-3 / 2000. Water quality. Determination of nitrate content. Sulfosalicylic acid spectrometric method
13	Nitrites (NO_2^-) (mg/L)	1	SR ISO 11905. Water quality. Determination of nitrogen
14	Chlorides (Cl^-)	500	STAS 8663-70. Surface water and wastewater. Determination of chlorides

The functional unit of the study allows the reporting of all data collected in the inventory phase and is the basis for comparison for the wastewater treatment systems. The functional unit adopted in this study is the volume of treated wastewater (m^3) in a day in the treatment plant (Fig. 1).

3.2. Inventory analysis

The volume of water entering in the treatment plant is represented by a minimum volume of 191.357 m^3/day and a maximum of 287.193 m^3/day. There is an installation for measuring the flows of treated water discharged into the emissary. The water norm for the main products of manufacture is for 1000 L milk/day. From Fig. 2a, which presents the volume of wastewater discharged from a dairy plant in the period 2015-2017, it can be observed that the volume decreased over time due to the fact that the largest amount of wastewater was recirculated.

In Fig. 2b is illustrated the variation over time of the filterable residue amount per L of wastewater discharged from the dairy plant considered in this study. It can be seen that the values have increased over time.

In accordance with [17] on the setting of pollutant loading limits for wastewater discharges to natural receptors, the indicators followed largely fall within these limits.

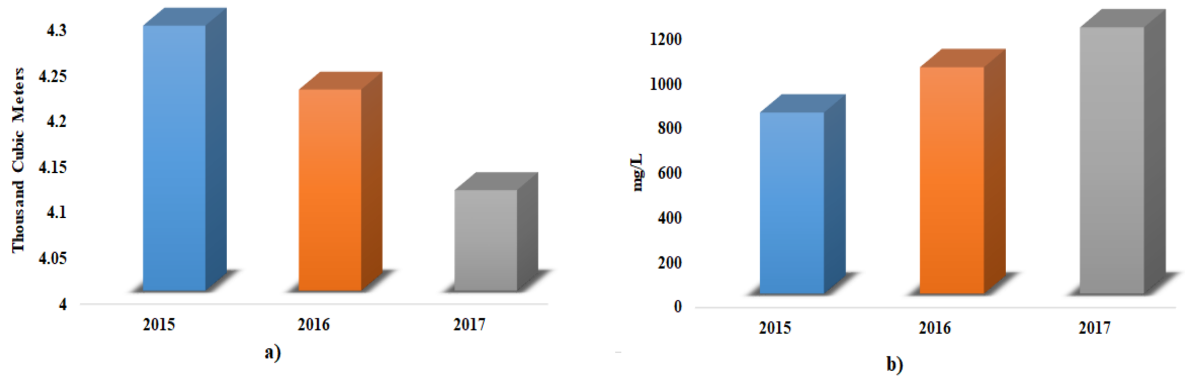


Fig. 2. a) Volume of wastewater discharged (thousand m^3) from dairy industry; b) filterable residue indicator (mg/L)

The values of the BOD/COD ratio assigned for the wastewater at the station exit during 2015-2017 indicate the presence of easily biodegradable organic substances.

According to Fig. 3a COD values are higher and a decrease of them is observed over time. Exceptions are ammonium and sulfates, which exceed the maximum permitted concentrations in 2015 (Fig. 3b). Also, an exception are extractable substances, phosphorus and detergents, which have exceeded the maximum permitted concentrations in 2015 (Fig. 3c). From Fig. 3b it can be seen that the values decreased over time for the indicators NH_4^+, N and SO_4^{2-}, while for chlorides there was a lower value in 2016 compared to 2015, after which there was again an increase in the concentration of chlorides emitted in 2017.

From Fig. 3c it can be seen that there has been a decrease in concentration over time for the following quality indicators: extractable substances, phosphorus, detergents, while for indicators NO_3^- and NO_2^- there is a decrease in emitted concentrations recorded in 2016, followed by an increase in 2017.

The values of the indicators determined after collecting and analyzing the samples from the water body, in which the treated wastewater was discharged, are illustrated in Fig. 4.

From Fig. 4a it can be observed that the values of the COD indicator decreased in 2016 and 2017, compared to the increase registered in 2015. From Fig. 4b it can be seen that the values of the indicators followed are within the allowed values. From Fig. 4c it can be seen that the values of the NO_3^- indicator increase in 2015 and decrease in the following years.

The energy consumption of the treatment plant is 450 kWh/month, 5400 kWh/year. The treatment plant also uses 40 kg $FeCl_3$/year, 80 kg polyelectrolyte /year, 36 kg NaOH/KOH/year, 36 kg HNO_3/year, 24 kg H_3PO_4/year, 36 kg H_2O_2/year, 48 kg polymers/year. The amount of sludge produced is 1500 kg/year.

There are also produced 200 kg/year of plastic and cardboard packaging and 50 kg glass waste /year, solid waste 3 m^3/month, sand 80 kg/month, grease 40 kg/month.

The sludge from the treatment plant is dehydrated and temporarily stored in the transport container, until it is picked up by authorized operators. It can be used in agriculture, land improvement, wet oxidation and gasification.

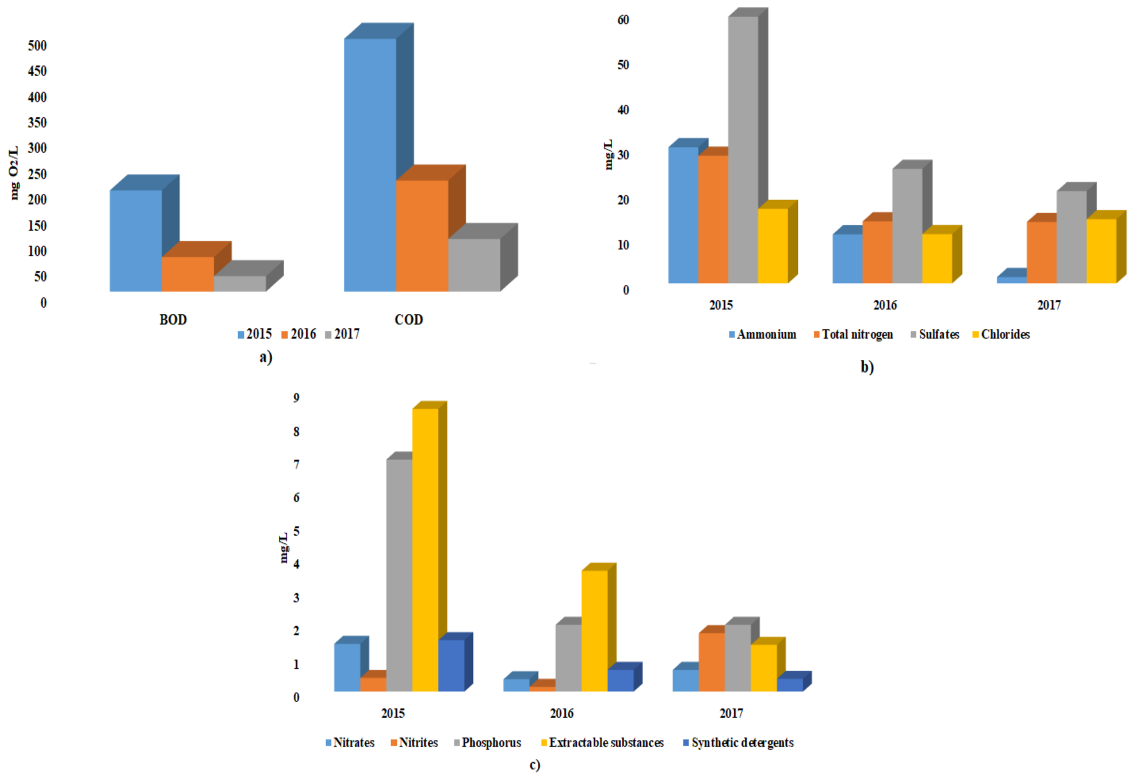


Fig. 3. Quality indicators of wastewater from a dairy factory between 2015-2017: a) biochemical oxygen demand (BOD) and chemical oxygen demand (COD); b) ammonium (NH_4^+), total nitrogen (N), sulfates (SO_4^{2-}), chlorides (Cl^-); c) nitrates (NO_3^-), nitrites (NO_2^-), phosphorus (P), extractable substances, synthetic detergents

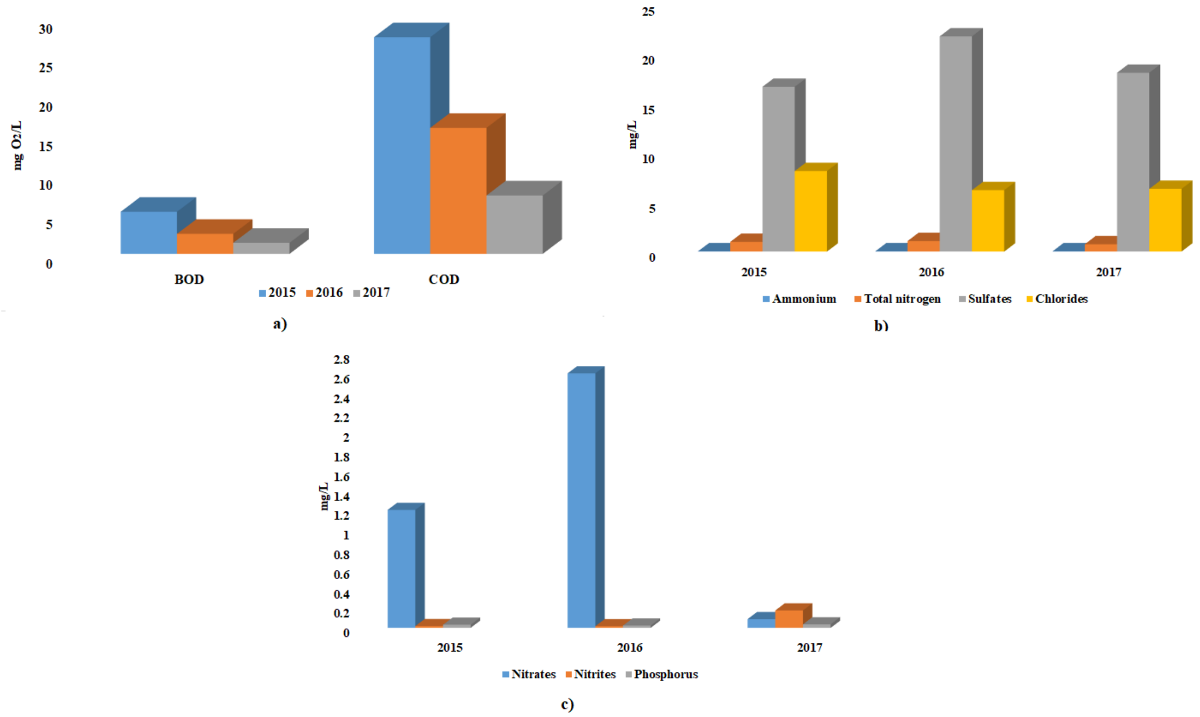


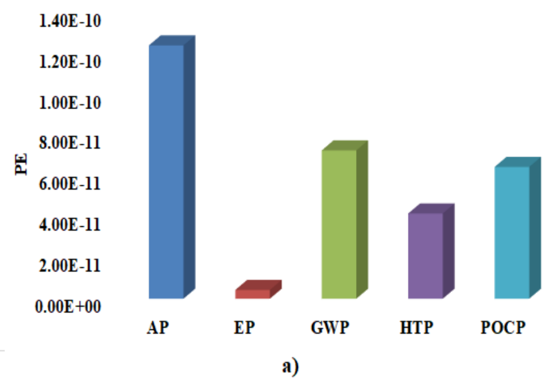
Fig. 4. Quality indicators values of the water collected from the water body in which the treated water is discharged: a) biochemical oxygen demand (BOD) and chemical oxygen demand (COD); b) ammonium (NH_4^+), total nitrogen (N), sulfates (SO_4^{2-}), chlorides (Cl^-); c) nitrates (NO_3^-), nitrites (NO_2^-), phosphorus (P)

3.3. *Life cycle impact assessment, results and discussion*

GaBi software was used to obtain the environmental impacts of wastewater treatment plant. CML 2001-2016 and EDIP 2003 methods were selected for the assessment. The limits of the system have a major influence on the results of life cycle assessment studies. If the impact values obtained are positive, this mean a negative impact on the environment. Fig. 5 show values for all impact categories due to electricity consumption, especially.

The process itself influences the eutrophication potential the most and the other impact categories the least. From Fig. 5 it can be seen that the acidification potential has the highest value, followed by the global warming potential, the photochemical ozone formation potential, and human toxicity potential, respectively. It can be observed that the lowest value was obtained for the eutrophication potential. Results showed that the values obtained for the potential eutrophication impact category are negative for the stages of primary settling, secondary settling, flotation and biological stage (-1.24E-05 kg PO_4^{3-}eq.; -9.26E-06 kg PO_4^{3-}eq.; -6.73E-06 kg PO_4^{3-}eq.; -1.21E-05 kg PO_4^{3-}eq.) which means environmental savings. Instead, for the mechanical stage the value is positive which means negative impact on the environment. The wastewater treatment plant from a dairy plant is designed to reduce the impact on the environment. By implementing all the measures imposed by environmental protection programs and by adopting the most modern technologies, the impact on the environment will be insignificant.

An impact on the environment could be possible due to accidental discharges of pollutants into natural receptors due to improper operation of the biological wastewater treatment stage, but this would only happen in the event of a malfunction. From the specific results on the impact obtained with the help of GaBi software, it can be said that the process itself influences the eutrophication potential the most and the other impact categories the least. The use of wastewater instead of drinking water for non-potable industrial use should be improved in the treatment system. Wastewater can be reused after the application of a tertiary treatment consisting of several stages, including reverse osmosis [20].



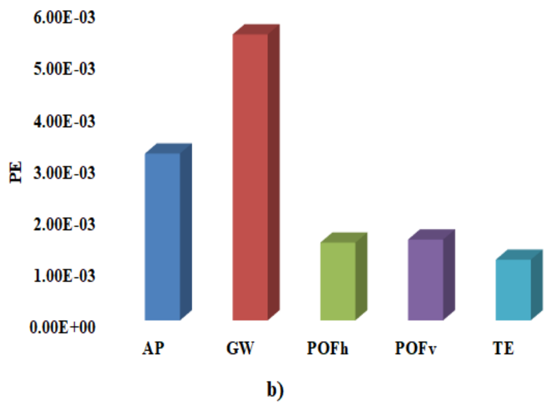


Fig. 5. Normalized values of environmental impacts obtained by applying: a) CML2001-2016 (AP - acidification potential, EP - eutrophication potential, GWP - global warming potential, HTP - human toxicity potential, POCP - photochemical ozone formation potential, PE - persons equiv.) and b) EDIP 2003 (AP- acidification potential, GW- global warming, POFh - photochemical ozone formation-impact on human and material health, POFv - photochemical ozone formation - impact on vegetation, TE - terrestrial eutrophication) methods

Another improvement to the treatment system would be the recognition of sludge as a resource and not as waste. Using sludge as a source of energy and resource recovery is a good alternative for its management, given the requirements of legislation and the principles of the circular economy. Recognition of sludge as a resource, not as waste, has led researchers to consider recovering valuable components from sludge, such as carbon and nutrients. A sustainable solution can be energy production from wastewater sludge [21].

4. Conclusions

Life cycle assessment has proved to be a useful tool that can be used to assess the environmental impact of wastewater treatment systems. The composition of wastewater from a dairy factory is quite complex, as it contains milk residues, dairy products, by-products, detergents and other components. Due to mechanical, chemical and biological processes, wastewater will be treated in a percentage of over 80%. The biological methods used to treat wastewater are the most effective and economical for removing organic substances. In accordance with [17] on the setting of pollutant loading limits for wastewater discharges into natural receptors, the indicators pursued largely fall within these limits.

Given the entire life cycle of wastewater treatment systems and the relative contribution of each phase, inventory analyzes were carried out on the use of materials, resource consumption and the impact on the environment associated with wastewater treatment. After environmental impact evaluation, it can be concluded that some environmental savings are performed due to the fact that the values for the potential eutrophication impact category are negative for the primary settling, secondary settling, flotation and biological stage stages. According to the results obtained, energy is the main contributor to the impact categories of abiotic depletion and global warming. The results indicated that the process itself mainly influences the eutrophication potential.

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