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An overview of wastewater treatment from the milk and dairy industry–case study of Central Serbia

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ABSTRACT

In order to preserve the environment, water consumption in dairies must be minimized and wastewater should be treated before discharging it into water recipients. The purpose of this paper is to provide a definition for water consumption centres and to derive a general equation for determining the specific water consumption at the monthly level specific water consumption (SWC), as well as to present the current state of water treatment of dairy wastewater on the territory of central Serbia. The results of the study on the tested sample of 40 dairies show that the average specific water consumption (SWC_A) at the monthly level–amounts to 3.47 m^3/m^3 of the treated milk. Despite the fact that there are laws that regulate emissions of pollutants, the observed emissions from the sample dairies (regardless of whether they have wastewater treatment plants installed or not) are very often up to several times higher than the permitted limit values. The paper also assesses the efficiency of equipment for wastewater treatment used in one of the tested dairies.

Keywords: Dairy; Specific water consumption; Wastewater treatment

1. Introduction

The functioning of any plant in the food industry, including the milk and dairy industry, cannot be imagined without the use of water. In dairies, the water is used for sanitary, processing, and technological purposes (plant washing, steam production, production of hot water, compressor cooling, and production of ice water). The end result of the water use in milk-processing plants is the formation of wastewater, which can in turn also be categorized in the same way [1–3].

In order to fulfil emission limit requirements and to protect the environment, dairies can use the following two techniques: minimizing water consumption and wastewater treatment.

Minimizing water consumption implies optimization of its use or water management. Numerous papers have been published worldwide on this subject. Lee and Okos have shown in Ref. [4] that reducing water consumption, wastewater production, and energy consumption in the food industry all have an economic background. Casani et al. have shown in Ref. [5] that the correct implementation of water reuse in the food industry positively reflects on the reduction of costs and on the environment. Meneses et al. [6] described the current situation and challenges in relation to water recovery and its reuse in the food industry. In Ref. [7], water reuse through the process integration in large-capacity milk processing plants is studied. Prisciandaro et al. [8] analysed the application of water reuse in 'closed systems.' The application of HACCP to the water-reuse in the food industry is explained in Ref. [9]. A case study on water protection for the milk and dairy industry (feasibility, safety, and economic implications of water generated in cleaning systems) is described in Ref. [10].

SWC, as well as SWC_A, depends on a large number of factors, such as the type of production program (production type and production recipe), the equipment maintenance, the age of equipment and the professional skills of employees.

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Table 1 shows the SWC_A values for some dairies in the world.

For the purpose of wastewater treatment, the following methods are available: mechanical or prior (primary) treatment, biological or postsecondary treatment and physical and chemical (tertiary) treatment. When it comes to the milk and dairy industry, there are a number of papers describing the different methods of wastewater treatment [14–16].

Sarkar et al. analysed the possibility of wastewater reuse from dairy industry. The authors investigated how different types of coagulants (organic and inorganic) influence the removal of colour and odours. They concluded that chitosan at very low dosage with Powdered activated charcoal has significant effect as coagulant for the dairy wastewater before membrane processing [17].

Melchiors et al. [18] investigated the use of electroflocculation and the reuse of solid whey in the treatment of wastewater from the milk and dairy industry. The application of oxygen injection in the treatment of wastewater from dairies was investigated by Martin-Rilo et al. [19]. A study was carried out by Deshannavar et al. [20] in which an anaerobic FB reactor with polypropylene rings was used to treat the wastewater of the dairy industry, whereas FF and FB anaerobic reactors were used in Ref. [21] for the same purposes.

Wastewater from the milk and dairy industry has a large variation in pH, COD, BOD_5, TSS, FOG and other parameters [22–24]. Data on the parameters of the wastewater effluents from the dairies, depending on the production program, are shown in Table 2.

2. Material and methods

2.1. Definition of water consumption centres

Based on the research carried out in 2016, there are about 140 active dairies in the Republic of Serbia, but the number of dairies varies depending on the year and even within the same year. About 30 dairies have processing capacities greater than 10 t/d and they purchase about 80%–85% of the total quantity of purchased milk. Small dairies have processing capacities between 3 and 10 t/d and purchase only 15%–20% of the total milk [31]. However, the majority of small dairies purchase less than 5 t/d which represents the economic minimum in the EU.

Based on questionnaire answers from 40 factories for the production of milk and dairy products on the territory of central Serbia, we define water consumption centres (WCC), introduce a general equation for specific water consumption (SWC), determine the average value of specific water consumption for the tested sample (SWC_A) and assess the current status of the treatment of wastewater from the dairy plants.

WCC can be industrial facilities, parts of the companies, equipment groups or individual equipment and any other segment of the company, which either generates a significant amount of wastewater or used large amounts of fresh water. There are several criteria to be considered when determining WCC [32,33]:

- The process or activity that consumes water should have a measurable output.

Table 1
Benchmarking of average specific water consumption, SWC_A, from dairy plants

Country	Water consumption (L water/L processed milk)			Source
	Milk and dairy drinks	Cheese and whey products	Milk powder, cheese and/or dairy drinks	
Sweden	0.98–2.8	2.0–2.5	1.7–4.0	[11]
Denmark	0.6–0.97	1.2–1.7	0.69–1.9	
Finland	1.2–2.9	2.0–3.1	1.4–4.6	
Norway	4.10	2.5–3.8	4.6–6.3	
Poland	0.5–0.75	2.22	1.8–5.3	
Australia	1.05–2.21	0.64–2.9	0.07–2.7	[12]
Canada (total)		1.0–5.0		[13]

Table 2
Composition of milk processing effluents

Product	Parameter					Source
	COD (g/L)	BOD_5 (g/L)	pH (–)	TSS (g/L)	FOG (g/L)	
Mixed dairy	0.5–10.4	0.24–5.9	4–11	0.06–5.80	0.02–1.92	[17,22–26]
Fluid milk	0.95–2.4	0.5–1.3	5–9.5	0.09–0.45	–	[27]
Yoghurt	6.5	–	4.53	–	–	[28]
Cheese	1–63.3	0.59–5	3.38–9.5	0.19–2.5	0.33–2.6	[22,25,26]
Cheese whey	50–102.1	27–60	3.92–6.5	1.27–22.15	0.9–14	[26,29,30]
Hard cheese whey	73.45	9.48	5.8	7.15	0.99	[25]
Soft cheese whey	58.55	26.77	5.35	8.31	0.49	[25]

- Water consumption and/or environmental impact can be directly measured.
- Standard performance indicators can be significant.
- Performance improvement goals can be established.

Fig. 1 shows the WCC of a dairy in Serbia, which produces short-term pasteurized milk.

2.2. Equations defining SWC

The best way to monitor water consumption in any milk processing plant is according to the volume of production, that is, the amount of processed milk in the dairy.

The dependence of water consumption on the amount of processed milk is most often close to linear and can be described as in Eq. (1) [32,33]:

$$E = m \times P + E_0 \quad (1)$$

where E (m^3/month)–is monthly consumption of water in the dairy, m–the slope that defines the dependence of E on P, P (m^3/month)–monthly quantity of processed milk in the dairy

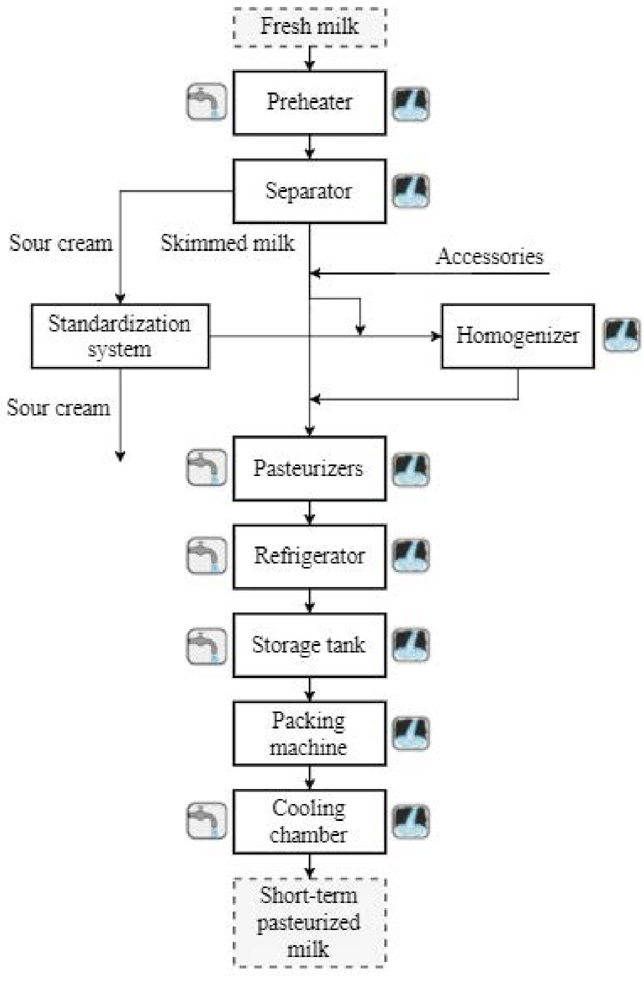

Fig. 1. Technological process of production of short-term pasteurized milk with water use sites and wastewater production.

and E_0 (m^3/month)–monthly consumption of water that does not depend on the amount of processed milk in the dairy.

The SWC (m^3/m^3) for each individual dairy is defined as the ratio of water and the amount of processed milk as in Eq. (2). The average specific water consumption in the territory of central Serbia (SWC_A (m^3/m^3)) for the tested sample of $N = 40$ dairies is determined based on Eq. (3) [32,33]:

$$SWC = m + \frac{E_0}{P} \quad (2)$$

$$SWC_A = \frac{\sum_{J=1}^{N} SWC_J}{N} \quad (3)$$

2.3. Permitted emission limits for pollutants in wastewater from dairies in the Republic of Serbia

The Government of the Republic of Serbia adopted a Decree on emission limit values of pollutants in surface waters and city sewage system (including septic tanks) [34]. In this way, dairies are obliged to purify wastewater resulting from the milk processing before discharging it.

Accredited testing laboratories on the territory of Serbia conducted physical and chemical wastewater tests that included quarterly monitoring of parameters using test methods regulated by the Serbian standards and legislations [35]. The permitted (limit) emissions of wastewater from the milk processing plants, depending on the type of recipient, are shown in Table 3.

3. Results and discussion

3.1. Survey results

A survey was carried out on the selected sample of dairies in order to determine different water supply methods, as well as the methods of wastewater treatment and discharge into the recipients.

From Fig. 2 it can be seen that the largest number of dairies in the central part of Serbia are supplied with water from the city water supply network (28 of them). Nine dairies are supplied with water from wells, whereas the remaining three dairies compensate for their water needs by combined use of water supply networks and wells.

The analysed sample shows that urban sewers and septic tanks (as much as 18 dairies) are equally used as recipients

Table 3
Limit emissions from wastewater from the milk processing plants depending on the type of recipient [34,35]

Parameter	Type of recipient	
	Sewage and septic tanks	Surface waters
COD (mg/L)	450	110
BOD_5 (mg/L)	300	25
pH	6.0–9.0	6.5–9.0
TSS (mg/L)	500	35
FOG (mg/L)	40	–

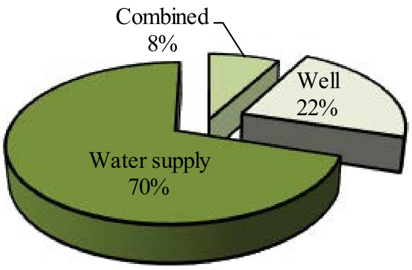

Fig. 2. The ways of supplying water to the milk and dairy industry.

(by 18 dairies each). Surface water as a recipient is less commonly used (by only four dairies), which represents 10% of the tested sample (Fig. 3).

When it comes to the treatment of wastewater within the analysed sample, 29 dairies do perform some treatment, as opposed to 11 that do not perform any treatment of wastewater at the exit from the plant (Fig. 4). The treatments are mainly reduced to the primary purification (performed by 26 of the dairies). Secondary purification is carried out by two dairies, whereas tertiary treatment is present only in one dairy farmer.

3.2. Specific water consumption

Figs. 5 and 6 show the dependence of the water consumption and SWC on the amount of the processed milk, respectively, for one milk producer in Serbia.

The SWC varies from dairy to dairy, which depends to a large extent on the production program and capacity of the plant.

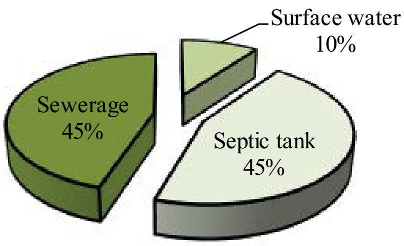

Fig. 3. Recipients for wastewater discharge.

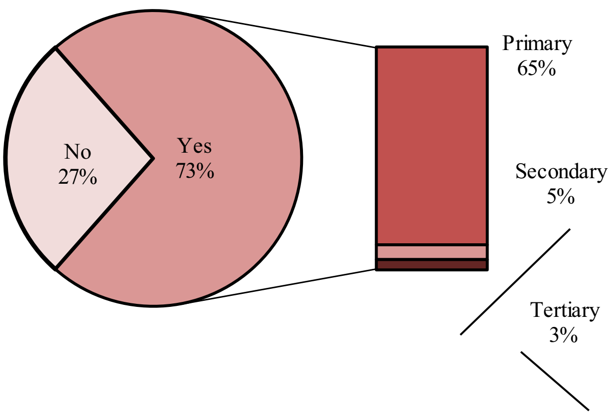

Fig. 4. Methods of wastewater treatment in milk processing plants.

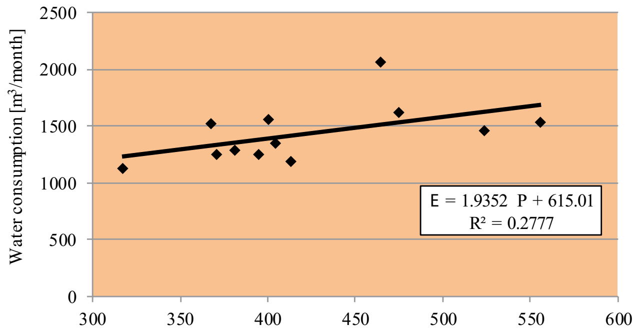

Fig. 5. Water consumption as a function of the amount of processed milk for one dairy in Serbia.

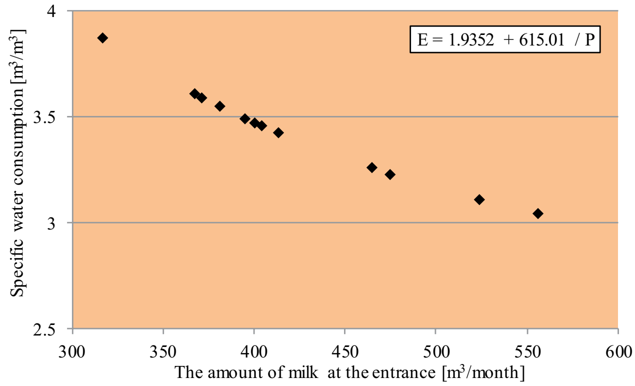

Fig. 6. Specific water consumption in one dairy in Serbia.

The SWC analysis was performed on the observed sample for dairies supplied with water from the city water supply networks only (28 dairies, or 70% of the analysed sample).

The analysis does not cover dairies that use water from their own wells, since in that case there are no related water consumption costs, and therefore no measurements of water consumption are performed or available. For the same reason, dairies with a combined water supply form both city networks and wells are not considered in this analysis either.

For some dairies, the SWC ranges between 4 and 5.13 m^3/m^3 of the processed milk, whereas for others, the SWC values are found to be within 2–3 m^3/m^3 of the processed milk.

Based on the analysis of the measured data, the SWC_A amounts to 3.47 m^3/m^3 of the processed milk (Fig. 7).

As milk producers in Serbia mainly deal with combined production (milk powder, cheese and/or dairy drinks), with a specific water consumption ranging from 2 to 5.13 m^3/m^3 of processed milk, it can be concluded that related dairy farmers in Australia consume less water to meet their needs, while dairies in Europe consume relatively similar amount of water as dairies in Serbia.

3.3. Results of physical and chemical wastewater testing

For dairies that discharge their wastewater into the sewage system or septic tanks, the results of pollutant emissions are shown in Figs. 8–12.

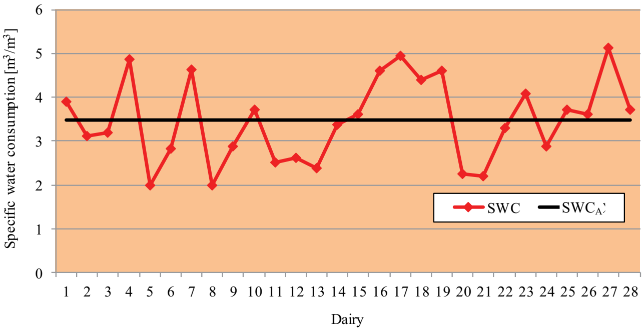

Fig. 7. Specific water consumption for dairies in Serbia supplied with water from the city network.

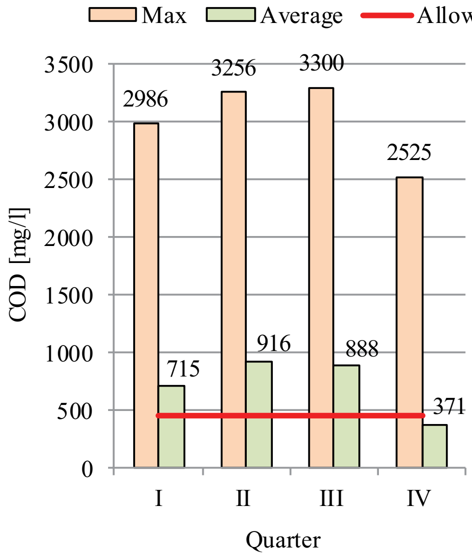

Fig. 8. Quarterly COD values for dairies that discharge wastewater into sewers or septic tanks.

Fig. 8 compiles the values of COD measured in different quarters of 2016. The maximum values of COD emitted by the analysed dairies reach 2,986 mg/L in the first quarter, 3,256 mg/L in the second quarter, 3,300 mg/L in the third quarter and 2,525 mg/L in the last quarter. The corresponding average COD values for the examined dairies were 715 mg/L in the first quarter, 916 mg/L in the second quarter, 888 mg/L in the third quarter, while only in the fourth quarter, the average COD value was lower than the allowed limit of 450 mg/L.

The values of BOD_5 for the examined dairies are shown in Fig. 9. The peak values occurring in different quarters are: 2,472, 2,084, 1,942 and 610 mg/L. The average values of BOD_5 are as follows: 427, 468, 443 and 146 mg/L. It can be observed that the COD and BOD_5 values exceed the mean permissible concentration levels up to 7–10 times in some of the cases.

Measured pH values (Fig. 10) range between 3.9 and 9.5 (in the first quarter), 3.5 and 11.9 (second quarter), 4.0 and 10.0 (third quarter) and 5.7 and 11.5 (fourth quarter). The average pH values remain within the limits permitted for each quarter, amounting to 7.0 in the third quarter (pH neutral) and spanning within the range of 7.1–7.7 for the

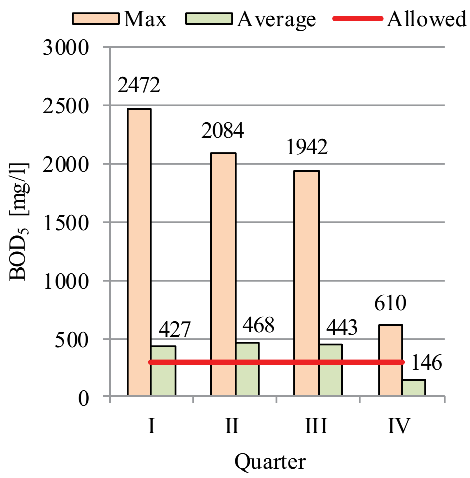

Fig. 9. Quarterly BOD_5 values for dairies that discharge wastewater into sewers or septic tanks.

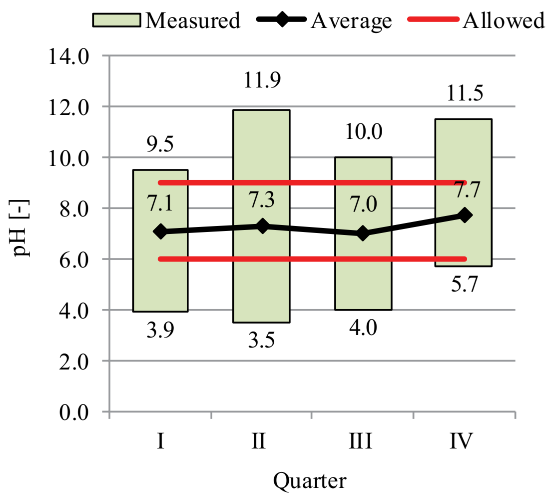

Fig. 10. Quarterly pH values for dairies that discharge wastewater into sewers or septic tanks.

other three quarters. The basic characteristic of wastewater generated in the technological processes is the presence of fats and oils, orthophosphates and parameters of microbiological pollution, which results in wastewater being slightly alkaline.

The maximum values of TSS (Fig. 11) concentrations in the analysed dairies reached 1,067 mg/L in the first quarter, 1,456 mg/L in the second quarter, 955 mg/L in the third quarter, while in the fourth quarter the maximum measured value of this parameter was 828 mg/L. The average concentration of TSS for examined dairies in central Serbia is lower than permitted (500 mg/L) and amounts to 190, 201, 216 and 172 mg/L.

Maximum and average, and allowed concentrations of FOG in sewage waters per quarter are shown in Fig. 12. The highest concentration of FOG was measured in the third quarter (860 mg/L). Then in the first (494 mg/L) and the second (344 mg/L) quarter, while in the fourth quarter the maximum concentration was 279 mg/L. The corresponding

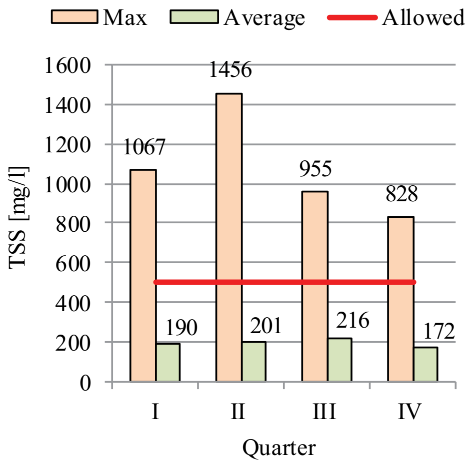

Fig. 11. Quarterly emission values for TSS for dairies that discharge wastewater into sewers or septic tanks.

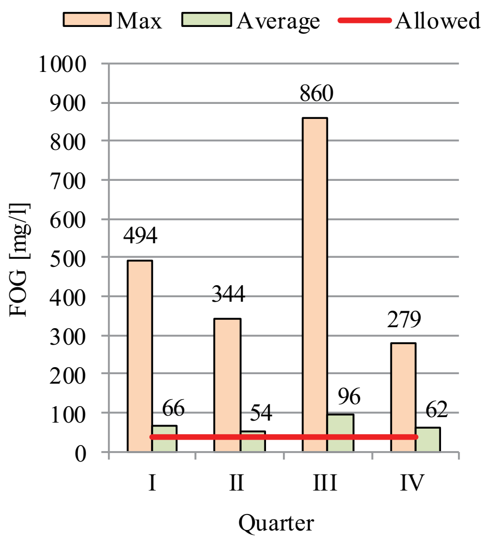

Fig. 12. Quarterly emission values for FOG for dairies that discharge wastewater into sewers or septic tanks.

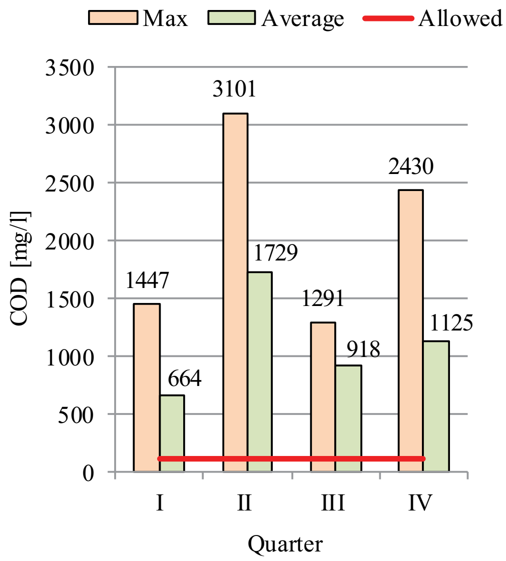

Fig. 13. Quarterly COD values for dairies that discharge wastewater into surface waters.

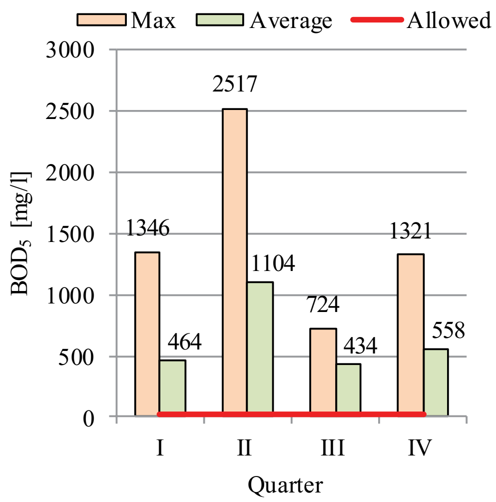

Fig. 14. Quarterly BOD_5 values for dairies that discharge wastewater into surface waters.

average FOG emission values are as follows: 66, 54, 96 and 62 mg/L.

The results of the emission of pollutants in the case the surface waters are used as recipient are shown in Figs. 13–17.

The maximum quarterly values of COD (Fig. 13) in the case of discharging wastewater into surface water are: 1,447 mg/L (first quarter), 3,101 mg/L (second quarter), 1,291 mg/L (third quarter) and 2,430 mg/L (fourth quarter). The average quarterly COD values are higher than the permissible limit for all quarters: 664, 1,729, 918 and 1,125 mg/L.

Physical and chemical analyses established that the values of BOD_5 vary significantly for different dairies (Fig. 14). For example, the value of BOD_5 reached 2,517 mg/L for the case of one dairy, whereas the average BOD_5 values range from 434 to 1,104 mg/L, which is more than the allowed emission limits for surface waters.

Fig. 15 shows quarterly measured, average and permitted pH values for dairies that discharge wastewater into surface waters. The average pH values for each quarter stay within the allowed limits: 8.4 (first quarter), 7.0 (second quarter), 7.4 (third quarter) and 8.5 (fourth quarter). The lowest pH value was measured in the third quarter (pH 6.1), whereas the highest one was measured in the first quarter (pH 10.5).

Sampling the wastewaters from dairies that use surface water as recipient, it was found that the quarterly average TSS values are as follows (Fig. 16): 70 mg/L (first quarter), 104 mg/L (second quarter), 124 mg/L (third quarter) and 84 mg/L (fourth quarter). The maximum TSS concentration was measured in the third quarter, amounting to 286 mg/L, followed by 204 mg/L in the second quarter, 168 mg/L in the first and 143 mg/L in the fourth quarter.

The maximum concentration of FOG (Fig. 17) was measured in the first quarter (164 mg/L). The average FOD value ranges between 22 mg/L (second quarter) and 49 mg/L (third quarter).

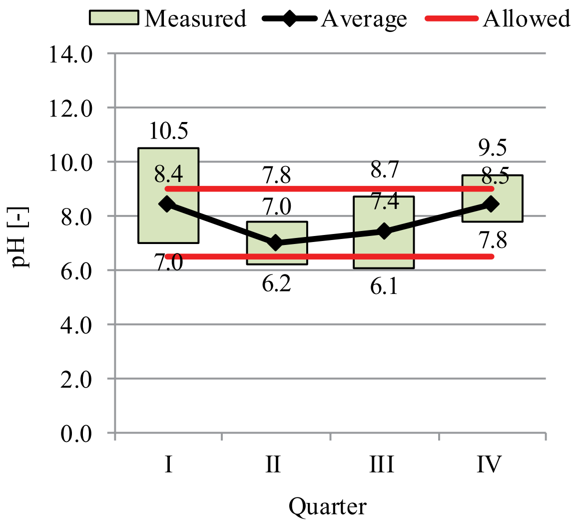

Fig. 15. Quarterly pH values for dairies that discharge wastewater into surface waters.

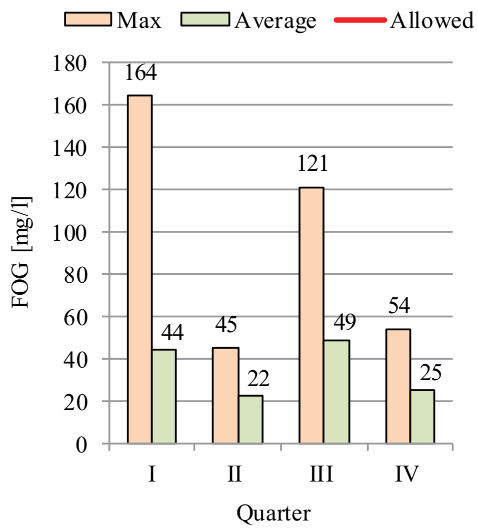

Fig. 17. Quarterly emission values for FOG for dairies that discharge wastewater into surface waters.

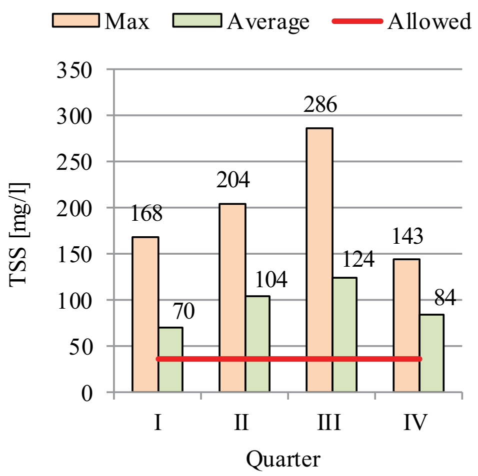

Fig. 16. Quarterly TSS emission values for dairies that discharge wastewater into surface waters.

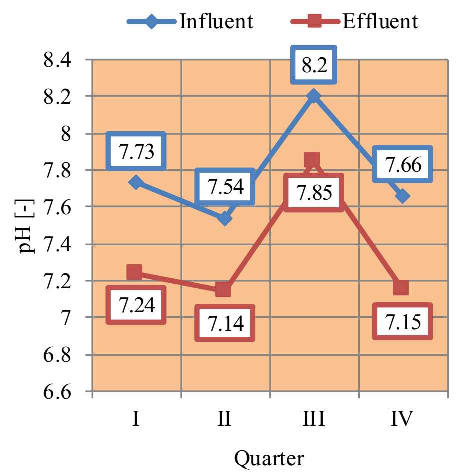

Fig. 18. pH values of wastewater influent and effluent.

Table 4 shows that the results of testing the quality of wastewater from mixed dairies in the territory of Central Serbia are in the range with the results of the wastewater test carried out by other researchers.

Based on the results shown, it can be concluded that the concentration of certain pollutants in some situations exceeds the allowed limits up to several times (even in dairies with wastewater treatment plants implemented). All this has negative consequences for the environment. In order to protect the environment, the Republic of Serbia has prescribed a number of legal norms and regulations related to the pollutant emission limits within which wastewater can be discharged in dairies. On the other hand, dairies are trying to implement strategies designed to help them survive on the market and wastewater treatment is not on the top of the list of their priorities. The situation is further aggravated by the fact that there is a lack of enforcement of laws on the dairies by inadequate inspection practices.

3.4. A good practice example

Considering that the majority of dairies have only primary wastewater treatment, if any, this section shows an example of good practice, that is, an application of grease separator in wastewater treatment. In Figs. 18–22, the efficiency of wastewater purification separators for one milk producer in Serbia, which releases wastewater into urban sewage, is shown.

The pollutant reduction efficiency is determined based on the measurement of parameters at the inlet and the outlet of the wastewater treatment plant. Changes in pH values and in the concentration of FOG, COD, BOD_5 and TSS were observed (similarly to the previous cases).

Fig. 18 shows quarterly pH values at the inlet and the outlet of the grease separator. In the first quarter, the pH was reduced from 7.73 to 7.24, in the second from 7.54 to 7.14, in the third quarter from 8.2 to 7.85, while in the fourth quarter the pH was reduced from 7.66 to 7.15.

Table 4
Parameters of wastewater in branch dairy companies

Mixed dairy		Parameter				
		COD (g/L)	BOD_5 (g/L)	pH (–)	TSS (g/L)	FOG (g/L)
Central Serbia	Sewerage or septic tank	0.31–3.3	0.15–2.47	3.5–11.9	0.04–1.45	0.03–0.86
	Surface water	0.27–3.1	0.19–2.52	6.1–10.5	0.03–0.29	0.027–0.16
Others [17,22–26]	–	0.5–10.4	0.24–5.9	4–11	0.06–5.80	0.02–1.92

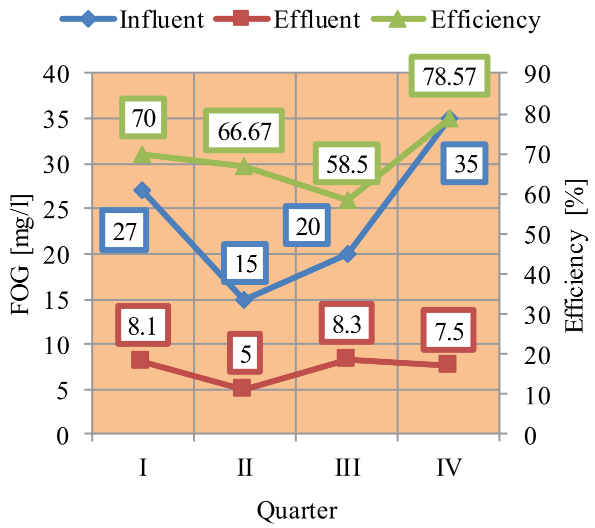

Fig. 19. FOG removal efficiency in wastewater.

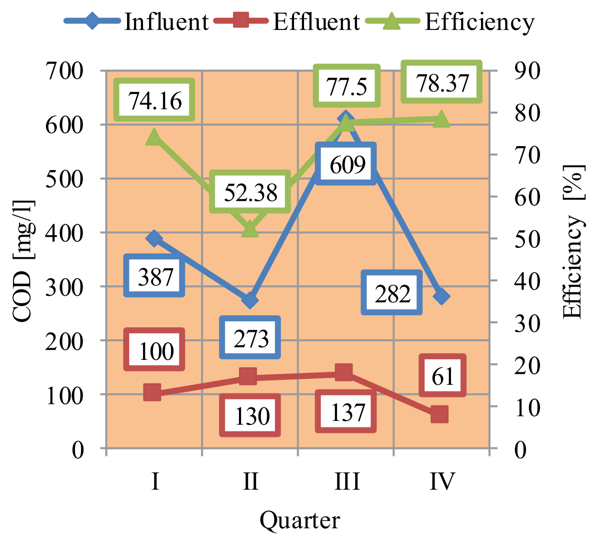

Fig. 20. COD removal efficiency in wastewater.

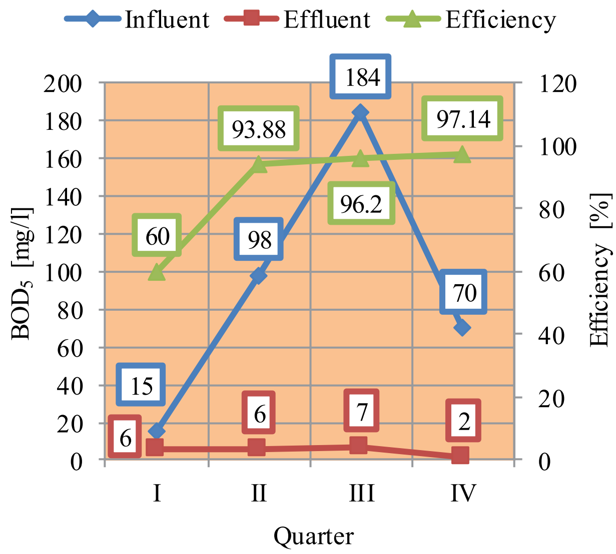

Fig. 21. BOD_5 removal efficiency in wastewater.

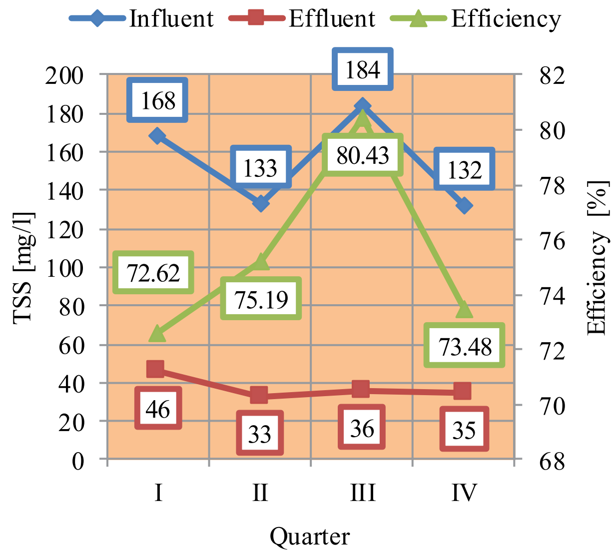

Fig. 22. TSS removal efficiency in wastewater.

The FOG reduction efficiency for the same case (Fig. 19) per quarter is 70% (first quarter), 66.67% (second quarter), 58.5% (third quarter) and 78.57% (fourth quarter).

In Fig. 20, it can be seen that the recorded efficiency of COD reduction is 74.16% in the first quarter, much lower in the second quarter (52.38%), the highest in the fourth quarter (78.37%), whereas in the third quarter it amounts to 77.5%.

Quarterly values of BOD5 at the outlet of the separator (see Fig. 21) are as follows: 6 mg/L (efficiency 60%), 6 mg/L (efficiency 93.88%), 7 mg/L (efficiency 96.2%) and 2 mg (efficiency 97.14%).

Fig. 22 shows that the concentration of TSS at the outlet of the purification device is lower than 50 mg/L. The device has achieved the highest level of the TSS reduction efficiency in the third quarter (80.43%), whereas the efficiency was the lowest in the first quarter (72.62%), followed by the fourth quarter (73.48%). In the second quarter, an efficiency of 75.19% was recorded.

4. Conclusion

The milk and dairy industry is a very sensitive branch of the food industry in terms of wastewater emissions. As mentioned earlier, despite the fact that there are binding laws that regulate emissions of pollutants, dairies in Serbia do not generally comply with them. Very often, wastewater is discharged without any prior treatment. Even the dairies with some of the wastewater treatment systems installed do not have sufficient measures in place to fulfil the emission limit requirements for wastewater pollutants. Most of the existing wastewater treatment plants in the dairy industry do not meet the requirements and the already installed plants have been outdated in terms of both, their capacity and the purification technology.

Regardless of the fact that there are many causes for this situation (such as lack of awareness and expertise, economic factors, political situation, state of the economy and market situation), the present conditions continue to degrade the environment. Therefore, a constant and better education, improved skills and expertise, raising the awareness and monitoring of parameters that affect the environment need to be put in place. This also entails large investments and harmonization of the legislation with the EU regulations in this sector.

Abbreviations

BOD_5 – biochemical oxygen demand
COD – chemical oxygen demand
FB – fluidized bed (anaerobic reactor)
FF – fluidized film (anaerobic reactor)
FOG – fat, oil and greases
HACCP – Hazard Analysis Critical Control Points
SWC – specific water consumption
SWC_A – average specific water consumption
TSS – total suspended solids
WCC – water consumption centres

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