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NEW CHALLENGES IN THE DAIRY WASTEWATER TREATMENT

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Abstract: *The efficiencies of three different dairy wastewater treatment technologies have been analyzed and compared on example of several milk, cheese and butter making facilities. It is shown that the standalone mechanical treatment is completely inefficient while the required clarification cannot be ensured by regular aerobic bio-treatment also because of rather unstable pH value in the wastewater. The modified landfill bio-treatment method involving seeding the spots with Chlorella is discussed as more stable, effective and less expensive alternative technology for the dairy wastewater treatment.*

Keywords: *dairy; dairy wastewater treatment; bio-treatment efficiency; Chlorella*

1. Introduction

Milk treatment is one of the leading branches in nowadays food processing industry. Over 210 dairies are currently functioning in Ukraine while the domestic market demand for various milk products is increasing continuously for about 2.7 % annually since 2008 [1, 2].

Any dairy produces some industrial wastewater with rather complex and hard to process composition including residual milk components, proteins, milk sugars, butterfat, detergents and other agents [3, 4]. Massive formation and discharge of such complex wastewater can seriously disturb the conditions of the receiving water body and provoke water blooming, fish suffocation and general decrease in the water quality. On the other hand, the problem of the dairy wastewater cleaning seems very common for many countries since this branch is widely distributed in many countries across Europe. That is why various aspects of the dairy wastewater treatment and reuse stay in focus of extensive investigations.

Main efforts in this field are given to the problems of wastewater treatment efficiency and better utilization of the wastes and byproducts formed in the course of milk processing. These materials cannot be discharged directly to water bodies or even to the general purpose sewage network without some preliminary treatment. Moreover, some milk treatment reagents can shift pH of the wastewater either towards acidic or alkaline reaction, which decreases bio treatment efficiency and causes the need in additional wastewater treatment stages.

In the light of the above, this paper deals with the analysis of the dairy wastewater treatment technologies efficiency on example of some milk processing lines. Our extended analysis will involve butter and cheese productions as well as drinking milk and fermented milk products technologies.

2. General survey of the dairy wastewater composition and efficiency of the traditional wastewater processing technologies

This is well known that the dairy wastewater composition is quite complex since it contains raw milk remainders, milk products, milk transformation products and byproducts, detergents and many other components. The dairy wastewaters are collected after various production stages including main technological operations, side operations, equipment and production shops cleaning, etc. The amount and composition of the resulting wastewater can vary widely depending on the plant's capacity, specialization, source materials used, technologies implemented and wastewater treatment methods.

The following plants were involved in this investigation:

- Private JSC "Monastyrsky milk plant" (1);
- LLC "Molochni dary" (2);
- LLC "Galievo butter plant" (3);
- JSC "Molochnyi kray" (4)

First three companies produce mainly cheese and butter while the last one specializes in drinking milk and fermented milk products manufacturing.

As an example, the milk processing plant (4) wastewater composition is shown in Table 1.

Unlike the above, cheese production lines cause formation of the lactose-enriched serum with low proteins content. Butter-making plants cause formation of the buttermilk wastewater containing much lactose and proteins but depleted with fats. Both serum and buttermilk effluents result in serious contamination of the wastewater. As an example, the cheese and butter production plant (2) wastewater composition is shown in Table 2.

As seen from comparison of Tables 1 and 2, the cheese/butter making wastewater contamination level is lower than that of the milk/fermented milk products making facilities. This situation is caused by the churn-milk catching equipment that operated at the latter plants as the wastewater pretreatment stage.

Table 1.

Wastewater composition parameters for the dairy JSC Molochnyi kray

№	Wastewater composition parameter	Wastewater quality parameters, mg/l (except pH)		
		Input to wastewater treatment line	Projected values after treatment	Real values after treatment
1	2	3	4	5
1	pH	5.6	6.5	6.2
2	Suspensions	500	15	6.1
3	Butterfat	25	0	0
4	COD	2400	75	132.1
5	BOD_5	1600	15	62.3
6	Ammonium nitrogen $N\text{-}NH_4^+$	42.8	0.39	0. 16
7	Nitrates, NO_3^-	4	18	15.6
8	Phosphates, PO_4^{3-}	75	1,0	20,5
9	Nitrites, NO_2^-	1.2	0.8	0.31
10	General iron	9.5	0.2	0.1
11	Surfactants	0.9	0.1	1.1
12	Chlorides, Cl^-	700	280	79.8
13	Sulfates, SO_4^{2-}	300	85	112.3

Table 2.

Wastewater composition parameters for the dairy LLC Molochni Dary

№	**Wastewater composition parameter**	**Value, mg/l (except pH)**	
		Sump input	**Sump output**
1	2	3	4
1	pH	8.73	8.31
2	COD	286.7	148.5
3	BOD_{full}	183.2	102.0
4	BOD_5	130.5	78.2
5	Suspensions	142.3	68
6	Ammonium nitrogen, $N\text{-}NH_4^+$	2.8	4,1
7	Nitrites, NO_2^-	0	0
8	Nitrates, NO_3^-	8.2	6.8
9	Chlorides, Cl^-	412	417
10	Sulfates, SO_4^{2-}	98	96
11	Phosphates, PO_4^{3-}	8.3	5.6
12	Dry residue	860	720
13	Fats	32	12
14	Surfactants	1.2	0.8
15	Phenols	0	0

This situation is caused by the churn-milk catching equipment that operated at the latter plants as the wastewater pretreatment stage. Churn milk-effluents are caught and collected by this equipment and then used for the cattle feeding mixtures making.

On the other hand, BOD_5 must be lowered to 15 mg/l before the wastewater can be discharged. This is the limit efficiency value for the biotreatment technologies [5], and we shall analyze various options related to application of this technology at some diaries.

Efficiency of the mechanical standalone treatment technology

This technology is implemented at plants (1) and (2). The production capacities of the plants are 11000 (1) and 400 (2) tons of milk per year. Butter is the main product of both plants.

Plant (1) is equipped with the gravity-flowing sewage system collecting all wastewater and transporting it to the multisectional mechanical water treatment settler. After mechanical cleaning, the wastewater is discharged to the nearby river Dobrodivka. Composition of this treated wastewater is shown in Table 3.

Table 3.

Composition of the plant (1) wastewater after mechanical treatment

№	**Wastewater quality parameter**	**Value, mg/l**
1	COD	489.6
2	BOD_{full}	186
3	BOD_5	143
4	Suspensions	126
5	Ammonium nitrogen, $N\text{-}NH_4^+$	0
6	Nitrites, NO_2^-	1.0
7	Nitrates, NO_3^-	8.7
8	Chlorides, Cl^-	183
9	Sulfates, SO_4^{2-}	68
10	Phosphates, PO_4^{3-}	2.83
11	Dry residue	786
12	Oil products	0.26
13	Phenols	0
14	Surfactants	0.32
15	pH	7.03
16	Fats	6.8

As seen from Table 3, mechanical treatment is unable to ensure required wastewater quality. For instance, BOD_5

value remains 9.5 times higher than the maximum permissible level [5]. Similarly, low efficiency of the standalone mechanical wastewater treatment can be seen for plant (2) where the wastewater is collected and then treated mechanically in the two-sectioned settler (see Table 2).

An efficiency of the combined dairy wastewater treatment technology, which includes the biotreatment stage, is analyzed in the next section.

Efficiency analysis for the combined dairy wastewater treatment technology

This technology is realized at plant (4) where the physico-chemical and biological treatment technologies are combined with mechanical cleaning.

An average wastewater treatment capacity of the plant (4) is ca. 6 m^3/day.

The technology includes the following stages (Fig. 1). First stage involves preliminary treatment in the fat-trap (position 1, Fig. 1). Then, the wastewater is collected in the pump-sewage station (position 2) and pumped periodically to the equalizing tank (position 3) where some additional reagents (alkali to keep required pH value and to facilitate better removing of lactose; iron chloride to intensify clarification of water, and flocculant to ensure formation of easy-to-remove flocks) are being added for better cleaning. Water contamination level is decreasing after adding the above mentioned reagents and as a result of the anaerobic oxidation of the organic pollutants by the developing biocenose. The suspended particles are being aggregated and form the sediment, which adsorbs additionally some solute species. Besides, some new soluble forms of organic substances and the products of their decomposition can also appear in the system. If the pH level is appropriate, the ammonium nitrogen is transferring gradually into the nitrite and nitrate forms by eutrophication. All these processes result in decrease in the wastewater COD value.

As mentioned above, alkali, iron chloride and flocculant are used for chemical treatment of the wastewater. These reagents should be added to the main supplying pipe of equalizer. A pipe (position 5) is used to transport required amounts of the caustic soda solution from the storage tank (position 4) to the equalizer pipe. Iron chloride is fed from the dissolution tank (position 6) using another pipe (position 7). Some amounts of insoluble hydroxides $Fe(OH)_3$ and $Ca(OH)_2$ are formed as a result of interaction between the two above reagents and the wastewater components. A solution of flocculant is stored in a separate tank (position 8) and should be added to the mixture using a pump (position 9) to ensure aggregation of the hydroxides flocks into floccules. Finally, COD and BOD_{full} decrease by 50 % and the suspended particles content drops by 70-80 % as a result of these treatment procedures.

Following this physico-chemical treatment, the wastewater is directed to the aeration tank-settler (position 10), where the processes of fats, surfactants, proteins and carbohydrates decomposition and organic pollutants oxidation occur. Besides, the transfer of the ammonium nitrogen into the nitrate form also continues at this stage. All these biochemical transformations are performed by activated sludge, bacteria and protozoa species present in the system as immobilized or floating forms, which consume oxygen pumped in by the air compressor (position 11). Finally, excessive activated sludge should be separated from the treated water in the same settler (position 10). Final decontamination is exercised using the sodium hypochlorite solution, which is prepared and added to the mixture using the dissolution tank (position 12) and the drop-dosing feeding equipment (position

13). This stage should be included in the flowchart in order to remove excessive pathogenic microbes usually present in the dairy wastewater. After complete treatment, the wastewater is discharged to river Siret.

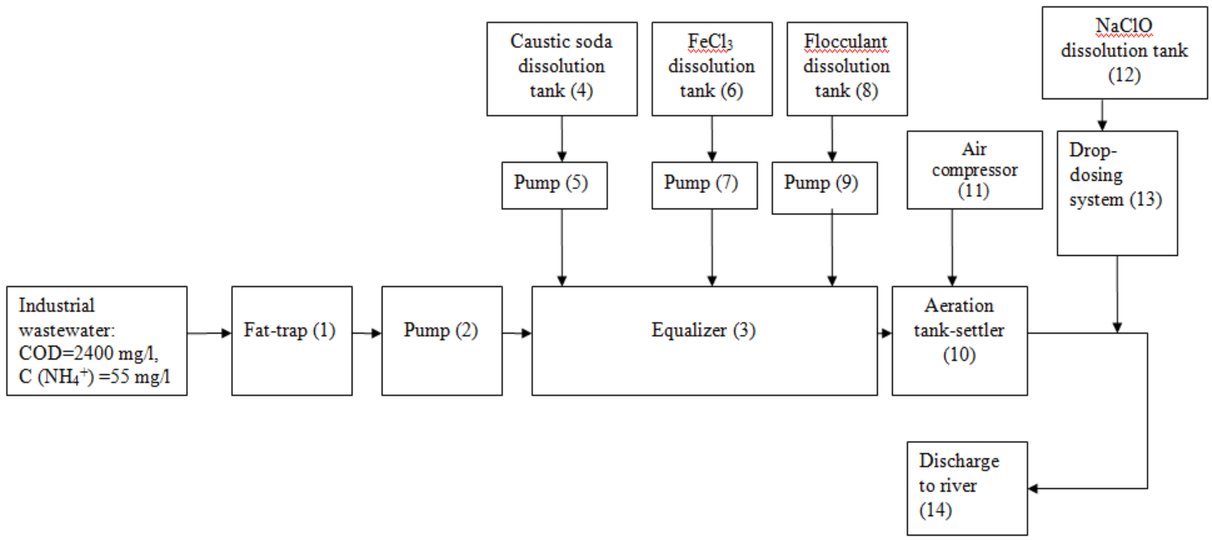

Fig. 1. The flowchart of the wastewater processing stages at the dairy (4)

It is expected that the final treated wastewater composition will comply with the values indicated in column 4, Table 1 as it is required by the Ukrainian legislation norms set for the wastewater to be discharged in the open water bodies.

However, real wastewater cleaning efficiency is much lower, which causes excessive concentrations of some pollution agents (see column 5, Table 1). For instance, real BOD_5 of the treated wastewater is 62.3 mg/l while the limit value is 15 mg/l; phosphates content is 20 mg/l against 1,0 mg/l, surfactants content is 1,1 mg/l against 0,1 mg/l. This proves low efficiency of the combined wastewater treatment technology with typical biotreatment stage as the main tool of water cleaning. In our opinion, this situation is caused mainly by principal inability to keep the pH value within the range 6.5-8.5, which is required to ensure the full biotreatment efficiency. The alkali dosing equipment cannot respond to small deviations in the wastewater pH level and either overdose or underdose the alkali reagent causing too alkaline or too acidic reaction. These factors result in swelling of activated sludge and decrease in its efficiency.

In this context, we consider the Chlorella-based cleaning technologies as a more appropriate option for the dairy wastewater treatment. This method is less expensive and more reliable for the wastewaters with unstable pH value.

3. Results and discussion of the Chlorella-based dairy wastewater treatment technologies efficiency

Chlorella is a microscopic unicellular green alga, which is a 2-10 μm immobile bubble without flagella. It is a quite undemanding organism with a very simple life cycle which exhibits fast and massive reproduction. This alga can be applied in many directions such as wastewater treatment, organic wastes recycling, phycotechnologies and others. An intense interest towards this alga is fed additionally by its composition: 40 % or more of important proteins, 20 % - lipids, 35 % - carbohydrates and about 10 % of ash residue in terms of dry weight. Besides, it contains some amounts of vitamins B, C and K. One of Chlorella components, 'clorelin' can exhibit some antibiotic activity. In some countries the Chlorella biomass is used as a food component after it passes special treatment [6]. It should be noted that the application of Chlorella to the acid winery wastewater treatment is quite effective [7]. Our previous investigation [8] proved also that this technology can be applied to treatment of the acid juice-making factory wastewater.

As seen from the comparative analysis of plant (3) wastewater treatment efficiency, the same technology is highly effective at dairy as well.

Table 4.

Comparison of the real and projected wastewater biotreatment efficiency for the plant (3)

Wastewater quality parameter	**Concentration, mg/l**		
	Real values (after the Chlorella-seeded landfill)	**Projected values (without Chlorella)**	**Remaining contamination*, %**
1	2	3	4
COD	62.8	80.0	78.5
BOD_5	14.2	15.0	94.6
Ammonium nitrogen	1.42	1.56	91
Nitrites	0.22	3.12	7.05
Nitrates	2.96	45.0	6.6
Suspensions	13.6	15.0	90.6
Chlorides	92.7	350.0	26.5
Sulfates	42.3	500	8.5
Phosphates	1.78	3.5	50.8
Dry residue	782	1000	78.2
Oil products	Not determined	0.3	0
Surfactants	Not determined	0.5	0
Phenols	Not determined	0.001	0
Iron	0.26	0.3	86.7

** - the values in this column represent the percentage of the contamination agent concentration remained after treatment by Chlorella compared to the projected concentration values (taken as 100 %)*

Table 5.

Composition of the treated wastewater after the Chlorella-enhanced biotreatment at the landfill spots

Wastewater quality parameter	**Concentration, mg/l**			
	Spot 1	**Spot 3**	**Spot 5**	**Average**
1	2	3	4	5
COD	35.8	48	96	59.9
BOD_5	11.5	12.0	18.0	13.8
Ammonium nitrogen	1.5	1.5	2.0	1.67
Nitrites	0.001	0.004	0.06	0.022
Nitrates	0.8	1	2.5	1.43

Plant (3) wastewater is collected by the local sewage system and then it self-flows to the pumping station, which transports it to the biotreatment landfill area. There are

5 landfill spots, and each of them is seeded with Chlorella spores each year before the summer season, which ensures significantly higher efficiency of the wastewater decontamination (see Table 4).

It should be emphasized that according to the specifics of the technological process, the treated dairy wastewater is discharged periodically, after completion of its biotreatment at each landfill spot. As seen from Table 5, the biotreatment process has enough time to complete till the end of the warm season at all landfill spots and the outcoming discharge composition meets all requirements set for the biotreated wastewater.

4. Conclusion

Neither plain mechanical wastewater cleaning nor typical aerobic biotreatment can ensure the required clarification of the dairy wastewater. The former option is ineffective because of massive organic contamination of such wastewater, while the latter is too sensitive to accidental pH deviations outside the range 6.5-8.5, which appear quite often at most dairies. An efficiency of the typical aerobic biotreatment can be increased to some extent by using the automatic pH control/alkali dosing system capable of self-adjusting to possible changes in the wastewater pH. However, it would require rather high expenses and wouldn't be completely secured from irregular acidic or alkaline jumps.

In our opinion, the Chlorella-based landfill biotreatment is a more appropriate solution. This technology remains effective within a wider pH range 4.5-7.5 and no additional wastewater treatment equipment is required. The need for additional land resources to establish the landfill spots is the only problem expected for this technology. However, the total landfill spots area is comparatively small and no serious obstacles are expected in the course of its introduction.

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