Original scientific paper - Izvorni znanstveni rad UDK: 637.1.02

The improvement of dairy wastewater treatment efficiency by the addition of bioactivator

Sanja Posavac[1], Tibela Landeka Dragičević[2], Marijana Zanoški Hren[2]*

[1]Dukat Dairy Industry Inc., Factory Sirela, Velike Sredice 11, Bjelovar
[2]Faculty of Food Technology and Biotechnology, Pierottijeva 6, Zagreb

Received - Prispjelo: 16.05.2010.
Accepted - Prihvaćeno: 18.08.2010.

Summary

The problem in the work of dairy wastewater treatment system of milk processing industry Dukat Dairy Industry Inc., Factory Sirela, which applies the technology of activated sludge are filamentous microorganisms that cause bulking of the activated sludge and consequent inefficient treatment of wastewater. Also, this activated sludge does not have good settling properties and separation from treated water. The factors which caused such poor sludge quality are: a sudden high organic load and changes in environmental factors. In order to improve the efficiency of the system, a role and contribution of bioactivator "Aquatop® BA" was studied. The operation of the system is monitored during the period January-May in the year 2006 (bioactivator not added) and in the year 2009 (with addition of bioactivator). By adding the bioactivator better formation of flocs and good settling of activated sludge, prevention of filamentous bacteria growth and stable quality of the effluent to the required values prescribed by the Croatian waters to the chemical oxygen demand (COD) <700 mg/L and biochemical oxygen demand (BOD) <250 mg/L were achieved.

Key words: activated sludge, bioactivator, dairy wastewater treatment, filamentous microorganisms

Introduction

Wastewater from milk processing industry contains a large amount of organic compounds, compounds with nitrogen and phosphorus, and it is characterized by great variations in the composition and flow, and fluctuations in pH as a result of various production processes and washing cycles after end of each production process (Barnett et al., 1994; Danalewich et al., 1998; Janczukowicz et al., 2008). Due to the presence of large amounts of readily biodegradable organic compounds, and especially high COD/N (chemical oxygen demand/nitrogen) ratio and low amounts of phosphorus, the activated sludge in dairy wastewater treatment system is of poor quality (Donkin, 1997; Hossain, 2004). Because of that the activated sludge flocs does not have the structure and size for good settling (Jenkins et al., 1993; Donkin, 1997), and the activated sludge is washed out of the system, in most cases as a result of overgrowth of filamentous microorganisms (Jenkins at al., 1993; Donkin, 1997; Ceruggs and Randall, 1998). This phenomenon is known as activated sludge bulking and it is a frequent occurrence in the aerobic treatment of dairy wastewater (Pipes, 1977; Donkin, 1997; Petruy and Lettinga, 1997; Danalewich et al., 1998).

On the activated sludge bulking have an influence the dissolved oxygen concentration in the aeration basin and a high COD/N ratio (Adamse, 1968; Goronszy and White, 1988), the concentration of dissolved organic compounds at which the microorganisms grow (F/M ratio - Food/Microorganisms ratio) (Goronszy and White, 1988), the presence of detergents (Wheatley et al., 1988; Goronszy, 1990; Albertson, 1991), long sludge age and process temperature over 18 °C (Pipes, 1978), the low

*Corresponding authorDopisni autor/: Phone/Tel.: +385 1 4605 285; E-mail: tdragic@pbf.hr

Table 1. The composition of wastewater from milk processing industry Dukat Dairy Industry Inc., Factory Sirela
Tablica 1. Sastav otpadne vode iz industrije prerade mlijeka Dukat mliječna industrija d.d., Tvornica Sirela

Compounds/Sastojci	Concentration/Koncentracija
COD/KPK (mg/L)	3000-6000
BOD/BPK (mg/L)	1800-3600
Suspended solids/Suspendirana tvar (mg/L)	1000-1500
Total solids/Ukupna tvar (mg/L)	4000-5500
Dissolved oxygen/Otopljeni kisik (mg/L)	0.10-0.50
Detergents, anionic/Detergenti, anionski (mg/L)	2-6
Grease and oil/Masti i ulja (mg/L)	15-50
Total N/Ukupni N (mg/L)	120-200
Total P/Ukupni P (mg/L)	20-50
pH	3-8

nutrients (N, P) (Greenberg et al., 1955) and micronutrients content (Wood and Tchobanoglous, 1975), the organic loading (Jenkins at al., 1993; Donkin, 1997; Schwarzenbeck at al., 2005) and process conditions (Chudoba, 1985).

The use of commercial preparations consisting of mixed microbial cultures, enzymes and/or nutrients, biopolymers, vitamins, to improve flocculation of activated sludge and the effectiveness of biological treatment of wastewater is known (Martin et al., 1985; Martin et al., 1989; Stephenson and Stephenson, 1992; Lemer et al., 1998; Van Limbergen et al., 1998; Loperena et al., 2007).

The aim of this study was to investigate the role and contribution of bioactivator - a commercial product to improve the efficiency of dairy wastewater treatment system of milk processing industry Dukat Dairy Industry Inc., Factory Sirela. The influence of the addition of bioactivator was monitored by determination of quality of raw and treated wastewater as well as by observation of microbiological quality of activated sludge.

Materials and methods

Wastewater

The characteristics of dairy wastewater used in this study are shown in Table 1. The wastewater is composed of technological and sanitary wastewater originating from the Factory Sirela and a part of rainwater. Technological wastewater produced from the cleaning process of technological equipment after production of fresh, semi-hard and hard cheeses, butter and milk powder also contains a part of whey, and chemicals for cleaning and disinfection, and microorganisms.

Bioactivator

A bioactivator of commercial name "Aquatop® BA" (Aqua Terra, Bioproduct GmbH, Germany) is composed of biopolymers, minerals and vitamins. Some of the properties of the bioactivator "Aquatop® BA" are: improvement of quality of activated sludge and settling abilities, improvement of process stability, reduction of foam occurrence and reduction of sludge bulking and sludge flotation. The bioactivator was prepared according to the manufacturer's protocol and periodically added in the appropriate quantity.

Wastewater treatment system of milk processing industry Dukat Dairy Industry Inc., Factory Sirela

The system of wastewater treatment of milk processing industry Dukat Dairy Industry Inc., Factory Sirela, applies a primary treatment (mechanical filtration, equalization, neutralization and flotation of suspended solids) and then secondary or biological treatment of wastewater with an average flow

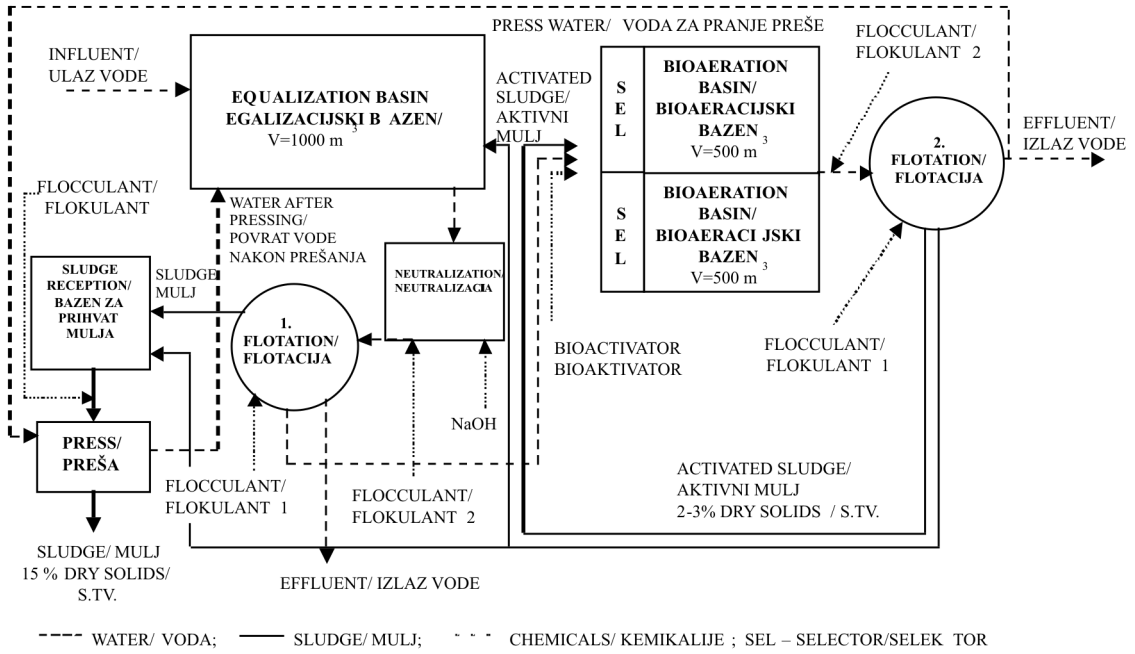

Figure 1. Schematic diagram of dairy wastewater treatment system of milk processing industry Dukat Dairy Industry Inc., Factory Sirela

Slika 1. Shematski prikaz sustava za obradbu otpadnih voda industrije prerade mlijeka Dukat mliječna industrija d.d., Tvornica Sirela

of 1000 m^3/d (Figure 1). After mechanical filtration the composition of wastewater is homogenized in equalization basin (1000 m^3) by mixing with air and than the wastewater is neutralized to the pH of 7.0-7.5. The final neutralization of wastewater to pH of 7.5 is carried out in neutralization basin by the addition of 49 % solution of NaOH. After that the chemicals for coagulation and flocculation are added. The flocs formation is enhanced by mixing of water and flocculants (flocculant 1 - inorganic polymer of polyaluminium hydroxychlorid, flocculant 2 - cationic acrylamide copolymer). Separation of water from the resulting sludge is carried out in the first flotation system. The part of such treated wastewater is discharged to the biological treatment plant (the capacity of the biological wastewater treatment system is 35 m^3/h, and a total capacity of the system is 55 m^3/h) and the rest of it is discharged from the system. Biological treatment is carried out in two bioaeration basins (each of volume 500 m^3) with a deep aeration system. Each bioreactor is equipped with a selector. Hydraulic retention time (HRT) is 24 hours. Activated sludge is separated from treated water in the secondary flotator. A part of the activated sludge is returned to bioaeration basins, and the remaining part is dehydrated. Treated wastewater overflows through the control-measuring shaft into the city sewers.

Analytical methods

Chemical oxygen demand (COD), biochemical oxygen demand (BOD), pH value, the concentration of: dissolved oxygen, compounds with nitrogen and phosphorus, activated sludge biomass (MLTSS), suspended solids, detergents, oils and fats and wastewater temperature were determined by standard methods (Standard Methods, 1998) and according to the ISO standards (ISO 10523 (1994); ISO 5815 (1989); ISO 5663 (1984); ISO 7150/1 (1984); ISO 6878/1 (1986)). The pH value was measured by a pH meter (Multiline P4, WTW) equipped with temperature sensor. The concentration of dissolved oxygen was measured using oxygen electrode (Multiline P4, WTW). All of the above parameters of chemical quality of raw and treated wastewater were determined immediately after sampling.

Results and discussion

Dairy wastewater is composed of high concentrations of organic compounds, expressed as COD and BOD, suspended particles, fat and compounds with nitrogen and phosphorus (Table 1). To the organic load also contribute the whey and chemicals for cleaning and disinfection, and microbiological contamination. The quality of dairy wastewater is variable and depends on the type of technological process which is applied. Fluctuation of pH (3.0 to 8.0) is a consequence of cleaning of production equipment by alkaline and acidic cleaning agents. About variability of wastewater composition from milk processing industry other authors also pointed out (Donkin, 1997; Danalewich et al., 1998; Janczukowicz et al., 2008), which directly affects its biodegradability (Janczukowicz et al., 2008). For efficient biological wastewater treatment is also important an efficient primary wastewater treatment (Albertson, 1991), especially the removal of fat because the fat breaks down slowly and with difficulty (Petruy and Lettinga, 1997) and removal of suspended particles. At Dukat Dairy Industry Inc., Factory Sirela the removal of COD of 46±6.8 %, BOD of 49.4±3.7 %, suspended particles of 65.2±4.98 %, total N of 44.7±9.8 %, total P of 22.3±24 %, and fats and oils of 43.5±5.1 % was achieved after primary wastewater treatment (year 2006). The removal of COD at Dukat Dairy Industry Inc., Factory Sirela before the addition of bioactivator is given for the period January-May in the year 2006 and are presented as average values (Figure 2), and as a daily average values for May in the year 2006 (Figure 3). From the results of determined parameters of quality of untreated and treated wastewater presented as average values (Figure 2), it was shown that the organic load at treatment system was 3043-5259 mg COD/L. Wastewater enters to the biological system with COD of 1360-2709 mg/L. The average values of COD in effluent discharged from wastewater treatment system of Dukat Dairy Industry Inc., Factory Sirela were in range 671-731 mg/L (Figure 2).

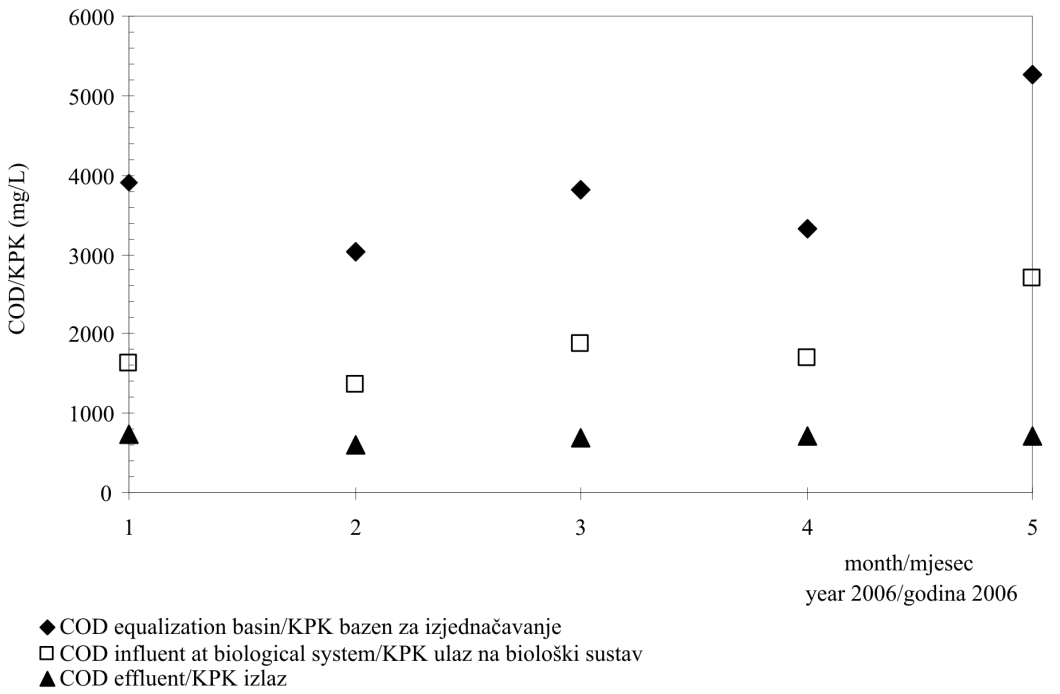

Figure 2. Average values of chemical oxygen demand (COD) obtained for the period of January-May in the year 2006 in the dairy wastewater treatment plant of milk processing industry Dukat Dairy Industry Inc., Factory Sirela

Slika 2. Prosječne vrijednosti kemijske potrošnje kisika (KPK) na uređaju za obradu otpadnih voda mljekarske industrije Dukat mliječna industrija d.d., Tvornica Sirela, za razdoblje siječanj-svibanj 2006. godine

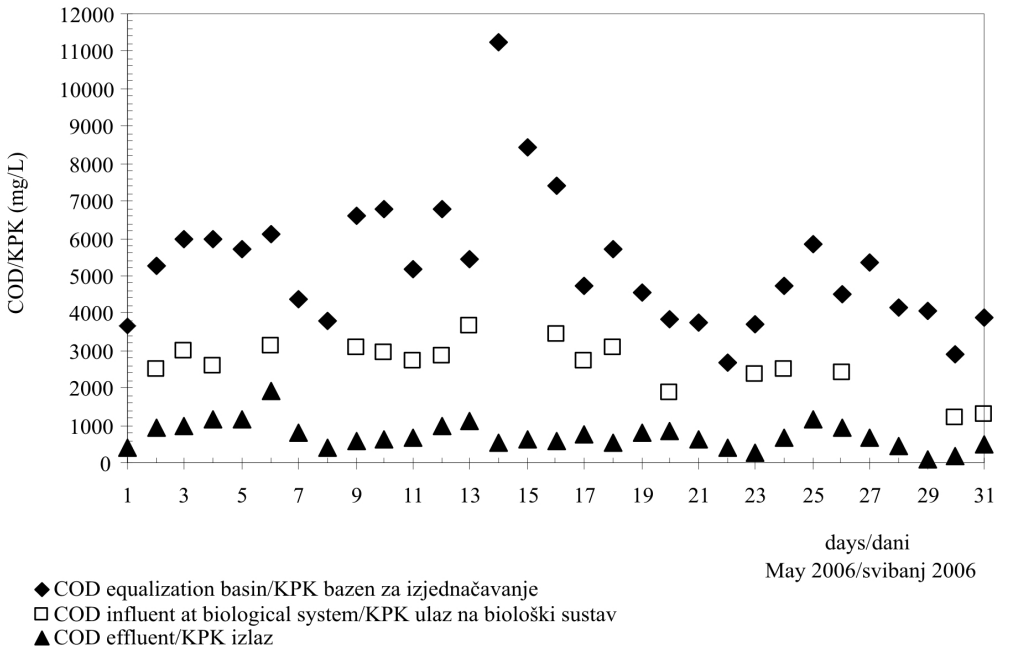

Figure 3. COD obtained in the dairy wastewater treatment plant of milk processing industry Dukat Dairy Industry Inc., Factory Sirela in May of the year 2006

Slika 3. KPK vrijednosti na uređaju za obradu otpadnih voda mljekarske industrije Dukat mliječna industrija d.d., Tvornica Sirela tijekom svibnja 2006. godine

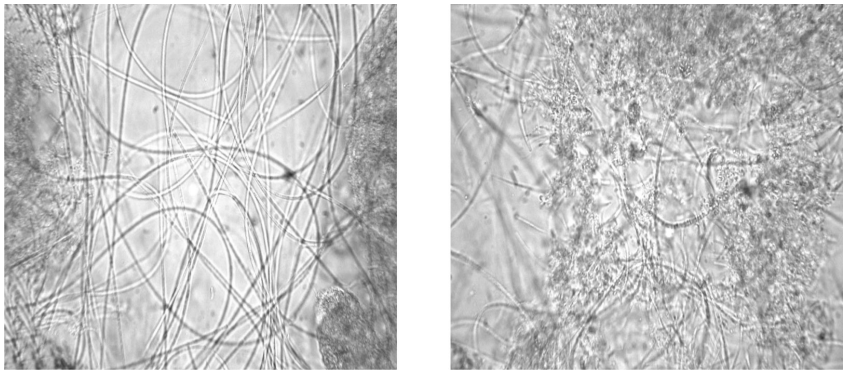

Figure 4. Microscopic appearance of activated sludge from the bioaeration basins of the wastewater treatment plant Dukat Dairy Industry Inc., Factory Sirela in the period without the addition of bioactivator "Aquatop® BA" (light microscope, magnification of 640 times)

Slika 4. Mikroskopski izgled aktivnog mulja (svjetlosni mikroskop, povećanje 640 x) uzorkovanog iz bioaeracijskih bazena sustava obradbe otpadnih voda Dukat mliječna industrija d.d., Tvornica Sirela u razdoblju bez dodatak bioaktivatora "Aquatop® BA"

From the results shown in figure 3 it is visible that COD effluent (value and up to 1920 mg/L) was more than permitted by the water rights permit (COD <700 mg/L). The reason for that was a high organic load of the system and disturbed quality of activated sludge (Figure 4). The activated sludge was of poor settling abilities, it was floating on the surface, and caused poor efficiency of wastewater treatment. The disturbed quality of sludge because of fluctuations in the composition of wastewater in terms of higher or lower loads with a biodegradable fraction of COD, the changes of organic loads, pres-

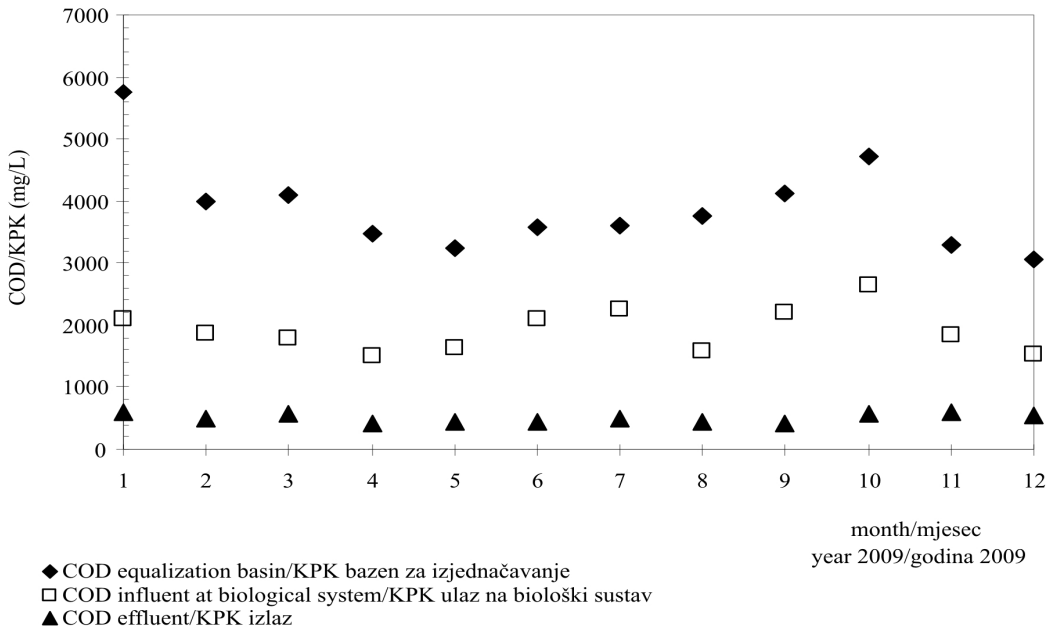

Figure 5. Average values of COD obtained in the dairy wastewater treatment plant of milk processing industry Dukat Dairy Industry Inc., Factory Sirela during the year 2009
Slika 5. Prosječne vrijednosti KPK na uređaju za obradu otpadnih voda mljekarske industrije Dukat mliječna industrija d.d., Tvornica Sirela, tijekom 2009. godine

ence of oils and fats and a low nutrient content was also pointed out by other authors (Greenberg et al., 1955; Pipes, 1977; Jenkins et al., 1993; Donkin, 1997; Danalewich et al., 1998; Hossain, 2004; Janczukowicz et al., 2008). The high COD with a high ratio of F/M causes the turbidity of treated wastewater (Goronszy and White, 1988).

According to the research of the work of 15 dairy wastewater treatment plants activated sludge bulking may occur periodically or it is constantly present (Danalewich et al., 1998). It is believed that this is due to the low dissolved oxygen concentration (which is favourable for the growth of filamentous microorganisms) and because of high organic loads (Danalewich et al., 1998).

In order to improve the efficiency of wastewater treatment of Dukat Dairy Industry Inc., Factory Sirela the role and contribution of bioactivator "Aquatop® BA" was investigated. The bioactivator was periodically added to the bioaeration basins, and its effect on the system performance during the year 2009 is shown on figure 5.

The appearance of activated sludge after the addition of bioactivator is shown on Figure 6.

The better flocculation of activated sludge, good settling, prevention of the growth of filamentous bacteria and stabile quality of treated wastewater to the required values prescribed by Croatian water of COD <700 mg/L and BOD <250 mg/L, was achieved after the addition of the bioactivator. In the literature it is emphasized that bioactivators-commercial products which are consist of microbial communities and are added to the system of dairy wastewater treatment are not effective if they are not added periodically in the system, because the microorganisms that are added do not retain in the system (washed out of the system) and other microorganisms become dominant (Loperena et al., 2007).

Furthermore, none of the commercially available bioaugmentation culture is effective in preventing the development of filamentous microorganisms, which results in bulking of activated sludge. It is believed that for the improving the work of wastewater treatment system it is better more precise process control rather than applying the bioaugmentation method (Martin and Zall, 1985; Martin and Zall, 1989). It was pointed out that the overgrowth

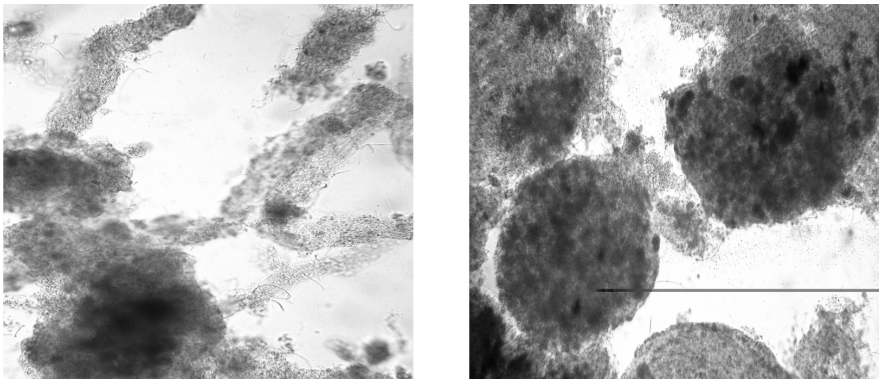

Figure 6. Microscopic appearance of activated sludge from the bioaeration basins of wastewater treatment plant Dukat Dairy Industry Inc., Factory Sirela in the period with the addition of bioactivator "Aquatop® BA" (light microscope, magnification of 640 times)

Slika 6. Mikroskopski izgled aktivnog mulja (svjetlosni mikroskop, povećanje 640 x) uzorkovanog iz bioaeracijskih bazena sustava obrade otpadnih voda Dukat mliječna industrija d.d., Tvornica Sirela u periodu uz dodatak bioaktivatora "Aquatop® BA"

of filamentous microorganisms in activated sludge is directly dependent on the composition of wastewater, the concentration of dissolved oxygen in the aeration tanks, dissolved organic material for growth of microbial biomass as well as process conditions (Chudoba, 1985). Furthermore, the high proportion of easy biodegradable organic compounds present in the dairy wastewater and the low nutrients content make dairy wastewater favourable substrate for the growth of filamentous microorganisms (Donkin, 1997). There is a little available literature data that reported about the use of commercial products as bioactivators, composed of biopolymers and/or vitamins and/or nutrients, for which the information about product state that have significant effects on the improvement of the operation of wastewater treatment system.

Conclusions

The wastewater of milk processing industry Dukat Dairy Industry Inc., Factory Sirela is highly loaded with organic compounds. It contains significant amounts of suspended solids and colloids that are removed before the biological wastewater treatment. Due to the sudden changes in the quality of wastewater and environmental conditions bulking of activated sludge was frequent occurrence on the system of wastewater treatment of Dukat Dairy Industry Inc., Factory Sirela. The reason for that is the overgrowth of filamentous microorganisms in the activated sludge which disrupts its quality causing bulking of activated sludge, the loss of sludge from the system and consequently inefficient wastewater treatment. Bioactivators based on the biopolymers, minerals and vitamins added to wastewater treatment system contribute to the prevention of the growth of filamentous microorganisms in activated sludge, better formation of activated sludge flocs, prevention of: foam formation, sludge bulking, flotation, the loss of activated sludge from the system and the stable quality of treated wastewater. By adding the bioactivator "Aquatop® BA" to the wastewater treatment system of Dukat Dairy Industry Inc., Factory Sirela it was achieved the quality of treated water to the required values according to the Croatian waters COD <700 mg/L and BOD <250 mg/L. Also, the microbiological quality of the activated sludge was improved. The bioactivator must be added periodically throughout the year in the appropriate quantity.

Poboljšanje učinkovitosti rada uređaja za obradu otpadne vode mljekarske industrije dodatkom bioaktivatora

Sažetak

Problem u radu sustava za obradu otpadne vode mljekarske industrije Dukat mliječna industrija d.d., Tvornica Sirela, koji primjenjuje tehnologiju aktivnog mulja čine filamentozne vrste mikroorganizama

koje izazivaju napuhavanje mulja, a posljedično tome neučinkovitu obradu otpadne vode. Također, takav mulj nema svojstva dobre taloživosti, odnosno odjeljivanja od pročišćene vode. Na takvo stanje utječe iznenadno veliko organsko opterećenje sustava i promjene okolišnih čimbenika. U svrhu poboljšanja rada sustava istražena je uloga i doprinos bioaktivatora "Aquatop® BA". Rad sustava motren je tijekom razdoblja siječanj-svibanj 2006. godine (nije dodavan bioaktivator) i 2009. godine (dodavan bioaktivator). Dodatkom bioaktivatora postiže se bolje povezivanje mikroorganizama u nakupine, dobro taloženje aktivnog mulja, sprječavanje rasta filamentoznih bakterija i ustaljena kakvoća izlaznog toka prema zahtijevanim vrijednostima propisanim Vodopravnom dozvolom i to kemijska potrošnja kisika (KPK) <700 mg/L, biokemijska potrošnja kisika (BPK) <250 mg/L.

Ključne riječi: aktivni mulj, bioaktivator, filamentozni mikroorganizmi, obrada otpadne vode mljekarske industrije

References

1. Adamse, A.D. (1968): Bulking of dairy waste activated sludge. *Water Research 2*, 715-722.
2. Albertson, O.E. (1991): Bulking sludge control-progress, practice and problems. *Water Science and Technology 23*, 835-846.
3. APHA (1998): Standard Methods for the Examination of Wastewater and Wastewater Treatment, American Public Health Association. American Water Works Association and Water Pollution Control Federation, Washington, D.C.
4. Barnett, J.W., Kerridge, G.J., Russell, J.M. (1994): Effluent treatment systems for the dairy industry. *Australian Biotechnology 42*, 26-30.
5. Ceruggs, C.E., Randall, C.W. (1998): Evaluation of filamentous microorganism growth factors in an industrial wastewater activated sludge system. *Water Science Technology 37* (4-5), 263-270.
6. Chudoba, J. (1985): Control of activated sludge filamentous bulking - VI. Formulation of basic principles. *Water Research 19* (8), 1017-1022.
7. Danalewich, J.R., Papagiannis, T.G., Belyea, R.L., Tumbleson, M.E., Raskin, L. (1998): Characterization of dairy waste streams, current treatment practices, and potential for biological nutrient removal. *Water Research 32* (12), 3555-3568.
8. Donkin, M.J. (1997): Bulking in aerobic biological systems treating dairy processing wastewaters. *International Journal of Dairy Technology 50* (2), 67-72.
9. Goronszy, M.C., White, J. (1988): Activated sludge treatment of high COD food processing wastes. *Proceedings of the 1988 Food Processing Waste Conference*, 393-411. Atlanta GA.
10. Goronszy, M.C. (1990): Batch reactor treatment of dairy wastewaters: a case history, *44th Purdue Industrial Waste Conference Proceedings*, 795-805. Purdue IN: Purdue University.
11. Greenberg, A.E., Klein, G., Kaufman, W.J. (1955): Effect of phosphorous on the activated sludge process. *Sewage Ind. Wastes 27*, 277-282.
12. Hossain, F. (2004): Activated sludge bulking: A review of causes and control strategies. *IE (I) Journal-EN* 85, 1-6.
13. ISO 10523 (1994): Water quality: Determination of pH
14. ISO 5663 (1984): Water quality: Determination of Kjeldahl nitrogen - methods after mineralization with selenium
15. ISO 5815 (1989): Water quality: Determination of biochemical oxygen demand after 5 days (BOD_5) - Dilution and seeding method
16. ISO 6878/1 (1986): Water quality: Determination of phosphorus - Part 1: Ammonium molybdate spectrometric method
17. ISO 7150/1 (1984): Water quality: Determination of ammonium
18. Janczukowicz, W., Zieliński, M., Dębowski, M. (2008): Biodegradability evaluation of dairy effluents originated in selected sections of dairy production. *Bioresource Technology 99*, 4199-4205.
19. Jenkins, D., Richard, M.G., Daigger, G.T. (1993): *Manual on the causes and control of activated sludge bulking and foaming*, Lewis Publishers, London.
20. Lemmer, H., Lind, G., Metzner, G., Nitschke, L., Schade, M. (1998): Vitamin addition in biological wastewater treatment. *Water Science and Technology 37* (4-5), 395-398.
21. Loperena, L., Ferrari, M.D., Saravia, V., Murro, D., Lima, C., Ferrando, L., Fernández, A., Lareo, C. (2007): Performance of a commercial inoculum for the aerobic biodegradation of a high fat content dairy wastewater, *Bioresource Technology 98*. 1045-1051.
22. Martin, J.H., Zall, R.R. (1985): Dairy processing wastewater bioaugmentation - An evaluation of effectiveness. *Proceedings of the 40th Industrial Waste Conference*, Purdue University, West Lafayette, Indiana, May 14-15, Butterworths, Boston, 351-360.
23. Martin, J.H., Zall, R.R. (1989): Bioaugmentation in the treatment of dairy processing wastewaters. *Dairy, Food and Environmental Sanitation 9*, 295-303.
24. Petruy, R., Lettinga, G. (1997): Digestion of a milk-fat emulsion. *Bioresource Technology 61*, 141-149.
25. Pipes, W.O. (1977): Microbiology of dairy waste activated sludge separation problems. *Industrial Wastes 23*, 26-31.
26. Pipes, W.O. (1978): Actinomycete scum production in activated sludge processes. *Journal of the Water Pollution Control Federation 50* (4), 628-634.

27. Stephenson, D., Stephenson, T. (1992): Bioaugmentation for enhancing biological wastewater treatment. *Biotechnology Advances 10* (4), 549-559.
28. Schwarzenbeck, N., Borges, J.M., Wilderer, P.A. (2005): Treatment of dairy effluents in an aerobic granular sludge sequencing batch reactor. *Applied Microbiology and Biotechnology 66*, 711-718.
29. Van Limbergen, H., Top, E.M., Verstraete, W. (1998): Bioaugmentation in activated sludge: current features and future perspectives. *Applied Microbiology and Biotechnology 50*, 16-23.
30. Vodopravna dozvola: Klasa UP/I-325-04/07-04/0023 Ur. broj: 374-21-4-07-2 izdana od Hrvatskih voda.
31. Wheatley, A.D., Johnson, K. A., Winstanley, C. I. (1988): Foaming in activated sludge plants treating dairy waste. *Environmental Technology Letters 9* (3), 181-190.
32. Wood, D.K., Tchobanoglous, G. (1975): Trace elements in biological waste treatment. *Journal of Water Pollution Control Federation 47*, 1933-1945.