Wastewater Treatment for Food Processing Industries

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Abstract. Rapid industrialization and urban growth coupled with continual improvement of urban spaces requires addressing the challenges of preventing negative anthropogenic impact on the environment. In particular, this applies to food processing, a strategic sector that sustainably provides people with high-quality food. Food processing affects water reservoirs the most. Closed cycles are the solution proposed to prevent or reduce the environmental impact of food processing wastes. This will help not only address environmental issues but also optimize the use of natural resources. Wastewaters contain fodder residues, table salt, detergents, nitrites, phosphates, alkali, acids; they might also contain pathogenic microflora. This paper presents an optimal technology for the neutralization and deep treatment of AIC wastewaters.

1. Relevance

Russian industries are one the rise once again, which creates a favorable investment climate and calls for upgrading both the facilities and the production management systems. The upgrades should use cutting-edge technology and ensure compliance with the state-of-the-art environmental standards while also improving the quality and international competitiveness of the product.

Russian and international experience shows that in a market economy, lack of funding may jeopardize any attempt to fully and optimally use recycled materials; as such, it necessitates novel integrated solutions. Such solutions are expected not only to increase the production of high-quality foods and fodder while reducing waste generation, but also to make the industry profitable by saving energy and resources, reducing contamination and lowering the waste discharge fees, as well as by implementing efficient wastewater treatment.

The goal hereof is to lay the scientific foundations for novel integrated solutions applicable to the biotechnology-backed food processing industry in the Republic of North Ossetia — Alania, which will make it eco-friendlier and more cost-effective while also raising the environmental standards, enhancing the wastewater treatment technology, and improving the region’s ecological conditions with a focus on applying the results to the regional production cycle management and decision-making system.

Hence the objective: to develop an optimal technology for the neutralization and deep treatment of food processing wastewaters so as to address the region’s environmental situation.

Foods tend to accumulate and concentrate all the environmentally hazardous substances.
Canned food may receive heavy-metal salts from the equipment and cans; the food-can interaction can also lead to the synthesis of new substances, whose effects on human health are unknown. Mechanical, thermal, and other processing of plant and animal tissue exposes their components to a variety of chemical reactions (pasteurization, sterilization, and grinding).

Properties of fruit and vegetable canning wastewaters are a function of such variables as the type and quantity of raw materials received for processing, the product range, the equipment in use, the water and wastewater recycling systems (whether in place or not) [1-2].

Wastewater is generated by such processes as hydraulic transport, sorting the raw materials on the belt, washing the materials and processed foods, cutting and portioning processed foods, thermal treatment and blanching, packing the processed foods, filling, sterilization, autoclaving, etc. 95% of facility-consumed water become wastewater [3-4].

Most food processing facilities generate three types of wastewaters: production waters (contaminated waters and process waters), household waters, and atmospheric waters. This is why such facilities use multiple sewerage systems: contaminated waters and household waters are discharged through one part of the system, whether single or segmented; process and atmospheric waters are carried by the other part. [5-13].

As public utility companies fail to treat wastewaters properly while food processing industry generates considerable discharge, the Terek River remains heavily polluted with organics and biogenic substances. In 2017, organic contamination averaged at 26.0 to 22.8 times MPC. Ammonium salt levels varied from 5.6 to 3.2 times MPC; phosphate levels were within a range of 5.4 to 1.7 times MPC. Petroleum contamination rose to 3.3 times MPC due to heavy rainfall and surficial ablation. Nitrites reached 4.5 times MPC, while copper, manganese, and zinc concentrations varied within 2.0 times the maximum permissible concentration [11].

There are five wastewater indicators that must be kept within specific thresholds at any point of sewerage, as they determine how wastewater will affect the piping and the wastewater treatment plants (WWTP). These are: BOD₅ (BOD₅) and the concentrations of sulfates, sulfides, fats, and petroleum products. Wastewater discharged by the Vladikavkaz Food Processing Plant LLC (“the Plant”) contains no sulfides.

Analysis of its wastewaters sampled over 2014–2017 shows that the factory’s wastewater contains the following harmful substances: suspended substances, chlorides, BOD, fats, synthetic surfactants, iron, and ammonia.

Besides, the wastewaters might also contain dry residue, nitrates, phosphates, sulfates, pesticides, and ether-soluble substances.

| Wastewater source                          | Harmful substance | Harmful substance content before treatment | Amount of harmful substances discarded | Total discharged wastewaters | thousand m³/year |
|--------------------------------------------|-------------------|------------------------------------------|--------------------------------------|-----------------------------|-----------------|
| The office, production sites, boiler rooms, and the vehicle base | Ammonium nitrogen | 1.20 | 2,496.0 | 2,496.0 | 0.05 | 20.171 | 41.956 |
|                                           | BOD₅              | 28.0 | 58,240.0 | 58,240.0 | 1.175 |              |      |
|                                           | Suspended         | 20.0 | 41,600.0 | 41,600.0 | 0.84  |              |      |
|                                           | substances        |     |          |          |      |              |      |
|                                           | Total iron        | 0.13 | 270.4    | 270.4    | 0.005 |              |      |
|                                           | Chlorides (anions)| 30.0 | 62,400.0 | 62,400.0 | 1.26  |              |      |
Table 2. Wastewaters discharged to the wastewater receivers of Vladikavkaz Food Processing Plant LLC.

| Harmful substances          | Concentration, mg/l | Untreated discharge, t/year | Total discharge t/year |
|----------------------------|---------------------|----------------------------|------------------------|
| Ammonium nitrogen          | 0.05                | 0.05                       | 0.05                   |
| BOD₅                       | 1.175               | 1.175                      | 1.175                  |
| Suspended substances       | 0.84                | 0.84                       | 0.84                   |
| Total iron                 | 0.005               | 0.005                      | 0.005                  |
| Chlorides (anions)         | 1.26                | 1.26                       | 1.26                   |

Pursuant to the goal, the first stage was to analyze the composition of the Plant’s original water (“the input”), see Table 3.

Then the input (w₁) was aerated, and its composition was re-checked on Days 3, 6, 13, 22, and 40, see Tables 4, 5, 6, 7, and 8. Changes in the concentrations of biomass, manganese, and iron were recorded on the same days, see Table 9 and Figure 1. On Day 28, the experimenters measured the oxidative capacity of the substrate w₁, see Table 10.

Table 3 presents the chemical and biological composition of the input w₁.

Table 3. Input w₁ analysis.

| Indicators                  | Concentration | MPC  |
|-----------------------------|---------------|------|
| pH                          | 6.5           | 6-9  |
| BOD₅ mgO₂/l                 | 3.5           | 3    |
| COD₅ mgO₂/l                 | 1,526.7       | 500  |
| BOD₅:COD%                   | 0.002         |      |
| N-NH₄⁺ mg/l                 | 6.0           | 5    |
| N-NO₂⁻ mg/l                 | 0.003         | 3.3  |
| N-NO₃⁻ mg/l                 | 1.3           | 45   |
| P-PO₄³⁻ mg/l                | 0.41          | 12   |
| Fe³⁺ mg/l                   | 2.9           | 0.3  |
| Mn tot. mg/l                | 0.5           | 0.1  |
| Suspended substances, mg/l  | 30            | 300  |
| PFU                         | 12            |      |

Analysis of the averaged data led to the following findings:

1. The BOD₅:COD ratio was below 60%, which meant biological treatment would be suboptimal. This necessitated other methods, e.g. electrochemical oxidation of organic matter.
2. Apparently, biochemical oxidation was inhibited by above-MPC concentration of heavy metals (Mn ≈ 0.1 mg/l, Fe ≈ 0.3 mg/l).

Table 4 presents the chemical and biological composition of the input w₁ as recoded after three days of aeration.
Table 4. Input $w_1$ analysis after 3-day aeration.

| Indicators         | Unit    | Concentration |
|--------------------|---------|---------------|
| pH                 | −       | 7.5           |
| BOD$_5$            | mgО/л   | 16.0          |
| COD                | mgО/л   | 361.2         |
| BOD$_5$ : COD      | %       | 0.04          |
| N-NH$_4^+$         | mg/л    | 8.0           |
| N-NO$_2^-$         | mg/л    | 0.007         |
| N-NO$_3^-$         | mg/л    | 1.6           |
| P-PO$_4^{3-}$      | mg/л    | 1.5           |
| Fe$^{3+}$          | mg/л    | 0.2           |
| Mn tot.            | mg/л    | 0.5           |
| Suspended substances | mg/л    | 20            |

Based on these results, we may conclude that:

1. Aeration caused the insoluble compounds to oxidize, which reduced COD while increasing BOD$_5$ by forming the organic compounds detectible by this method.
2. Increase in nitrogen concentrations (in all forms) indicated that the oxidation of organic matter had destroyed protein molecules and caused amino acids to dissolve in water. In the presence of dissolved oxygen, these compounds were hydrolyzed, which raised the concentrations of biogenic compounds in water.
3. Dissolved oxygen lowered the concentrations of the compounds of Fe$^{3+}$ and Mn$_{tot}$ while synthesizing the oxides of these compounds.

Table 5 presents the chemical and biological composition of the input $w_1$ as recorded on Day 6.

Table 5. Input $w_1$ analysis, Day 6.

| Indicators         | Unit    | Concentration |
|--------------------|---------|---------------|
| pH                 | −       | 7.3           |
| BOD$_5$            | mgО/л   | 7.5           |
| COD                | mgО/л   | 608.0         |
| BOD$_5$ : COD      | %       | 0.01          |
| N-NH$_4^+$         | mg/л    | 5.5           |
| N-NO$_2^-$         | mg/л    | 0.01          |
| N-NO$_3^-$         | mg/л    | 0.5           |
| P-PO$_4^{3-}$      | mg/л    | 1.4           |
| Fe$^{3+}$          | mg/л    | 0.07          |
| Mn tot.            | mg/л    | 0.4           |
| Suspended substances | mg/л    | 3             |

This indicates that:

1. Further aeration reduced the concentration of the dissolved organic matter.
2. Further aeration lowered the concentration of ammonium nitrogen, i.e. caused nitrification.
3. Reduction in PO$_4^{3-}$ indicated that aeration caused new microbial life to emerge: microorganisms use it to build new cells.
4. Heavy-metal concentrations continued to drop.

Table 6 presents the chemical and biological composition of the input $w_{13}$ as recorded on Day 13.
Table 6. Input w1 analysis, Day 13.

| Indicators      | Unit      | Concentration |
|-----------------|-----------|---------------|
| pH              | –         | 7.5           |
| BOD$_5$         | mgO$_2$/l | 7.5           |
| COD             | mgO$_2$/l | 400           |
| BOD$_5$ : COD   | %         | 0.02          |
| N-NH$_4^+$      | mg/l      | 15.5          |
| N-NO$_2$        | mg/l      | 0.05          |
| N-NO$_3$        | mg/l      | 0.5           |
| P-PO$_4^{3-}$   | mg/l      | 2.5           |
| Fe$^{3+}$       | mg/l      | 0             |
| Mn$_{tot.}$     | mg/l      | 0.3           |
| Suspended substances | mg/l | 680           |

This indicates that:
1. Further aeration reduced the concentration of the dissolved organic matter.
2. Further aeration lowered the concentration of ammonium nitrogen, i.e. caused nitrification.
3. Reduction in PO$_4^{3-}$ indicated that aeration caused new microbial life to emerge: microorganisms use it to build new cells.
4. Heavy-metal concentrations continued to drop.

Table 7 presents the chemical and biological composition of the input w$_1$ as recorded on Day 22.

Table 7. Input w$_{22}$ analysis, Day 22.

| Indicators      | Unit      | Concentration |
|-----------------|-----------|---------------|
| pH              | –         | 5.3           |
| BOD$_5$         | mgO$_2$/l | 9.0           |
| COD             | mgO$_2$/l | 738.7         |
| BOD$_5$ : COD   | %         | 0.01          |
| N-NH$_4^+$      | mg/l      | 14.0          |
| N-NO$_2$        | mg/l      | 0.01          |
| N-NO$_3$        | mg/l      | 0.7           |
| P-PO$_4^{3-}$   | mg/l      | 2.2           |
| Fe$^{3+}$       | mg/l      | -             |
| Mn$_{tot.}$     | mg/l      | 0.2           |
| Suspended substances | mg/l | 10            |

Analysis of the averaged data led to the following findings:
1. Aeration caused the organic matter to oxidize, which raised the COD.
2. Drop in water pH value resulted in the accumulation of nitrite nitrogen and inhibited further nitrification.
3. Increase in the concentration of suspended substances indicated an increase in microbial biomass.

Table 8 presents the chemical and biological composition of the input w$_1$ as recorded on Day 40.
Table 8. Input w₁ analysis, Day 40.

| Indicators       | Unit | Concentration |
|------------------|------|---------------|
| pH               | -    | 7.4           |
| BOD₅             | mgO₂/l | 12.5         |
| COD              | mgO₂/l | 410.4        |
| BOD₅ : COD       | %    | 0.03          |
| N-NH₄⁺           | mg/l | 3.0           |
| N-NO₂⁻           | mg/l | 0.05          |
| N-NO₃⁻           | mg/l | 1.8           |
| P-PO₄³⁻          | mg/l | 0.02          |
| Fe³⁺             | mg/l | -             |
| Mn₉             | mg/l | 0             |
| Suspended substances | mg/l | 20           |

Based on these results, we may conclude that:

1. 40-day aeration did not increase the biomass, as the wastewater contained heavy metals.
2. Heavy metals had to be removed for biological treatment.

Table 11 and Figure 1 show how the concentration of biomass, manganese, and iron in the input w₁ changed over 40 days.

Table 9. How the concentration of biomass, manganese, and iron in the input w₁ changed over 40 days of aeration.

| Day | Unit | Concentration |
|-----|------|---------------|
|     | Suspended substances | Mn₉ | Fe³⁺ |
| Initial value | mg/l | 30 | 0.5 | 2.9 |
| 3    | mg/l | 20 | 0.45 | 0.17 |
| 6    | mg/l | 3 | 0.36 | 0.07 |
| 13   | mg/l | 680 | 0.37 | 0.13 |
| 22   | mg/l | 10 | 0.22 | 0 |
| 40   | mg/l | 20 | 0 | – |

Analyzing this reveals that aeration resulted in a gradual accumulation of manganese in microbial cells. Lysis began on Day 13, which raised the concentration of manganese in treated water.

Table 10. Changes in the composition of the input w₁ due to oxidation in contact.

| No. p/p | Indicators       | Unit | Init. data | Day 3 | Day 6 | Day 13 | Day 22 | Day 40 | MPC |
|---------|------------------|------|------------|-------|-------|--------|--------|--------|-----|
| 1       | pH               | -    | 6.5        | 7.5   | 7.3   | 7.5    | 5.3    | 7.4    | 6.9 |
| 2       | BOD₅             | mgO₂/l | 3.5    | 16.0  | 7.5   | 7.5    | 9.0    | 12.5   | 3   |
| 3       | COD              | mgO₂/l | 1,526.7 | 361.2 | 680.0 | 400    | 738.7  | 410.4  | 500 |
| 4       | BOD₅ : COD       | %    | 0.2      | 0.04  | 0.01  | 0.14   | 0.01   | 0.03   |     |
| 5       | N-NH₄⁺           | mg/l | 6.0      | 8.0   | 5.5   | 15.5   | 14.0   | 3.0    | 5   |
| 6       | N-NO₂⁻           | mg/l | 0.003    | 0.007 | 0.01  | 0.05   | 0.01   | 0.05   | 3.3 |
| 7       | N-NO₃⁻           | mg/l | 1.3      | 1.6   | 0.5   | 0.5    | 0.7    | 1.8    | 45  |
| 8       | P-PO₄³⁻          | mg/l | 0.41     | 1.5   | 1.4   | 2.5    | 2.2    | 0.02   | 12  |
| 9       | Fe³⁺             | mg/l | 2.9      | 0.2   | 0.07  | 0      | –      | –      | 0.3 |
| 10      | Mn₉             | mg/l | 0.5      | 0.5   | 0.4   | 0.3    | 0.2    | 0      | 0.1 |
| 11      | Suspended sub.   | mg/l | 30       | 20    | 3     | 680    | 10     | 20     | 300 |

Analyzing this reveals that aeration resulted in a gradual accumulation of manganese in microbial cells. Lysis began on Day 13, which raised the concentration of manganese in treated water.
Based on the results shown in Table 10, we may conclude that:

1. The aeration tank needs to use silt aged 13 to 16 days to maximize the water treatment performance.
2. Protein hydrolysis peaks on Days 13 and 22.
3. Silt growth peaks on Day 13. Further aeration results in lysis, which causes the manganese concentrations to skyrocket.

References

[1] Biragova N F 2003 Biological sorbents for the food industry Materials of the international scientific conference “Dynamics of processes in nature, society and technology: informational aspects (Taganrog) pp 4-6
[2] Biragova N F 2003 The main methods of greening food production Materials of the international scientific conference “Dynamics of processes in nature, society and technology: informational aspects (Taganrog) pp 7-10
[3] Komarov V I 1996 Food safety problems Food industry 2 p 26
[4] Komarov V I, Lebedev V I, Manuylova T A 1998 Problems of using secondary raw materials of industries and processing industry and their impact on the environment Storage and processing of agricultural raw materials 2 p 6
[5] Guidelines for environmental impact assessments in the development of justifications for investment in construction, feasibility studies and or projects for the construction, reconstruction, expansion, modernization, conservation or liquidation of household and or other facilities and complexes Letter of the Ministry of Natural Resources from 01/23/96 No 02-02/35-181
[6] Yakovenko V L, Ustinnikov B A, Bogdanov Yu P, Gromov S I 1981 Production reference Raw materials, technology and technochemical control (M. : Light and food industry)
[7] Alborov I D 2001 Terek river basin pollution Bulletin of the MANEB 4(40) (Vladikavkaz) pp 33-35
[8] Rybalsky N G, Lyakh S P 1990 Biotechnological potential of consortia of microorganisms in the national economy (M.) 200 p
[9] Wiegel J 1980 Expimentia vol 36 p 1434
[10] Larson L, Nielsen P, Ahring B 1997 Thermoanaerobacter methane and ethanol-producing extremaly thermophilic anaerobic bacterium from a hot-spring in Iceland *Archives of Microbiology* vol 168 2 pp 114-119

[11] Khramtsov A G 1999 Secondary raw materials and ways of their rational use in a market economy *News of universities. Food technology* 5-6 pp 14-17

[12] GN 2.1.5.689-98 Maximum Permissible Concentrations (MPC) of chemicals in the water of water bodies of drinking, cultural and domestic water use (M.)

[13] Report on the environmental situation in the Republic of North Ossetia-Alania in 2017 (Vladikavkaz) 20 p

[14] 2000 Hygienic requirements for surface water protection Sanitary rules and norms SanPiN 2.1.5.980-00 Ministry of Health of Russia (Moscow)

[15] Serpokrylov N S and others 2009 Ecology of wastewater treatment by physicochemical methods (M.: DIA) 262 p

[16] Voronov Yu V, Yakovlev S V 2006 Sewage and wastewater treatment: textbook For Universities (direction "Construction") 4th ed. and reslave (M.: DIA: Publishing house of MGSU) 704 p

[17] Alekseev E V 2007 Physico-chemical wastewater treatment: Textbook (M.:Publishing house of the Association of construction universities) 248 p

[18] Kuznetsov A E, Gradova N B 2006 The scientific basis of ecobiotechnology: Textbook (M.: Mir) 504 p

[19] Hentze M 2006 Wastewater treatment: Trans. from English (M.: Mir) 480 p

[20] Ryabchikov B E 2004 Modern methods of preparing water for industrial and domestic use (M.: DeLi print) 328 p