Quality assessment of activated sludge biological treatment pulp and paper plant with variable load

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Abstract. The quality assessment of activated sludge of biological treatment facilities of pulp and paper mill depending on the type of load is given. Considered three cases of the load on the activated sludge and given their characteristics in the sedimentary and hydrological indicators under conditions of variable load. Depending on the type of load, there is a satisfactory operation of activated sludge, or its swelling caused by the bacteria Zoogloea ramigera or filamentous forms of microorganisms.

1. Introduction
Pulp and paper plants are considered to be one of the leading industries in wastewater generation due to the technological process specifics: up to 350 m$^3$ of water are required for the production of one ton of enterprise products in average [1].

The sewage of the pulp and paper industry contains a large amount of hardly oxidizable compounds, such as fatty and resin acids, sulfurous compounds, lignin and its derivatives. In addition, a high content of suspended substances is observed in wastewater - particles of bark, cellulose fibers, and mineral particles.

In addition to physico-chemical methods of wastewater treatment, enterprises of the pulp and paper industry also use a biological method using aeration tanks, which is based on the ability of microorganisms to oxidize organic compounds dissolved in wastewater. At the same time, changes in the composition of wastewaters or salvo discharges of large effluent volumes entail a violation of the habitat conditions of the active sludge microorganisms.

Wastewater from pulp and paper enterprises are often characterized by composition inconstancy. In one period, wastewater can be characterized by high values of certain indicators, in another period it can fundamentally change in the direction of indicators' increase or decrease. Such variability of the chemical composition of wastewater negatively affect on the quality of activated sludge and its inhabitants.

The purpose of the research was to assess the activated sludge quality from biological wastewater treatment under variable load conditions at a pulp and paper industry enterprise.

2. Materials and methods
The biological treatment facilities of the pulp and paper industry of the Perm Kray were selected as an experimental site. The wastewater of this enterprise is characterized by the variability of the chemical
composition and formation of variable volume, while the enterprise occasionally has a salvo discharge of highly polluted wastewater, which increase the load on the treatment facilities.

To assess the impact of load on activated sludge, three load cases were considered:
- variant 1 – the average load on activated sludge in the range of 300-350 mg/g;
- variant 2 – high loads on active sludge 500 mg/g and above;
- variant 3 – the average load on the active within 250 mg/g with excess toxic substances (high content of sulfonated lignin, etc.).

The impact of the load on activated sludge was assessed by the following indicators: the dynamics of sedimentation (sedimentation characteristics), the characteristics of active sludge cotton, the structure and properties of active sludge flakes, the species diversity of the biocenosis.

Wastewater which is supplied to the biological wastewater treatment facilities of the pulp and paper enterprise was used for experimental studies.

To assess the quality of the activated sludge, the sludge mass from the biological treatment plant from the pulp-and-paper enterprise, selected under various conditions of the treatment plant operation, was used.

3. Results

The characteristics of the qualitative composition of wastewater for different experimental options are presented in table 1. The composition of the investigated wastewater is typical for the pulp and paper industry.

**Table 1.** Characteristics of the qualitative composition of wastewater supplied to the biological treatment facilities.

| Indicator            | Unit       | Indicator value                |
|----------------------|------------|-------------------------------|
|                      | Variant 1  | Variant 2                    | Variant 3                   |
| COD                  | mg/dm³     | 1500 – 1600                   | 2000 - 3500                 | 1150 - 1291               |
| BOD₅                 | mg/dm³     | 620,0 – 780,0                 | 920,0 – 1309,0              | 342,0 – 500,0            |
| Suspended substances | mg/dm³     | 108,0 – 128,0                 | 108,0 – 148,0               | 108,0 – 115,0            |
| Ammonium ion         | mg/dm³     | 14,1 – 23,0                   | 14,1 – 23,0                 | 14,1 – 23,0              |
| Phosphates           | mg/dm³     | 1,1 – 1,7                     | 1,1 – 1,7                   | 1,1 – 1,7                |
| Lignosulfonic acid   | mg/dm³     | 285,0 – 352,0                 | 285,0 – 652,0               | 450,0 – 652,0            |
| Oil products         | mg/dm³     | 1,3 – 3,7                     | 1,3 – 3,7                   | 1,3 – 3,7                |
| Nitrate anion        | mg/dm³     | 3,5 – 14,3                    | 3,5 – 14,3                  | 3,5 – 14,3               |
| Nitrite anion        | mg/dm³     | 0,01 – 0,3                    | 0,01 – 0,3                  | 0,01 – 0,3               |
| Synthetic surfactants| mg/dm³     | 2,7 – 4,8                     | 2,7 – 4,8                   | 2,7 – 4,8                |
| Sulfate anion        | mg/dm³     | 97,0 – 401,0                  | 97,0 – 401,0                | 97,0 – 401,0             |
| Dry residue          | mg/dm³     | 194,0 – 2000,0                | 800,0 – 3106,0              | 194,0 – 3106,0           |
| Phenol               | mg/dm³     | 0,01 – 1,1                    | 0,01 – 1,1                  | 0,01 – 1,1               |
| Formaldehyde         | mg/dm³     | 0,03 – 0,7                    | 0,03 – 0,7                  | 0,03 – 0,7               |
| Chloride anion       | mg/dm³     | 22,3 – 113,0                  | 22,3 – 113,0                | 22,3 – 113,0             |

The dynamics of sedimentation of activated sludge in experimental variants are shown on the figure 1 shows. The best sedimentation characteristics had activated sludge in variant 1 at medium loads. Active sludge had the worst characteristics at high loads and at medium loads with a high content of toxic substances.
Figure 1. Dynamics of sedimentation of activated sludge under different loads.

Figure 2. Active sludge of different experimental variants: a - ciliates p. Opercularia in activated sludge (variant 1); b - bacteria Zoogela ramigera in variant 2; c - development of filamentous forms of microorganisms in variant 3.
The evaluation of the activated sludge’s stat in the experimental variants showed that, depending on the load (from medium to high), the biocenosis of activated sludge changes in the direction of deterioration.

The microscopic picture of the activated sludge at different loads is presented in figure 2.

4. Discussion

In first variant, at moderate loads, activated sludge was characterized by dense bacterial cotton without the prevalence of fungal filaments, consisting of live bacteria, mainly coccus and rod forms. Biocenosis of activated sludge was represented by a significant number of protozoa of various species: single species of colorless flagellates r. *Bodo*, free-floating infusoria p. *Paramecium (Paramecium Aurelia)*, attached forms of ciliates: p. *Vorticella* and colonial r. *Opercularia* (figure 2). The frequency of these microorganism species on a five-point scale ranged from 2 (p. *Paramecium*) to 5 points (p. *Vorticella, Opercularia*).

Gel swelling of activated sludge, which is characterized by an excess amount of exopolymer gel, was observed under high loads in second variant. Exopolymer gel is secreted by saprophytic bacteria for the degradation mechanism of difficult-establishing connections. The of activated sludge was loose; the predominant species in the biocenosis was *Zooglea ramigera*: the simplest species were not found.

The filamentous swelling of activated sludge was observed in the third variant at medium loads with a high content of toxic substances. This is due to the development of actinomycetes and saprophytic fungi, or by sulfur bacteria. At the same time, the active sludge’s structure is loose, with a predominance of a large number of free bacteria coccal and rod forms. The biocenosis was characterized by a small number of the simplest microorganisms, represented mainly by colorless flagellates p. *Bodo*.

5. Conclusion

The results of experimental studies have shown that at different loads on activated sludge from biological facilities of a pulp and paper enterprise, there is a qualitative change in activated sludge according to sedimentation and hydrobiological indicators. At medium loads, activated sludge is in a satisfactory condition, has good sedimentation characteristics, as evidenced by the dynamics of subsidence, and it is also characterized by a rich and diverse biocenosis. The quality of the activated sludge sharply decreases when the quality of cleaning deteriorates and the load increases. Sedimentation characteristics deterioration as well as swelling of the activated sludge (both filamentous or gel, depending on the type of load) are observed. To maintain the activated sludge in a satisfactory condition, it is necessary to monitor the incoming sewage to biological treatment facilities, not to allow increased loads on the activated sludge.

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