Study of the effect of electron irradiation on the density of the activated sludge in aqueous solution

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Abstract. Complex experimental studies on the effect of electron irradiation on the deposition rate of active sludge in aqueous systems by the optical method have been carried out. The obtained dependences of density ($\rho$) on time ($t$) are of the same nature for different radiation sources. The experimental curves of the dependence of the active sludge density on time are satisfactorily described by an exponential model.

1. Introduction

As it is known, industrial, agricultural production and the accompanying urbanization, which are developing at a very rapid pace, have led to an unprecedented degree of environmental pollution in the history of mankind. The increase in the number of consumers of natural resources caused a jump in the level of sewage and the degree of their ecological danger, which led to an increase in their direct discharge into natural watercourses, but their biological decomposition and self-purification is very slow [1]. Sewage treatment is now increasingly replaced by artificially created and industrial facilities, as they are a protective barrier to natural hydrobionts [2]. The present state of the quality of water in natural reservoirs is largely determined by the degree of purity of wastewater that has undergone biological treatment, since they constitute the bulk of the total volume of sewage. The efficiency of purification is tightly related to the processes of self-purification in natural reservoirs. However, the various methods of intensifying biological purification that are being developed open up the possibility of a significant improvement in the latter. Biological purification should be considered as an obligatory final link before discharge of sewage into the water body, therefore, as a powerful protective barrier against pollution of the natural environment [3].

The increased requirements to the quality of treated wastewater discharged into water bodies, in connection with the approval of the maximum permissible discharges (MPD) of pollutants and the solution of issues of re-use of biologically treated waters in production, necessitates the intensification of the operation of existing treatment facilities, the search for new opportunities to improve the quality of treated sewage waters [4]. Intensification of biological purification through reconstruction of existing facilities is associated with capital costs and technical difficulties, so now the development of hydrobiological, microbiological and biochemical methods for improving the operation of structures is more promising [5]. In recent years, the work related to the study of the effect of various types of irradiation on the structure and physico-chemical properties of various materials has been of great practical interest [6–8]. We have begun study on the effect of electron irradiation on the structure and properties of various biomaterials, which under such impacts vary greatly [9, 10]. At the same time, the
quality of systems also changes significantly. The quality of the treatment facilities can be determined by various methods, including by means of a sludge index and sedimentation rate. A well-precipitated sludge has a sludge index of about 60 mL/g, a less dense – 80 – 90 mL/g, and the sludge index higher than 300 mL/g indicates a failure of the treatment plant. This paper is devoted to determining the density of unirradiated and irradiated sludge by the optical method in aqueous solutions.

2. Experimental procedure
To determine the parameters of activated sludge (biomaterial), an experimental setup was created, the scheme of which is shown in Figure 1. The installation consists of a laser source, radiation detector, electronic unit, racks and various holders. The sludge, placed in a flask with water, was carefully shaken and installed between the laser and the detector. The dependence of the illumination (intensity) of light (green and red lines of the laser) on time was recorded.

3. Discussion of results
As a result of the studies (green and red ray), it was found that the total sedimentation of the sludge occurs for about 100 seconds. Figures 2 and 3 show the time dependences of the illumination of laser radiation. As follows from these Figures, the magnitude of the illumination, first increases sharply, and then gradually goes to saturation.

To determine the sludge index and sedimentation rate of activated sludge, the dependence of the active sludge density in water on time was used. The relationship between the illumination and the density of activated sludge in water was determined by the equation: (1)

$$\rho = \rho_{\text{max}} \cdot \frac{E_{\text{max}} - E}{E_{\text{max}}}$$

where $\rho_{\text{max}}$ is the maximum density of activated sludge in water; $E_{\text{max}}$ is illumination with complete sedimentation of the activated sludge; $E$ is illumination at a given time.
Figure 2. Time dependences of the illumination of green (a) and red (b) laser radiations as they pass through the activated sludge.

Figure 2 shows the experimental data on the dependence of the activated sludge density on time, obtained using the dependence of $E$ on $t$ under irradiation with red and green lasers (dots). It is seen that in time the density decreases gradually in both cases. Similar experiments were performed on electrons and photons (gamma rays and X-rays) irradiated activated sludge (Figures 3–5). In this case, irradiation affects significantly the experimental dependences. As can be seen from the Figures, the nature of the $\rho$ dependence on $t$ after irradiation does not change. The experimental curves are explained within the framework of the exponential model proposed by the authors. The essence of it is as follows. The active sludge, which is in solution, is affected constantly by gravity. In the first approximation, the density change $d\rho$ at some (almost any) depth is proportional to the density $\rho$ itself (with the minus sign, since the density decreases with time) and the time variation $dt$. Proceeding from this assumption, we will write down the differential equation for density variation $d\rho$. Thus:

$$d\rho = -\rho dt / t_0.$$  \hspace{1cm} \text{(2)}

Integrating $t$ from 0 to $t_0$ and from $\rho$ to 0, we obtain (3).

$$\rho = \rho_{\text{max}} \exp(-t/t_0).$$  \hspace{1cm} \text{(3)}

In equation (3), the value of $t_0$ is the time during which the density of the activated sludge decreases by $e$–fold.

Figures 3 – 5 show the dependence of the activated sludge density on time in comparison with the experimental data. From the curves of the dependence of the density ($\rho$) on time ($t$) it follows that they are of the same nature for different radiation sources. At high radiation doses (Figure 4), the density of activated sludge decreases (the deposition rate increases), as it becomes less active. When irradiated with low doses of 3 R (Figure 5), the sedimentation rate decreases, indicating an increase in the activity of sludge in the aqueous solution. According to the calculations, the activated sludge index from Lake Sorbulak was 90 mL/g, and the average sedimentation rate was 2/3 mL/min.
Figure 3. Dependence of the density of non-irradiated sludge on time during the passage of green (a) and red (b) laser radiations through activated sludge.

Figure 4. Dependence of the density of sludge irradiated with electrons at the dose of 500 kGy on time as green (a) and red (b) laser radiations pass through the activated sludge.

Figure 5. Dependence of the density of sludge irradiated with photons with the dose of 3 R on time as green (a) and red (b) laser radiations pass through the activated sludge.
4. Conclusions
1. From the curves of the dependence of the density ($\rho$) on time ($t$), patterns having the same nature for different radiation sources were obtained. According to the calculations, the activated sludge index from Lake Sorbulak was 90 mL/g, and the average sedimentation rate was 2/3 mL/min.
2. Different types of irradiation of biomaterial samples lead to an increase in the sludge index, which is associated with a decrease in natural purification. The reason for this is the reduction in the number of living microorganisms.
3. The curves of the dependence of the density ($\rho$) on time ($t$) are described satisfactorily in the framework of the exponential model.

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