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Low-oxygen method of wastewater treatment with effective nutrients removal

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Abstract. The paper presents the results of the research of energy efficient municipal wastewater treatment technology for oxidation ditches. The research includes laboratory experiments with the lab-scale models of oxidation diches and artificial wastewater and full-scale experiments with real wastewater. The lab-scale models allowed to model hydraulic regimes of different types of oxidation ditches. As a result of experiments, it has been proved the possibility of wastewater treatment with an effective nitrogen removal in the oxidation ditches at reduced concentrations of dissolved oxygen (0.5-0.6 mg/L) with extremely low organic loads and inner recirculation index about 450% (with average flow speed about 0.2 m/s). The design of the oxidation ditches makes it possible to achieve effective wastewater treatment from nitrogen compounds with a reduced amount of organic substrate and a concentration of dissolved oxygen. The operating recommendations for these types of bioreactors have been compiled.

1. Introduction

The main indicator of any technological scheme for wastewater treatment is the efficiency of technological processes. Wastewater treatment technologies must comply with the balance of low costs and high quality of treatment. One of the possible solutions to achieve the high quality of wastewater treatment with a reduction in total costs is the modernization of existing solutions that could be used both in the reconstruction and in the construction of new facilities [1].

From the point of view of domestic wastewater treatment, the main problem is the quality of nutrients (nitrogen and phosphorus compounds) removal [2]. Many treatment plants in Russia, even if they are built using modern technologies, contain design failures, or are not provided with the required operations. Thus, it seems necessary to develop wastewater treatment technologies that involve the deep removal of nutrients and are applicable at relatively low capital and operating costs. However, the technology should not impose increased operational requirements [3].

Oxidation ditches are one of the early models of bioreactors for wastewater treatment with freely floating activated sludge. For the operation of the oxidation ditches, a prolonged aeration regime was originally proposed at an increased specific content of dissolved oxygen per unit of organic loads [4]. But the technological schemes used in wastewater treatment in classical oxidation ditches do not provide an effective removal of nitrogen compounds. In this connection, it seems promising to develop the technology of simultaneous nitrification and denitrification in oxidation ditches [5].

Simultaneous nitrification and denitrification is a phenomenon in which both these reactions occur simultaneously in the same volume of bioreactor under practical identical conditions due to the emergence of stable anoxic microzones in the centers of large flocs at reduced concentrations of dissolved oxygen [6]. The hydraulic regime of the oxidation ditches under conditions of reduced aeration intensity and a high flow rate of the sludge mixture creates favorable conditions for the formation of large flocs of activated sludge and ensures a uniform distribution of the organic substrate [7]. In this case, unlike technological schemes with alternating aerobic and anoxic zones, the process of simultaneous nitrification and denitrification is possible at critically low BOD / N ratios [8].

In order to successfully implement the simultaneous nitrification and denitrification process, it is necessary to determine the optimum process parameters (flow rate, dissolved oxygen concentration, sludge age, specific loads, etc.) based on the incoming wastewater composition, hydraulic conditions for maintaining large activated sludge flocs and a control system technological parameters [9].

2. Materials and methods

The modeling of the biological wastewater treatment processes in the oxidation ditches consisted of three stages. To simulate wastewater treatment processes, various types of laboratory bioreactors were designed to allow for long-term experiments in a semi-automatic mode.

As the initial wastewater for the laboratory experiment, a model liquid based on peptone was used with the addition of solutions of acetates, phosphates and ammonium chloride. The proportion of easily oxidizable organic matter in the working solution, if necessary, was regulated by the addition of ethanol. The values of individual chemical parameters of the model liquid were selected in such a way as to correspond to the typical wastewater of small settlements of the Russian Federation [10].

The laboratory models were monitored by a set of regular sanitary-chemical analyzes, batch tests and analyzes, and an automated collection system for individual indicators. For sanitary and chemical analyzes, sampling was carried out from specially designated control points of the models, as well as from a tank with a working model liquid and from a discharge tray.

To control the biological activity of biomass, studies were regularly carried out to determine the rate of nitrification, denitrification, and aerobic oxidation of organic substances with activated sludge outside the experimental stand. Sampling of activated sludge was carried out from the return sludge feed systems provided for in the design of the test benches.

Regular complex tests were performed to study the sedimentation characteristics of activated sludge, which included the determination of the sludge index (SVI), the determination of the sludge index at a nominal dose of silt equal to 3.5 g / l ($SVI_{3.5}$), and the construction of a sedimentation curve for the actual dose of sludge and 4-5 additional sedimentation curves for dilute (with water from the bioreactor) or concentrated biomass. The sedimentation rate of the biomass (V_{hs}) was determined from the sedimentation curves under conditions of mutual influence of flocs. In addition, the flocculation potential of the activated sludge was determined at various technological parameters of the system (dispersed suspended solids or flocculated suspended solids - DSS / FSS test) using the Stuart SW6 laboratory flocculator.

3. Results and discussion

The first stage of the experiment consisted of two stages. At the first stage of the experiment, a laboratory model of an oxidation ditch with a vertical flow of a circulating sludge mixture was used, consisting of a bioreactor and a secondary settler. In fact, at this stage of the experiment, an ideal oxidation ditch of complete mixing was modeled, devoid of stagnant zones. The work of the model was studied at high and moderate concentrations of dissolved oxygen and at different flow rates of the liquid mixture. It was experimentally confirmed that the higher flow rate — the higher efficiency of nitrification (Table 1). When the flow rate is reduced to the minimum values (typical for the classic aerated tanks), the efficiency of nitrification was reduced by 20% at oxygen concentrations of 1-1.5 mg / l, which is especially critical for low-oxygen conditions. At this stage, it was possible to achieve the formation of large flocs of activated sludge due to the high velocity and uniformity of the flow, but

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the concentration of dissolved oxygen was too high for the occurrence of stable anoxic microzones in it, which meant the low efficiency of denitrification and the removal of total nitrogen as a whole.

Table 1. Dependence of the efficiency of processes on the flow velocity at a dissolved oxygen concentration of 1-1.5 mg / l

	Average velocity of liquid mixture, m/s		
	0.02	0.1	0.2
Organics oxidation, %	93.9	95.6	96.9
Nitrification, %	75.7	86.9	92.9
Total Nitrogen reduction, %	28.1	33.5	49.5

The results of the first stage of the experiment are shown at table 2. As a result of the stage, it was concluded that in oxidation ditches under conditions of high flow rates, processes that increase the efficiency of nitrification and denitrification in uncharacteristic conditions are possible.

Table 2. Results of the stage 1.1

	Influent	Effluent		
	115	8.5	5.3	3.2
BOD_5, mgO_2/l	124	12.4	6.2	4.2
$N\text{-}NH_4$, mg/l	11.47	4.66	1.84	0.89
$N\text{-}NO_2$, mg/l	–	0.81	0.20	0.04
$N\text{-}NO_3$, mg/l	–	15.76	8.31	3.1

In this connection, the model has been made with structural changes that allow to regulate the concentration of dissolved oxygen in any physically possible range, and also added a second module of the bioreactor, connected in series to the first one. This setup was a model of a two-corridor circulation oxidation channel.

The task of this stage was to start and study the operation of the system under low-oxygen operating conditions, in connection with which four modes were investigated:

1. Oxygen in the first corridor is from 0 to 0.1 mg/l, in the second corridor is 1.5 mg/l;
2. Oxygen in the first corridor 0.4 mg/l, in the second corridor 0.8 mg/l;
3. Oxygen in the first corridor 0.3 mg/l, in the second corridor 0.3 mg/l;
4. Oxygen in the first and second corridors 0.5 mg/l.

The first and third regimes proved to be ineffective due to an underestimated concentration of dissolved oxygen in one or both corridors. This led to a filamentous bulking of the biomass and a virtual cessation of the removal of nitrogen compounds. The first and fourth regimes showed an acceptable treatment efficiency, while the dissolved oxygen concentration of 0.5 mg/l at the 4th stage of the experiment was sufficient to ensure nitrification and oxidation of the organic matter in view of the high flow rate and the reduced load on the organic sludge.

For each of the regimes, the aerobic oxidation rates of organics, the nitrification rates from the Lineweer-Burke graphs, expressed by the Michaelis-Menten equations, were calculated, and additional series of analyzes were performed to determine the maximum rate of nitrification and denitrification for working biomass *ex situ*.

The reaction rates in the second period, when the unit operated in a two-corridor mode with different oxygen zones, turned out to be quite high, which is associated with a high flow rate. The specific nitrification rate is shown at the figure 1.

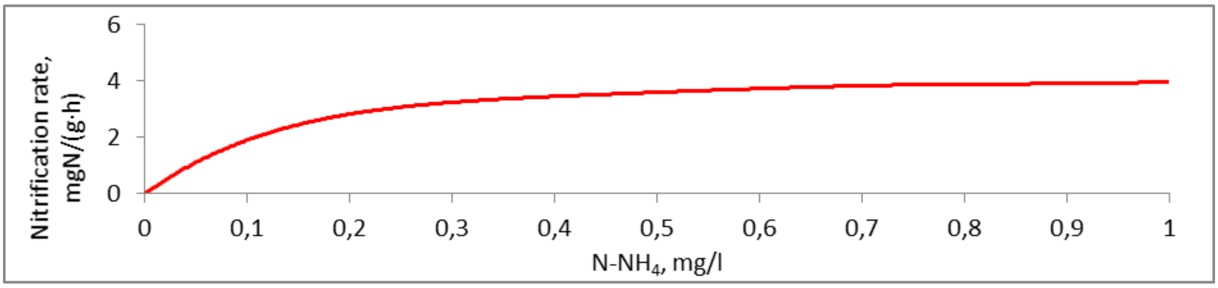

Figure 1. The specific nitrification rate for stage 1.2-2

The specific organic oxidation rate is shown at the figure 2.

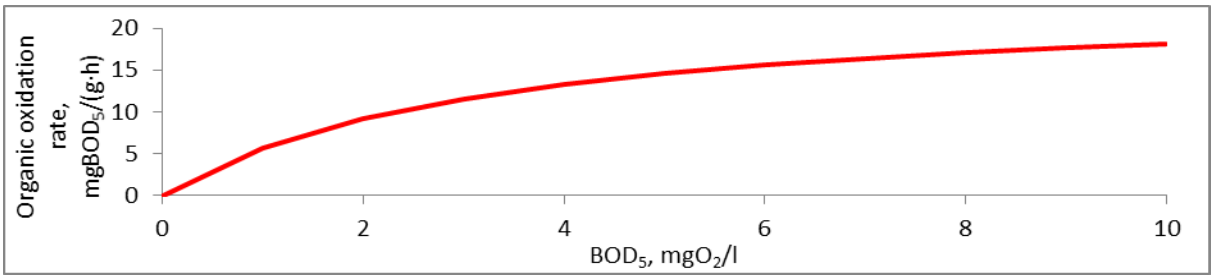

Figure 2. The specific organic oxidation rate for stage 1.2-2

The rates and efficiency of treatment in period 4, corresponding to identical concentrations of dissolved oxygen in each corridor, were commensurately high. The results are shown at the figure 3 (for nitrification) and at the figure 4 (for organic oxidation).

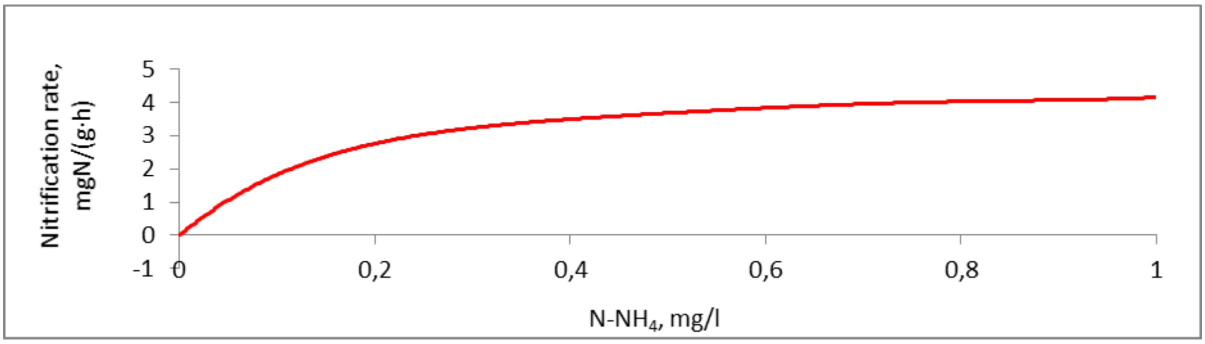

Figure 3. The specific nitrification rate for stage 1.2-4

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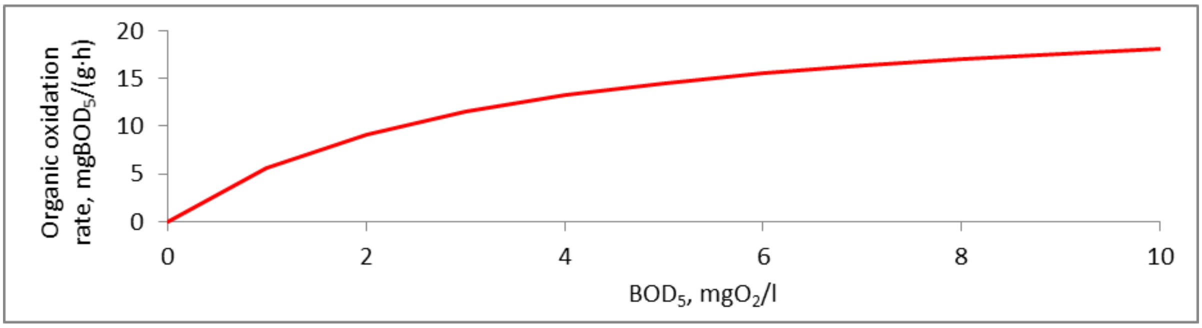

Figure 4. The specific organic oxidation rate for stage 1.2-4

This scheme was recognized as the most successful because with the corresponding indicators of water treatment quality and process speeds, the single-channel design of the circulation oxidation channel is, firstly, much simpler than multicore, and secondly, it corresponds to lower operating costs.

The second stage of the experiment was performed on an experimental bench with a horizontal flow of the circulating sludge mixture, which made it possible to approximate the experiment to operating conditions. The stand consisted of two lines, each of which included a bioreactor and a secondary settler with adjustable working volumes.

This stage of the experiment was carried out according to the invariant plan. The plan consisted of 3 factors. As the factors, the following technological parameters were adopted: the average concentration of dissolved oxygen by the volume of the experimental stand, the length of stay of the waste water in the installation and the specific load on the activated sludge by organic contamination.

Activated sludge on the first experimental line during most of the experiment was in a state of filamentous bulking, which is due to increased organic load in conditions of low oxygen concentrations. At the second experimental line, with a lower value of the dissolved oxygen concentration, the organic load also decreased to the minimum values. The system was more stable.

The average rate of biomass sedimentation under conditions of mutual influence of flocs of activated sludge on the first line ($V_{hs}(X) = 8.708 \cdot e^{-0.412 \cdot Xtss}$) was significantly lower than on the second line ($V_{hs}(X) = 12.559 \cdot e^{-0.409 \cdot Xtssi}$), which is associated with a large water saturation of the flocs. The velocities were calculated on the basis of a large number of sedimentation tests for each operating mode of the system separately and can be used to refine the calculations of secondary settling tanks operating in a system with simultaneous nitrification and denitrification.

On the second line, it was possible to achieve sufficiently high rates of nitrification, oxidation of organic matter and denitrification (figure 5 and figure 6). Two of the four experiments were considered successful. The concentration of dissolved oxygen in the experiments was 0.5 mg/l, the organic load was 0.07 and. On the basis of the results of the long work of the system, mathematical dependencies describing the ongoing processes of nitrification and denitrification were obtained. Technological conditions of successful experiments were chosen to test the operation of the oxidation ditch on real water.

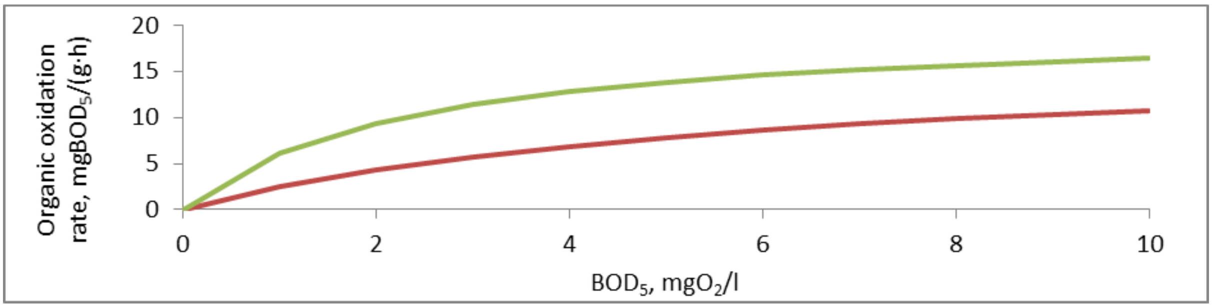

Figure 5. The specific organic oxidation rate for stage 2.2-4

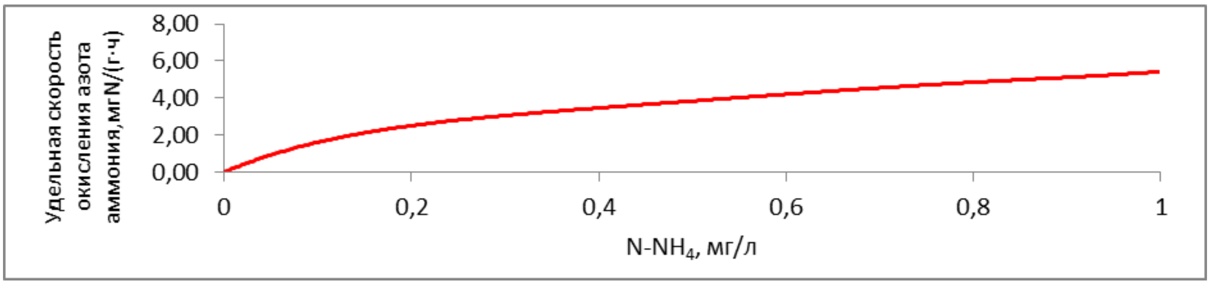

Figure 6. The specific nitrification rate for stage 2.2-4

After the completion of laboratory experiments on a model fluid, verification and refinement of the results obtained required a real wastewater. In the model, some design changes were made necessary for the operation of the plant in the conditions of the operating treatment facilities. Since the collection of wastewater was carried out from the receiving chamber of treatment facilities, it was necessary to provide an additional system of protection against ingress of large mechanical impurities, petroleum products and fats into the system. The fractionation of the organic component of waste water was preliminary performed for comparison with preliminary laboratory tests and the denitrification potential of waste water was estimated. The work was performed at a dissolved oxygen concentration of 0.5-0.6 mg/l, a flow rate of 0.3 m/s and a residence time of sewage in the reactor of 7 hours.

The experiment showed comparable results with laboratory studies. Smaller reaction rates are due to less readily available organics in the total COD content, as well as the presence of inhibitory impurities. At the same time, the system on real wastewater proved to be more resistant to filamentous swelling in view of the fact that it was not a closed biont. The multi-species composition of microorganisms contained in the incoming wastewater had a regulating effect on swelling. The reactions rates are shown at the figure 7 and at the figure 8. The specific nitrification rate for real wastewater (1):

$$v_N = \frac{5.02 \cdot C_{N\text{-}NH4}}{0.13 + C_{N\text{-}NH4}} \quad (1)$$

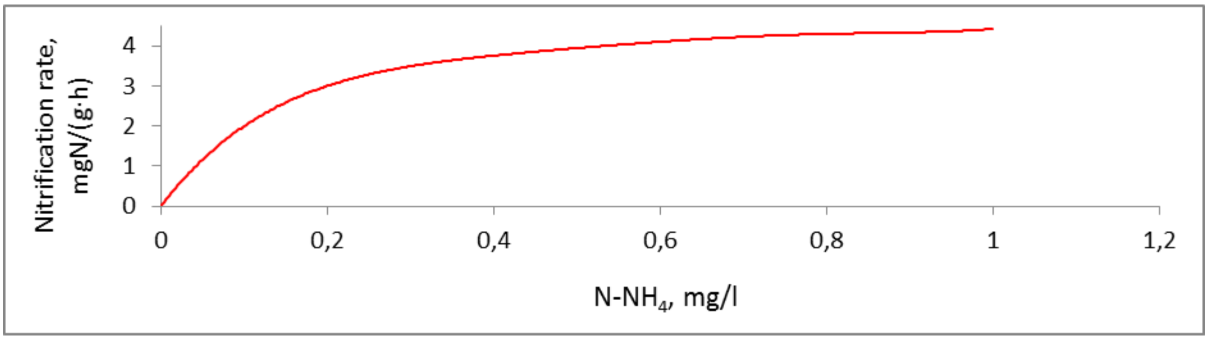

Figure 7. The specific nitrification rate for stage 3

The specific organic oxidation rate for real wastewater (2):

$$v_N = \frac{19.76 \cdot L_{ex}}{5.42 + L_{ex}} \quad (2)$$

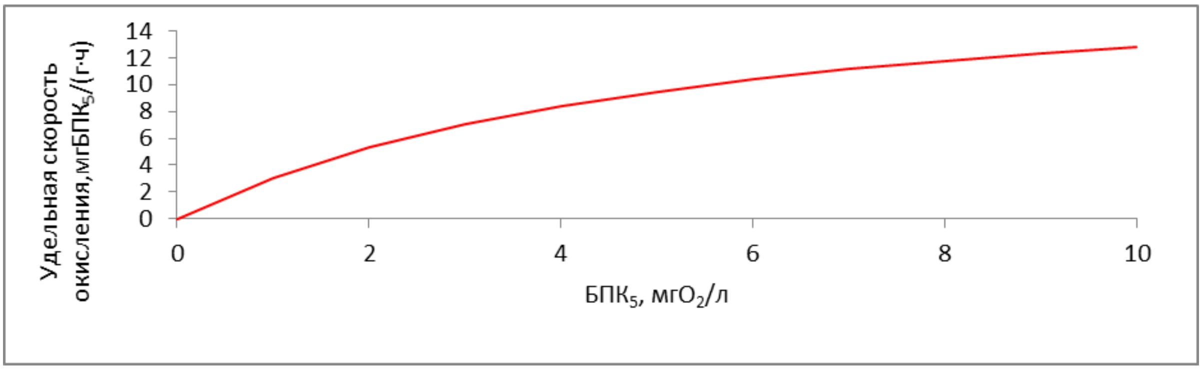

Figure 8. The specific organic oxidation rate for stage 3

4. Conclusions

The results of the laboratory experiment confirmed the possibility of effective simultaneous nitrification and denitrification in the absence of external inhibitors, at concentrations of dissolved oxygen in the range 0.4-0.6 mg/l and at a specific organic loads of not more than 0.15 gBOD/g·day.

The results of the experiment on real sewage water confirmed the emergence of a process of simultaneous nitrification and denitrification at high flow rates and low concentrations of dissolved oxygen in the air.

In addition, the sedimentation characteristics of the biomass are determined and the dependence of the deposition rate of the flocs of activated sludge operating in the regime of simultaneous nitrification and denitrification on the sludge dose is obtained.

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References

[1] Jimenez J, Bott C, Regmi P and Rieger L 2013 *Proceedings of the Water Environment Federation* **4** 492-505
[2] Gogina E and Gulshin I 2016 *Pr. Eng.* **153** 189-194
[3] Liu Y, Shi H, Xia L, Shi H, Shen T, Wanga Z, Wangb G and Wang Y 2010 *Bioresource Technology* **101** 901-906
[4] Makisha N 2016 *Pr. Eng.* **165** 1087-1091
[5] Makisha N, Voronov Y, Poupyrev E and Volshanik V 2015 *IJAER* 10 **21** 41919–41922
[6] Zhang P and Qi Z 2007 *Front. Sci. Engin. China* 1 **1** 49-52
[7] Loosdrecht M C, Nielsen P H, Lopez-Vazquez C M and Brdjanovic D 2016 *Experimental Methods in Wastewater Treatment* (IWA Publishing)
[8] Zhou X, Han Y and Guo X 2015 *Chemical Engineering Journal* **259** 715-723
[9] Lesage N, Sperandio M, Lafforgue C and Cockx A 2003 *Trans IChemE* Part A **81** 1259
[10] Ruzhitskaya O and Gogina E 2014 *AMR* **919–921** 2153–2156