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Biotechnological degradation of the radioactive cellulose containing waste

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Abstract

The constant increasing of radioactive waste quantity elaborates effective and safe methods for their influence upon the environment reduction. The aim of the study is to develop biotechnological methods for the radioactive cellulose-containing waste (cotton textile) compaction and to investigate the process of radionuclides adsorption with some microorganism biomass. Strains of *Trichoderma* and *Aspergillus* fungi, degrading the cotton textile, were investigated. The most effective one was selected. The optimum conditions for the textile pre-treatment resulting in a high cellulose destruction activity were also determined. The best results were obtained in case of thermochemical textile pre-treatment by autoclaving in a 3% aqueous solution of NaOH during 90 min. To achieve the effective textile degradation, the necessity of enzymatic inductors introduction into the nutrient medium was established. Cultivation under these conditions in 15 days revealed considerable textile destruction by the fungus *Trichoderma reezei*. The compaction proved to be increased more than two times this; besides, a removal ratio up to 54% for ^{60}Co was achieved by the fungus. Textile biodestruction with industrial enzymes was also studied. It was found necessary to inoculate the biodestruction system with yeast cells to reduce the glucose inhibition. The sorption of ^{60}Co, ^{90}Sr, ^{137}Cs in fungi and yeast biomass was also studied. The observed results formed the initial data for working up a technology for the textile biodegradation.

Keywords: Radioactive cellulose containing waste; Biodestruction; Cellulolytic activity; Cellulolytic enzymes; Pre-treatment; Compaction; Radionuclide adsorption

1. Introduction

One of the actual problems of applied ecology is to work out effective and safe technologies for the waste disposal and/or reduction of the influence on the environment. Nowadays, the search tendency for some new ecologically safe and energy saving technologies is observed. Biological conversion of radioactive cellulose containing waste is the one in quest. The aim of the given study is to investigate some aspects of radioactive cellulose containing waste (cotton overalls polluted by radionuclides) biotransformation. This substratum is very specific: the cotton cellulose is hardly degradable because of its highly ordered structure compared

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with cellulose of other origin. However, the achievement of high conversion degree is possible because of low lignin quantity in cotton textile (not more than 1%) [1]. Nevertheless, all the known practical elaborations in cellulose containing waste utilization are generally dealt with biological plant leavings reprocessing in order to produce hydrocarbons or alcohol [2].

2. Experimental

The task of this research work is the elaboration of radioactive cellulose containing waste compaction method. The proposed process must involve the substrata quantity reduction and the radionuclides concentration.

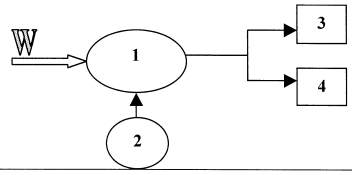
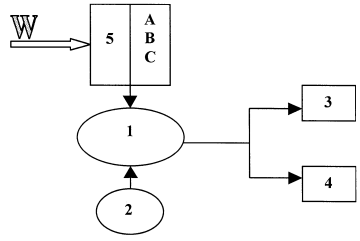
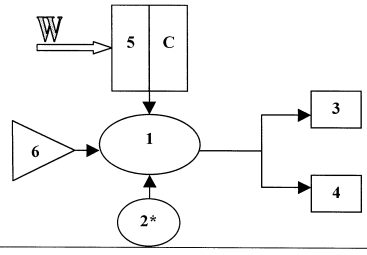
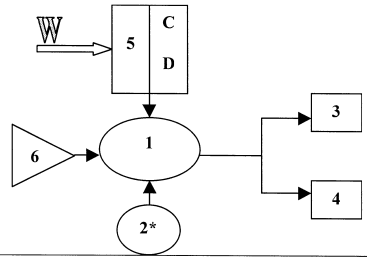
Technological scheme	Duration (t), day	Compaction degree (K), wt. %	Compaction intensity (K/(t·100%)), day $^{-1}$
1) 	200	25	0,001
2) 	90 (A)	22	0,002
	60 (B)	43	0,007
	60 (C)	51	0,008
3) 	30	50	0,017
4) 	25 (C)	54	0,022
	15 (D)	75	0,050

Fig. 1. The influence of process conditions on the cotton textile biodegradation efficiency by the fungus *T. reezei*. (1) Biodegradation stage deep cultivation. Aeration. Mineral nutrient medium. (2) Inoculate of deep microorganism culture. (2∗) Inoculate of surface microorganisms culture. (3) Liquid radioactive waste decontamination. (4) Solid radioactive waste decontamination. (5) Pre-treatment ((A) 0.1% H_2SO_4, 0.5 atm, 30 min; (B) 0.5 atm, 30 min; (C) 1 atm, 30 min; (D) 3% NaOH, 1.5 atm, 90 min). (6) Cellulolytic enzymes inductors introduction. (W) radioactive cellulose containing waste.

Taking into account the specifics of processed radioactive cellulose containing waste, the conversion expenditures reduction and technological steps quantity minimization were chosen as the main criteria for the biodestruction technology to be worked out.

The abilities of microorganisms to utilize different cellulose containing materials [2–4] and to adsorb the ions of radioactive elements [5–7] are well known. Selected fungi such as *Trichoderma* and *Aspergillus* showed different cellulolytic activity. The enzymatic activity was determined by the Chomodi-Nelsen's method [2] and by the degree of textile weight decrease. Being compared with the cellulose destruction activity of various cellulolytic microorganisms, a strain of *Trichoderma reezei* fungus from the GosNII 'Biotechnologia' collection was chosen for further studies.

The deep cultivation of *T. reezei* fungus was carried out in conical flasks (250 ml by volume). The aeration was provided with a laboratory rotatory shaker KE 12-250 T. The speed of mixing was about 150 rpm. The pre-cut cotton overalls (size 2×2 cm) were taken as a source of carbon for fungus growth.

3. Results and discussion

In the one-step process of cotton textile biotransformation the compaction up to 50% (by weight) was achieved. But the process took about 200 days. To increase the enzymatic activity, inductors of cellulolytic enzymes, nutrient medium composition and different methods of textile pre-processing were investigated (Fig. 1). The best results were obtained in the use of food industry waste as inductors of cellulolytic enzymes. At the same time, the processing of textile by a 3% solution of NaOH with steam during 90 min under pressure considerably decreases the biotransformation time. The compaction of investigated waste increased up to 75% by weight and to 50% by volume.

Besides, studies of sorption properties of the fungi *Trichoderma viride, T. reezei* and *Aspergillus niger* show that kinetic curves are the same for the radionuclides ^{60}Co, ^{90}Sr, ^{137}Cs. The sorption curves for given radioisotopes are specified with two obvious stages. The first stage is a rapid ion exchange sorption on the cell surface within several hours and the second

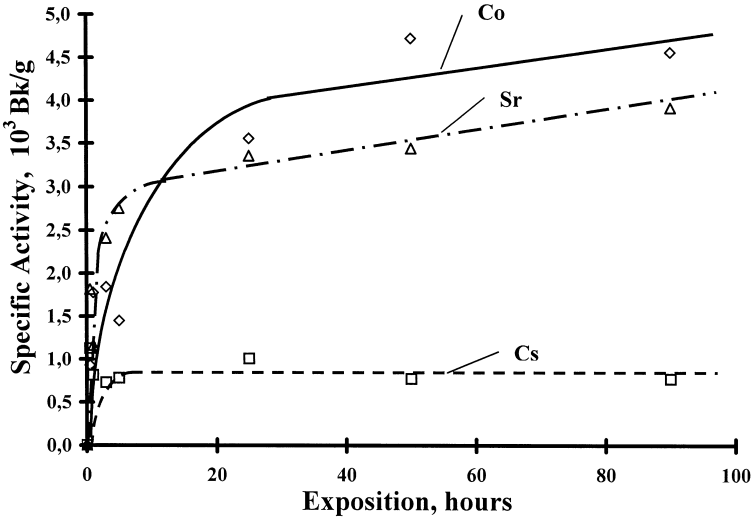


Fig. 2. Adsorption kinetic curves for *T. reezei* biomass (pH = 5.5).

one is a passive metabolic inclusion of radionuclides, which lasts more then 90 h (Fig. 2). The pH and the concentration of radionuclides influence on some sorption parameters was also determined. It was found out that the radionuclides sorption was improved when the pH of the medium rose (Table 1). But the radionuclides concentration influence on sorption was non-linear and complicated (Table 2).

The series of experiments dealing with the cotton textile biodestruction by an industrial cellulolytic enzyme 'Celloviridin G3x' was also carried out. It was found out that the maximum compaction occurred at 1.5–2% of enzyme concentration (to the substratum weight) with 70–80 g/l of textile in the system according to Ref. [3]. After 50 days, the compaction (by weight) mounted up to 30%, and a considerable part of textile (up to 85% of the initial weight) was degraded into the compact state of 'wool', resulting in up to 80% waste compaction (by volume). During the biodestruction, a considerable inhibition by enzymatic hydrolysis products (reducing sugars—glucose, etc.) was observed. In order to minimize the inhibition, the yeast *Candida tropicalis* was used at the initial inoculation of enzymes. The radionuclides sorption by yeast cells has similar dependencies for the pH and the initial radionuclide concentration as for the abovementioned fungi biomass, and made the removal ratio 10.1%, 7.3%, 60% at pH = 5.5 for ^{60}Co, ^{90}Sr, ^{137}Cs correspondingly.

Therefore, it was experimentally established that biomass of investigated fungi and yeast had no high sorption capacity, but their sorption properties are sufficient to remove radionuclides with the spent biomass during the radioactive cellulose containing waste biodestruction process.

Table 1
The dependence of *T. reezei* adsorption properties on pH (concentration of radionuclides is about $1 \cdot 10^6$ Bk/l)

Radionuclide	pH	Radionuclide distribution factor, ml/g	Removal ratio, %
^{60}Co	4	5.7	5.8
	5.5	15.9	14.7
	7	21.0	18.6
^{137}Cs	4	6.0	6.1
	5.5	18.9	17.0
	7	30.9	25.1
^{90}Sr	4	0.8	0.8
	5.5	2.7	2.9
	7	7.5	8.2

Table 2
The dependence of *T. reezei* adsorption properties on radionuclides concentration (pH = 5.5)

Radionuclide	Radionuclide concentration, Bk/l	Radionuclide distribution factor, ml/g	Removal ratio, %
^{60}Co	$1.7 \cdot 10^4$	106.9	53.7
	$6.4 \cdot 10^5$	17.4	15.9
	$5.5 \cdot 10^6$	7.2	7.3
^{137}Cs	$1.4 \cdot 10^4$	32.1	25.8
	$9.7 \cdot 10^4$	6.4	6.5
	$1.1 \cdot 10^6$	1.2	1.2
^{90}Sr	$8.1 \cdot 10^4$	43.6	32.1
	$4.6 \cdot 10^5$	8.1	16.4
	$3.7 \cdot 10^6$	0.01	3.4

4. Conclusions

The principal possibility of the biotechnological destruction of radioactive cellulose containing waste was confirmed by results of compaction of processed waste materials and the radioactivity concentration. The practical efficiency of the proposed technology will be defined by technical and economic estimation. Further microbial and analytical investigations in the problem of the biodegradation of radioactive cellulose containing waste are considered to be necessary.

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