

Differential Pattern of Arsenic Binding by the Cell Wall in Two Arsenite Tolerant Bacillus Strains Isolated from Arsenic Contaminated Soil

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Abstract

Arsenite binding was evaluated in two *Bacillus* strains i.e., *B. megaterium* and *B. pumilus*, isolated from arsenic contaminated soil of Unnao district of Uttar Pradesh (India). Initial results showed that more than 90% of arsenite was removed by surface binding by the cell wall component in both the tested species of bacteria. Results on the concentration dependent arsenic binding in bacterial strains exhibited higher efficiency of arsenite binding in *B. megaterium* (q_{max}- 1000 mg g⁻i protein) than *B. pumilus* (q_{max}- 666.7 mg g⁻i protein). The pH optima for arsenic (As)
binding in both *B. megaterium* (pH 6.0) and *B. pumilis* (pH 8.0) were found to be different dependent arsenite binding by *B. megaterium* showed maximum binding at 30ºC, while arsenic binding maxima in *B. pumilus* showed a broad temperature range (25ºC to 35ºC). The kinetic parameters on arsenite binding revealed that both the bacterial strains followed pseudo-second order kinetics. The As adsorption behavior of the bacterial strains was better explained by Langmuir isotherm rather than Freundlich model. Results of FTIR spectra on surface binding of As revealed major spectral changes in the band region of 1600 cm-1 to 800 cm-1 in case of *B. megaterium*, indicating involvement of mainly amines, alkenes and C-N functional groups. Whereas FTIR spectrum of *B. pumilus* showed changes in the band region of 3433 cm⁻¹ to 2924 cm⁻¹ indicating the involvement of hydroxyl, alkanes, alkenes, amides , and aromatic functional groups in the arsenic binding. A corollary of these results indicated differential binding of arsenite in both the *Bacillus* strains was on account of different arsenite binding ligands on cell surface as evident from the FTIR results as well as different pH and temperature optima.

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contaminated soil of Gaja Khera, Shukla Gaja Khera, Shukla Ganj and Murtaza Nagara, Shukla Ganj and Murtaza Na i in Un**gles in Unger** in its $(27 \t40'$, $80 \t00'$) \mathbb{N}_{eq} pria. As per survey of U.P. Jal Nigam (a statutory body of State Government and regulations of State Government and regulations over the development and regulations over the development and regulations over the development of water supply and sewerage systems of states \mathbb{R}_0 , these areas have been \mathbb{R}_0 declared as arsenic affected as arsenic affected areas. The soil samples were collected from \mathbf{m}_0 15 cm in sterile plastic bags. The arsenite tolerant colonies of \mathbf{r}_i bacteria were isolated and screened on nutrient agar plates containing 40 m $\,$ are standard microbiological techniques $\,$ microbiological techniques $\,$ were employed to screen the microorganism. Discrete arsenic tolerant bacterial colonies were picked up and maintained in nutrient broth r_n ini r_n 40 m_n are nine

 $\mathbf i$, $\mathbf i$ is also beginned by using standard by using standard morphological and biochemical tests [17] and then send for 16S rDNA sequencing at Genetech, Biotech Park, Lucknow (U.P., India). The gene sequences of these strains in the identified at the interval α bacterial strains are *Bacillus megaterium* (Accession no. KC633281) **a.** *Bacillus pumilus* (Accession no. Res. C633283).

Arsenic biosorption experiment

Biosorption of articles was measured in $m_{\rm B}$ and $m_{\rm B}$ are $m_{\rm B}$ $f(x) = \mathbf{r}_1$ in $\mathbf{r}_2 = 20$ m. BSMY II. Exponentially growing culture was \mathbf{r}_1 harvested by centrifugation \mathbf{r} (3000 \rightarrow 15 min), was hed in distilled water and the pellets were suspended in the flasks containing different **concentrations (0-100** \mathbf{m}_1 ⁻¹) of \mathbf{N}_1 . The shaking in shaking i incubator at $30\,$ C temperature for $120\,$ minutes. At the end of incubation period, $\mathbf{r}_{\mathbf{r}}$ of sample was taken and centrifuged (1500 \mathbf{r} 10 min). Supernatant was collected in test tubes for the measurement r_0 to the measurement α remaining as concentration in the medium. was defined to distinct water to remove any unbound metal. The remove and metal. The remove and metal. $2 \mu_{\text{m}} = 10 \mu_{\text{m}} = 0.$ A fig. with Thereafter, cells were with $2 m$ to measure the measure the members of \mathbf{A} was hed cell pellets were washed with distilled was hed at 60°C.
In deterministic was help with dried at 60°C s and were digested in action of $\frac{1}{2}$ mixture of $\frac{1}{2}$. An intervalse of $\frac{1}{2}$ P_{\bullet} and C \mathcal{A}_4 described by \mathcal{A}_2 . Total EDTA was hed fraction was hed fraction was \mathcal{A}_2 also treated in the same way. The substraction of \mathbf{A} from the total as removed from the medium gave the concentration of intracellular uptake of arsenite concentrations of articles are not articles are not articles of the concentration.
Surface bound are not are not all the concentrations of the concentrations of the concentrations of the co $m_{\rm e}$ calculated from EDTA was habitated from EDTA

To study the effect of p on \mathbf{H} of \mathbf{H} of arsenite (III) \mathbf{H} bacterial strains, experiments were conducted at initial pH $4, 5, 6, 7, 8$
 \mathbb{R} and 9. Effect of temperature was determined in temperature range of 25°C, 30°C, 35°C, 40°C, 45°C. initial concentration of as was fixed 50 $\mu_{\rm m}^{-1}$ for both the above experiments. Rest of the procedure was $\mu_{\rm m}$ same as described for adsorption experiment.

Determination of adsorption isotherms

Ani southerm is a plot of a plot amount of solution per unit amount and solution per unit amount amount amount of adsorbent against the corresponding equilibrium concentration in $t_{\rm th}$ solution $t_{\rm th}$ temperature constant. can be drawn from these isotherms, which are useful in designing of adsorption systems. Langmuir and Freundlich isotherms have been used in this study.

Langmuir isotherm

 \times ranged is ournained from a kinetic derivation of \mathbf{r}_k ett de \mathbf{m}_p between added and desorbed \mathbf{m}_p gives $\mathbf{19}$. This gives ζ , i in ζ , i in ζ $=$ $_{\mathbf{m}}$. $_{\mathbf{A}}$.C + $_{\mathbf{A}}$.C

where, qe is the amount of adsorbate adsorbed per unit amount of adsorbent at the $\mathbf{m}_{\mathbf{a}}$ is the adsorption coefficient $\mathbf{m}_{\mathbf{a}}$ and $\mathbf{m}_{\mathbf{a}}$ of adsorption energy) and qm the amount of adsorbate adsorbed per unit amount of $\mathbf r$ and $\mathbf r$ addsorption (limiting α in $i \rightarrow i$.

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$$
\frac{C_e}{q_e} = \frac{1}{q_{max}} + \frac{C_e}{q_{max}}
$$

 $\overline{\mathcal{C}}$ is im reducing $(m_{\rm e}^{-1})$, $m_{\rm e}$ and $m_{\rm e}$ $i = m_0 \cdot n_1$ adsorbed per gram of adsorbent at equilibrium (mg g-1), qmax is equilibrium (mg g-1), qmax is equilibrium (mg
The experiment at equilibrium (mg g-1), qmax is equilibrium (mg g-1), qmax is equilibrium (mg g-1), qmax is e \mathbf{r}_i . Languar constant \mathbf{r}_i addsorption capacity and \mathbf{r}_i b is energy of adsorption. The value of qmax and b were calculated from the slope and intercept of the graph.

Freundlich isotherm

This isotherm is derived from empirical consideration and expressed as-

$$
\mathbf{C} = \mathbf{C}^{-1/\mathbf{r}}
$$

where, is the amount add and add $(m_{\tilde{g}}-1)$, Ce is equilibrium **concentration (mg** \langle ¹), K is the addition coefficient \mathbf{i} is the addition coefficient \mathbf{i} **constant (mg** g^{-1}), which is a measure of adding α is a measure of adsorption capacity or α $f(x) = \frac{1}{2} \int_0^1 \frac{1}{2} \$ standard free energy change, empirical constant 'n' is a measure of the α intensity (20) .

$$
\mathbb{E} \left[\mathbf{H}_0 \right] \left(\mathbf{A} \right] \left(\mathbf{H}_0 \right) \left(\mathbf{I} \right) \left(\mathbf{A} \right) \left(\mathbf{H}_0 \right) \left(\mathbf{A} \right) \left(\mathbf{H}_0 \right) \left(\mathbf{A} \right) \left(\mathbf{H}_0 \right) \left(\mathbf{A} \right) \left(\math
$$

$$
Log q_e = (1/n) log C_e + log K_f
$$

Thus a plot between log \mathbf{R}_C and \mathbf{r}_i . \mathbf{C}_i is a straight line. A and B are calculated from plotting f are calculated from plotting A C_{c} , which is responsively metal concentration. A side \mathbf{r}' value are indicative of high adsorption throughout the concentration \mathbf{r}_i and \mathbf{r}_i and \mathbf{r}_i and \mathbf{r}_i and \mathbf{r}_i and \mathbf{r}_i addsorption the throughout indicates low adsorption that t_n . A low t_n indicates high concentration \mathbf{A} low \mathbf{A} low \mathbf{A} adsorption at strong solute concentration.

Determination of adsorption kinetics

Kinetic study of metal adsorption by the selected bacterial strains was carried out at 50 μ m $^{-1}$ initial concentration of arsenic at rooms μ
concert as carried in the article at rooms of a rooms of a rooms of a rooms of a $t_{\rm th}$ temperature, where $t_{\rm th}$ and $t_{\rm th}$ and $t_{\rm th}$ ime intervals (5, 15, 30, 45, 60, 90, 180 and 240 minutes) until as removals attains a saturation level. The Lagergren first order and pseudo-second-
The Lagergren first order and pseudo-second-second-second-second-second-second-
order models were used to test adsorption kinetics data to investigate r_i \dot{m} \dot{n} is bit.

The Lagergren rate equation is most widely used model for the so solute from a solution and the first order rate for an experimental solution and the first order rate \mathbf{r}_0 expression is given as (21) .

$$
\log (q_e - q_t) = \log Q_e - \frac{k_1}{2.303} t
$$

 \mathscr{P} are the and $\mathscr{P}_\mathbb{R}$ and $\mathscr{P}_\mathbb{R}$ and $\mathscr{P}_\mathbb{R}$ adsorbed on $\mathscr{P}_\mathbb{R}$ the algal surface at time $\mathbf{r}_\mathbf{a}$, $\mathbf{r}_\mathbf{a}$, and $\mathbf{r}_\mathbf{a}$, $\mathbf{r}_\mathbf{a}$, $\mathbf{r}_\mathbf{a}$, $\mathbf{r}_\mathbf{a}$, $\mathbf{r}_\mathbf{a}$, $\mathbf{r}_\mathbf{a}$, $\mathbf{r}_\mathbf{a}$ constant of first order adsorption. The slope and intercept of the plot ϕ (qeeqt) versus the value of ϕ versus the value of ϕ $\mathbf{R}_{1,1}$

$$
\lim_{\lambda \to 0} \limsup_{n \to \infty} \frac{1}{n} \limsup_{n \to \infty} \limsup_{n \
$$

$$
\frac{1}{q} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t
$$

where *k*² (g mg−1 min−1) is the rate constant of second-order adsorption. The slope and intercept of the plot of t/q versus t were used to determine the value of q $_{1}$ $_{2}$ \mathbf{A} . \mathbf{A} is important to \mathbf{A} this model the experimental estimation of *q*^e is not necessary.

Fourier transforms infrared (FTIR) spectroscopy

FTIR spectroscopy was used to detect the detect the members in the members of \mathbf{r}_i \mathbf{r}_i ities in bacteria modernia which are responsible for biosonic \mathbf{r}_i arsenic. The bacterial pellet treated with fixed concentration of arsenic $f(x)$ hours were collected and over \mathbf{r}_0 and \mathbf{r}_0 is 12 hours at 50°C. A m_0 and m_0 is m_1 is mass was mixed with KBr (1:100). Then \mathbf{m} isture was grounded into fine particles with a pest-left and mortar an was compressed into translucent sample disk by a manual hydraulic sample disk by a manual hydraulic \mathbf{r}_0 p ressured for both control and treated cells were measured treated cells were measured measured measured measured measured $\mathbb{P}_\mathbf{0}$ with the range of 400-4000 cm $_{\mathbb{M}}^{-1}$ using a Br window by Fourier and the range of the $\mathbb{M}_{\mathbf{e}}$ of $\mathbb{M}_{\mathbf{e}}$ and $\mathbb{M}_{\mathbf{e}}$ and $\mathbb{M}_{\mathbf{e}}$ and $\mathbb{M}_{\mathbf{e}}$ and $\mathbb{M}_{\mathbf{e}}$ and $\mathbb{M}_{\mathbf{e}}$ Transform Spectrom Spectrophotometer (i , 6700, Thermoscientific UseA). The background obtained from the scan of $\mathbb{B}_\mathbb{R}$ was applied the scan of pure KBr was automatically in subtracted from the sample spectra.

Statistical analysis

 A _l the experiments were conducted in triplicates and triplicates and triplicates and the reported A value for each studies \mathbb{P}_n is the means \mathbb{P}_n of \mathbb{R} were analyzed by ≤ 0.05 . i. \mathbf{r} on \mathbf{r} , i.e. \mathbf{i} \mathbf{r} (A $\mathbb{E}(\mathbf{A})$. ≤ 0.05 . \mathbf{i} i. \mathbf{i} in the shown by different alphabets by using Duncant alphabets by using Duncant alphabets by using \mathbf{A} \mathbf{r}_i , i.e., \mathbf{r}_i , \ldots (DMT) using the SPSS software (\mathbb{Z}_p , i.e., 7).

Results and Discussion

Effect of pH on surface binding and intracellular uptake

 \mathbb{R} 0871 \mathbb{M} to detect the were constant \mathbb{R} to \mathbb{R} were constant cell

artice *Bacillus* **species.** A function **b** function **in** temperature between **in** temperature between in the species. 30° C $\,$ 35° C showed decline in surface binding as well as intracellular intracellular interacellular interacellular interacellular interacellular interacellular interacellular interacellular interacellular inter uptake of arsenic. Meena et al*.* [31] reported that an increase in metal sorption with temperature might be attributed to either increase in the number of active surface sites available for sorption on the adsorbent or due to decrease in the boundary layer thickness surrounding the sorbent, which results in the reduced mass transfer results \mathbf{r}_i adsorbate.

E ect of As concentration

Effect of different concentrations (10 m) m^{-1} to 100 m^{-1}) arsenic on surface binding and intracellular uptake efficiency of a known \mathbf{r}_0 and of \mathbf{r}_0 be at optimum parameterial biomass at \mathbf{r}_0 in $i = 3$. Continuous increase in uptake was observed with increasing concentrations of arsenic up to 50 μ mg 1 . Later on, the rate of A addsorption became more or less or less or less constant in both the strains. These results were in agreement with the ndings of several other workers who suggested that metal sorption

increases to increasing m and the become concentration, and then become contration, and then become m saturated a form of $\mathbf{i}_\mathbf{k}$, and $\mathbf{i}_\mathbf{k}$ at $\mathbf{n}_\mathbf{k}$, $\mathbf{n}_\mathbf{k}$, $32,33$. At $\mathbf{n}_\mathbf{k}$ $\mathbf i$. The number concentration, the number of $\mathbf A$ species available for binding \mathbf{A}_i surface of bacteria was enhanced, which ultimately was \mathbf{A}_i used, which use \mathbf{M}_i used, which increase the biosorption of A (34. Maximum surface binding $(76%)$ and intracellular uptake (12%) of article was observed in *B. megaterium.* in in contributed about 6 times more in total removal of arsenite when compared with the intracellular uptake of A s. These results \mathbf{r}_e conformity with the previous reports that a large proportion of metals remained adsorbed onto the cell surface, and a very small fraction of m_{e} intered into the interacellular compartment μ_{e} and $26,35$ -37. A higher contribution of cell surface binding of metal could be an advantageous point in the sense that the adsorbed metals can be recovered by using a suitable desorbing agents, especially in the case of precious metals. The $\ln\ln l$ checking of \mathbf{m}_e is the extracellular surface is the ex main defense strategy adopted by the microorganisms in mitigation of i i $38,39$.

Figure 4: Langmuir and Freundlich isotherm for the adsorption of Arsenic by *Bacillus megaterium* (A) and *Bacillus pumilus* (B).

1/Ce

0 0.1 0.2 0 $\frac{1}{1000}$ 2

LOG Ce

Table 1: Langmuir and Freundlich isotherm constants for the adsorption of Arsenic by *B. megaterium* and *B. pumilus.*

Table 2:

Biosorption isotherms

 ${\bf A}$ dsorpti ${\bf t}$ are not arbeid to understand the nature of ${\bf t}$ are nature of ${\bf t}$ adsorption by fitting the experimental data to Langmuir and Freundlich isotherm models. During modeling of the adsorption of arsenic by bacterial strains, the relations of \mathbf{r}_e and \mathbf{r}_e and $(q_\mathrm{max}$ and $b)$ and \ldots **n**ei i constants ($K_{\tilde{F}}$ and *n*) along with the regression coefficient 2)), we calculated as shown in Table 1. The Langmuir model as single model assumption monolayer biosorption onto a surface with a finite number of identical is a neit sum so in ~ 1 , $\sim 1/$ Ce (i 4). Languir constants q_{max} defined the total addition capacity and b denotes the metal binding affinity of cell. The *qmax* values of the bacterial s_{max} in the set of q_{max}
i.e. s_{max} *B. megaterium > B. pumilus* (Table 1). Based on q_{max} , it was revealed that **B. megaterium** showed higher biosorption capacity for arsenic as compare to *B. pumius*. Hasim and C_h 29 have suggested that a bioson g_{max} and h_{max} is b_{max} and h_{max} and h_{max} and h_{max} \mathbf{p} cienterform q_max and low b_max individual cases where metal ions to be removed are present in traces.

In the case of \mathbf{r}_1 is isotherm, K_F represents the adsorption coefficient and *n* is related to the effect of concentration of metal ions. The nature of $m_{\rm F}$ adsorption could be defined by both $K_{\rm f}$ and n values, we are $\mathbf{r}_\bullet \times \mathbb{R}$ (i.e. 4) for the additional \mathbf{r}_\bullet of arsenic by both the bacterial strain were found to be non-linear throughout the concentration range studies \mathbf{r}_i , \mathbf{r}_i and \mathbf{r}_i (K_c)) was found negative in both the strains which show that \mathbf{h}_i the following free free free isotherm. Based on the \sim values, i was observed that the nature of adsorption of adsorption of anti- $\mathcal{L}_\mathbf{A}$ instrains could be contained on $\mathbf{A}_\mathbf{A}$. And in nodel and in nodel and in $\mathbf{A}_\mathbf{A}$ i case adsorption data fit the Freundlich model. These results are in and \mathbf{r}_1 , \mathbf{r}_2 is a studied the additional theorem of article the adsorption of article the article the article term of article ter in E coling followed that are not arrived that are not contained that are E and E $i \ldots$ m.

Biosorption kinetics

Lagergren first order and pseudo second order plots were constructed for the adsorption of arsenic by both the *Bacillus* strains at

concentration of 50 µg ml-1 (Figure 5) to test the adsorption kinetics and nature of biosorption. The t/q *vs* t plot for pseudo second order kinetics i and i straight line where i first order kinetics log (qeeqt) *vs* did not fairly follow a linear relationship. The results suggested that the second order kinetics is applicable in the case of arsenite biosorption $\tilde{\mathbf{J}}$ the bacterial strains. The rate constants for both the bacterial strains for were calculated from the Lagergren first-order and pseudo-second-
Lager and pseudo-second-second-second-second-second-second-second-second-second-second-second-second-second-se $\mathbf{r}_{\mathbf{a}}$ as shown in Table 2. The value of regression coefficient $\mathbf{r}_{\mathbf{a}}$ is denoted $\binom{2}{2}$) for the second order addition model is relatively high-vertex is relatively highly however \mathbf{I}_1 the values of $\frac{2}{\sqrt{2}}$

is a separate a shift to 1604 cm-¹ position. A similar **r**_n 1428 r_1^{-1} 1429 r_1^{-1} could be attributed to carbon and independent in \mathbf{r}_1 and \mathbf{r}_2 in the band \mathbf{r}_3 of all \mathbf{r}_4 as \mathbf{r}_5 as \mathbf{r}_6 x_i 885 x_i^{-1} after add x_i and $(1, 3)$.

i in $\mathbb{F}_{\mathbf{a}}$ 3433 $\mathbb{F}_{\mathbf{a}}^{-1}$ 3426 $\mathbb{F}_{\mathbf{a}}^{-1}$ in *B. pumilus* in stretching stretching and hydroxyl groups. A shift in the peaks $m_{\rm A}$ 3080 $m_{\rm A}^{-1}$ 3066 $m_{\rm A}^{-1}$ to attributed to C—H stretching of i. \ldots 2924 $\mathbf{r}_{\mathbf{A}}^{-1}$ was assigned to $\mathbf{C}_{\mathbf{A}}$ of $\mathbf{C}_{\mathbf{A}}$ stretching in ρ and the wavelength as shown the wavelength of 2926 $m_{\rm h}$ ¹ in and \mathbf{r}_1 interaction with a some new peaks (2960 \mathbf{r}_1^{-1} and 970 \mathbf{r}_i ¹), \mathbf{r}_i becomes in the arsenite treated in the arsenite trea cells. These changes indicated that alkanes, alkenes and sulphonates moieties present on to the bacterial cell surface were involved in the in in the peaks in the some peaks in the 1460 region of nietro groups also shifted to 1453 amplies at interaction with (3) .

The cell surfaces of many microorganisms consist of polysaccharides, proteins and lipids, these macromolecules confer s several functional groups can binding with the binding α th ions in \mathbf{r}_0 45 . The present results showed a shift in the IR peaks for C peaks f , $\mathsf{C}_{\mathbb{P}}$ and all alkene, \mathbb{P}_2 moeity, amines, amide and sulphonate groups when treated with arsenite, indicating involvement of these functional moieties in the arsenite binding. Many workers have also used the FTIR spectra for qualitative and preliminary analysis of the chemical functional groups present in the cell wall of microorganisms. The IR signature of cell surface moieties yields basic information on the nature of the possible cell surface and metal ion 46 -49. The carboxyl, hydroxyl, amino, phosphate and sulphate $\mathbf r$ microbial cell surface have been implicated in the binding of various $\mathbf{r}_{\mathbf{A}}$ conducted molecules \mathbf{f}_1 . Carboxylic, C-H of alkane, amine, a \mathbf{r}_i minor group were \mathbf{r}_i the binding of arsenite (III) in *E. coli* [16]*.*

Conclusion

Based in the foregoing evidence \mathbb{R} , it may be concluded that surface \mathbb{R} in in the bacterial $\sim 90\%$ on the bacterial cell surface might be the primary mode of arsenite removal and arsenite removal and arsenite to \mathbf{r}_i i s very alterial strains. However, pH and temperature optima of temperature optima of temperature optima of temperature optima of \mathbf{h}_i \mathbf{N} are not the \mathbf{N} results clearly demonstrated the $\mathbf{r}_\mathbf{N}$ results constraints constraints of $\mathbf{r}_\mathbf{N}$ results constraints of $\mathbf{r}_\mathbf{N}$ results of $\mathbf{r}_\mathbf{N}$ results of $\mathbf{r}_\mathbf{N}$ res that both the *Bacillus* strains involve different functional groups in the \vec{n} are inding upon the cell wall characteristics of each characteristics of each characteristics of \vec{n} P_1 and P_2

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Removal of As (V) from waste-waters by chemically modified fungal biomass. Water Res. 2003, **37**: 4544-4552.

- 16. Wu Y.H., Feng S.X., Li B. & Mi X.M. The characteristics of *Escherichia coli* adsorption of arsenic (III) from aqueous solution.
	- W. J. Microbiol. Biotechnol*.* 2010, **26**: 249-256.
- 17. Lechevalier H.A.

The Actinomycetes III, a practical quide to generic identification of actinomycetes. In: Bergey's Manual of Systematic Bacteriology, Williams, S.T., Sharpe, M.E. & Holt, J.G. (eds). Williams & Wilkins Company, Baltimore, Maryland, 1989 pp. 2344-2347.

18. Martin J.H. Bioaccumulation of heavy metals by littoral and pelagic marine organisms. USEPA. 1979, 600/3–77–038.

- 19. Langmuir I. The adsorption of gases on plane surface of glass, mica and platinum. J. Am. Chem. Soc. 1918, **40**: 1361-1403.
- 20. Freundlich H. & Helle W.J. Rubber dye adsorption in lusungen. J. Am. Chem. Soc. 1939, **61**: 2-28.
- 21. Ho Y.S. & McKay G. The sorption of lead (II) ions on peat. Water Res. 1999a, **33**: 578-584.
- 22. Ho Y.S. & McKay G. Pseudo-second order model for sorption processes. Process Biochem. 1999b, **34**: 451-465.
- 23. Huang J.P., Huang C.P. & Morehart A.L. The removal of Cu (II) from diluted aqueous solution by *Saccharomyces cerevisiae* . Water Res. 1990, **24**: 433-439.
- 24. Matheickal J.T., Yu Q. & Woodburn G.M. Biosorption of cadmium of marine algae *Durivillaea potatorum*. Water Res. 1999, **33**: 335-342.
- 25. Sanchez A., Balleste A., Blazquez M.L., González F., Muñoz J. & Hammaini, A. Biosorption of copper and zinc by *Cymodocea nodosa.* FEMS Microbiol. Rev. 1999, **23**: 527-536.
- 26. Miyatake M. & Hayashi S. Characteristics of arsenic removal from aqueous solution by *Bacillus megaterium* Strain UM-123. J. of Environ. Biol. 2009, **9**: 123-129.
- 27. Klimmek S., Stan H.J., Wilke A., Bunke G. & Buchholz R. Comparative analysis of the biosorption of cadmium, lead, nickel and zinc by algae.