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Sorption of Cadmium Ions Using Inactive Biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* Consortium from the Aqueous Solutions

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A B S T R A C T

Aquatic environment contamination with a high concentration of noxious heavy metals rises as an alarming condition and arises as a severe threat to all living organisms. Consequently, there is an urgent need to focus on advanced approaches for the remediation of aquatic systems. The present study aims to test the capacity of consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* for the sorption of cadmium ions from the polluted aqueous media. The optimum environment for the maximum sorption (84.22 %) of Cd was achieved after 80 minutes of time interval at pH 6, biomass 0.2 g and 20 mg/L of cadmium metal concentration. The adsorption data were well fitted to the Langmuir isotherm for cadmium adsorption (R^2= 0.9956) than the Freundlich isotherm (R^2= 0.9772), though the rate kinetics data were calculated by pseudo irst and second order models. The highest adsorption capability attained by consortium biomass for Cd ions was found about 55.86 mg/g. Thus, the present work implied that consortium biomass of *Pseudomonas fluorescens* and*Bacillus subtilis* could be utilized as an efficient biosorbent for eliminating cadmium ions from aqueous solutions.

Introduction

Heavy metal toxicity is the condition that arises when the metal concentration is found above the permissible limit in the environment and which shows a deleterious impact on the entire ecological system. During the last few decades, the indiscriminate release of heavy metal pollutants in aquatic systems has increased enormously that increasing the accumulation of toxicants in the food chain which affects the biological system adversely. Heavy metals namely cadmium, arsenic, chromium and lead are ingenious, silent, nuisance killers and the condition becomes worse when heavy metal ions frights to pollute the environment by both natural and anthropogenic origins. These metal ions enter the ecosystem through the combustion of fossil fuels, mining, refining and several industrial activities (Xie *et al.*, 1996). Cadmium is known as a highly noxious pollutant, which is dangerous to all living organisms comparatively at fewer concentrations around 0.001–0.1 mg/L (Alkorta *et al.,* 2004). Cadmium introduces to living beings across the food chain that can produce several deadly diseases (Zeng *et al.,* 2009). The main driving forces which increase the global water demand are rising population, improving living standards, development, changing consumption patterns, and expansion of agriculture sectors which result in deterioration of quality and quantity of water and became a vital concern worldwide. There is an urgent exigency to preserve water to meet forthcoming demands by developing new approaches for remediation of contaminated water. Several conventional methods are used for the removal of metal ions from aqueous media namely chemical precipitation, membrane separation, coagulation and reverse osmosis (Kratochvil and Volesky, 1998) but these methods are highly expensive and discharge a huge mass of toxic sludge, which is quite tough to maintain (Zouboulis *et al.,* 2004).

Bioremediation is the environment-friendly, cost-efficient cleaning technique used for rectification of contaminated environment by using biological agents such as fungi, green plants, and microbes. At present, microbial and phytobial agents emerging as promising tools for remediation. They can accumulate metal toxic pollutants and detoxify the polluted environment. Algae, bacteria and fungi and yeasts are proficient agents which have the potential of accumulating and eliminating heavy metals from wastewaters (Volesky, 1986).

Biosorption is the adsorption process that involves the passive uptake of heavy metal ions from wastewater by non-living biomass of biological agents such as algae, plants, bacteria and fungi. It does not require energy so it is a cell-independent process. The chief advantages of this process are low operating cost, easy storage, consume less time and chiefly does not produce any toxic by-products for metal adsorption (Hemambika *et al.,* 2011). The biosorption mechanism depends on twofold phases a solid phase (biosorbent) and other is a liquid phase (solvent) which holds metal ions that need to be adsorbed. Nowadays, bacteria are useful biosorbents because various functional groups such as amino, hydroxyl and carboxyl groups are attached to their cell wall, which has a massive binding capacity towards the metal. Microorganisms such as bacteria, fungi, yeast, and algae from their natural habitats are excellent sources for a biosorbent (Wang and Chen, 2009). Bioremediation potential towards heavy metal ions has been evaluated by different bacteria likely *Micrococcus*, *Bacillus and Escherichia* (Duda-Chodak *et al.,* 2013). The elimination of metallic ions from wastewaters by some bacteria like *Pseudomonas, Bacillus,* had been studied by a few authors (Azza *et al.,* 2009). The potential of some bacteria like *Pseudomonas aeruginosa, Bacillus sphaericus* and *Penicillium chrysogenum* has been tested for the removal of Cr, Ni, Pb and Cd metal ions from the aqueous media (Alvarez *et al.,* 1999). Nonliving biomass of diverse bacterial strains (*Citrobacter, Geobacillus, Klebsiella, Bacillus*) is utilized for the retention of metallic ions from the waste water (Puranik and Paknikar, 1999; Tunali *et al.,* 2006). Yadav *et al.,* (2012) discussed that *Pseudomonas putida* can adsorb cadmium from synthetic aquatic solutions. Many studies have testified to the resilient and accumulative capability of bacteria against the cadmium metal ions (Macaskie *et al.,* 1987; Wang *et al.,* 1997). The biomass of *Pseudomonas aeruginosa* proved to be a suitable sorbent for the expulsion and retention of Cd, Pb and Cu from the contaminated water solutions (Zivkovic *et al.,* 2018). *Bacillus subtilis* have an enormous potential to bind with heavy metal ions due to the presence of teichoic acids and other different cell wall structures (Colak *et al.,* 2011). *Bacillus*is common and easily accessible bacteria and few authors have described its adsorption capacity towards metallic ions (Bai *et al.,* 2014). The efficacy of any sorbent mainly depends on some factors such as solution pH, biomass dose, contact time and metal ion concentration. The data relating to equilibrium is well expressed by Freundlich and Langmuir adsorption models which establish the relationship between biosorbent and adsorbate for the adsorption process (Muhamad *et* *al.,* 1998). Nowadays, the biosorption technique received attention worldwide for the removal of metal ions by utilizing bacterial biosorbent from contaminated environments.

Therefore, the objective of this study is to check the adsorption efficacy of the consortium of *Pseudomonas fluorescens* and *Bacillus subtilis* inactive biomass for the pollutant cadmium from aqueous media and the batch experiments were also conducted to determine the effects of different operational parameters on adsorption such as the solution pH, metal ion concentration of the solution, biomass dosage and contact time. The equilibrium adsorption data were studied by applying Langmuir, Freundlich, pseudo- first and pseudo-second order models.

Materials and Methods

The microorganisms

Gram negative *Pseudomonas fluorescens* (NCIM 2100) and gram positive *Bacillus subtilis* (NCIM 2063) microorganisms, selected for the present study were bought from the National Collection of Industrial Microorganisms (NCIM), Pune in a freeze-dried culture and preserved at -20°C. The standard sterile techniques were used for the inoculation of cultures.

Bacterial identification and characterization

The selected bacterial isolates (*Pseudomonas fluorescens* and *Bacillus subtilis*) were identified by the 2010 edition of Bergey's Manual of Systematic Bacteriology (Holt *et al.,* 1994). These tests include gram staining and biochemical tests such as catalase, indole, oxidase, vogesproskauer, nitrate, methyl red etc.

Chemicals and reagents

In the present work $CdCl_2$ (Merck) metal salt was taken for the preparation of standards.1.63 gm of $CdCl_2$was dissolved in 1000 ml of distilled water to make a 1000 ppm stock solution and then the stock is diluted further to obtain desired metal concentrations (20, 40 60, 80, 100 mg/L).

Instrumentation

Heavy metal analysis was done by Atomic Absorption Spectrophotometer (Perkin Elmer AAnalyst 100, USA). The pH of the solution was measured by using a digital pH meter (HI96107, Hanna Instruments). Biosorption batch experiments were conducted in (Incubator Shaker, Metrex Scientific Instruments, Delhi) and nonliving (inactive) biomass of bacteria was obtained in (Hot Air Oven, Universal, India). The Falcon tubes for centrifugation were procured from (Thomas Scientific, India) and water samples filtration was done by membrane filter paper (0.45 µm).

Bacterial biosorbent (biomass) preparation

Primarily, nutrient medium preparation and sterilization were done for the selected bacterial strains *Pseudomonas fluorescens* and *Bacillus subtilis* and then a loop containing bacterial culture was taken and then streaked on the agar plate to grow more colonies. Afterwards, for the subculturing of *Pseudomonas fluorescens* and *Bacillus subtilis* the bacterial culture of each strain was transported to a 250 ml Erlenmeyer flask containing 200 ml of nutrient broth sterilized media. The media was permitted to cool and then 200µl of each bacterial solution was inoculated, under a laminar airflow chamber and then the flasks were kept in an incubator shaker at room temperature for two days at the speed of 200 rpm to obtain the biomass. The consortium that is the mixed biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* was prepared by adding equal proportions of both the biomasses. The desired biomass was collected after the centrifugation at 9000 rpm speed for ten minutes and then the supernatant was disposed of and the cell pellet was gathered and washed two times with deionized water to confirm that no impurities were found on the cell surface. The cell pellet was centrifuged again and then the pellet was kept in a hot air oven at 90^0C for 12 hrs. to acquire dead (inactive) cells. The obtained inactive biomass was used for further biosorption experiments.

Biosorption studies

In the present work, a consortium of selected bacterial strains was assessed for the adsorption of toxic cadmium ions and mixed biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* was used for the adsorption experiments. The potential of mixed biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* in heavy metal uptake was determined *in vitro* conditions at various operational parameters namely a) pH b) biomass dosage c) contact time d) initial metal concentration.

The batch adsorption experiments were performed by suspending an adequate amount of adsorbent biomass within 100 ml of cadmium solution of the desired metal dose in the 250 ml Erlenmeyer flasks.

The flasks were placed in an incubator shaker at 200 rpm speed to reach equilibrium and then the samples were centrifuged and the supernatant was analyzed to estimate the metal concentration by AAS.

pH optimization

To determine the effect of pH on the biosorption efficiency of metal in the range (1 to 8), an adequate proportion of mixed biomass was suspended in 100 ml of the solution having 20 mg/L of Cd concentration and then the flasks were placed to attain equilibrium. Samples centrifugation and filtration were done accordingly and the supernatant was collected to estimate the remaining metal concentration of the samples.

Biosorbent dose optimization

To study the impact of consortium biomass dose on adsorption percentage, experiments were performed at different doses of biomass (1 mg/ml to 4 mg/ml) with a 100 ml solution of 20 mg/L of cadmium metal concentration by maintaining optimal ranges of other parameters. The flasks were placed on a rotatory shaker to achieve equilibrium and then the samples were gathered for the estimation of the metal concentration.

Contact time optimization

To examine the effect of contact time on adsorption, an optimal amount of biomass was suspended in a medium of 100 ml having 20 mg/L cadmium metal concentration and experiments were executed at optimal pH and biomass ranges at a temperature 30^0C±0.5^0C andthen the flasks were placed on a rotary shaker at 200 rpm speed to accomplish equilibrium. After a certain time (10 to 120 minutes) samples were collected to analyze the residual metal content of the solution.

Initial metal concentration optimization

To examine the influence of metal concentration, experiments were executed at different initial metal concentration doses (20 to 100 mg/L) of cadmium by maintaining shaker temperature at 30^0 C at the optimal ranges of all the other parameters obtained from earlier experiments. To achieve equilibrium, flasks were placed on a rotatory shaker and the sorption percentage was evaluated by the initial and final metal concentrations of the solution.

Data assessment

Adsorption isotherms

The isotherms Langmuir and Freundlich were applied to determine the data related to the adsorption of cadmium ions and also give information about achieving the equilibrium among the mixed biomass and the sorbate that is the metal concentration of the medium (Onyancha *et al.*, 2008). The Langmuir and Freundlich model isotherms equations are as follows:

Langmuir equation:

$$q_e = \frac{q_{max}\, b\, C_e}{(1 + b\, C_e)}$$

Freundlich equation:

$$q_e = K_F (C_e)^{1/n}$$

Where q_e is the metal uptake (mg metal / g biomass), q_{max} is the maximum amount of metal uptake (mg/g), b is the Langmuir constant linked with the adsorbent and sorbate and K_F is a Freundlich constant, C_e metal ion concentration at equilibrium (mg/l) and 1/n is adsorption intensity.

Data estimation for the Langmuir and Freundlich models, the amount of metal bound to the adsorbents (q_e) and the percentage biosorption of cadmium metal were calculated as follows:

$$q_e = \frac{(C_0 - C_e)}{m} \; x \; v$$

$$Biosorption\ (\%) = \frac{(C_0 - C_e)}{C_0} \; x\, 100$$

Where q_e is the metal uptake (mg/g), C_0 and C_e are the initial and final metal concentrations (mg/l) respectively, V is the volume of solution (L), and m is the consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* (grams).

Chemical Kinetics

The kinetic data for cadmium adsorption by two unified kinetic models (Yang and Duri, 2005).

Pseudo first-order kinetic model

Pseudo second-order kinetic model

Pseudo-first-order and pseudo-second-order kinetic equations explain that adsorption is a chemical reaction and adsorption rate is studied by the first and second-order reactions respectively. The rate equations are given below:

$$\frac{dq_t}{d_t} = k_1 (q_e - q_t)$$

$$\frac{dq_t}{d_t} = k_2 (q_e - q_t)^2$$

Where (qe) mg/g is the metal uptake at equilibrium, (qt) mg/g is the metal uptake at time (t) minutes, and (k1) minutes^{-1} and (k2) g mg^{-1} minutes^{-1} are the rate constant for pseudo-first-order and pseudo-second-order respectively.

Results and Discussion

Biochemical characterization of strains

Characterization of selected bacterial strains was done based on biochemical tests by Bergey's Manual of Determinative Bacteriology (as given in Table.1 and Fig.1)

Biosorption experiments

In the current study, consortium culture of *Pseudomonas fluorescens and Bacillus subtilis* was used as a sorbent for the adsorption of cadmium metal ions. The batch experiments were done by taking the benefit of both bacterial sorbents in the form of a consortium for cadmium adsorption.

The experiments were conducted at diverse parameters such as pH, exposure time, biosorbent amount and metal concentration. The effect of diverse parameters on the adsorption of cadmium using consortium culture are enumerated as follows:

Effect of pH

The pH of the medium plays a vital role in the adsorption process as electrostatic charges magnitude provided by metal ions is sustain by the pH of the medium. Biosorption batch experiments were executed at a pH range of 1 to 8 as given Fig.4; and the results for mix culture of *Pseudomonas fluorescens* and *Bacillus subtilis* showed the maximum adsorption (84.22 %) at pH 6 and minimum adsorption almost 40% at pH 1. The trend of pH shows that with the rise of pH range, adsorption of metal also increases till pH 6 and afterwards, shows slight decline with rising of pH. Analogous results were observed by (Vijayaraghavan and Yun, 2008) who reported that the drop in removal rate at higher pH ranges was possibly as the low solubility of metal complexes, which amply allows precipitation and may convolute the adsorption process.

Wang and Chen (2009) observed related results for *Bacillus* and *Pseudomonas* species that they have the massive competence to adsorb copper, cadmium and lead ions at moderate pH. Pardo *et al.,* (2003), also narrated that maximum biosorption of copper and lead metal ions took place at pH 6 of the solution by using *Pseudomonas putida*.

Effect of biomass concentration

The effect of biomass dosage on adsorption of cadmium ions was determined by using different ranges of biomass from 1 to 4 mg/ml. The influence of biomass dosage on adsorption percentage was seen in Fig.5; the adsorption percentage rises with an increase in biomass concentration until 2 mg/ml and beyond this it was reported nearly constant and from the above experimental data, it has been concluded that biomass is a substantial factor to be considered for adsorption but the needlessly increased biomass does not require for metal removal.

Maximum adsorption of 84.22 % was attained at 2 mg/ml and this optimal biomass dose was used for subsequent experiments. From the present study, it can be reported that 2 mg/ml biomass was found optimum for maximum adsorption of cadmium by consortium culture.

In many insistences, low biomass concentration results in greater uptakes. (Aksu and Cagatay, 2006; Vijayaraghavan *et al.,* 2006). It has been testified that a greater concentration of biosorbents can trigger cell agglomeration and contraction in the intercellular expanse (Pons and Fuste, 1993). Itoh *et al.,* (1975) determined that when the intercellular expanse is more at biomass concentration, metal adsorption was higher and this condition confirms optimum electrostatic interaction among the cells.

Effect of contact time

Adsorption batch experiments for cadmium ions by using consortium were performed at different intervals of time at optimum ranges of other parameters such as pH 6, biomass dosage 2 mg/ml and metal concentration of 20 mg/L. Result is inferred in Fig.6; that the percentage of adsorption increases with an increase in exposure time. The percentage of adsorption for the metal increased considerably with the time from 10 minutes (48.74 %) to 80 minutes (84.22 %) and then it was found nearly constant, the adsorption rate was rapid in the initial intervals of contact time and then found closely constant, once the equilibrium is attained. The maximum adsorption occurred for consortium culture at 80 minutes of equilibrium time and a further increase in exposure time did not affect the adsorption rate.

Relatively, the sorption process was finished in a very short duration of time by the result given by authors (Chen *et al.,* 2005; Tsezos and Volesky, 1982), the optimum time for lead ions were 50 and 40 minutes for *Bacillus subtilis* and *Bacillus cereus* respectively. The sufficient contact time on the adsorption rate of metal ions onto the biomass of *Bacillus subtilis* was found at 45 min, where the maximum adsorption was seen and afterward, there was no substantial rise was noticed. Henceforth, the adsorption of heavy metal ions was very rapid in the early stages of the experiment because an enormous number of unoccupied sites were existing on the cell wall of biomass (Colak *et al.,* 2011).

Effect of metal concentration

The impact of different ranges of initial metal concentration of cadmium was determined by using a consortium of *Pseudomonas fluorescens* and *Bacillus subtilis*. The batch experiments were performed from the range of 20 to 100 mg/L in the presence of an optimum range of other factors.

Table.1 Biochemical characterization of isolates, (+) and (-) sign indicate positive and negative reactions, respectively

S. No.	Biochemical Test	*Bacillus subtilis*	*Pseudomonas fluorescens*
1	Indole	-	-
2	V.P Test	+	-
3	Methyl Red	-	-
4	Catalase	+	+
5	Urease	-	-
6	Oxidase	-	+
7	H_2S	-	+
8	Lactose	-	-
9	Citrate	+	+
10	Glucose	-	-

Table.2 Kinetic data of consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* for sorption of cadmium

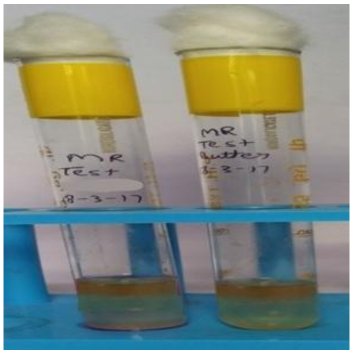
Kinetic Data of Consortium for Cadmium (Cd)						
Metal	Pseudo First Order			Pseudo Second Order		
Cadmium (Cd)	K_1	q_e	R^2	K_2	q_e	R^2
	0.0543	6.133711306	0.9998	0.014238527	9.074410163	0.9991

Table.3 Langmuir and Freundlich models linear representation for heavy metal cadmium by using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

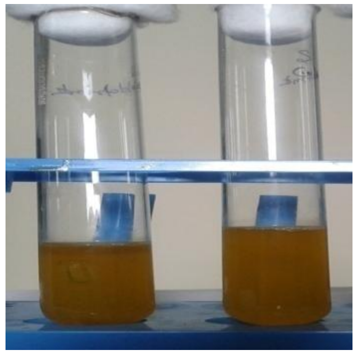
Adsorption Data of Consortium for Cadmium (Cd)						
Metal	Langmuir Parameters			Freundlich Parameters		
Cadmium (Cd)	q_m	b	R^2	K_F	1/n	R^2
	55.86592179	0.058592471	0.9956	4.363148556	0.6431	0.9772

Fig.1 Biochemical tests for *Pseudomonas fluorescens* and *Bacillus subtilis*

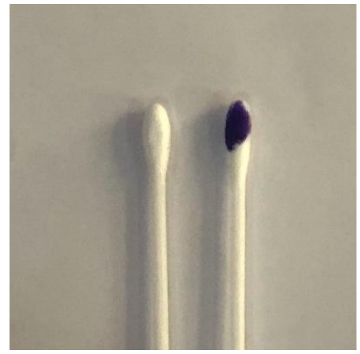
Methyl Red Test



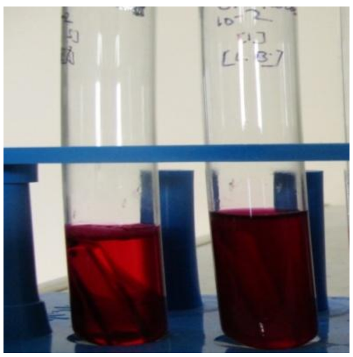
Urease Test



Oxidase Test



Glucose Test



Simmon's Citrate Test

CatalaseTest

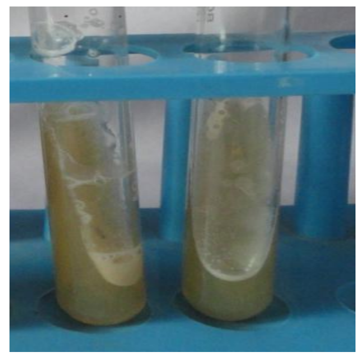


Fig.2 Consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

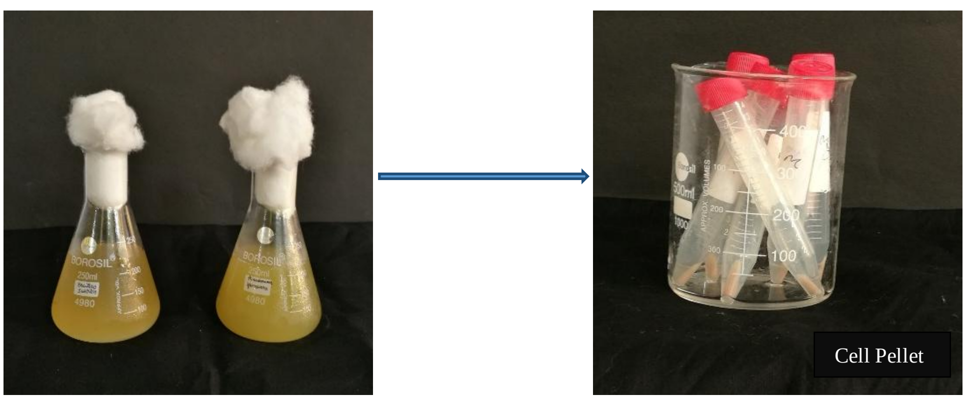


Fig.3 Sorption experiment design at different ranges of biomass

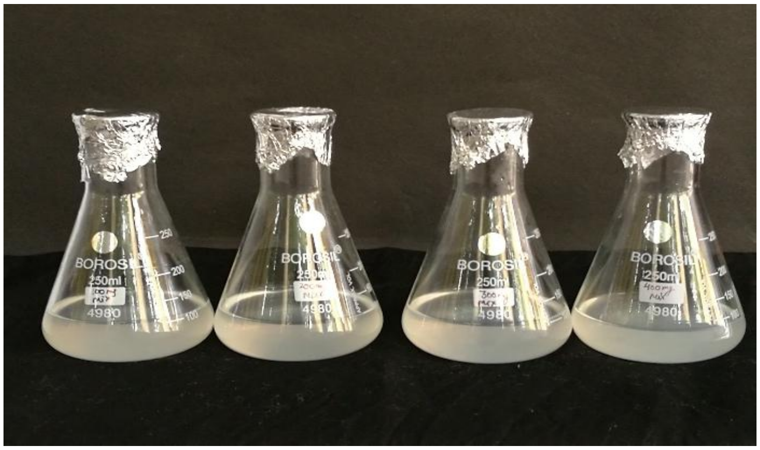


Fig.4 Effect of pH on biosorption of cadmium using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

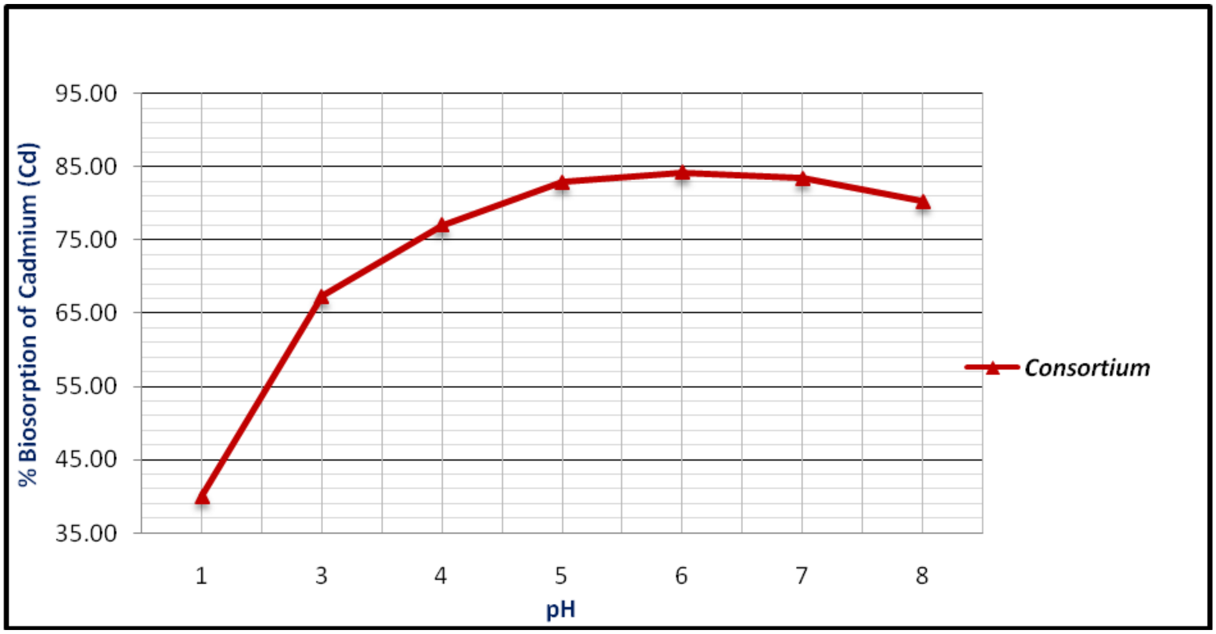


Fig.5 Effect of biomass amount on biosorption of cadmium using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

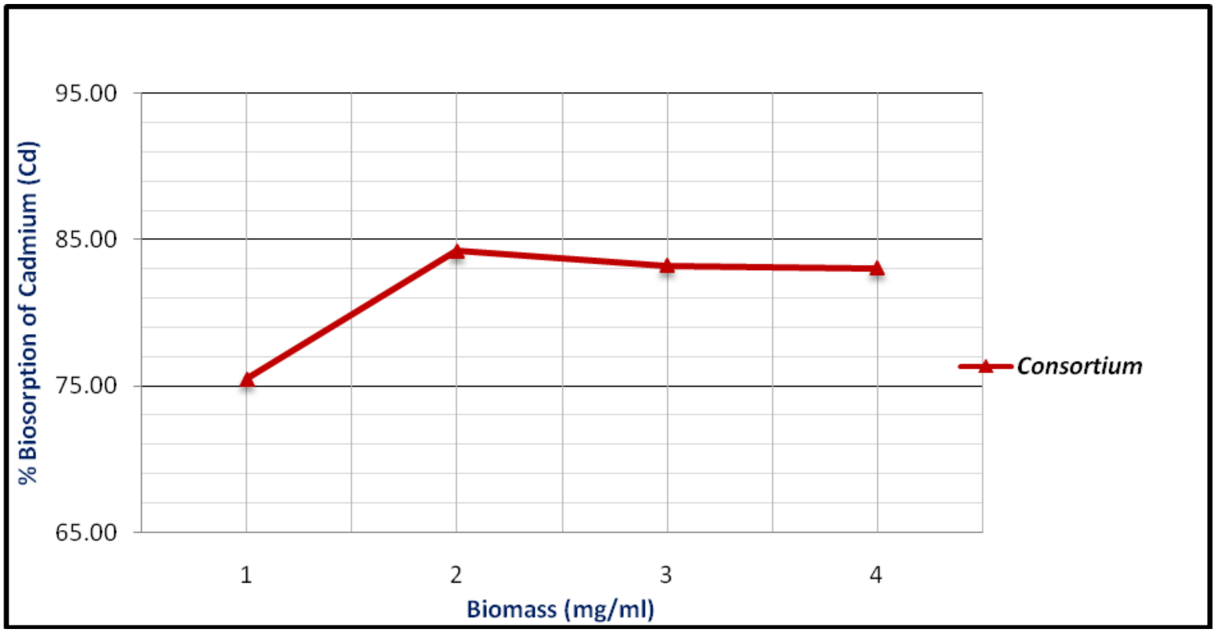


Fig.6 Effect of contact time on biosorption of cadmium using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

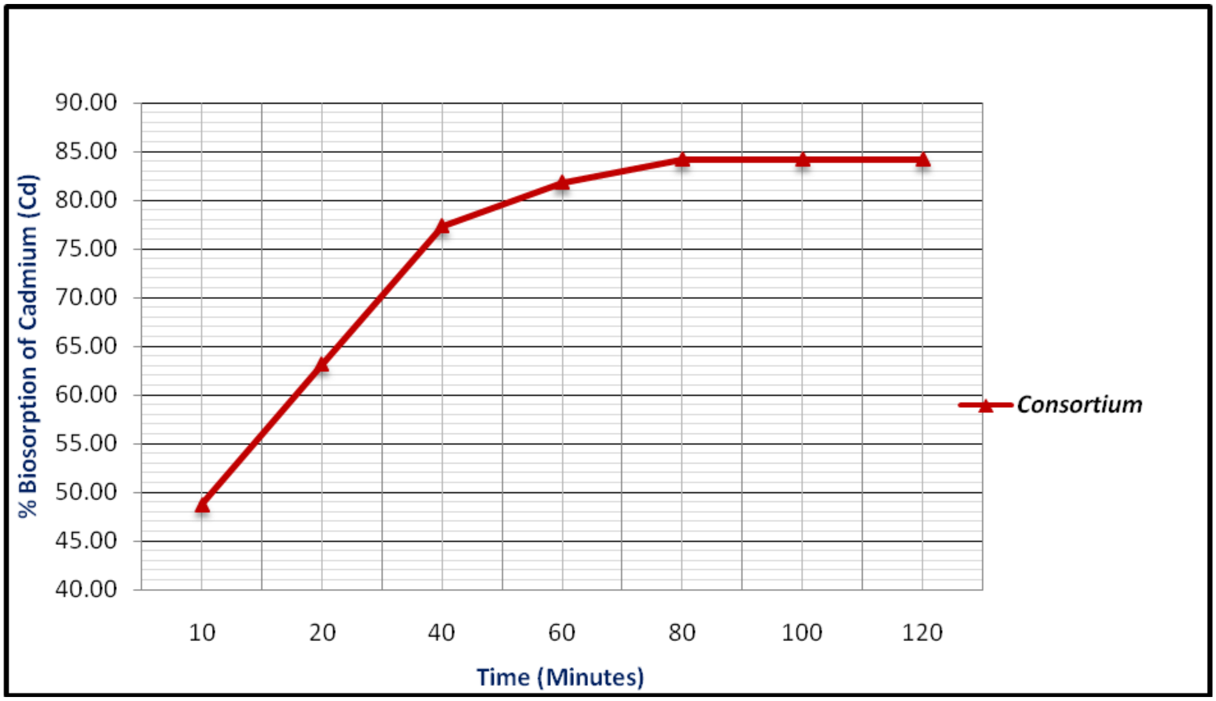


Fig.7 Effect of initial metal concentration on biosorption of cadmium using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

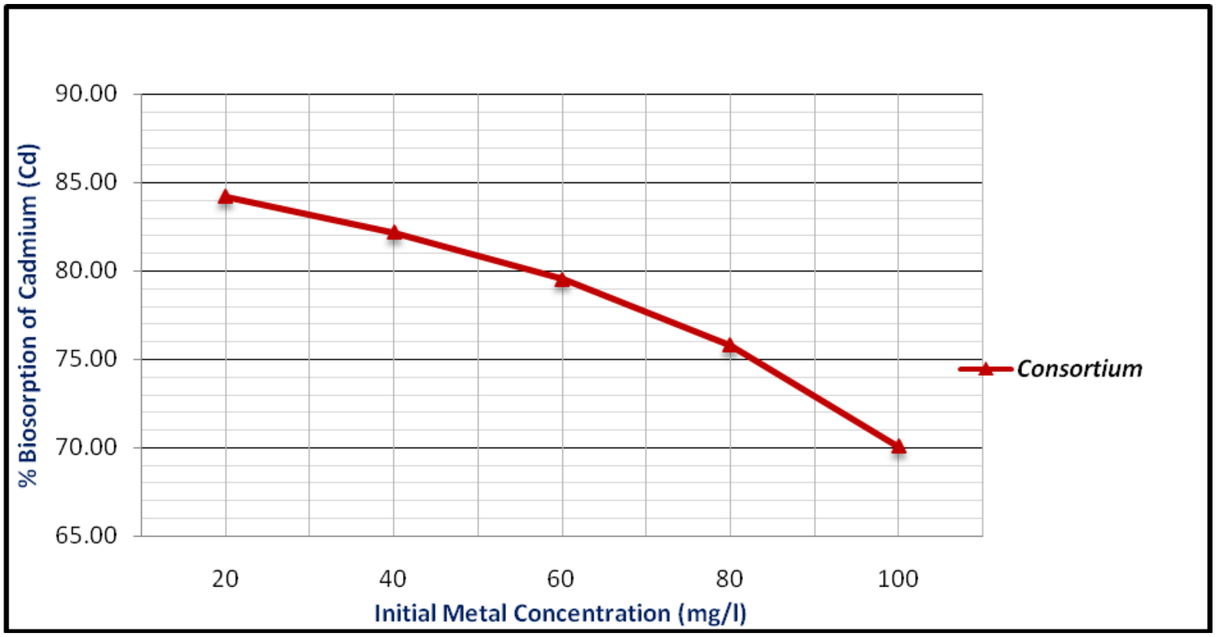


Fig.8(a) First order kinetics for cadmium biosorption using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

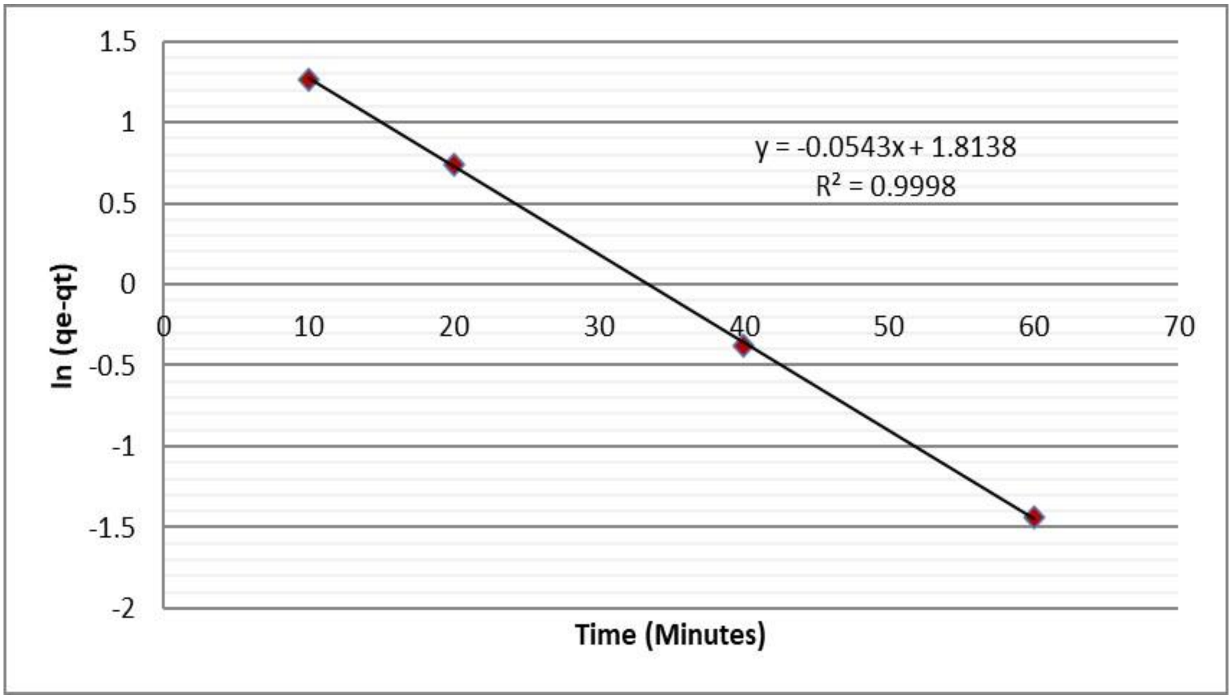


Fig.8(b) Second order kinetics for cadmium biosorption using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

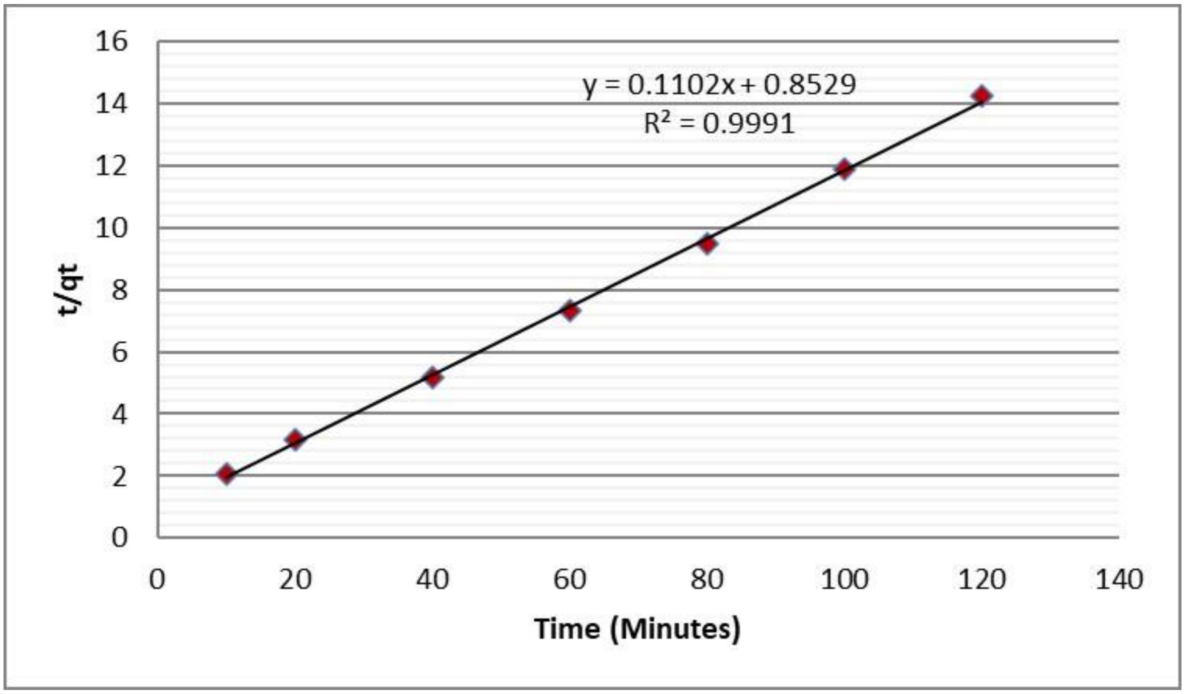


Fig.9(a) Langmiur adsorption isotherm for cadmium biosorption by using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*

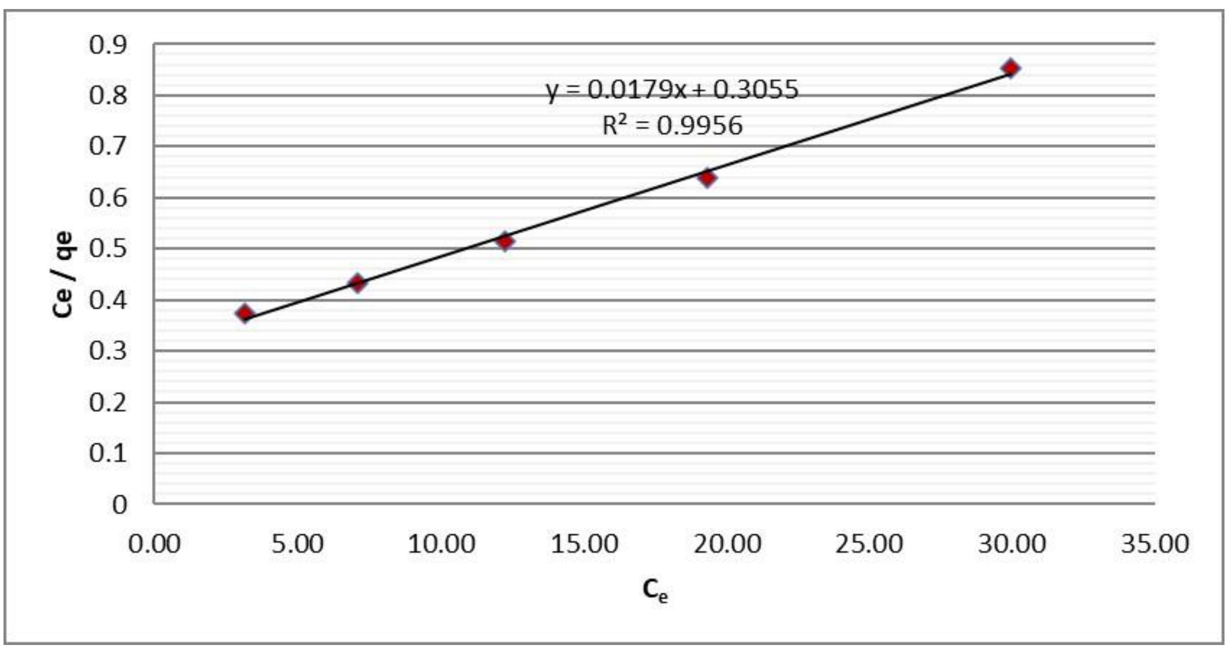
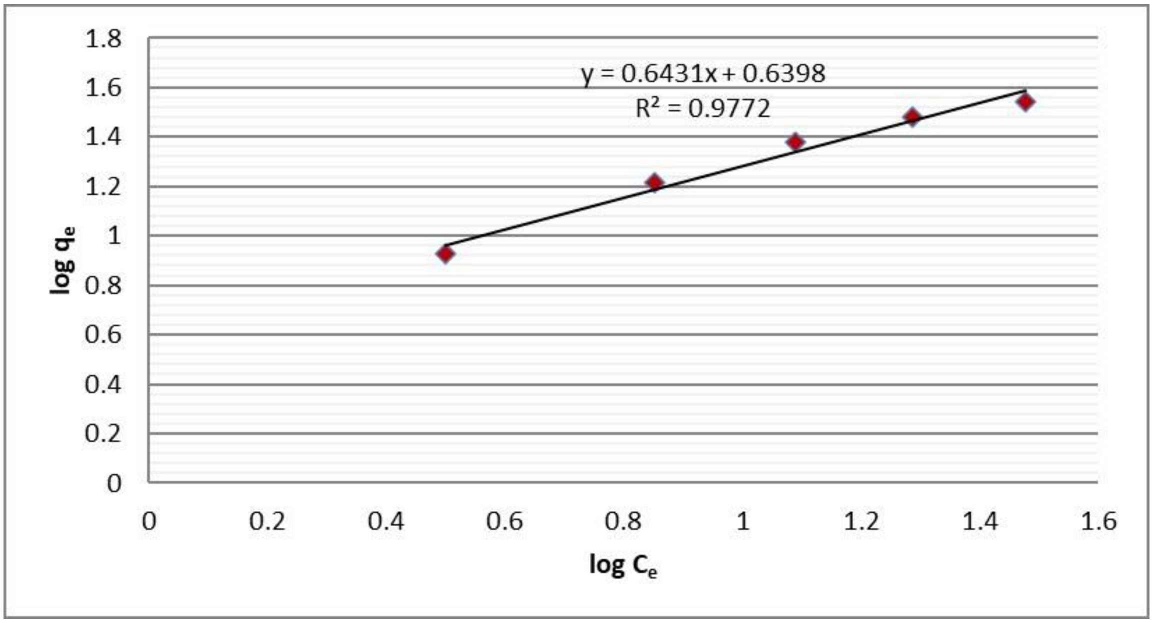


Fig.9(b) Freundlich adsorption isotherm for cadmium biosorption by using consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*



Results showed that the highest biosorption percentage 84.22 % was perceived at a low initial metal concentration at 20mg/L and the minimum biosorption was detected around 70.08 % at 100 mg/L, the trend is shown in Fig.7; the percentage of biosorption was reduced with an increase in metal concentration.

The maximum sorption of cadmium metal was retrieved at a lowermost metal ion concentration of 20 mg/L. Conversely, the best metal ions retention happened at the lowermost value of metal concentration. The adsorption rate declines with the rise in the concentration of metal ions that at higher concentrations, a less adsorption yield was spotted resulting in an immediate saturation of binding sites for the adsorption process (Kadukova and Vircikova, 2005; Pandiyan and Mahendradas, 2011).

Similar results were also testified by Norberg (1984), that the highest adsorption of cadmium ions was reported at 60 mg/L by *Zoogloeara migera* inactive biomass. In the case of *Micrococcus* species, the best growth was reported at 40 mg/L lead in synthetic aqueous media (Kiran *et al.*, 2005).

Chemical kinetics

Kinetic models were employed for adsorption of cadmium metal ions for inactive biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* consortium. The kinetic data were evaluated by the first-order and second-order equations. The calculation of the first order equation was plotted for ln (qe-qt) against t is given in Fig.8 (a) and the calculation of the second order equation was plotted for t/qt against t is given in Fig.8 (b). The coefficient of correlation for pseudo-first-order and pseudo-second-order was found around R^2= 0.9998 and R^2 = 0.9991 respectively.

Kinetic data (Table.2) indicated that the pseudo-first order equation was well fitted with cadmium adsorption by consortium culturethan the pseudo-second order equation.

The data related to rate kinetics were used to regulate the adsorption process and its adsorption rate which includes mass transport and chemical reaction (Mehmet and Sukru, 2006). The unified kinetic models are utilized to elucidate the liquid-solid phase association in the adsorption process (Kosa *et al.,* 2012; Ahment and Mustafa, 2009).

Adsorption isotherms

Langmuir and Freundlich isotherms were examined for the sorption of cadmium ions by inactive mix biomass of *Pseudomonas fluorescens* and *Bacillus subtilis*. The investigational results of the Langmuir isotherm are described in Fig.9 (a) and Freundlich models are exhibited in Fig. 9 (b). The coefficient of determination (R^2) for both the models was found more than 0.95 and almost close to 1. This infers that both isotherms fittingly explain the adsorption data for the cadmium metal. The summarized linear regression data of KF, n, q max and b values were also estimated in Table-3for Langmuir and Freundlich models for cadmium adsorption by using inactive biomass of consortium. The data related to adsorption of the cadmium ions revealed that Langmuir isotherm (R^2= 0.9956) was better fitted as an assessment to Freundlich model (R^2= 0.9772) and the highest adsorption capacity (q max) accomplished by consortium culture for cadmium metal was found about 55.86 mg/g. Furthermore, at larger concentrations, the metallic ions require to transport to the surface of biomass by the process of intra particular diffusion and the hydrolyzed ions may transportat an extremely gradual rate (Gabr *et al.,* 2008; Sang *et al.,* 2009). Several studies related to both the postulated Langmuir and Freundlich isotherms for obtaining metal adsorption data were described by some authors (Pardo *et al.,* 2003; Saret *et al.,* 1999). The Langmuir and Freundlich model is the best testified models employed by various instigators, since they are simple, informative and engrained models for the adsorption of metal ions (Vijayaraghavan and Yun, 2008).

In the present work, consortium biomass of *Pseudomonas fluorescens* and *Bacillus subtilis* was used for the removal of cadmium ions from the aqueous solutions. The sorption experiments were carried out in the batch system and the obtained results showed that the highest sorption of cadmium ions was achieved at pH 6, biosorbent dose 0.2 g, after 80 min of contact time at 20 mg/L Cd dose. The Langmuir and Freundlich model was implemented for the adsorption description of cadmium by using consortium biomass. The sorption data close-fitting to the Langmuir model and the highest sorption capacity achieved was about 55.86 mg/g. The evaluation of rate kinetic data obeyed well the pseudo-first order kinetics model, which measures that the rate monitoring step is the chemical reaction among functional groups of consortium biomass and cadmium metal ions in aqueous media. Therefore, the experimental results indicated that the consortium biomass of selected biosorbents is an efficient substitute for the sorption of cadmium ions from aquatic systems.

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