

# PERFORMANCE EVALUATION OF FIXED BED FOR BIOSORPTION OF CADMIUM IONS BY SOME SELECTED MICROBIAL BIOSORBENTS

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## ABSTRACT

*Batch process systems are not attractive for industrial application and treatment of large volume of wastewater to column mode operation. This research evaluated the performance of continuous fixed bed process system for biosorption of cadmium ions from wastewater by immobilised nonliving Bacillus Circulans and Saccharomyces Cerevisiae biosorbents, respectively. The effects of flow rate, bed height and column diameter on biosorption of Cadmium ions onto immobilised biosorbents of Bacillus Circulans and Saccharomyces Cerevisiae in a fixed bed contactor were investigated, respectively; the final concentration of the cadmium ions in the effluent was obtained using standard methods for examination of wastewater. The fixed bed process systems results shows that lower flow rate 10 ml/min tends to move downwards towards the abscissa and gives better treatment efficiency to higher flow rate 30 ml/min which tends to move towards the ordinate whereas higher column bed height 9 cm gives better treatment efficiency to lower column bed heights 6 cm and 3 cm and increases with increase in column internal diameter from 1.0 to 1.5 cm for a constant bed column height. Biosorption capacity and percentage removal were observed to give better results at flow rate of 10 ml/min and column bed height 9 cm for cadmium ions onto immobilised nonliving Bacillus Circulans and Saccharomyces Cerevisiae biosorbents. The results show that better performances were recorded by immobilised nonliving Bacillus Circulans to Saccharomyces Cerevisiae.*

**Keywords:** Biosorption, fixed bed, flow rate, bed height, column diameter

## 1 INTRODUCTION

**B**iosorption process is an attractive technique that involves a solid phase or biological material (sorbent or biosorbent) and a liquid phase or water (solvent) containing a dissolved species to be sorbed (heavy metal ion) [1, 2]. This process is shown by disequilibrium of the surface forces by the contact of a solid surface with a liquid phase (sorbate), forming a surface layer of solutes on the adsorbent and resulting in the accumulation of metals by physicochemical interactions of metal ions with cell components of biological species (microorganisms). Therefore, Biosorption is said to be a passive, rapid, reversible and independent metabolic energy process carried out by active or inactive microorganisms [3]. The manufacturing of extracellular polymeric substances (EPS) by microorganisms is intimately connected to adherence processes that facilitate cellular adhesion to surfaces, formation of cell-to-cell aggregation in form of flocs, biofilm, sludges and biogranules that are useful in the biosorption and bio-sequestration of metal or metalloid ions. Extracellular polymeric substances (EPS), is a complex biopolymer that mainly composed of polysaccharide, protein, humic substances, uronic acid, nucleic acid and lipids [4]. The utilisation of nonliving microorganisms may give some advantages compare to living organism, such as lower sensitivity concentration of toxic wastes, lack of requirements for continuous supply of nutrients, easy desorption and recovery, and storage for extended periods at room temperature without putrefaction occurring [5, 6]. The continuous fixed bed provides most significant practical data and parameters for biosorption of

biosorbate using any biosorbent of interest. The solution continuously enters and leaves the column, so that the complete equilibrium is never reached at any stage between the biosorbate in solution and the amount adsorbed. Equilibrium has to be continuously established each time the biosorbent meets fresh concentrations; therefore, equilibrium in continuous or column mode is referred to as dynamic equilibrium [7]. Whereas, for Batch biosorption mode, the equilibrium attained is said to be static in nature, as it does not change further with time. The aim of this study is to determine the potential of immobilised nonliving *Bacillus Circulans* and *Saccharomyces Cerevisiae* to remediate Cadmium ions from wastewater in a continuous fixed bed process system.

## 2 MATERIALS AND METHODS

### 2.1 Preparation of Solution and Serial Dilution

An aqueous solution of Cadmium ions was prepared from Cadmium nitrate ( $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ ) with known concentration of  $100 \text{ mg/l}$  which served as synthetic wastewater. The Cadmium ions solution operating pH of 7.0 and 6.0 were achieved using 0.1 M NaOH or HCl for *Bacillus Circulans* and *Saccharomyces Cerevisiae* in the continuous fixed bed process system, respectively.

### 2.2 Immobilisation of Biosorbent

Entrapment method that involved drop wise addition of biomass suspended in polymer matrix of 2% (w/v) sodium alginate solution and 5% (w/v) biomass was adapted [8, 9]. The beads were produced when the alginate biomass slurry was introduced drop wise into 250 ml of dissolved dehydrate 0.1 M  $\text{CaCl}_2$  using 20 ml syringe for polymerisation. The resultant beads after production were kept using Haier Thermocool Refrigerator HRD – 231SX at 4 °C (freezer) in  $\text{CaCl}_2$  solution for 12 to 14 h for hardening. It was then washed with 500 ml distilled water twice. The drained beads were spread on a dryer tray using GENLAB ENGLAND – N535 oven and kept at 80 to 100 °C for an hour and later adjusted to 40 °C till the whole beads were dried. After drying, each strain of immobilised biomass bead was kept inside a tight bottle for future use as biosorbent.

### 2.3 The Fixed Bed Process Systems

The continuous fixed bed experimental process system set up was adapted from Abdul Raffar *et al.* [10] and Yunnen *et al.* [11] with some modification. The first bed was made from a plexiglass tube with inner diameter 1.0 cm and height 30.0 cm while the second column was constructed from a tube of inner diameter 1.5 cm and same height 30.0 cm as the first column. A layer of glass wool 1 cm was installed at the bottom and top of the bed. An immobilised biomass was served as biosorbent packed with different height (cm) varying from 3 to 9 cm for both *Bacillus circulans* and *Saccharomyces cerevisiae*, respectively. The effect of flow rate was evaluated by varying the flow rate from 10 to 30 ml/min. The inlet tube was placed at the bottom of the column and the metal solution was pumped into the column using a peristaltic pump in an up-flow mode. The experiments were conducted at room temperature of 32 °C. The concentrations of Cadmium ions after biosorption were evaluated using standard method for examination of water and wastewater [12]. The concentration of the effluent stream of Cadmium ions was detected each using VGP210-Atomic absorption spectroscopy. Figure 1, shows the schematic presentation of the fixed bed contactor process system.

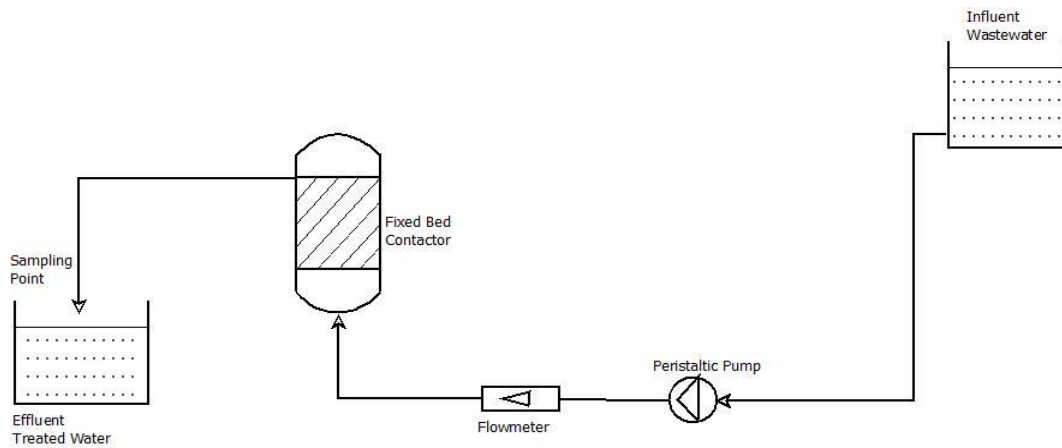


Figure 1. Schematic Presentation of the Fixed Bed Process System

### 3 RESULTS AND DISCUSSION

Results of some factors that affect the biosorption of cadmium ions onto *Bacillus circulans* and *Saccharomyces cerevisiae* in a continuous fixed bed process system are shown in Figures 2 to 7, respectively.

#### 3.1 Effect of Flow rate on Column Biosorption

Effects of flow rate on column biosorption in a fixed bed process system are illustrated in Figures 2 to 5.

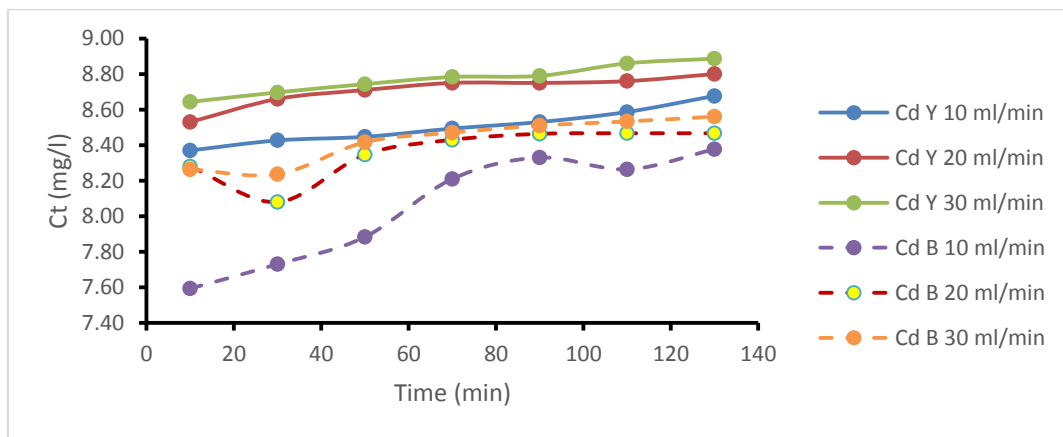


Figure 2. Effect of Flow rate for Cadmium ions Biosorption onto *Bacillus Circulans* and *Saccharomyces Cerevisiae* [H=9 cm, d=1.0 cm]

Figure 2 shows that if the biosorption occur under the same operating condition for a specific biosorbate onto biosorbent; the rate of mass transfer tends to increase with increase in flow rate leading to faster exhaustion of the biosorbent to that of lower flow rate. This is explained by Samuel *et al.* [13], where adapted bacterial consortia immobilised in alginate beads served as biosorbent for biosorption of chromium (IV) ions, where an increase in flow rate leads to faster exhaustion of the biosorbent. The flow rate 10 ml/min for both cadmium ions onto *Saccharomyces cerevisiae* (Cd Y) and cadmium ions onto *Bacillus circulans* (Cd B) gave lower concentration of cadmium ions in the effluent to that of 20 ml/min and 30 ml/min after biosorption has taken place in the column. This indicate that lower flow rate gives more time for mass transfer into the pores of the biosorbents which permits the cadmium ions access to more binding sites within each biosorbent of *Saccharomyces cerevisiae* and *Bacillus circulans*.

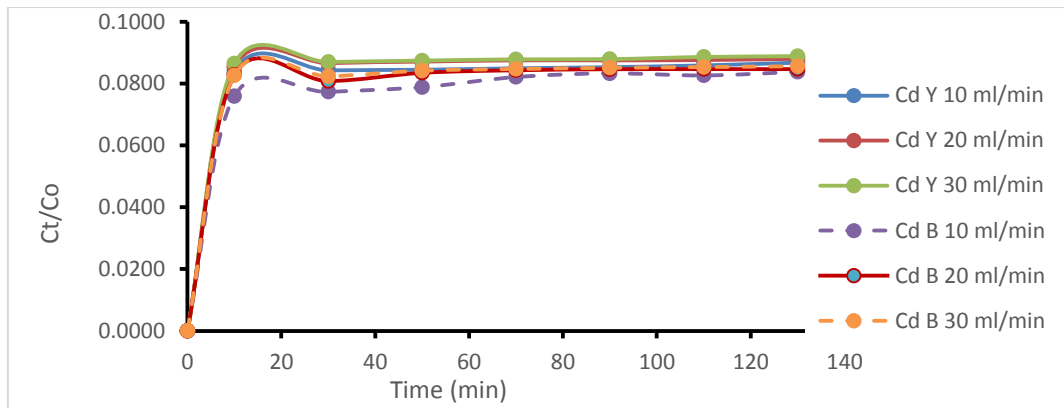


Figure 3. Breakthrough Curves for Cadmium ions Biosorption onto Bacillus Circulans and Saccharomyces Cerevisiae [H=9 cm, d=1.0 cm]

Figure 3 shows that the breakthrough curve plot of higher flow rate tends to move towards the ordinate and above that of lower flow rate which tends to move downwards toward the abscissa. This also confirmed that flow rate 10 ml/min for both cadmium ions onto *Saccharomyces cerevisiae* (Cd Y) and cadmium ions onto *Bacillus circulans* (Cd B) gave lower concentration of cadmium ions in the effluent to that of 20 ml/min and 30 ml/min after biosorption has taken place in the column.

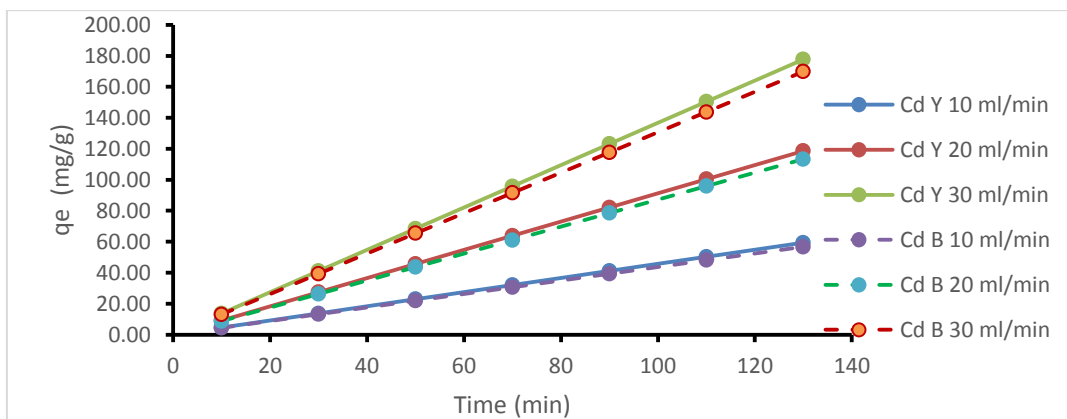


Figure 4. Biosorption Capacity of Cadmium ions onto Bacillus Circulans and Saccharomyces Cerevisiae [H=9 cm, d=1.0 cm]

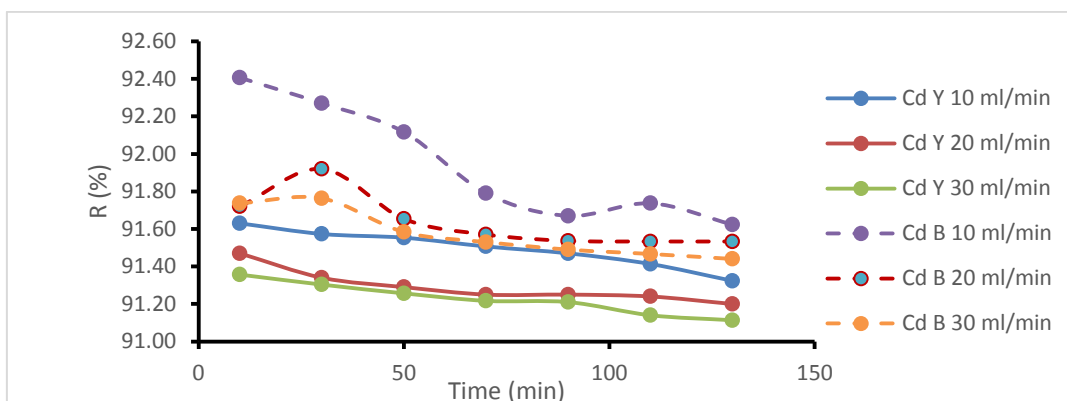


Figure 5. Removal Percentage of Cadmium ions Biosorption onto Bacillus Circulans and Saccharomyces Cerevisiae [H=9 cm, d=1.0 cm]

The fixed bed investigation on biosorption capacity and removal percentage of cadmium ions are presented in Figures 4 and 5, respectively. Biosorption capacity and percentage removal were also observed to give better results at flow rate of 10 ml/min for cadmium ions onto *Saccharomyces*

*cerevisiae* (Cd Y) and *Bacillus circulans* (Cd B). The results of this study also show similarity to that obtained by Cruz-Olivares *et al.* [14], where lead ions biosorption onto residue of allspice in a fixed bed column confirmed lower flow rate give more time for mass transfer in the pores of biosorbent resulting in better performance than higher flow rate. Biosorption of cadmium ions onto *Bacillus circulans* (Cd B) at different flow rate under investigation gave a better result to that of cadmium ions onto *Saccharomyces cerevisiae* (Cd Y).

### 3.2 Effect of Bed Height on Column Biosorption

Effect of bed column height for cadmium ions biosorption in a fixed bed is presented in Figure 6.

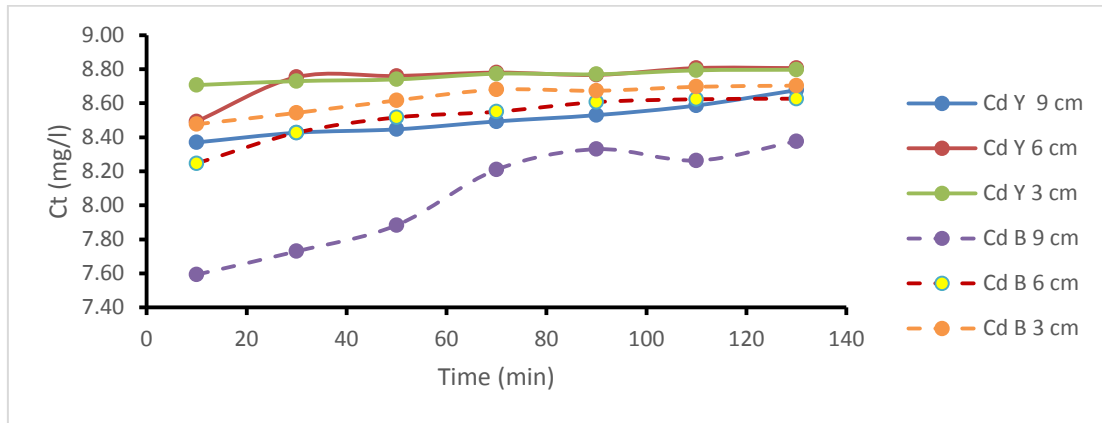


Figure 6. Effect of Bed Height for Cadmium ions Biosorption onto *Bacillus Circulans* and *Saccharomyces Cerevisiae* [Q=10 ml/min, d=1.0 cm]

The height of the column was investigated at 9, 6 and 3 cm to test its effect for further scale up of the bed due to availability of the microbial biosorbent. It was found that as the height of bed column increases so does the performance of the column increases. This might be due to increase in the surface area and the availability of more binding site on *Saccharomyces cerevisiae* as well as *Bacillus circulans* biosorbents. These results concur with what was obtained by Abdul Raffar *et al.* [10], where biosorption of copper ions onto immobilised *Saccharomyces cerevisiae* in a packed bed column give better treatment at the high height. The final concentrations of the cadmium ions in effluent were recorded to be lower for 9 cm bed height for both cadmium ions onto *Saccharomyces cerevisiae* (Cd Y) and cadmium ions onto *Bacillus circulans* (Cd B). Above all, better performance was observed with cadmium ions onto *Bacillus circulans* (Cd B) for each bed height investigated.

### 3.3 Effect of Column Diameter on Biosorption

Effects of column diameter for cadmium ions biosorption onto *saccharomyces cerevisiae* and *bacillus circulans* are presented in Figure 7.

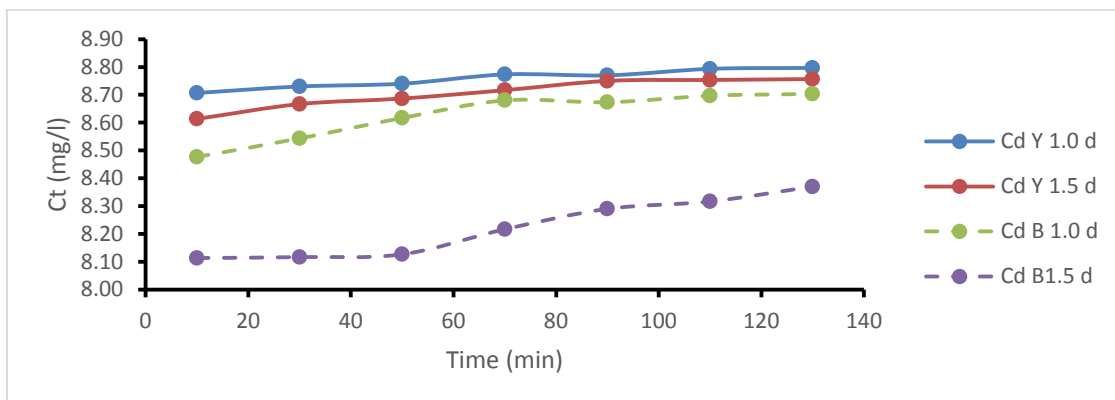


Figure 7. Effect of Column Diameter for Cadmium ions Biosorption onto *Bacillus Circulans* and *Saccharomyces Cerevisiae* [Q=10 ml/min, H=3 cm]

A constant bed column height 3 cm were maintained for two different columns of internal diameter 1.0 cm and 1.5 cm denoted by 1.0 *d* and 1.5 *d* as shown in Figure 7, respectively. It was established that cadmium ions biosorption in a fixed bed increases with increase in column internal diameter for a constant bed column height. This might also be as a result of increase in surface area and presence of more binding site for cadmium ions biosorption onto the two different biosorbent under investigation. This is in agreement with what was reported by Kariuki *et al.* [15] that increasing the biomass dosage progressively increases the biosorption sites for the biosorbate. *Bacillus Circulans* with column bed diameter 1.5 cm gives better results for biosorption of cadmium compared to that of *Saccharomyces Cerevisiae*.

#### 4 CONCLUSIONS

The investigations revealed that continuous fixed bed experimental process system could be used for biosorption of cadmium ions at room temperature of 32 °C using immobilised nonliving *Bacillus Circulans* and *Saccharomyces Cerevisiae* as biosorbents. The immobilised nonliving *Bacillus Circulans* gives better performance to immobilised nonliving *Saccharomyces Cerevisiae* in all the analysis carried out with respect to effect of flow rate, bed height and column diameter on biosorption of Cadmium ions. Lower flow rate shows better performance to higher flow rate; whereas higher biosorbent dosage demonstrates better performance to lower biosorbent dosage has clearly depicted by column bed height and column internal diameter for cadmium ions onto *Bacillus Circulans* and *Saccharomyces Cerevisiae*.

#### REFERENCES

1. Asfaram, A., Ghaedi, M., Ghezlbash, G.R., Dil, E.A., Tyagi, I., Agarwal, S. and Gupta, V.K. (2016). Biosorption of Malachite Green by Novel Biosorbent *Yarrowia Lipolytica*sf7: Application of Response Surface Methodology. *Journal of Molecular Liquids*, vol. 214, pp. 249-258.
2. Nadeem, R., Manzoor, Q., Iqbal, M. and Nisar, J. (2016). Biosorption of Pb (II) onto Immobilized and Native *Mangifera Indica* Waste Biomass. *Journal of Industrial and Engineering Chemistry*, vol. 35, pp. 185-194.
3. Vendruscolo, F., Ferreira, G.L.R., Filho, N.R.A. (2017). Biosorption of Hexavalent Chromium by Microorganisms: A Review Paper. *International Biodeterioration and Biodegradation*, vol. 119, pp. 87-95.
4. Oyetibo, G.O., Miyauchi, K., Huang, Y., Chien, M.F., Ilori, M.O., Amund, O.O., Endo, G. (2017). Biotechnological Remedies for The Estuarine Environment Polluted with Heavy Metals and Persistent Organic Pollutants. *International Biodeterioration and Biodegradation*, vol. 119, pp. 614-625.
5. Macek, T. and Mackova, M. (2011). Potential of Biosorption Technology: In Kotrba, P., Mackova, M. and Urbanek, V. (Eds.), *Microbial Biosorption of Metals*, Springer Science+Business Media B.V., pp. 7-17.
6. Colak, F., Olgun, A., Atar, N. and Yazıcıođlu, D. (2013). Heavy Metal Resistances and Biosorptive Behaviors of *Paenibacillus Polymyxa*: Batch and Column Studies. *Journal of Industrial and Engineering Chemistry*, vol. 19, pp. 863-869.
7. Hossain, M.A. (2013). Development of Novel Biosorbents in Removing Heavy Metals from Aqueous Solution, PhD Thesis, Environmental Engineering, School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology, University of Technology, Sydney, Australia, pp. 263-527.
8. Kumar, R., Bhatia, D., Singh R., Rani, S. and Bishnoi, N.R. (2011). Sorption of Heavy Metals from Electroplating Effluent using Immobilized Biomass *Trichoderma viride* in a Continuous Packed Bed Column. *International Biodeterioration and Biodegradation*, vol. 65, pp. 1133-1139.



9. Ilamathi, R., Nirmala, G.S. and Muruganandam, L. (2014). Heavy Metals Biosorption in Liquid Solid Fluidized Bed by Immobilized Consortia in Alginate beads. *International Journal of Chem Tech Research*, vol. 6, no.1, pp. 652-662.
10. Abdul-Raffar, N.I., Senusi, F. and Chang, S.H. (2015). Biosorption of Copper Ion using immobilized *Saccharomyces Cerevisiae* in a continuous Packed-Bed column. *Journal of Scientific Research and Development*, vol. 2, no. 14, pp. 132-138.
11. Yunnen, C., Ye, W., Chen, L., Lin, G., Jinxia, N. and Rushan, R. (2017). Continuous Fixed-Bed Column Study and Adsorption Modeling: Removal of Arsenate and Arsenite in Aqueous Solution by Organic Modified Spent Grains. *Pol. J. Environ. Stud.*, vol. 26, no.4, pp. 1847-1854.
12. Standard Methods (1998). Standard Methods for Examination of Water and Wastewater: In Clesceri, L. S., Greenberg, A. E. and Eaton, A. D. *American Public Health Association. Washington D. C. 20<sup>th</sup> ed.* Section 3120, pp. 337-343.
13. Samuel, J., Pulimi, M., Paul, M.L., Maurya, A., Chandrasekaran, N. and Mukherjee, A. (2013). Batch and Continuous Flow Studies of Adsorptive Removal of Cr (VI) by Adapted Bacterial Consortia Immobilized in Alginate Beads. *Bioresource Technology*, vol. 128, pp. 423-430.
14. Cruz-Olivares, J., Pérez-Alonso, C., Barrera-Díaz, C., Ureña-Nuñez, F., Chaparro-Mercado, M.C. and Bilyeu, B. (2013). Modeling of Lead (II) Biosorption by Residue of Allspice in a Fixed-Bed Column. *Chemical Engineering Journal*, vol. 228, pp. 21–27.
15. Kariuki, Z., Kiptoo, J. and Onyancha, D. (2017). Biosorption Studies of Lead and Copper using Rogers Mushroom Biomass '*Lepiota hystrix*'. *South African Journal of Chemical Engineering*, vol. 23, pp. 62-70.