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REMOVAL OF NICKEL USING VARIOUS BIOSRBENTS: REVIEW

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ABSTRACT: *Nickel ion is one of the non-biodegradable toxic heavy metals commonly found in industrial effluents which causes severe health challenges when excessively accumulated in the food chain of various living organisms and the environment through mutagenesis and carcinogenicity. Different physicochemical conventional techniques have been used for nickel ion removal from wastewaters. However, these methods are energy-consuming, expensive and generate secondary pollutants as by-products. Hence, the need for a potential alternative to these existing techniques. The use of agricultural and biological materials as biosorbent for heavy metals removal has been found to be the potential alternatives to these existing conventional methods. This study is aimed at the review of various reports of various authors on the removal of nickel ion from wastewaters using biosorbents of agricultural and biological origin. The use of algal, bacteria, fungi as biosorbent under the growing, living, non-living conditions in batch and continuous operation were reviewed and reported. Langmuir and Freundlich's models were observed to be widely reported to fit in the biosorption of the Nickel ions from wastewater. Also, the study revealed that living, dead and non-living cells of these microorganisms were widely used as biosorbents as compared growing cells due to its toxicity.*

KEYWORDS: Nickel Ion, Microorganisms, Biosorbents, Conventional Method, Heavy Metals, Non-Biodegradable

INTRODUCTION

Heavy metals have proven to be one of the major contaminants in drinking water and causes of serious threat to the animals, humans and the environment (Hau *et al*., 2012; Singh *et al*., 2010; Patrick, 2006). These metals are widely found in the wastewater from many industries such as metallurgical, alloying, steel, pigments, petrol, plastic industries and among others (Podder and Majumder, 2016; Hemidouche *et al*., 2016). Nickel ion is one of the non-biodegradable toxic heavy metals ion commonly present in effluents from industries such as galvanization, smelting, mining, dyeing operation, batteries manufacturing, and steel factories and among others (Langǎrd, 1994). The WHO, through water sanitation and hygiene, has estimated the allowable toxic limit of Nickel concentration in insoluble compounds of 1.0mg/m-^{3}, nickel carbonyl of 0.05-0.12mg/m-^{3}, and nickel sulfide of 1.0mg/m-3 (Hadadian *et* al., 2018). At an amount beyond the allowable concentration, several diseases such as cancer, renal edema, skin dermatitis, gastrointestinal disorder (Langǎrd, 1994), reduced central nervous function, the respiratory and hepatic disorder may occur (Hemidouche *et al*., 2016). Therefore, the need for the removal of Ni ion from effluents before it is discharged into the environment.

Different conventional Physicochemical methods have been used for the removal of heavy metals from solution, these include reverse osmosis (Ozaki *et al*., 2002; Petrinic *et al*., 2015), precipitation (Sakai *et al*., 2009; Charerntanyarak, 1999), phyto-extraction, ultra-filtration (Barakat and Schmidt, 2010), membrane technologies, evaporation recovery, sedimentation (Konsowa, 2010; Dean *et al*.,1972), ion exchange (Zewail and Yousef, 2015; Dąbrowski *et al*.,2004) and adsorption. These techniques are ineffective in removing metals ion present in trace from effluents. Also, they are expensive and energy-consuming, and their operation generates a secondary pollutant as a by-product (Bai and Abraham, 2001). This has necessitated the development of the biosorption technique, which is an eco-friendly process to remove heavy metals without generating any form of dangerous waste as by-products.

Biological Treatment Methods

Biosorption involves the removal of pollutants such as heavy metals from effluent using biological materials (Sahmoune, 2018). This method has been recognized as a potential alternative to conventional techniques for the treatment of contaminated wastewater (Stratten, 1987; Volesky, 1990). The strong binding strength between these biosorbents and the various functional groups like alcohol, aldehydes, ketones, phenolic, carboxylic and ether of various effluents make the use of these biosorbent attractive for the removal of heavy metals (Sud *et al*.,2008; Ahluwalia and Goyal.,2007; Demirbas, 2008). Various biomasses, both chemical pretreated and untreated, have been studied for Ni ion removal from solutions. Among the factors that influence the adsorption capacities of biomasses are adsorbent dose, contact time, temperature, initial metal concentration, and the pH of the solution (Bilal *et* al., 2013). However, pH has been reported to be one of the most important factors influencing the metal uptake.

The application of growing, resting and non-living cells of micro-organisms have been reported to remove Ni ion from effluents (Martins *et al.*, 2016; Mahmood, *et al.*,2015; Sahmoune, 2018; Kleinubing *et al*., 2011; Miono *et al*., 2019). However, non-living cell microorganisms have mostly been used for the removal of the Ni ion. This is due to the absence of both toxicity limitations and the need for media growth and nutrients. Although, growing cells have an advantage over non-lining and resting cells, in that the metal can be removed and at the same time as the microorganism is growing. However, the use of living cells is limited because the high metal concentration inhibits the cell growth of the microorganism. This problem can readily be solved using metal tolerant organisms (Sen and Dastidar, 2010). The removal of metal ions from aqueous solution is largely dependent on the tolerance and removal capacities of the growing biomass used.

Biosorption of Ni ion using alga, fungal or bacterial biomass, and agricultural waste has been adopted as a potential alternative to the conventional technique of wastewater treatment and drinking water. Low cost of operation, non-generation of a secondary pollutant, high adsorption capacity, generation and reuse of the biosorbent and easy metal recovery are the advantages of biosorption over the existing methods.

Agricultural Waste

The application of cellulosic, lignocellulosic and agricultural waste or derivative of the agricultural waste for Ni ion removal has been studied and reported by various authors. Table 1.0 shows the reports and findings of some of these authors. The presence of lignin, cellulose

and various functional groups on the agricultural biomasses has made it suitable for heavy metal removal (Lesmana *et al*., 2009)

Table 1: Application of Agricultural Wastes

Biosorbent	Reactor/ condition	Initial Ni ion concentration	Maximum Ni removal	Best fit model	Reference
Rice Husk	Batch Reactor P^H=2-6, dose=20 g/l, time=10-180 min, 180 rpm	100 mg/l	51.8% (P^H=6.0, dose= 20 g/l, 180 rpm, t= 25^{o}C, q_{max} =8.86 mg/g, b= 0.011 l/mg, R^2 =0.8919, K_f = 0.18 mg/g, n= 1.56 l/mg, R^2 = 0.898, q_D = 2.56, B_D= 0.32 mol^2kj^2, E_D =1.25 kJ/mol, R^2 = 0.5689	Langmuir and Freundlish	Bansal *et al*., 2009
Coffee Husk Spent Coffee	Batch Reactor P^H =6, dose =1 g/l	30 - 120 mg/l	57.14 mg/g (P^H=6, dose =1 mg/l) 51.91 mg/g (P^H=6, dose =1 mg/l)	Langmuir	Rodriquez *et al*., 2017
Teff straw	Batch Reactor P^H = 1-11, 25^{o}C-73^{o}C, 30 – 70 min, dose = 3.53 mg/l	3.53 mg/l	88% (60 min, P^H = 6.5, 75^o C) q_{max} = 41.2 mg/g, b = 0.189 l/mg, R^2 = 0.998, k_f =1.24, n =1.10, R^2 = 0.748.	Langmuir	Desta, 2013.
Eggshell	Batch Reactor Dose = 0.2 g, 0-180 min,300 rpm, 25±2^{o}C.	100 mg/l	85% (60 min)	Langmuir and Pseudo-second order	Deangelis *et al*., 2017.
Fern Asplenium nidusl	Batch Reactor Dose= 0.2 g, P^H = 1-7, 60-180 rpm, 27^{o}C	1 -20 mg/l	58% (P^H = 7, 27^{o}C, 5 mg/l, 30 min)	Langmuir, Freundlichand Pseudo-second order	Dissanyake *et al*., 2016
Dalbergia bean	Batch reactor P^H = 2-10, dose= 0.1 – 0.3 g, 2 hrs, 120 rpm	5- 25 mg/l	70% (dose = 0.2 g, 120 rpm, 20 min)	Temkin and Elovich second order	Lahot and Tiwari 2017

Biosorbent	Reactor/ condition	Initial Ni ion concentration	Maximum Ni removal	Best fit model	Reference
Olive stone	Batch Reactor P^H = 2 – 7.5, Dose = 0.2 g, 20±2°C, 30 rpm	1.5 x 10^{-4} M	85% (P^H = 5.5, 60 min, dose = 0.2 g) Q_{max} = 3.63 x 10^{-5} mol/g, b = 3.16 x 10^3 l/mol, k_f = 2.4 x 10^{-5}, 1/n = 0.20.	Langmuir and Pseudo-second order	Fiol *et al*., 2016
Callinectes sapidus crab	Batch Reactor P^H = 2-9, 25 – 55°C, dose= 1 – 20 g/l, 3-130 min	10 mg/l	95.1 % (P^H = 6, 60 min, 25°C, dose = 3 g/l, 10mg/l) q_{max} = 29.15 mg/g, k = 0.161l L/mg, R^2 = 0.9677, n = 1.937, k_f = 5.003, R^2 = 0.9901, DS = -17.79 J/ molK^{-1}, DH = -26.26 kJ/mol	Freundlich	Foroutan *et al*., 2019.
Sugarcane baggasse	Batch reactor P^H = 2.5 - 7.52, dose =500-1500 mg/l, 100 – 200 rpm, 25°C, 5-120 min	50 mg/L	75% (P^H = 7.52, 60 min, 150 rpm, 50 mg/L, 25°C)		Garg *et al*., 2008
Cassiafistula (Golden shower)	Batch Reactor P^H = 3-8, dose = 0.05-0.3 g/100 ml, 24 hr, 100 rpm, 30°C.	0.1 g/100 ml	100% (P^H = 6, dose = 0.1 g/ 100 ml, 25 mg/L, 720 min)	Langmuir and second order	Hanif *et al*., 2007
Syzygiumcumim leaves	Batch reactor P^H = 1-7, Dose=0.5-2.0 g/L, 10-35°C.	50 – 200 mg/l	80% (P^H = 6.0, dose = 1.5 g, 12 hrs, 50 mg/l, 30°C)	Langmuir, Freundlich, Temkin and Dubini-Radushkevich and pseudo-second order	Kaur *et al*., 2013.
Popular deltoid leaves			75%		

Biosorbent	Reactor/ condition	Initial Ni ion concentration	Maximum Ni removal	Best fit model	Reference
Extausted coffee	Batch reactor 50-300 rpm, dose =50-1800 mg, 5-120 min	50 mg/l	72% (P^H=6, dose= 1.8 mg, 60 min, 1.2 g/l)	Freundlich, Temkin and Pseudo-second order	Mahajan and Sud, 2013
Arachis hypogea shells in natural (AHSN) Arachis hypogea shells in bead form (AHSB)			AHSN: (k_f= 0.6857, n=1.012, R^2 =0.8265, q_{max} = 2.82, b=0.042, R^2 = 0.9021, B=8.08, A=1620.4, R^2 = 0.9354. AHSB: (k_f= 0.6852, n=1.024, R^2 =0.8254, q_{max} = 2.79, b=0.038, R^2 = 0.9112, B=8.18, A=1626.2, R^2 = 0.9364.		
Cucumis melo peel	Batch reactor P^H = 6, 10-210 min, dose= 250 mg, 25±2°C	100-400 mg/L	98.78% (P^H =6, dose = 250 mg, 180 min, 250 mg/L)	Elovich, pseudo-first order	Manjuladevi *et al*., 2018
Shelled moringa oleifera seed powder	Batch reactor P^H = 4.5- 8.5, dose = 2-6	10-100 mg/L	75.64% (dose = 4 g, 25 mg/L, P^H = 6.5, 40 min)		Raj *et al*., 2010
Coconut copra meal	Batch reactor P^H = 2-7, dose = 0.1-20 g/50 ml, 50 rpm, 15, 35 and 65°C	60, 100 and 120 mg/l	3.77 mg/g (P^H = 5.0, dose = 20 g/l, 120 mg/l, 2 hrs, 150 rpm) k_l = 0.0036, R^2 =0.994, k_f = 4.08, n=2.216, R^2 = 0.976	Freundlich and Pseudo-second order	Saleem *et al*., 2015.
Citrus Limetta Peels	Batch Reactor P^H = 3-7, dose = 1-20 mg/l, 0-180 min, 30°C	25-500 mg/l	27.78 mg/g (P^H = 6, dose = 2 g/l, 45 min, 250 mg/l)	Langmuir and pseudo-second order	Singh and Shukla, 2017

Biosorbent	Reactor/ condition	Initial Ni ion concentration	Maximum Ni removal	Best fit model	Reference
Acacia Leucocephala bark	Batch reactor P^H = ±5, dose = 0.1-0.7 mg/l, 150 rpm, 30-50^{o}C	30-200 mg/l	91% (P^H = 5, 120 min)	Langmuir and pseudo-second order	Subbaiah *et al.*, 2009
Teak leaves	Batch reactor P^H = 2-8, dose = 1-10g/l, 5-120 min, 303-323K	25-200 mg/l	75.64% (50 mg/l, P^H = 6, dose = 8 g/l, 30 min, 303K)	Langmuir and pseudo-second order	Vilvanathan *et al* .,2014
Pleurotus ostreatus spent mushroom	Batch reactor P^H = 4-8, dose = 0.1 – 8g, 0.5-30 min, 125 rpm	10-250 mg/l	3.04 mg/g (30 min, dose = 0.7 g, 50 mg/l)	Langmuir and pseudo-second order	Tay *et al.*, 2011
Ficus Religiosa (Peepal) leaves	P^H =1-7, dose = 10g/l, 10-90 min, 200 rpm, 33^{o}C	100 mg/l	6.35 mg/g (60 min, P^H = 6, dose = 10 g/l, 33^{o}C) q_{max} = 25.71 mg/g, b = 0.0129, R^2 = 0.85 K_f = 1.25, n=2.44, R^2 = 6.94	Freundlich and Pseudo-second order	Aslam *et al.*, 2010

Algal Biomass

Algae are common photosynthetic microorganisms that exist in both marine and freshwaters. The suitability of algae in the uptake of heavy metals is largely due to its multilayer cells and the presence of various functional groups on the biomass (Wang and Chen, 2009). The adsorption using algal biomass can be described as follows: the first step is the cell surface binding where the Ni ion binds to the algal biomass. The process occurs independently. The second step is the slower stage which involves the intramolecular accumulation of the metal in the algal due to the concurrent growth and the adsorption process (Sen and Dastidar 2010). Various reports on the use of algal biomass for Ni removal are shown in Table 2.

Table 2: The Use of Algal Biomass

Biosorbent	Reactor/ condition	Initial Ni concentration	Maximum Ni removal	Best fit model	Reference
Sargassum filipendulla	Fixed bed column Dose= 3 g, v = 5 ml/min, 21°C, P^H =4.5	2.15 mmol/L	1.07 mmol/g (P^H =4.5, 5 ml/min) q_{max} = 1.070, b=4.0654 $mmol^{-1}$, R^2 =0.998	Langmuir	Kleinübing *et al*.,2011)
Durvillaea antarctica	Batch reactor P^H = 5-11, 5-240 min, 160 rpm, 20°C	7.5-300 mg/l	32.85 mg/g (P^H = 5, 240 min) k_f = 1.289, n= 1.597, R^2 =0.941. q_{max} =51.28 mg/g, k=0.0009, R^2 = 0.942	Sips	Guarin-Romero *et al*., 2019.
Padinasantae-crucis	Batch rector P^H = 2-8, dose = 1-4 g/l, 200 rpm, 5-60 min, 25-55°C	80 mg/l	78.74 mg/g (P^H = 5, 60 min, dose =3 g/l)		Foroutan *et al*., 2018
Caulerpa racemose *Ulva lactuca*	Batch reactor 10-90 min, 80 rpm, dose= 2g		28.84% (dose 2 g, 50 min, 25°C) 36.77% (dose 2 g, 60 min, 25°C)	Langmuir and Freundlich, Pseudo-second order	Pandya *et al*., 2018
Ulva lactuca	Batch reactor P^H= 2-8, 0-250 min, 288K- 308K, dose= 0.5-5g/l	0-400 mg/l	38.28 mg/g (dose =0.5 g/l, P^H = 5, 30 min)	Langmuir and Pseudo-second order	Long *et al*., 2018
*Gracilaria (*marine alga)	Batch reactor P^H = 1-9, dose =0.2-1, 200 rpm, 25°C	5-50 mg/l	83.55% (P^H =5, dose =2.5 g, 30,40 mg/l, 15 min)	Langmuir and second order	Esmaeili *et al*., 2011
Chlorella sorokiniama	Batch reactor Immobilized cell P^H = 2-6, 5-120 min, 25°C, 100 rpm,	2.5-200 mg/l	60.57 mg/g (200 mg/l, P^H =5, dose= 1 g/l, 25°C)	Langmuir and Freundlich	Akhtar *et al*., 2004

Biosorbent	Reactor/ condition	Initial Ni concentration	Maximum Ni removal	Best fit model	Reference
Ulva reticulate (marine green alga)	Packed column H=15, 20, 25 cm, 5-20 ml/min	100 mg/l	46.5 mg/g (P^H =3, h= 25 cm,30°C, P^H =4, 5 ml/min, 100 mg/l)	Thomas	Vijayaraghavan *et al*., 2005
Undaria pinnalifida ($CaCl_2$ treated)	Batch reactor P^H =3-7, dose= 0.1-0.5g	5-50 mg/l	24.71 mg/g (P^H =4.7, dose= 0.1 g, 30 mg/l, 120 min)	Langmuir and Pseudo-second order	Chen *et al*., 2005
Cyanophyta (Blue Algae)	Batch reactor Dead blue cell 0-140 min, 298-232K, P^H=2-8, 0.1-2.0 g	10-120 mg/l	82.1% (P^H = 5, 90 min, dose= 0.6 g, 200 rpm) q_{max} =19.43 mg/g, b = 0.0093, R^2 =0.9961. k_f =3.5250, n =2.525, R^2= 0.881	Langmuir	Abbas and Ali, 2018.
Oedogobium hatei (untreated) Acid treated	Batch reactor P^H =2.2-7, dose= 0.1-1g/l, 298-318K	100 and 200 mg/l	40.9mg/g (P^H = 5, dose = 0.7g/l,200 mg/l) 44.1 mg/g	Freundlich, Langmuir, Pseudo-first and second order	Gupta *et al*., 2010
Sargassum filipendula (Alginate etraction residue)	Batch reactor Dead cell	0.1-18 mmol/l	61.1 mg/g (P^H = 3.5, 323K, dose =2 g/l)	Langmuir	Moino *et al*.,2019
Sargassum sp (marine brown algae) Untretaed Acid treated	Batch reactor Living cell P^H = 2.2-9.2, dose=0.1-0.7,50-500 rpm	500 ppm	181.5 mg/g (P^H =5, 30°C, 120 min, dose =0.5 g) 250mg/l	Langmuir and Pseudo-first order	Kalyani *et al*.,2003

Bacteria Biomass

The suitability and application of bacterial have been reported by different authors. The unique microstructure of the organisms (bacterial and cyanobacterial) which contains polysaccharides, proteins, lipids with different functional groups enable the adsorbents to remove heavy metals from effluents through the interaction of the metal ions with the functional group (Volesky, 2007). Living, dead and immobilized cells of the biomass are capable of Ni ion removal and shown in table 3.

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Table 3: The Use of Bacteria Biomass

Biosorbent	Reactor/ condition	Initial Ni concentration	Maximum Ni removal	Best fit model	Reference
Pseudomonas fluorescence (living cell) *Bacillus pamilus* (non-living cell)	Batch reactor P^H = 3-8, 1 hr, 150 rpm	50-300 mg/l	91.4mg/g (100 mg/l, 30°C,P^H =7, 1 hr) 73.9 mg/g		Werzba and Latala, 2010
Bacillus subtillis	Batch reactor P^H=2-7, 30°C, 0-60 min, 200 rpm, dose=1 g/l	14.3-245.8 mg/l	58.7 mg/g (P^H =6, 50 mg/l)	Langmuir	Wierzba, 2015
Stenotrophomonas maltophilia			54.3 mg/g (45.6 mg/l)		
Brevundimonas vesicularis	Batch reactor Non-living cell P^H =2-10, dose=40-200mg, 150 rpm, 1-8 hr	25-200mg/l	52.4% (P^H = 6, 100 mg/l, 90 min, dose=0.1 g	Langmuir	Singh and Gadi,2012
Rhodocolus opacus	Batch reactor P^H =2-6, 175 rpm,25-45°C, dose=2-5 g/l, 0-180 min	50mg/l	92% (P^H= 5, dose=3 g/l, 40 mg/l, 20 min)	Freundlich	Cayllahua *et al*., 2009.
Microcollus species	Batcg reactor Isolates P^H = 3-11, 150 rpm, 29-36°C	50-500 mg/l	55% (50 mg/l, P^H = 7, 55 hr, 55°C)		Congeeraram *et al*., 2007
Pseudomonas aeruginosa ASU 6a	Batch reactor Living cell P^H = 2-7, 5-60 min	0-160 ppm	113.6 mg/g (P^H = 7, 30°C, 30 min, dose = 1g, 50 mg/l)	Langmuir and Freundlich	Gabr *et al*., 2008
Pseudomonas sp	Batch reactor Living cells P^H =3-8, 10-600 mg, dose=6 g/l, 4500rpm	50 mg/l	50.8 mg/g (P^H = 5, dose=1 g/l)	Freundlich	Gialamouidu *et al*., 2009
Staphylococcus xylosus			89mg/g (P^H =6, dose = 1 g/l,1.5 hr)		

Biosorbent	Reactor/ condition	Initial Ni concentration	Maximum Ni removal	Best fit model	Reference
*Bacillus lacterosporus (*MTCC 1628)	Batch reactor Dead biomass P^H =3-9, 0-180 min, 20-40^{o}C, dose= 2-40g/l, 150 rpm	10-50 mg/l	44.44 mg/g (P^H = 7, 2 hr, 50 mg/l, 30^{o}C)	Langmuir and Pseudo-second order	Kulkarni *et al*., 2014
Bacillus brevis	Batch reactor Immobilized biomass P^H = 2-6, 125 rpm, 25-40^{o}C	10-60 mg/l	75.21% (P^H =6, 40^{o}C, 35 mg/l)	Second order polynomial equation	Kurmar *et al*., 2009
Curtobacterium sp (FM0I)	Batch reactor Dead biomass P^H = 3-8, dose =1-30 mg, 10-50^{o}C	0.125 -0.5 mM	140.99 mg/g (1.5 mM, P^H = 6, 40 min)	Langmuir, Pseudo-first and second order	Masoumi *et al*., 2016
Bacillus cerus M_{16}	Batch reactor Bacterial strain P^H = 3-8, dose =1-6 g/l, 20-40^{o}C, 0-24 hr, 5500 rpm	25-1100 mg/l	88.5% (P^H = 7, 40^{o}C, dose= 2 g/l, 26.95 mg/l)	Redlich-Peterson and Pseudo-second order	Naskar *et al*., 2015
Bacillus thuringiensis (Vegetative cell) *Bacillus thuringiensis* (spire-crystal mixture)	Batch reactor P^H =4-8, 25-45^{o}C, 13000 rpm	25-250 mg/l	21.5 mg/g (P^H = 6, 35^{o}C, dose=1 g/l, 100 mg/l, 5 min) 34.3 mg/g (P^H = 6, 35^{o}C, dose=1 g/l, 100 mg/l, 5 min)	Langmuir	Oztuk, 2007
Streptomeyces rimosus (NaOH treated)	Batch reactor Dead cell	10-600 mg/l	32.6 mg/g (P^H = 6.5, dose= 3 g/l, 2 hr, 100 mg/l, 250 rpm)	Langmuir	Selatnia *et al*., 2004
Pseudomonas p (treated)	Batch reactor P^H = 2.5 -9.5, 5-120 min, 9000 rpm	50-250 mg/l	336.84 mg/g (P^H = 4.5, 60 min, 45^{o}C)	Langmuir	Zhang *et al*., 2004

Fungi Biomass

Fungi and yeast are the common eukaryotic biomass which is readily used as adsorbents for heavy metal removal. Their easy growth under a wide range of conditions to produce enzymes enhances their ability to remove heavy metals from wastewater (Sen and Dastidar, 2010). Fungal biomass is generally resistant to a higher concentration of heavy metals. Heavy metals in trace amounts act as a micronutrient for fungus growth hence its suitability in removing trace metals from wastewaters. The reports of various authors on the use of fungi and yeast in the removal of Ni from wastewaters are shown in table 4.

Table 4: The Use of Fungi Biomass

Biosorbent	Reactor/condition	Initial Ni concentration	Maximum Ni removal	Best fit model	Reference
Yarrowia lipoltica	Batch reactor Dead biomass P^H = 3-8,dose= 0.5-3 g/l, 20-40^{o}C, 120 rpm	10-300 mg/l	14.08 mg/g (P^H =6, dose = 2 g/l, 60 min, 100 mg/l, 30^{o}C)	Langmuir	Wierzba *et al*., 2017
Trichoderma harzianum	Batch reactor Living cell P^H = 3-7, 10-40^{o}C, 4-8 days	50 mg/l	90.2 % (P^H = 4.5, 50 g/l, 7 days, 30^{o}C) q_{max} = 383.9, b =0.212, R^2= 0.939, k_f = 2.605, 1/n = 1.84, R^2 = 0.874	Langmuir and Freundlich	Sarka *et al*., 2010
Pleurotus mutilus	Batch reactor Non-living cells P^H= 3-10, 2-120 min, 24^{o}C.	50-500 mg/l	47.10 mg/g (P^H =8, 479 mg/l, 3 hr)	Langmuir and Pseudo-second order	Daoud *et al*., 2018
Phomopsis sp	Batch reactor Treated biomass P^H = 4-6	0.1-1.0 mM	110µmol/g (24 hr, P^H = 4-6, dose = 20 mg, 1.0 mmol/l)	Langmuir and Freundlich	Saiano *et al*., 2005
Rhizomucor tauricus	Batch reactor Immobilized cell P^H =3-6, 10-50^{o}C, dose =2-10 mg	25-100 mg/l	394 mg/g (P^H =6, 4 hr, 30^{o}C)	Langmuir and Freundlich	Kumar *et al*., 2012
Aspergillis niger (Alkali treated)	Batch reactor Dried biomass P^H = 2.8-7.2, dose = 1.6 -6 g/l	24-90 mg/l	1.6 mg/g (P^H = 6.01,89.93 mg/l, dose= 5.22 g/l)		Amini and Younesi, 2009

Aspergillus tamarii	Batch reactor Dead biomass P^H = 1-6, 10-200 min, dose= 0.5-1.5 g, 20-50^{o}C, 50-200 rpm	5-50 mg/l	58.74% (P^H = 6, 150 rpm, 25^{o}C, dose= 0.5 g)		Sahin *et al*., 2012
Aspergillus species	Batch reactor P^H = 3-11, 26 hr	50-500 mg/l	90% (P^H = 5, 30 hr, 50 mg/l, 35^{o}C)		Congeevaram *et al*., 2007
Pleirotus mutilus	Batch reactor Non-living cell P^H = 3-10, 30-90 min, 250 rpm, 24^{o}C, particle size= 50-300µm	50-500 mg/l	48.94 mg/g (P^H =8, 79 min, 488 mg/l)	OVAT (one variable at a time) and Taguchi model	Daoud and Seleatnia 2019
Aspergillus flavas ($CaCl_2$)	Batch reactor P^H = 2-8, 5-150 min, dose= 1-8 g/l, 298.15-323.15K	50 mg/l	32.26 mg/g(50 mg/l, dose =4 g/l, 60 min, 298.15 K) b=0.147, R^2 = 0.9349, n= 1.65, k_f = 4.845, R^2 = 0.9124.	Freundlich and Langmuir	Foroutan *et al*., 2017
Pencillium fellutinum (composite with bentonite)	Batch reactor P^H =2-6, 10-120 min, 30-60^{o}C, 0.05-0.3 g	50-225 mg/l	161 mg/g (P^H =6, 200 mg/l, 30 min, dose= 0.05 g/l)	Langmuir and Pseudo-second order	Rashid *et al*., 2016
Mucor hiemalis	Batch reactor Dead biomass P^H =2-8, dose= 0.05-3 g/l, 10-60^{o}C, 60-210 rpm	50-500 mg/l	15.83 mg/g (P^H =8, 50 mg/l, dose= 0.5g/l, 30^{o}C, 120 rpm, 60 min)	Freundlich and Langmuir	Shroff and Vaidy, 2011.
Penicillium janthinellum (Untreated)	Batch reactor P^H = 2.0 -7, 90 min, dose = 0.1-2 g/l	150 mg/l	47% (P^H = 4.5, 33 mg/l, 89min, dose= 1.6 g/l)		Aytar *et al*., 2013
Trametes versicolor (Rainbow)	Batch reactor P^H = 2-7, dose = 0.1-0.6g/01L, 210 min	20-100 mg/l	212.5 mg/g (P^H = 4, dose =0.6g/0.1L, 210min, 100 mg/l)	Langmuir	Subbaiah and Yun, 2013

CONCLUSION AND RECOMMENDATION

The literature reviewed shows that non-living and resting cells of microorganisms (Algal, bacterial, Fungi) were mostly used in the reports with little information on the use of growing cells due to their toxicity level. The review shows that the batch method was mainly utilized in the adsorption studies of the various biosorbent, thereby limiting the extent to which the effluent can be studied and the number of studied factors. Further research should be carried out using continuous column adsorption experiments to enhance the handling of a large amount of wastewater and the provision of a wide range of variables for the study. Synthetic wastewater was used in most of the literature reviewed to study the uptake capacity of the biosorbent, this, as a result, provided information on the studies which more would have been gotten from the study of the interaction of other trace elements in the treated wastewater if actual industrial wastewater was used in the operation. Finally, the uptake of the Ni ion was studied at a lower concentration of the ion. There is a need for further study of the adsorption capacity at higher metal ion concentration.

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