State of the Art of Technologies for Zn^{2+} Ions Removal from Industrial Effluents with Adsorption: Examination of Process Parameters (Part I)

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Abstract

Adsorption technology is an eco-friendly approach for Zn^{2+} ions removal. For that, she attracted a great deal of attention in the last decades as a cost-efficient method for industrial effluents treatment. This paper documents the results of most recent studies removal of these ions from industrial effluents by adsorption onto several materials. The maximum adsorption efficiency of each adsorbent was optimized in terms of various operating conditions. In this paper, the influence of operational parameters such as solution pH, contact time, adsorbent dosage, particle size, temperature of the aqueous solution, initial zinc concentration and agitation speed has been presented and discussed.

Keyword: Adsorbents, Adsorption, Industrial effluents, Process parameters, Zn^{2+} ions, Zinc removal

I. INTRODUCTION

Zinc is a necessary trace element for human health which is implicated, in small doses, for many biological processes, including protein synthesis and nucleic acid metabolism [1], its deficiency can lead to significant clinical problems [2]. However, in excess of the beneficial range, it can also have inhibitory effects on neurons, glia and other cell types [3]. For these reasons, the World Health Organization (WHO) has stipulated that the zinc content in drinking water must not exceed 3mg/l [4].
High zinc in drinking water may be through effluents discharges especially of surface treatments industry and mining industry wastewater [5].

The contamination of aqueous environment by Zn^{2+}, through industrial effluents, is a serious problem which represent a universal concern to the research community on account of their non-biodegradability and toxicity. Accordingly, attention has been paid to reduce the concentrations of Zn^{2+} ions in the effluents.

Divers technologies are available for zinc removal, including chemical precipitation [6-7], coagulation /flocculation, electro-coagulation [8], electro-flotation [9], adsorption [10-16], cementation, reverse osmosis [17], ion flotation [18], solvent extraction [19] and ion exchange [20-22]. However, each method has its own pros and cons. Of these, adsorption method in industrial effluents treatment is indeed particularly attractive, in recent years, due to their low cost and respect of the environment. Hence, various materials have been tested in several studies to improve their effective application for Zn^{2+} ions removal from wastewater. In this context, most of the researches have widely focused on agricultural and industrial wastes recovery as promising and cheaper adsorbents for environmental purposes (Table 1). In the present review, the influence of different parameters such as temperature T, contact time t_c, pH solution, initial metal concentration $\boldsymbol{C_0}$, adsorbent dosage $\boldsymbol{r}$, particle size and agitation speed As on the efficiency of the adsorption process in removal of Zn^{2+} ions have been presented and discussed.

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Table - 1:
Zn^{2+} ions removal of different sorbents developed from agricultural and industrial wastes

Adsorbents	q (mg/g)	R (%)	C_0 (mg/l)	t_c (min)	pH	r (g/l)	T (°C)	As (rpm)	Ref.
Cocoa pod husk	14	-	80	150	6	5	30	150	[23]
Rice straw (pretreated)	0.1mmol/g	-	1mM	90	5	6	25	-	[24]
Cassava waste biomass	55.8	-	10mM	60	5	5	30	-	[25]
Cassava waste biomass	11.1	-	-	20-30	4-5	-	-	-	[26]
Cassava waste biomass (pretreated)	33.6	>80	-	20-30	4-5	-	-	-	[26]
Cassava waste biomass (pretreated)	559.7	-	10mM	60	5	5	30	-	[25]
Waste olive cake	22	93	10	120	6-7	5	25	200	[27]
Waste olive cake (pretreated)	27	-	10	120	6-7	5	25	200	[27]
Groundnut shells(pretreated)	9.5								[28]
Chestnut shell (pretreated)	9.2	> 90	100	1440	4.6	10	25	90	[29]
Chestnut shell (pretreated)	2.4	90	20-100	5760	5.5	10	25	-	[30]
Jute fibres	3.5	-	83.9	120	5.8	-	35	-	[31]
Jute fibres (pretreated)	5.9	-	83.9	120	5.8	-	35	-	[31]
Oxidised jute	8	-	83.9	120	5.8	-	35	-	[31]
Sphagnum peat	-	99.4	0.1	720	5.6	0.2-4	25	-	[32]
Mentha arvensis distillation waste	107.7	-	100	240	6	1	50	50	[33]
Rapeseed waste	13.8	98	48-119	1440	4.5-5	10-30	25	-	[34]
Tea factory waste	8.9	99	50	240	4.2	4	30	150	[35]
Jatropha curcas press cake	-	70.5	10-50	100	4	5	28	150	[36]
Orange peel	21.2	-	50	120	5.5	4	25	120	[37]
Orange peel (pretreated)	56.1	86.6	50	120	5.5	4	25	120	[37]
Orange peel	25	-	50-200	120	5	5	30	120	[38]
Orange peel (pretreated)	80	83	50-200	120	5	5	30	120	[38]
Fish bones (pretreated)	9.9	98	20-100	480	5	18	30 ±1	125	[39]
Sunflower residue	45.4	-	100	120	8	2	23±2	-	[40]
Potato residue	52.6	-	100	600	7	2	23±2	-	[40]
Canola residue	41.7	-	100	200	7	2	23±2	-	[40]
Walnut shell	33.3	-	100	200	8	2	23±2	-	[40]
Ngella sativa seeds (pretreated)	93	-	100-1000	90	4	0.4	30	400	[13]
Carrot residue (pretreated)	2.3	90	50	1440	5	2.5	-	-	[41]
Coffee husks (pretreated)	5.5	48-79	50-100	4320	4	6.6	25±2	100	[42]
Pistachio Shells	-.	97.90	367.2	10	6	8	25±1	-	[43]
Crab shell particles (pretreated)	123.7	90	500	90	6	5	23±2	200	[44]
Sludge of rose petals (pretreated)	104.1	-	10-640	1440	5	1	30	120	[45]
Newspaper pulp (pretreated)	9.2	-	10.3	30	5.8	1	-	-	[46]
Boron waste	73.6	-	50-250	60	6	1	25	200	[47]
activated alumina	13.6	90.8	25	240	5	10	30	-	[14]
rice husk ash	14.3	95.8	25	180	5	10	30	-	[14]
Clarified sludge	15.5	98.7	25	60	5	10	30	-	[14]
Neem bark (pretreated)	13.2	84.7	25	300	5	10	30	110-125	[48]
Neem bark (pretreated)	13.2	-	3-50	240	5	10	30	-	[14]
Azadirachta indica bark	33.4	84	20	45	6	3.3	30±1	-	[49]
Saw dust	14.1	87.2	25	300	5	10	30	110-125	[48]
Beech sawdust	2	-	5-200	60	4.8-5.3	20	23±2	-	[50]
Cassava tubers bark waste	11.8	-	10-100	30	5	-	30	-	[51]
Cassava tubers bark waste (pretreated)	37.8	-	10-100	30	5	-	30	-	[51]
Teakwood sawdust (pretreated)	17	-	-	120	5.2	-	35	-	[28]

II. ADSORBENT MATERIALS

During the last two decades, the wastes by-products showed considerable capacity for heavy metals adsorption, these non-conventional and low-cost adsorbents revealed high affinity for Zn^{2+} ions, such as rapeseed waste [34], rice straw [24], cassava waste [25, 26], tea factory waste [35], orange peel [37, 38], pistachio shells [43], chestnut shell [29, 30], coffee husk [42], carrot residue [41], pigeon pea husk [52], waste olive cake [27], crab shell [44], fish bones [39], cocoa pod husk [23], wheat straw [53], jatropha curcas press cake [36], newspaper pulp [46], boron waste [47]. Wood by-products including sawdusts and wood barks have also attracted considerable attention as promising adsorbent. These woody materials contain a large number of organic functional groups such as carboxyl, carbonyl, phenyl hydroxyl, amino, imidazole, sulfhydryl, and sulfonic groups. These groups have good abilities to attach heavy metals. The maximum sorption capacities of some agricultural and industrial wastes as well as their optimum conditions are summarized in Table 1.

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Many different species of phyto-biomass have been investigated as potential biosorbents for Zn^{2+} ions, including plants such as avena fatua [54] moringa oleifera [55], myriophyllum spicatum [56], oil palm frond [57], syzygium cumini L. leaves [58], alternanthera philoxeroides [59], spirodela polyrhiza [60] and numerous algae like spirogyra insignis [61], chlorella minutissima [62], ulva fasciata sp. [63, 64], codium vermilara [61], asparagpsis armata [61], oedogonium sp. [65], laminaria hyperborean [66], gelidium [67], sargassum filipendula [68], undaria pinnatifida [69], macrocystis pyrifera [70]. The optimum removal conditions for some of these biosorbents are presented in Table 2.

Although previous studies have been focused on Zn^{2+} removal by bacteria, there is still potential research space for improving Zn^{2+} adsorption performance of yeast and fungal biomass. Adsorption efficiencies of some of these biomasses are presented in Table 3.

Among various adsorbents reported in the literature, mineral and rock powders which are found naturally or prepared synthetically are identified as a suitable candidate in the Zn^{2+} uptake, such as scoria [71], chinese loess [72], natural zeolite [73], clinoptilolites [74], and different types of clay, such as Sarooj clay [75], bentonite [76] [77], montmorillonite [78].Table 4 gives the comparison of mineral and rock powders from Zn^{2+} ions adsorption.

III. ADSORPTION PROCESS

The adsorption of Zn^{2+} ions from industrial effluents onto several adsorbents was frequently carried out using the batch equilibrium technique. Therefore, the most common experiments for assessing the adsorption affinity of Zn^{2+} is to contact a fixed volume (V) of the industrial effluent with a given amount (m) of adsorbent at a constant temperature in a thermostated shaking waterbath in order to elucidate the optimum operational conditions that affect adsorption efficiency of the system and to determine the residual concentration of Zn^{2+} ions in the solution at equilibrium (C_e).

In many studies, the measurement of Zn^{2+} ions concentrations was conducted using atomic absorption spectrophotometry [23, 31, 33, 35, 37, 38, 43, 60, 79-83]. Still the inductively coupled plasma-optical emission spectrometer was widely used by several researchers [32, 44, 46, 62, 65, 69, 70, 84-87]. In addition, the UV Visible Spectrophotometer was also used for determination of Zn^{2+} content in the effluent [14]. In other study, concentrations of Zn^{2+} ions were determined by standard EDTA titration [88].

The operational parameters, adsorption capacity and percentage removal of Zn^{2+} ions, were performed to evaluate the effectiveness of the treatment. Thus the adsorption capacity of each material and percentage of adsorbed Zn^{2+} ions were calculated from Zn^{2+} concentration differences in the effluent before and after adsorption process using the following equations:

$$q = \frac{(C_0 - C_e)}{m} V \quad (1)$$

$$R\% = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (2)$$

Where, C_0 and C_e are the initial and equilibrium concentration of Zn^{2+} ions (mg/l), respectively, m is the mass of adsorbent (g) and V is the solution volume (l).

Table - 2:
Phyto-biomass adsorption capacities in the literatures for Zn^{2+} adsorption

Adsorbents	*q (mg/g)*	*R (%)*	*C_0 (mg/l)*	*t_c (min)*	*pH*	*r (g/l)*	*T (°C)*	*As (rpm)*	*Ref.*
Plants biomass									
Spirodela polyrhiza L.	*28.5*	*86.4*	*5-35*	*120*	*6*	*10*	*30*	*180*	*[60]*
Alternanthera philoxeroides	*18.5*	*-*	*40-100*	*300*	*6*	*5*	*23±2*	*200*	*[59]*
Moringa oleifera	*40.9*	*74*	*50-200*	*50*	*7*	*0.5*	*30*	*100*	*[55]*
Moringa oleifera biomass (pretreated)	*45.7*	*91.5*	*50-200*	*50*	*7*	*0.5*	*30*	*100*	*[55]*
Myriophyllum spicatum	*15.5*	*-*	*2-64*	*120*	*5-6*	*8*	*25*	*-*	*[56]*
Botrytis cinerea (heat inactivated)	*12.9*	*-*	*100*	*30*	*5-6*	*2*	*25*	*120*	*[89]*
Syzygium cumini L.	*35.8*	*80.5*	*20*	*10*	*6*	*3.3*	*-*	*180*	*[58]*
Ficus Hispida leaf powder	*38.2*	*77*	*20*	*25*	*4*	*3.3*	*30*	*160*	*[83]*
Oil palm frond	*37.3*	*-*	*100*	*60*	*5.5*	*10*	*25*	*150*	*[57]*
Oil palm frond (pretreated)	*23.3*	*-*	*100*	*60*	*5.5*	*10*	*25*	*150*	*[57]*
Olive leaves	*-*	*30.3*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Reed leaves	*-*	*38.2*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Carob leaves	*-*	*29.4*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Willow leaves	*-*	*58.4*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Loquat leaves	*-*	*74.8*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Walnut leaves	*-*	*82.1*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Sisso leaves	*-*	*71.5*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Pine leaves	*-*	*61.1*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Cinchona leaves	*-*	*51.9*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*
Pistache leaves	*-*	*61.2*	*20*	*9000*	*6*	*15*	*20*	*-*	*[90]*

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Oak leaves	-	45	20	9000	6	15	20	-	[90]
Ficus leaves	-	63.4	20	9000	6	15	20	-	[90]
Poplar leaves	-	81.6	20	9000	6	15	20	-	[90]
Cypress leaves	-	42.2	20	9000	6	15	20	-	[90]
Guava leaves	-	78.3	20	9000	6	15	20	-	[90]
Algal biomass									
Ulva fasciata sp.	13.5	74	20-100	20	5	3.3	30	-	[63]
Codium vermilara	23.8	-	10-150	120	6	0.5	-	-	[61]
Spirogyra insignis	21.1	-	10-150	120	6	1	-	-	[61]
Asparagpsis armata	21.6	-	10-150	120	6	0.5	-	-	[61]
Chondrus crispus	45.7	-	10-150	120	6	0.5	-	-	[61]
Ascophyllum nodosum	42	-	10-150	120	6	0.5	-	-	[61]
Fucus spiralis	53.2	-	10-150	120	6	0.5	-	-	[61]
Chlorella minutissima (Growing algae)	33.7 ±4.9	-	6mM	20	7	4	28	140	[62]
Chlorella minutissima (Freeze-dried algae)	123.4	-	6mM	20	6	4	28	140	[62]
Oedogonium sp. (Freeze-dried biomass)	47.2	-	50-500	30	5	20	25	150	[65]
Gelidium (Dead biomass)	13	-	10-300	60	5	-	20	100	[67]
Agar extraction algal waste	7.1	-	10-300	60	5	-	20	100	[67]
Laminaria hyperborea	19.2	-	49.8	30	5	2	25	-	[66]
Sargassum muticum	34.1	-	39	30	5	2	25	-	[66]
Fucus spiralis	34.3	-	38.5	30	5	2	25	-	[66]
Bifurcaria bifurcate	30.3	-	44.8	30	5	2	25	-	[66]

Table - 3:
Yeast, bacterial and fungal biomass used for Zn^{2+} removal

Adsorbents	q (mg/g)	R (%)	C_0 (mg/l)	t_c (min)	pH	r (g/l)	T (°C)	As (rpm)	Ref.
Bacterial biomass									
Rhodococcus opacus	1.3	88	5	30	7	2	26	175	[81]
Pseudomonas putida (Living cells)	27.4	-	6.5-279	1440	5	1	30	200	[79]
Pseudomonas aeruginosa	87.7	-	70	4320	7	10	26-30	150	[84]
Streptomyces ciscaucasicus strain (Living cells)	42.7	-	1-150	420-480	5	2	28	90	[91]
Streptomyces ciscaucasicus strain (Nonliving cells)	54	-	1-150	420-480	5	2	28	90	[91]
Fungal biomass									
P. chrysosporium (Immobilized within loofa sponge)	50.9	-	10-500	60	6	1	20±2	100	[92]
Aspergillus niger (Living cells)	23.7	-	150	1440	6	-	25-30	120	[93]
Yeast biomass									
Candida utilis (Immobilized by calcium alginate gel)	181.7	-	25-300	240	5.2	1	45	150	[80]
Candida tropicalis (Immobilized by calcium alginate gel)	148	-	25-300	240	5.2	1	45	150	[80]
Candida rugosa	46.7	65.4	90	240	6	1.5	30	120	[94]
Candida laurentii	40.9	54.8	90	240	6	1.5	30	120	[94]

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Table - 4:
Mineral and rock powders from Zn^{2+} removal

Adsorbents	*q (mg/g)*	*R (%)*	*C_0 (mg/l)*	*t_c (min)*	*pH*	*r (g/l)*	*T (°C)*	*As (rpm)*	*Ref.*
Bentonite	*68.4*	-	*30*	*180*	*6.7*	*0.2*	*30*	*80*	*[76]*
Cankırı bentonite	*80.6*	-	*20-160*	*120*	*8*	*5*	*23*	*200*	*[77]*
Brazilian illite–kaolinite	*12.8mmol/g*	-	*0.2-5.5mM*	*180*	*5*	*0.8*	*25*	-	*[95]*
Brazilian illite–kaolinite (pretreated)	*23mmol/g*	-	*0.2-5.5mM*	*180*	*5*	*0.8*	*25*	-	*[95]*
Organofunctionalized-kaolinite	*1.57 mmol/g*	-	*40*	*360*	*6*	-	*25*	-	*[96]*
Kaolin clay mineral	*250*	-	*10-90*	*60*	*6.6*	*0.2-0.7*	*30*	*80*	*[97]*
Clay (sodium bentonite)	*103.8*	-	*1-210*	*1440*	*5.5*	*1.2*	*25*	-	*[98]*
Clay (calcareous mudstone)	*49.5*	-	*1-210*	*1440*	*5.5*	*1.2*	*25*	-	*[98]*
Clay (red claystone)	*75.6*	-	*1-210*	*1440*	*5.5*	*1.2*	*25*	-	*[98]*
Bentonite	*24*	-	*12.5-200*	*2880*	*4*	*1*	-	*100*	*[99]*
Bentonite (pretreated)	*54*	-	*12.5-200*	*2880*	*4*	*1*	-	*100*	*[99]*
Montmorillonite (pretreated)	*0.1mmol/g*	*>94.7*	*0.1-1mM*	*10*	*4*	*5*	-	-	*[78]*
Illite	*4.9*	*97.4*	-	*10*	*7*	*1.6*	*25±1*	-	*[100]*
Moroccan stevensite	*0.3mmol/g*	-	*0.15mM*	*180*	*6*	*0.1-0.2*	*25±2*	-	*[101]*
Bentonite	*73.5*	-	*100*	*150*	*7*	*1*	*25*	*130*	*[86]*
Alkaline Ca-bentonite	*149*	*99*	*100*	*150*	*4-7*	*1*	*25*	*130*	*[86]*

IV. ADSORPTION PARAMETERS

The adsorption capacity of Zn^{2+} ions by several materials depends on various process parameters controlling relationship between the adsorbent and the adsorbate from liquid phase, viz. the solution pH, and contact time, initial metal concentration in the solution, agitation speed, temperature, grain size and dosage.

A. Influence of Initial pH

The effect of pH on Zn^{2+} ions adsorption has been studied by many researches using a variety of adsorbent [14, 23, 33, 43, 46, 55, 58, 60, 91, 92, 94, 102, 103], and the results indicated that the amount adsorbed increased with higher solution pH, achieving a constant relative uptake in the range between 5 and 7. The pH dependence of zinc uptake can be explained considering the nature of sorbents and the degree of ionization and speciation of the adsorbate in solution (Fig. 1). Generally, at low pH values, low metal has been adsorbed due to the competition of Zn^{2+} ions with H^+ ions for the available adsorption sites. When the pH was increased, the competing effect of H^+ decreased and the positively charged metal ions took up the free binding sites [88]. However, at pH value higher than 7, adsorption capacity decline in the case of formation of $Zn(OH)_2$ during reaction of Zn^{2+} ions with OH^-.

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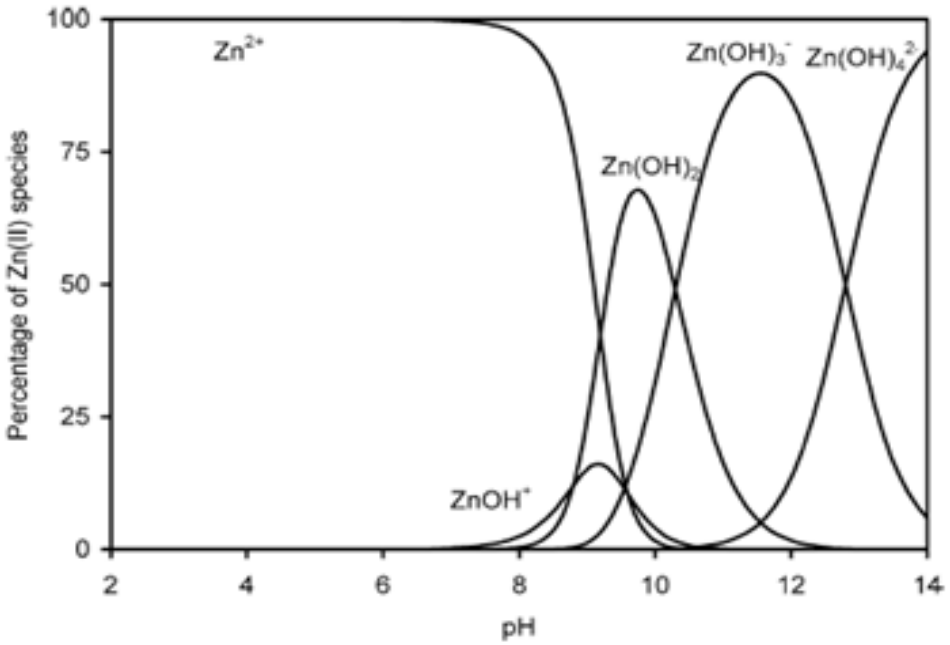

Fig. 1: Speciation diagram of Zinc in aqueous solution [104]

B. Effect of Contact Time

In the adsorption process the time of reaction affects the treatment efficiency. Most studies [34, 40, 43, 73, 76, 83] showed that the amount of adsorption increases with increasing contact time. In fact, the uptake of Zn^{2+} ions occurred in two steps: a first one is faster for a short duration of 5-30 min and slower second one, which continued until the equilibrium was achieved. This behavior can be attributed to the availability of a large number of vacant binding sites for Zn^{2+} ions at initial stage, but over time the occupation of the remaining vacant sites will be difficult as a result of the repulsive forces between sorbed metal ions on the sorbent surface and ions present in solution [40]. Therefore, the sorption rate reduced with time until saturation.

Studies of the adsorption kinetics of Zn^{2+} ions removal revealed that equilibrium were reached within a few hours of contact with the adsorbent. Some researchers [58, 62, 63, 78, 81, 83, 89, 100] have observed a much shorter equilibrium time of Zn^{2+} sorption. While, other authors have found that many days were needed to attain equilibrium, for example the equilibrium was achieved after 3 days on Chestnut shell [30] 4 days on coffee husk [42] and 6 days on some dry plant leaves [90].

C. Effect of Initial Metal Concentration

The adsorption of Zn^{2+} ions is affected by another important factor, initial metal concentration. Several studies [14, 23, 33, 34, 55, 60, 83], report that the Zn^{2+} uptake increases however the percentage adsorption of Zn^{2+} decreases with increase in Zn^{2+} ions concentration. This finding may be attributed to the interaction between Zn^{2+} ions and adsorbent, as result of limited active site on the adsorbent surface [105].

D. Effect of Adsorbent Dose

The effect of adsorbent dosage on adsorption of Zn^{2+} ions has been investigated by several researchers [33, 39, 43, 47, 55, 58, 60, 76, 83, 102]. Most studies of Zn^{2+} sequestration show that the efficiency of removal increases by raising the mass of adsorbent due to the introduction of more binding sites. However the amount adsorbed per unit mass, decreases as result of an unsaturation of adsorption sites during the adsorption reactions [106] or to the particle interaction such as aggregation, resulted from high sorbent concentration [107].

E. Effect of Particle Size of Adsorbent

Several studies have shown that the adsorption capacity of Zn^{2+} ions decreased with particle size increases [33, 34, 58, 59, 83]. The increase in adsorption with smallest size may be attributed to an increase in the total surface area which provided more active surface sites available for Zn^{2+} ions uptake.

F. Effect of Shaking Speed

The main purpose of this factor is to promote good contact between adsorbate and the interfacial area of the adsorbents in order to raise the mass-transfer rate.The relationship between the agitation speed and percent Zn^{2+} ions removed from aqueous solution has been investigated by some researchers [33, 73, 91]. Most studies of Zn^{2+} adsorption show that an increase in stirring speed enhances the adsorption process but this is true up to a certain limit [33]. This effect can be attributed to a decrease in the thickness of the boundary layer surrounding the adsorbent particles, which promoted the transference of Zn^{2+} ions to adsorbents

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[73]. However, at higher agitation speed, adsorbed Zn^{2+} ions experienced a strong centrifugal force as consequence of desorbing metal from the surface of the adsorbent.

Thus, much work [23, 27, 35-39, 42, 44, 45, 47, 60, 62, 67, 77, 80, 83, 84, 86, 89, 92-94, 99, 108-111], showed that the maximum adsorption capacity reported for Zn^{2+} was obtained at moderate agitation speed between 100 and 200 rpm, defined as the optimum agitation speed for complete dispersion.

G. Effect of Temperature

Temperature is one of the most important factors that control the adsorption process. The effect of temperature on the adsorption capacity of Zn^{2+} ions has been investigated by a number of scientists [33, 60, 65, 83, 103, 108, 109], and two trends have been observed. Some authors [23, 35, 59, 65, 83, 109, 112] showed that the adsorption capacity increased with temperature increases indicating the endothermic nature of the adsorption process. This positive trend may be attributed to increasing the mobility of the Zn^{2+} ions and an increase in the number of active sites for the adsorption with increasing temperature [103] or due to decrease in the boundary layer thickness surrounding the adsorbent in order that the mass transfer resistance of Zn^{2+} in the boundary layer decreased [23]. While other researchers [60, 76, 97, 108] noticed a negative trend i.e. the amount of Zn^{2+} ions adsorbed decreased with the rise in temperature involving that the process is exothermic. The decrease in the adsorption with increasing temperature was suggested to be due to the decrease in the adsorptive forces between the Zn^{2+} ions and active sites of the adsorbent at higher temperature.

On the other hand, adsorption process is not operated at high temperature because it could make this process prohibitive. Hence, most adsorption studies are carried out at room temperature or usually regulated within the range of 20 - 30◦C.

V. CONCLUSION

The literature survey results lead us to the conclusion that for removal of Zn^{2+}, various materials can be used as adsorbents with little or no pretreatment and can therefore give fruitful results. Some of the higher adsorption capacities reported for Zn^{2+} ions are 559.74 mg/g on treated cassava waste biomass, 50 mg/g on kaolin clay mineral, and 181.70 mg/g on immobilized candida utilis, 149 mg/g on alkaline Ca-bentonite and 104.16 mg/g on modified distillation sludge of rose. The variation in the amount adsorbed per unit mass between the various adsorbents corresponds to variation in the structure as well number of functional groups which play key roles in the metal uptake along with other operational parameters. The adsorption capacities of the sorbents were found dependent on reaction time, adsorbate concentration, temperature, pH, agitation rate of solution. On the other hand, the adsorption efficiencies were found to be better onto modified materials compared to raw ones. These results will be presented and discussed in a forthcoming paper.

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