

A Review on Copper Pollution and its Removal From Water Bodies by Pollution Control Technologies

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Copper is a metal of choice for technologists and is an important engineering material. It is one of the toxic metals, which causes many health hazards and harmful biochemical effects on living beings. In this review, introduction, chemistry, uses, sources, effects of copper and copper pollution and its removal from water bodies using pollution control technologies have been discussed.

KEYWORD

Copper, Adsorption, Removal, Water bodies, Pollution.

INTRODUCTION

Copper is an important engineering material of choice of technologies having wide industrial applications. It is regarded as one of the earliest known toxic metals. It provides raw materials for copper forming industry. The levels of copper in the environment is elevated due to its emissions from various industries as well as natural and other man-made sources. The elevated levels of copper in the environment has drawn the keen attention of environmentalists, because these are posing serious threat to mankind as well as flora and fauna. Copper pollution is deleterious for health because of its non-biodegradability, biological magnification and long persistent in the environment. Copper is found in chalophile/chalcopyrite deposits along with Pd, Cd, Zn, etc., which are used in the manufacture of several important alloys and other industries. Copper is released from plumbing system (Gustavo *et al.*, 2007). Its ingestion beyond the permissible level causes various types of acute and chronic disorders and health hazards in flora, fauna and human beings. Regular and prolonged ingestion of copper in more than the prescribed amount for human beings (that is to the line of 15-75 mg)

is reported to cause Wilson's disease. Prescribed limit for copper in drinking water is 0.05 mg/L as per WHO norms and also 0.05 mg/L as per ISI prescribed limits, 1983.

Chemistry of copper

Copper metal is placed in group IB of the periodic table. It is placed with d-block elements in modern periodic table. The melting point of pure Cu is $1083.0 \pm 0.1^\circ\text{C}$ (Samuel, 1954). The knowledge of chemistry of copper is essential to know the ecological and biological effects of Cu toxicity in the environment. Cu is associated with complex formation in biological systems.

Production of copper

The world refined copper usage has increased from 13,000(000, tonne) in 1997 to approx. 17,000(000, tonne) in 2006 (Copper Topics, 2007). The important copper resources of India are at Khetri (Rajasthan), Malanjkhand (M.P.), Dariba and Chandmari (Rajasthan), Agnigundala (A.P.), Rekha, Ghatshila (Jharkhand). Refined copper production in India was reported about 415,000 tonne during the year 2004-05 (copper Topics, 2006). Domestic copper is recovered from low grade sulphide ore using pyrometallurgical procedure. The four hydrometallurgical methods are practiced also for extraction of copper. The capacity of Cu smelter at Ghatshila in East Singhbhum district of Jharkhand will be enhanced from

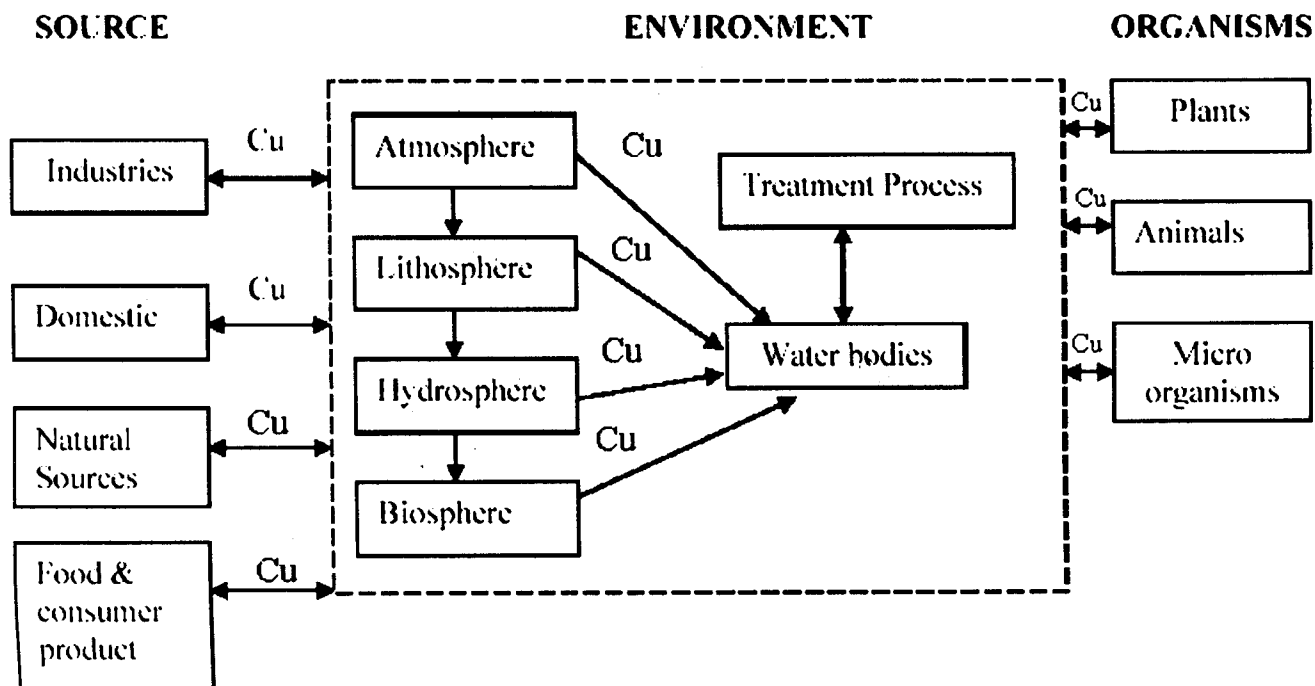


Figure 1. Copper pollution : Source, pathways and interaction with organisms

16,500 tonne per annum to 20,000 tonne per annum by May'2008 through modernization and technical upgradation (Copper Topics, 2007). Hindustan Copper Corporation is developing its main deposits of the country.

Uses of copper

Copper is an important engineering metal, widely used for various engineering purposes. It is used for manufacture of several alloys. It is also used in ceramics and pesticides. Cu is used in manufacture of wires for various industries, namely electrical, electronics, automotive, electrical appliances, white goods, etc., and other products in copper forming industries. Some heavy metals and substances must not be present in more quantity in alloys as per ROHs norms (limit).

Sources of copper contamination

Copper enters into the environment through natural and anthropogenic sources. The contamination of air and water, by copper is contributed from mining, milling, concentrating, refining of copper ores, electroplating industries, petroleum and refining melt-

ing plant and misc. units and from industrial smelts, namely iron and steel and fertilizer industries. Copper is discharged into the industrial effluents of various industries, like chlor-alkali, electroplating, paints and dyes, petroleum refining, fertilizers, mining and metallurgy, explosives, pesticides, iron and steel industries, burning of wood, etc., water pollution due to copper also results from the discharge of mine tailings disposal of flyash and disposal of municipal and industrial wastes (Dara, 1993). Separation of the traces of copper bearing minerals from the mass of wastes is essential to economic recovery of the metal (Rao and Rao, 1989). The main sources of pollution in copper metal industry are : Solid waste from mines, mine water and effluents from water treatment plants, tailings from floatation cells, sulphur containing gases, bled electrolyte from electro-refining plant, acid spillage from sulphuric acid plant, etc., (Bhatia, 2002). The above sources contribute wealthy share to the copper pollution of water bodies. The sources and pathways of copper entering into water bodies have been shown in the figure 1.

Table 1. Standards for copper in drinking water and industrial/sewage effluent discharge, in mg/L

Drinking water		Industrial or sewage effluents (IS:2490-1982)			Into public sewer
WHO (1971)	IS:10500 (1983)	Into inland surface	On land for irrigation water	Into marine coastal plane	
0.05	0.05	3.0		3.0	3.0

Standard

Standards are legally prescribed limits of pollution which are established under statutory authority. The standards for copper in drinking water and industrial/sewage effluent discharges have been given in table-1.

Copper toxicity and biochemical effect

Copper is a toxic metal. It causes a disease named 'Wilson's disease'. It causes harmful biochemical effects, toxicity and hazards in flora, fauna and human beings. Intake of Cu through air, water and food beyond its permissible limit causes disease. Ingestion of 15-75 mg of Cu causes gastro-intestinal disorders. Excessive intake of Cu may cause hemolysis, hepatotoxic and nephrotoxic effects. Copper toxicity leads to severe mucosal irritation, corrosion, widespread capillary damage, hepatic and renal damage and central nervous system irritation followed by depression (Krishnamurthy *et al.*, 1991). Application of copper salts to the skin is corrosive and may lead to papulovesicular eczema. Local action on the eye produces inflammation. Workers involved in use of fungicides containing copper sulphate develop a respiratory disorder called 'Vineyard sprayer's lungs' which is characterized by the development of interstitial pulmonary lesions and nodular fibro-hyaline scars. This may lead to even lung cancer.

CONTROL OF COPPER POLLUTION FROM WATER/WASTEWATER

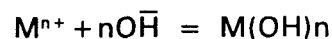
Control technology for copper pollution is a very significant facet of environmental studies. The industrial effluents/wastewaters containing metal bearing wastewater should be treated for removal of copper con-

centration prior to their discharge into the receiving water bodies and the concentration value should be carried within TLV for Cu. A number of processes are known which are employed for the treatment of copper bearing effluents from various industries.

General techniques for the removal of copper

The techniques employed for removal of copper from metal bearing wastewaters are precipitation ion-exchange, reverse osmosis, cementation (Dean *et al.*, 1972). Solvent extraction and adsorption, etc.

Precipitation : The heavy metal copper action can be removed effectively from aqueous solutions with lime by precipitation as its metal hydroxide, according to the reaction :

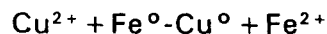


The extent of this reaction is governed by the concentration of the metal ion and pH of the solution. The metal ions get precipitated over a range of pH values. Thus precipitation of Cu^{++} , Pb^{++} and Fe^{++} as hydrated oxides of other salts is often used industrially to reduce the concentration of these ions in solution (Moore, 1972). A number of organic compounds have also been tried for precipitation of heavy metals (Thackson *et al.*, 1980).

Ion exchange : Ion exchange technique has been successfully employed for the removal of copper and other heavy metals from wastewaters. This method is considered economical for the recovery and recycling of wastewater in electroplating operations, but as a whole, ion exchange process is

expensive and requires recharge of resin and the disposal of substantial volume of spent and the contaminant regenerant solution.

Cementation : Cementation is the recovery of an ionized metal from solution by spontaneous electrochemical reduction to the elemental metallic state, with consequent oxidation of a sacrificial metal. A typical example of this process is the reaction of copper ions with iron, namely



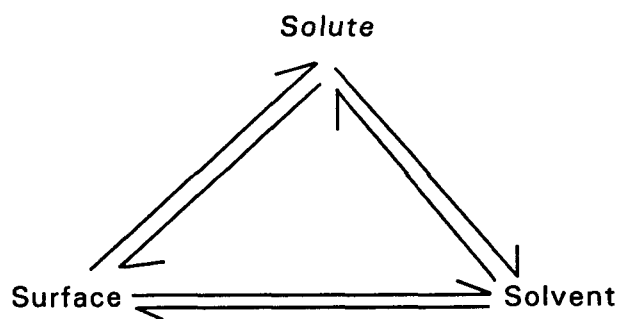
However, this process is used only to a limited extent these days, though used for copper (Patterson *et al.*, 1977).

Floatation : Foam floatation has distinct advantages when dealing with large volume of highly contaminated wastes that are quite dilute in the ions to be removed. In the adsorbing colloid floatation technique, the removal of adsorbed material on colloidal particles is achieved through the use of surfactant by floatation. By this method, removal of lead ions from wastewater has been reported by Thackson *et al.* (1980).

Solvent-extraction : Solvent extraction is a process in which a substance is transferred from one liquid phase into another liquid phase. The equilibrium stage of this process is known as liquid-liquid partition. Since two phases should be reasonably immiscible the vast majority of studies made concerns the systems where one liquid phase is usually an aqueous solution and the second phase is an organic solvent capable of dissolving the distribuend atleast to some extent. An extractant is a substance with solvent properties used in a solution of a suitable diluent. The diluent without having extractant properties itself is used to dissolve the extractant and improve its physical properties; the extractant and the diluent together act as solvent. A brief review on the use of extraction technique for the removal of metals, such as Cu, Ni, Cr and Zn was published by Clevenger and Novak. They have used chelating agents, such as 8-hydroxyquinoline, acetyl-acetone and dithizone, etc. However, there are eco-

nomic limitations for these processes since most of the chelating agents are quite expensive. Among other methods, removal of heavy metals by biological treatment and by using electrolyte ferrite formation have also been reported recently but not with much success.

Adsorption : During recent years, adsorption has also come to the forefront as one of the significant techniques for the removal of heavy metals from polluted /wastewaters. The process of adsorption has been found quite useful and popular due to its low maintenance cost, high efficiency and easy operation (Culp, 1963). The phenomenon of adsorption involves the interface accumulation of a substance at an interface. It can occur at liquid-liquid, gas-liquid, gas-solid or liquid-solid interfaces. The matter being concentrated is called adsorbate and the adsorbing material is known as the adsorbent (Shrivastav, 1998). A full understanding of the adsorption process requires that the interaction of a solute with a surface be characterized in terms of physico-chemical properties of the solvent, solute and adsorbent and the same can be represented by the following figure :



The significant chemical interactions are those of the solute with the surface and the solute with the solvent. However, the interaction of the solvent with the surface is of little significance when water is used as the solvent. Thus, a number of solid materials, conventional and non-conventional having large surface sites for adsorption have been utilized as adsorbents. The list is very wide and includes from the most widely used activated carbon to activated alumina, clay minerals, flyash, coal, wastewool, peatm-

oss, saw-dust, serpentine mineral, blast-furnace slag, etc. Various adsorbents have been used for removal of copper from water/wastewaters which are : Polyvinyl benzene trimethyl ammonium chloride PVBTMAC (Wing *et al.*, 1974), clay minerals – Kaolinite and montmorillonite (Griffin *et al.*, 1976), serpentine mineral (Sunder-eshen *et al.*, 1978), straw (Larsen and Schierup, 1981), seed husks of *Citrullus vulgaris* (Okieimen *et al.*, 1978), sulphate reducing bacteria 'disulphovibrio desulphuricans' (Kar and Shukla *et al.*, 1992), coal based absorbents- Bituminous coal (Coughline *et al.*, 1995), goethite (Coughline *et al.*, 1995), uptake of copper by plants and animals was also studied by many persons. Sorption of Cd, Pb, Cu, Zn on treated and untreated foam stripes (PUF) was studied by us (Shrivastava and Rupainwar, 1997). Some absorbents have been used for removal of Cu, for example algal biomass, and biosorbents by Volesky (2003). Another absorbents, like bottom ash (Kaur *et al.*, 1995), granulated slag-steel plant (Looba and Pandey, 1993), inorganic particulates (Aulita *et al.*, 1991) oxides of manganese and iron (Mc Kenzie, 1980), bacillus biosorption (Hossain, 2006), commercial activated carbon (Kannan *et al.*, 2005), etc., have been employed successively for removal of copper from water / wastewater.

Huang (1977) investigated the role of possible metallo-organic species co-ordination in the removal of heavy metals (Huang, 1977). The sorption of Cu(II) by Delaware soil for instance is greatly enhanced by foreign species, such as phosphate, organic acids or colour forming compounds. The metal ions have tremendous binding capacity for many types of naturally occurring organic ligands, such as humic acid and fulvic acids (Iverson *et al.*, 1978). To meet the current need of devising cost effective treatment and disposal technology, newly identified biomass (cow-dung) was contemplated to reduce the treatment cost of metal bearing industrial effluents in lieu of hydroxide precipitation technique. The conventional methods, such as chemical precipitation,

cementation, ion-exchange, electro-deposition, membrane system and activated carbon adsorption (Kiff, 1987) are not cost effective in Indian context. Hence, low cost non-conventional methods and material are searched for a long time. Industrial wastes, such as flyash (Virarghavan *et al.*, 1992), charred waste of oxalic acid plant (Nandita *et al.*, 1990), bottom ash (Kaur *et al.*, 1991), steel plant granulated slag (Looba and Pandey, 1993), polymerized onion skin (Kumar *et al.*, 1981), chitosan (Masri *et al.*, 1974), low grade manganese ore (Prasad and Venkobachar, 1988) and agricultural wastes, such as rice husk, tree bark peanut skin, walnut expeller meal, paddy husk, rice straw (Larsen and Schierup, 1981), apple waste (Maranon *et al.*, 1991), microbes (Brierly, 1987), powdered leaves (Sushella *et al.*, 1985), red wood bark (Randal *et al.*, 1975), bark samples (Kumar and Dara, 1986) fixed bed sorption by saw-dust (Shrivastava *et al.*, 1995) hydrous iron and manganese oxide (Gadde *et al.*, 1974), goethite (Forbes *et al.*, 1976), Amorphous iron oxyhydroxide (Benjamin *et al.*, 1981), flyash (Copper Topics, 2007), modified activated carbons (Youssef *et al.*, 1992) have been used for removal of Cu and other heavy metals. Peat-moss, a complex material containing lignin and cellulose as major constituents was found to be economical and convenient absorbents for the treatment of wastewater containing Cu and other heavy metals (Coupal *et al.*, 1976). The biosorption of Cu was reported by (Aksu *et al.*, 1998; Muraleedharan *et al.*, 1995; Green *et al.*, 1987).

SPECIFIC TREATMENT OF COPPER BEARING WATER/WASTEWATER

Copper is released into the environment from solid waste, liquid waste and gas disposal from mining, concentrator, smelter, electro-refinery, melting point and misc. units. The main sources of pollution in copper industry are : Solid wastes from mines, mine water and effluents from water treatment plants, tailings from floatation cells, sulphur containing gases, bled electrolyte from electro-refinery plant, acid spilages from

sulphuric acids, etc. At Hindustan Copper Ltd., various steps have been installed to combat pollution and to achieve the goal of 'zero pollution' in primary copper industry. The copper forming industry includes rolling, drawing, extruding and/or forging copper and copper alloys. The products of copper forming vary from wires to brewery kettles. Five different copper forming processes are-Hot rolling, cold rolling, extension forging, annealing. In addition, there are some additional processes which may take place at a copper forming plant include-Pickling, alkaline cleaning, solution heat treatment, rolling and drawing process, solution heat treating and drawing process, solution heat treating and annealing quenches, alkaline cleaning rinse and baths, pickling baths, rinses and fume scrubbers, wastes generation (solid wastes, air borne wastes, water borne wastes, oil and grease toxic organics and metals). Copper and other heavy metals can be removed from the waste stream by alkaline, sulphide, phosphate or carbonation precipitation, followed by filtration and ion exchange. In many instances, metals can be recovered from sludges and ion exchange resins, and every opportunity to do so should be thoroughly investigated. Adsorption technology is employed also for removal for copper from wastewaters effluents.

Treatment of effluents from tank house

During the electro-refining operations impurities, like Ni, Fe, As, Sb, etc., from anodes dissolve into the electrolyte but do not deposit on the cathode. Consequently, there is a build up these elements in the electrolyte, which is a solution of copper sulphate in dilute sulphuric acid. To maintain the quality of the electro-deposited copper, it is essential to contain the impurity level in the electrolyte. For this, a certain amount of electrolyte is bled off from the system and sent for purification. Purification may be done in either of the following two ways :

(1) The removal of copper, arsenic and antimony by electrolysis in the liberator cells, followed by concentration of the liquors for

removal of nickel, iron and zinc, etc.

(2) Essentially, the above procedure is followed except that the electrolysis in liberator cells is preceded by the removal of a part of copper by concentration and crystallization.

The basic principle are same in both the cases. First the copper is removed from the electrolyte. This makes possible part removal of arsenic and antimony by electrolysis and recovery of nickel in a marketable form in the second stage. In one method, the decopperised solution is concentrated in vacuum or direct fired evaporators or both. This concentration removes practically all of the nickel, iron and zinc and small amounts of arsenic and antimony in the form of a sludge. This sludge may be marketed or further treated for the production of purified nickel compounds. The final acid, called the 'black acid' is marketed, returned to the main solution circuit, utilized in other operations or neutralized with lime and discarded.

In yet another method, copper sulphate is separated from the other metal sulphates by fractional crystallization in two more stages but complete separation of copper and other heavy metals is not obtained by crystallization. In subsequent operations, copper is completely removed in liberator tanks. After removal of copper and the required amount of arsenic and antimony, crude nickel sulphate is produced by concentration and crystallization, so that the possibility of pollution is minimized. The modern techniques involve the employment of dialysis to supplement the conventional methods of purification of electrolytes under favourable conditions. There is a need to design a plant, which economically feasible (cost effective) cheap operating maintenance and total cost.

Effluents from ancillary sources and central pollution treatment system

Wastewater from water treatment plants (both demineraliser and softener units) wash water from tank house and acid plants, overflows during power failure, etc., need spe-

cial treatment facilities to achieve the zero pollution level (for water effluents) as demanded by legislation. The strategy adopted for such cases varies from situation to situation, but one of the main methods is to install a centralized treatment plant to insure against such situations. Salient features of the typical method proposed at Khetri Copper Complex are : Installation of independent treatment facilities for individual water treatment plants for pH control. Automatic pH control in neutralization units for strick check on acidic effluents, if any from acid plants, segregation of spillages, produced during power failure from concentration plant, and recover copper bearing sludge, Independent treatment circuit for fertilizer section, and installation of combined effluent treatment plant.

CONCLUSION

In this way, copper industry produces a significant share to copper pollution in the environment due to its various industrial processes. Industrial effluents in the form of solid, liquid and gas contaminate the environment. Control of solid and liquid effluents is relatively easy, but treatment of gaseous effluents, that is sulphur dioxide is very costly. Hindustan Copper Ltd., has taken various steps to combat pollution and to achieve the target of 'zero pollution' for the primary copper industry in the country. A review of the current literature and the available processes discussed above shows that an integrated approach is necessary to remove heavy metals from industrial wastewaters. To achieve the stringent standards for efficient disposal into natural bodies of water, adsorption may be termed as one of the most expedient approach to the problem as a final step in a series of techniques to be used.

Furthermore, the adsorbent systems reported so far have generally dealt with the theoretical thermodynamic and a basic practical aspects for the removal of one particular metal only, for example copper or even lead but in the real life situations, the industrial effluents coming out of a specific unit, of-

ten contain several other constituents and more than one metal. It is, therefore, virtually important that the mechanism and details of such systems containing two or more metals should be worked out in full details so that the same can be applied for development of an appropriate ETP system. There seems to be a good scope for extension of research work on the above aspect of removal of the heavy metals which includes copper also using adsorption technique. As already mentioned for all these processes to be developed, the most important factor would be the cost of the process and economic viability of the proposed system. Virtually, no attempt has been reported in the past highlighting this aspect or for development of the ETP based on adsorption methodology. This is another area, which requires serious attention of research workers, during the next few years. It is anticipated that during the coming years, a lot of good work will be definitely reported in this direction and we would have tailor made systems for the treatment of an effluent from a specific industrial unit for the removal of copper and other heavy metals.

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REFERENCE

- Aksu, Z., *et al.* 1998a. The biosorption of copper (II). Ed C. Vulgaris and Z. Ramigera. *Env. Tech.*, pp 13.
- Aulita, T.V. and W.F. Pickering. 1987. The specific sorption of trace amounts of Pb, Cu, Cd by inorganic particulates. *Water, Air, Soil Poll.*, 35 : 171-185.
- Benjamin, M.M. and J.O. Leckie. 1981. Multiple site adsorption of Cd, Cu, Zn and Pb on amorphous Iron oxyhydroxide. *J. Colloid Interface Sci.*, 79 : 209.
- Bhatia, S.C. 2002. Handbook of industrial pollution control in chemical process and

- allied industries (vol II). C.B.S. Publishers and Distributor, New Delhi. pp 68-69.
- Brierly, A. James. 1987. Microbial removal of metals from industrial wastewaters. *J. Water Wastewater Int.*, pp 31.
- Copper Topics. 2006. Statistics. Vol.31, No.1, pp 24.
- Copper Topics. 2007. Statistics. Vol.32, No.3, pp 14.
- Copper Topics. 2007. Statistics. Vol.32, No.3, pp 19.
- Coughlin, B.R. and A.T. Stone. 1995. Pb(II) on goethite : Effect of acidification FE(II) addition and picolinic acid addition. *Env. Sci. Tech.*, 29(2) : 2445.
- Coupal, B. and J.M. Lalancette. 1976. The treatment of wastewaters with peat moss. *Water Res.*, 10 : 1071-1076.
- Culp, R.J. 1963. *Water Poll. Cont. Federation*. 35 : 799.
- Dara, S.S. 1993. A. text book of environmental chemistry and pollution control. S. Chand and Company Ltd., Ramnagar, New Delhi.
- Dean, J.G., F.L. Basqui and Lanouette. 1972. Removing heavy metals form wastewater. *Env. Sci. Tech.*, 6 : 518.
- Forbes, E.A., et al. 1976. The specific adsorption divalent Cd, Co, Cu Pb, Zn on goethite. *J. Soil Sci.*, 27 : 154.
- Gadde, R. and H.A. Laitinen. 1974. Studies of heavy metal adsorption by hydrous iron and manganese oxides. *Anal. Chem.*, 46 : 2022.
- Green, B., R. McPherson and D. Darnall. 1987. In Metals speciation separation and recovery. Ed W. Patterson and R. Passion. Lewis Publishers, Chelsea. pp 9.
- Griffin, R.A., R.R. Frost and N.F. Shimp. 1976. Water research Symposium, 259-68 (Report). EPA-600/9-76-015.
- Gustavo, R., et al. 2007. Enhanced copper release from pipes by alternating stagnation and flow events. *Env. Sci Tech.*, 41 (21) : 7430-7436.
- Hossain, S.K. Masud. 2006. Studies on bacterial growth and Cu(II) biosorption using *Bacillus subtilis*. *Indian J. Env. Prot.*, 26(12) : 1090-1092.
- Huang C.P. 1977. Removal of heavy metals from industrial effluents. *J. Env. Eng. Div. vision, ASCE*. 118 (EE6) : 923-947.
- Iverson, W.P. and N.K. Brickman. 1978. Water pollution microbiology (vol 2). Ed R. Mitchell. Wiley Inter Science, New York. pp 201-233.
- Kannan, N. and S. Menaka Devi. 2005. Studies on the removal of Cu(II) and lead (II) ions by adsorption on commercial activated carbon. *Indian J. Env. Prot.*, 25 : 28-37.
- Kar, R.N., B.N. Sahoo and L.B. Shukla. 1992. Removal of heavy metals from mine water using sulphate reducing bacteria. *Poll. Res.*, 11(1) : 13-18.
- Kaur A., et al. 1991. Removal of Cu and Pb from wastewater by adsorption on bottom ash. *Indian J. Env. Prot.*, 11 : 433-435.
- Kiff, R. J. 1987. General inorganic effluents. In Surveys in industrial wastewater treatment-Manufacturing and chemical industries (vol 3). Ed D. Barnes, C.F. Forster and S.E. Hruday. Longman, New York.
- Krishnamurthy, C.R. and P. Vishwanathan. 1991. Toxic metals in the Indian environment. Tata Mc Graw Hill Publishing Company Limited, New Delhi. pp 188.
- Kumar, P. and S.S. Dara. 1981. Binding metal ions with polymerized onion skin. *J. Poly. Sci.*, 19 : 397-402.
- Kumar, P. and S.S. Dara. 1986. Modified barks for scavenging, toxic heavy metals, *Indian J. Env. Health*. 22(3) : 196.
- Larsen, V.J. and H.H. Schierup. 1981. The use of straw for removal of heavy metals from wastewater. *J. Env. Quality*. 10 (2) 188.
- Loomba, K. and G.S. Pandey. 1993. Selective removal of some toxic metals ions [Hg (II), Cu(II), Pb(II) and Zn(II)] by reduction using steel plants granulated slag. *Indian J. Env. Health*. A28 : 105-112.
- Maranon, E. and H. Sastre. 1991. Heavy metal removal in packed beds using apple waste. *Bioresour. Tech.*, 38 : 39-43.
- Masri, S.M., F.W. Reuter and M. Friedman. 1974. Binding of metal captions by natural substances. *J. Applied Polymer. Sci.*, 18 : 673.
- Mc Kenzie, R.M. 1980. The adsorption of lead and other heavy metals on oxides of manganese and iron. *Australian J. Soil Res.*, 18 : 61-73.
- Moore, W.A. 1972. Interaction of heavy

- metals and biological sewage treatment process. Public Health Service, Cincinnati, Ohio. Pub. No. 999, wp-22.
- Muraleedharan, T.R., L. Iyengar and C. Venkobachar. 1995. Screening of tropical wood rotting mushrooms for copper biosorption. *Applied Env. Microbiol.*, 61(9).
- Nandita, S. and G.S. Pandey. 1990. Charred waste of oxalic acid plant as an adsorbent of toxic ions and dyes, *Biological Wastes*. 32 : 145-148.
- Okieimen and V.U. Onyenkpa. 1990. Removal of heavy metal ions from aqueous solution with melon (*Citrullus vulgaris*) seed husks. *Biological Wastes*. 21 (1) : 11.
- Pandey, K.K., G. Prasad and V.N. Singh. 1985. Cu(II) removal from aqueous soln by flyash. *Water Res.*, 19(7) : 869.
- Patterson, J.W. and Jancuk. 1977. Cementation treatment of copper in wastewater. 32nd Industrial Waste Conference. Perdue University. Proceeding, pp 853.
- Prasad, S.C. and C. Venkobachar. 1988. An investigation on cadmium (II) removal by low grade manganese ore. *Asian Env.*, 19 (3) : 11.
- Randal, J.M. and E. Hautala. 1975. Removal of heavy metal ions from wastewater solution by control with agricultural byproducts. 30th Industrial waste Conference. Perdue University.
- Rao, M.N. and H.V.N. Rao. 1989. Air pollution. Tata Mc Graw Hill Publishing Company, New Delhi. pp 244-245.
- Samuel, L. Hoyt. 1954. ASME handbook, metal properties. Mc Graw Hill Book Inc., New York. pp 299.
- Shrivastava, A.K. 1998. Studies on the pollution of water by lead and other heavy metals being studies of river Ganga and Varuna river water quality and special emphasis on lead and other heavy metals. Ph.D. Thesis. Banaras Hindu University, Varanasi.
- Shrivastava, A.K., G. Prasad and D.C. Rupainwar. 1995. Removal of Cu(II) from effluents by fixed bed sorption onto saw dust, 32nd Annual Convention of Chemists. Jaipur.
- Shrivastava, A.K., G. Prasad, and D.C. Rupainwar. 1997. Sorption of Pb, Cd, Cu and zinc on treated and untreated foam stripes (PUF). 84th Ind. Sc. Cong., Chem. Part (III), New Delhi.
- Singh, D.K. and Jyotsana Lal. 1992. Removal of toxic metal ions from wastewater by coal based adsorbent. *Poll. Res.*, 11(1) : 37-42.
- Sundereshen, B.D., et al. 1978. Removal of Fe, Mn, Cu, As, Pb, Cd by serpentine mineral. *Indian J. Env. Health*. 20 : 413.
- Sushella, K., M.S. Parathu and S.C. Nandi. 1985. Removal of chromium from tannery effluents using powdered leaves. National Seminar on Pollution control and environmental management. Nagpur.
- Thackson, E.L. 1980. Lead removal with adsorbing colloid floatation. *Water Poll. Cont. Fed.*, 52 : 317.
- Virarghavan, T. and M.M. Dronamraju. 1992. Utilization of coal ash in water pollution control. *Int. J. Env. Studies*. 40 : 79-85.
- Volesky, B. 2003. Sorption and biosorption. BV-Sorbex. St.Lambert, Quebec, Canada.
- Wing, R.E., et al. 1974. Starch based products in heavy metals removal. *J. Water Poll. Cont. Fed.*, 46 : 2043.
- Youssef, A.M. and M.R. Mustafa. 1992. Removal of Cu ions by modified activated carbons. *Indian J. Tech.*, 30 (8) : 413-416.

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