Remediation of Low Level Hexavalent Chromium from Water by Activated Sludge Process: A Review

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Abstract: The techniques available for the treatment of hexavalent chromium [Cr (VI)] include, chemical reduction followed by precipitation, ion exchange, membrane separation, and reverse osmosis. However, they are not techno-economically feasible due to high cost and problems of disposal of low density sludge generated in these processes. Microbial remediation techniques i.e. both aerobic and anaerobic processes have shown enough potential using single consortia in lab scale reactor and researchers have advocated that this can prove to be the most economical technique. Activated sludge process is the most common treatment system for municipal and industrial wastewater. However, high concentration of Cr (VI) (>5ppm) can affect the microbial growth of activated sludge. Concentration of Cr (VI) at which it stimulates or affects the growth of microorganisms is often controversial. The aim of this review is to investigate the efficiency of activated sludge process for the remediation of low concentration of Cr (VI) (<2ppm) from water. Most of the studies revealed that microbial reduction followed by precipitation and biosorption could be one of the possible mechanisms for the removal of Cr (VI). Instead of physiochemical treatment adopted by mine industries in India, Activated sludge process can efficiently be used for the removal of low concentration of Cr (VI).

Keywords: Hexavalent Chromium, Activated Sludge Process, Biosorption, Precipitation

1. INTRODUCTION

Chromium is a heavy metal used for the various purposes in many industries such as steel alloys, chemical manufacturing, paint and dyes, tanneries etc. This is usually released in the environment in the form of Cr (VI) and Cr (III) state. Both the form of chromium is found injurious however Cr (VI) is 100 times more harmful than Cr (III) even at the low concentration [1].

The Sukinda Vally of Odisha accounts for 93% of total chromite production in India [2]. The Cr (VI) generation is the major environmental concern of this region. The contamination of Cr (VI) in local water bodies and underground water is the most serious problem due to its carcinogenic properties. According to World health Organization (WHO-2012) the level of Cr (VI) should not increase more than 0.05mg/l. Indian Standard also prescribe the maximum limit of Total Cr is

0.05mg/l in drinking water (IS 10500-2012). Maximum tolerance limit of Cr (VI) in inland water is 0.1 mg/l [3].

The most common technique used in Sukinda Valley for Cr (VI) removal is physiochemical reduction with ferrous sulfate and precipitation by lime. This process consumes huge amount of chemicals and produce a lot of low density toxic sludge which creates disposal problems. So this process is not economically feasible. There were many studies carried out on the bioremediation of Cr (VI) and researchers advocated that this may prove to be environmental friendly and feasible [4][5][6]. A number of bacterial consortia have been proved 100% efficient for the remediation of Cr (VI) from water [7]. Although Cr (VI) is very toxic and cause harm to the microorganisms' growth, a numbers of reports support that Cr (VI) does not cause harm to the microorganisms at low level (less than 5 mg/l). Reports also support that at higher level (> 25 mg/l) of Cr (VI) the activities of microorganisms in activated sludge adversely affected [8].

The aim of this review is to discuss the efficiency of ASP process for remediation of low concentration of Cr (VI). ASP is the most popular biological treatment process of wastewater. This is based on the bacterial and other microorganism population in an aerated tank. Since the process of single culture of microorganism is difficult for the large scale field, mixed cultured is easy and will give fruitful results on the large volume of wastewater with low concentration of chromium content.

2. ACTIVATED SLUDGE PROCESS FOR REMOVAL OF CR (VI):

ASPs are the most popular technique commonly used for the treatment of municipal and industrial wastewaters. There are numbers of studies have done on the metal removal efficiency of ASP reactor. ASPs are totally based on the microbial activities. Cell biomass (alive and dead both) both have property to reduce and adsorb the metal [9]. Cr (VI) is very toxic than Cr (III) and can damage the microbial cell, being less toxic Cr (III) can be more efficiently removed by ASP. Cr (VI) also can be removed through ASP in which Cr (VI) first reduced into Cr (III) by the bacterial enzymatic activities and Cr (III) settled in the sludge/ dead bacterial biomass in the form of Cr $(OH)_3$. The studies showed that 96-99 % of the chromium present in the ASP sludge as Cr (III) [10]. Imai and Gloyna (1988) find that at higher pH and longer retention time the adsorption capacity of sludge increase [11].

The mechanism of Cr (VI) removal involves following processes:

- Reduction of Cr (VI) to Cr (III)
- Precipitation of Cr (III)

- Adsorption of Cr (VI) and Cr (III) by suspended solids present in the system
- Biosorption by Bacterial cell
- Effect of chromium on cell biomass

The reduction of Cr(VI) to Cr(III) by different microbial culture is possible in the both aerobic and anaerobic condition. Table 1 shows different microbial species found efficient in reducing of Cr(VI) in aerobic conditions [12][13][14]. When Cr(VI) is reduced to Cr(III) due to its low solubility and impermeability to cell membrane this is either precipitated in the form $Cr(OH)_3$ or gets biosorbed. Although ASP works in the presence of oxygen, studies show that the oxidation of Cr(III) to Cr(VI) does not take place [11][15]. This can be attributed Cr(III) is more readily adsorbed before the oxidation reaction is facilitated [11]. Many studies also demonstrated that suspended solids concentration in the ASP greatly influences the chromium adsorption [15]. This is due to the fact that suspended solids present in the water provide more surface area for adsorption of Chromium. In the some studies large part of Cr(VI) was adsorbed by the MLSS of ASP system and reduced Cr(III) was immediately detected on the suspended solids [10]. Both forms of Chromium are adsorbed by the suspended solids, although some studies says there are no any correlation between Cr(VI) and suspended solids[15].

Table 1: Microbial species capable of reducing Cr(VI)

Name of microbes	Mechanism	Description	Reference
Psudomonas fluorecens(LB300)	Bioreduction	Cr(VI) removal 70-99.7%	[16]
Psudomonas ambigua G-1	Bioreduction	At HRT 36 hours it reduces 76.6% of Cr(VI).	[17]
Bacillus subtilis	Biosorption	Reduce Cr(VI) in range of 0.1 to 1mM.conc.	[18]
Acinetobactor haemolyticus	Bioreduction	Complete Cr(VI) reduction occur up to 10–30 mg/L. Incomplete reduction takes place at >70 mg/L.	[19]
Bacillus sphaericus	Bioreduction	Tolerate 800 mg/L Cr(VI) and reduce >80% of Cr(VI).	[20]
Streptomyces griseus	Bioreduction	Can reduce 5–60 ppm of Cr(VI)	[21]
B. cereus ATCC 10987, B.cereus 213 16S, B.Thueningenesis, B.myocides Microbacterium	Bioreduction	100% reduction of Cr(VI) in 65h incubation.	[22]

3. DISCUSSION

There are several possible mechanisms in the remediation of Cr(VI) from ASP as describe above. The given Cr(VI) dose in the ASP system might be reduced into Cr(III) by suspended particles present in the ASP reactor and biosorbed or precipitated through the bacterial cell wall [15]. Precipitated metals may be removed either by independent settling or by physical trapping in the sludge floc matrix. Stasinakis (2004) removed 40% of the total added Cr(VI) during activated sludge process and the remaining Cr(VI) was sorbed by the sludge flocs mainly in the form of Cr(III)[10]. According to Chen 2005 an acclimated activated sludge remove 100% of Cr(VI) and approx 98.56% total chromium at influent level 20mg/day. However, at higher concentration (60 mg/day) of Cr(VI) the removal efficiency decreases. The increase of glucose concentration in influent improves the efficiency i.e. increased from 98.64 to 100% for Cr(VI) and from 97.16 to 98.48% for Cr(III) [23].

Several studies have been done on the effect of Chromium on the microorganisms of ASP [24][8][25]. However Cr(VI) is toxic and influence the growth of microorganisms in ASP and most of researchers refer that small concentration (1- 5mg/l) of Cr(VI) prove beneficial microorganisms and stimulate the growth of microorganisms in ASP [25].Some studies refer that after an optimum Cr(VI) concentration, the reduction rate gradually decreases and the microbes started to loss their reducing efficiency due to Cr(VI) toxicity [26].The maximum dose at which the microorganisms significantly affected and reduce their reducing capacity is often controversial. Some researchers proven that the presence of Cr(VI) in concentration range of 10-50mg/l has no any harmful effect on the growth of microorganism in ASP [24][8].

4. CONCLUSION

Conventional methods used for low level of chromium is techno-economically not feasible due to operational and maintenance cost in the form of chemical and disposal of huge volume of less density toxic sludge. Reduction of Cr (VI) can be achieved > 95% by ASP system for the wastewater containing low levels of Cr (VI). Removal of Cr (VI) is mediated by microbial reduction followed by precipitation and biosorption of Cr (III). Presence of SS helps and stimulates the adsorption of reduced Cr (III). On the economical point of view ASP treatment system could be prove more efficient and economically cheap than conventional physiochemical treatment systems currently used in various Chromite Mines in India.

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