Influence of C/N Ratio in Activated Sludge to Remove Cr (VI)

Arseto Yekti Bagastyo*, Natalia Diani Triana*

Abstract

Bio-sorption is an environmental friendly process for heavy metal removal. This can be achieved by using effective and low cost materials such as activated sludge. Extracellular Polymeric Substance (EPS) in activated sludge plays as the key role on the bio-sorption. The amount and composition of EPS produced in activated sludge are affected by C/N ratio in medium. Three C/N ratios (in mg COD mg TKN-1) in mixed liquor were used to investigate the effect of C/N ratio on the Cr (VI) bio-sorption process in batch reactors using the activated sludge from the municipal sewage treatment plant with 5, 50 and 100 mg L-1 of initial [Cr (VI)]. Higher [Cr (VI)] led to higher Cr (VI) removal for almost all bio-sorption tests, except C/N 9 at 100 mg L-1 [Cr (VI)]. Variation of C/N ratio did not give substantial effects on Cr (VI) removal at 5 and 50 mg L-1 [Cr (VI)], i.e., >4,7 and >47 mg L-1 [Cr (VI)] were removed, respectively. Bio-sorption with 100 mg L-1 [Cr (VI)] showed varied removal from 19.63-75.87 mg L-1 [Cr (VI)]. The highest removal of Cr (VI) was found in bio-sorption process with C/N ratio 43, i.e., 97.04%, 99.73% and 75.87% for 5, 50 and 100 mg L-1 [Cr (VI)], respectively. In conclusion, activated sludge system with C/N ratio adjusted to 9, 21 and 43 could remove [Cr (VI)] up to 50 mg L-1, while the higher adjusted C/N ratio might be required for higher [Cr (VI)].

Keywords: Activated sludge, bio-sorption, C/N ratio, Cr (VI)

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Introduction

Chromium is one of heavy metals which has characteristics of high toxicity, easily uptake and has ability to accumulate in food chain. However, chromium and its substances are still widely used in industrial activities like electroplating, leather tanning, metal processing, pulp, steel fabrication, paint and pigments, wood preservatives, oil refinery, cement, dying, power plant, and canning industries (Januarita and Herdiansyah, 2003; Lokeshwari and Joshi, 2009; Junaidi et al., 2010). The chromium wastewater generated from these industrial activities will affect the environment.

Two chromium ions commonly found in the environment are Cr (III) and Cr (VI) which have specific characteristic of toxicity, mobilization, and bioavailability. Cr (VI) is highly soluble in water, very toxic, corrosive, and carcinogenic due to its ability to make macromolecule complexes inside cell of organism. Conversely, Cr (III) is less toxic than Cr (VI), non-corrosive, non-irritating, and is an essential metal for mammal, especially for glucose, carbohydrate, lipid and protein metabolism. It is also needed as a co-factor for insulin activity (Januarita and Herdiansyah, 2003; Lokeshwari and Joshi, 2009; Junaidi et al., 2010).

Therefore, Cr (VI) has been taken into account for environmental and health problems.

The heavy metals contamination can be treated by conducting biological method, as an alternative to the physical and chemical methods. Bioremediation process using bacteria or other microorganisms has shown a very good removal of heavy metals, including Cr. The mechanisms of bioremediation process comprise of bio-sorption and bio-accumulation process (Chojnacka, 2010; Zulaika et al., 2012).

Bio-sorption is an adsorption process/metal ion attachment to the biomass surface through physical and chemical processes (Hammaini et al., 2003; Prabu et al., 2012) or metal binding/accumulating through metabolically mediated process (Ahalya et al., 2003). Iyer et al. (2005) showed that bio-sorption mechanism usually related to the complex formation between metals and carboxyl, hydroxyl, and phenol groups in Extracellular Polymeric Substances (EPS) on bacterial cell surface. These compounds have a function as chelating agents of heavy metal to the cell surface (Iyer et al., 2005). Bioaccumulation is an advanced process of bio-sorption to remove heavy metals, where intracellular accumulation is conducted. This process usually related to the availability of operon gen in the cell microorganism which depends on metal
accumulated (Silver, 1996; Zulaika et al., 2012). Effectiveness of bio-sorption process is based on various metal binding capacities by biological materials.

Activated sludge is one of effective bio-sorbent materials. It is a complex system consists of combined flocks containing heterogeneous microorganisms (Hammaini et al., 2003; Sari et al., 2013). It also contains organic matter and slime materials. Microorganisms contained in activated sludge are the various types of bacteria, yeast, fungi and protozoa. These microorganisms make the activated sludge becomes more effective to remove heavy metals through the availabilities of higher binding capacity from various types of microorganisms. Furthermore, activated sludge is readily available, low cost material, and able to be re-used (Bailey et al., 1999; Plaza et al., 2011).

When using activated sludge as bio-sorbent materials, one of important factors to be considered is C/N ratio, which could affect the composition and amount of EPS produced. Various C/N ratios will affect the composition of protein and polysaccharide in EPS compound (Yuncu et al., 2006). Low C/N ratio will produce EPS which mainly containing protein, while the high C/N ratio will produce EPS which mainly containing carbohydrate. Both of protein and carbohydrate have different function which could affect the effectiveness of bio-sorption process. Therefore, the aims of this study are to assess the influence of C/N ratio and initial concentration of Cr (VI) contaminant on removal of Cr (VI) by bio-sorption using activated sludge.

Methodology

Activated Sludge Sampling and Adjustment Process

Activated sludge used was taken as mixed liquor from oxidation ditch unit at IPLT Keputih, Surabaya. The activated sludge was characterized to parameters of pH, temperature, moisture content, and C/N ratio and adjusted to the environmental condition as well as continuously aerated. Adjustment process is continuously made to parameters of C/N ratio and pH value. C/N ratio is maintained every 2 days according to the variations of this study by adding urea and glucose. Three variations of C/N ratio used were 9, 21, and 43 in mg COD mg TKN-1. pH value maintained at 7 every 1-2 days to optimize metabolic activities of microorganism contained in activated sludge by using H2SO4 2 N or NaOH 6 N depends on sludge condition. Adjustment process was conducted for 2 weeks until the steady state condition of activated sludge was reached and the Mixed Liquor Suspended Solid (MLSS) value reached for 3000-4000 mg L-1 as in Orozco et al. (2010). Steady state condition was demonstrated by constant ratio of MLSS to Mixed Liquor Volatile Suspended Solid (MLVSS) value.

Preparation of Activated Sludge as Bio-sorbent Material

The steady state condition of activated sludge was further adjusted until the pH value reached 7 using H2SO4 2N or NaOH 6N. The sludge was centrifuged at 3000 rpm for 25 minutes and the sludge cake was taken for bio-sorbent material. The quantity of activated sludge needed for each reactor as bio-sorbent material was calculated based on moisture content obtained in each activated sludge until the concentration of dry weight bio-sorbent material in each reactor reached 10 g L-1. This concentration was obtained as optimum concentration of bio-sorbent material in heavy metal bio-sorption process according to Wu et al. (2010).

Analytical Method

Cr (VI) concentration, total amount of chromium, and C/N ratio was used as main parameters in this study, while pH, temperature, MLSS, MLVSS and moisture content were used as additional parameters. The concentration of Cr (VI), COD and TKN (for determining C/N ratio), MLSS, MLVSS and moisture content were determined according to Standard Methods (APHA, 1998). Detail of measurement is given as below:

- [Cr (VI)]

Colorimetric method using UV-Vis spectrophotometer at 538 nm (according to the result of optimum wavelength by preliminary test) was used for analysis of Cr (VI) concentration. Sample from each reactor at each interval time analysis was first filtered using cellulose acetate membrane filter (Sartorus) 0.45 μm. The biomass was discarded and the filtrate was analysed for the concentration of Cr (VI).

- Total chromium

This analysis was done to the final sample (t=72 hours) from certain reactors using Atomic Absorption Spectrophotometer (AAS) method. Total chromium analyses were done in order to determine the form of the remaining chromium. This analysis were conducted by Lingkungan Laboratorium, LPPM ITS.

- Mixed Liquor Suspended Solid (MLSS) and Mixed Liquor Volatile Suspended Solid (MLVSS)

MLSS and MLVSS were measured during the adjustment process of activated sludge using gravimetric method.

- pH

pH value was analysed using digital pH meter.

- C/N ratio

C/N ratio was measured using comparison of COD to the total Kjeldahl nitrogen during the adjustment

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process and analysis of activated sludge characteristics. Carbon content was analysed using COD analysis by closed reflux titration method to the soluble sample of activated sludge which obtained from centrifuge process and filtered again using Whatmann™ 42 ashless filter paper.

- Temperature
Temperature was measured at initial analysis of activated sludge using thermometer.
- Moisture content
Mixed liquor sample was first centrifuged and the activated sludge resulted as sludge cake was taken as sample of analysis. Certain amount of sludge cake was taken and the moisture content was analysed using gravimetric method. The parameter of moisture content was measured before the activated sludge used as bio-sorbent material in the tests.

Bio-sorption Test

Before running the bio-sorption test, preliminary experiment was carried out in order to investigate the optimum time needed for sorption process in the reactor and to determine 6 interval time of analysis. This experiment was conducted by using activated sludge with C/N ratio of 9 mg COD mg TKN\(^{-1}\) as the bio-sorbent material and 50 mg/L initial concentration of Cr (VI). Samples from this reactor were taken at different time intervals and the concentration of Cr (VI) in the sludge cake was analysed.

Bio-sorption tests were performed in Erlenmeyer flask 1000 mL which operated with volume of 765 mL using bio-slurry system without pH adjustment. Bio-sorption tests were carried out by mixing activated sludge, as sludge cake, from each variation of C/N ratio to the reactor filled with different concentration of Cr (VI) solution. Bio-sorption tests were also conducted using activated sludge without adjusting of C/N ratio (which then called as IPLT sludge) and samples using aquadest without addition of Cr (VI) as controls. The sample was then stirred in room temperature for 72 hours according to the optimum operating time of reactor obtained from the preliminary experiment. The initial concentrations of Cr (VI) used were 5, 50 and 100 mg L\(^{-1}\) using \(\text{K}_2\text{Cr}_2\text{O}_7\) solution.

A volume of 15 mL of sample in each reactor was taken at 0, 4, 8, 12, 24, 72 hours of operation. The condition of pH value in the reactor was analysed at each sampling time. The concentration of Cr (VI) in the sample was analysed according to the analysis technique explained before.

Results and Discussion

Activated Sludge Characteristics

Table 1 shows the characteristics of activated sludge taken in this study. The moisture content of activated sludge was ranged between 89-92.5%. pH value of these activated sludge was ranged in neutral condition between 6-7 and the temperature was about 28 °C. This value of pH represents a good condition for microorganisms contained in the activated sludge to treat organic materials. It is also an optimum value for metabolic activities of microorganisms in the typical activated sludge and the microbial growth (Orozco et al., 2010).

<table>
<thead>
<tr>
<th>Sludge</th>
<th>Moisture Content (%)</th>
<th>pH</th>
<th>Temperature (°C)</th>
<th>COD (mg/L)</th>
<th>TKN (mg/L)</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPLT Sludge</td>
<td>91.9</td>
<td>6.03</td>
<td>27.5</td>
<td>24,000</td>
<td>38.10</td>
<td>629.9</td>
</tr>
<tr>
<td>C/N 9</td>
<td>91.0</td>
<td>7.36</td>
<td>28.0</td>
<td>18,666.67</td>
<td>68.05</td>
<td>274.3</td>
</tr>
<tr>
<td>C/N 21</td>
<td>89.2</td>
<td>7.66</td>
<td>28.0</td>
<td>32,903.23</td>
<td>60.17</td>
<td>564.9</td>
</tr>
<tr>
<td>C/N 43</td>
<td>92.5</td>
<td>7.32</td>
<td>28.5</td>
<td>18,666.67</td>
<td>44.40</td>
<td>420.4</td>
</tr>
</tbody>
</table>

For the C/N ratios of activated sludge taken, it has a great difference with the ratio of typical activated sludge from municipal wastewater treatment which are ranged between 25:1 until 20:1 (Durmay and Sanin, 2001). This may happen due to the different type of wastewater which also brings the different load. It is also possible for the excess load to enter the unit process regardless to condition of the unit.

Effect of Initial Cr (VI) Concentration

According to Arief et al. (2008), initial metal ion concentration can affect the removal efficiency through some factors, i.e. the availability of specific surface of functional groups and the ability of the functional groups to bind metal ions, especially in high concentrations. The difference of initial Cr (VI) concentrations given will affect the rate and ability of
activated sludge to remove Cr (VI). Figure 1 shows the removal of Cr (VI) at different initial Cr (VI) concentrations. It was shown that the higher initial Cr (VI) concentration led to the higher removal of Cr (VI). The different removal of Cr (VI) was likely due to the increase of driving force in the media which is in line with the increase of initial Cr (VI) concentrations. This is consistent with Arief et al. (2008), that basically the initial metal concentration will acts as driving force to pass through the resistance of mass transfer in metal ion transport between the liquid and biomass’s surface. This can be seen at t=0 h, the increased initial concentration of Cr (VI) (50 to 100 mg L\(^{-1}\)) resulted in higher removal of Cr(VI) in IPLT sludge, C/N 9, C/N 21, and C/N 43, i.e. 11.43 mg L\(^{-1}\) to 18.57 mg L\(^{-1}\), 3.57 mg L\(^{-1}\) to 11.07 mg L\(^{-1}\), 20.71 mg L\(^{-1}\) to 29.29 mg L\(^{-1}\), 10.36 mg L\(^{-1}\) to 16.79 mg L\(^{-1}\), respectively. Similarly, the removal of Cr (VI) was increased up to 44% in all sample at prolonged operational time (t=72 h). This increase indicates the high ability of the bio-sorbent material to remove Cr (VI). Possibly, this relates to the high number of active site to bind metal and the bio-sorption capacity, hence different mechanism of biosorption process may occur.

![Figure 1](image1.png)

**Figure 1.** Cr (VI) removed in different initial Cr (VI) concentration: (a) IPLT sludge; (b) C/N 21

Physical-chemical sorption process seemed to be dominantly involved in the bio-sorption test with 5 mg L\(^{-1}\) of Cr (VI) initial concentration. This kind of sorption process depends on the number of active sites and functional groups available at active sludge. At the lower initial concentration of Cr (VI), the number of active site at bio-sorbent surface and functional groups were available enough to make a high removal. The removal process includes the physical adsorption, ion exchange, or chemical interaction between the metal and functional groups at microorganism’s surface. These process formed complexes of Cr (VI) and then precipitated. As the load of Cr (VI) concentration increased, these active sites and functional groups available will be filled faster and easier, which may provide different mechanism of Cr (VI) removal. Multilayer sorption or intracellular accumulation mechanism with support of EPS or another compound produced by microorganism to remove Cr (VI) may be occurred.

Activated sludge with C/N 9 made an exception when used in bio-sorption test with initial Cr (VI) concentration of 100 mg L\(^{-1}\). The increase of initial Cr (VI) concentration from 50 mg L\(^{-1}\) to 100 mg L\(^{-1}\) given to this sludge led to the significant decrease of Cr (VI) removal up to 41.5% at t=72 h. This indicates the low ability of this activated sludge variety to remove Cr (VI). The effects of C/N to the number of active site available in microorganisms, as well as to the EPS produced in this sludge led to the decrease of Cr (VI) removal occurred.

**Effect of C/N Ratio**

Bio-sorption tests with the initial Cr (VI) concentration of 5 and 100 mg L\(^{-1}\) were conducted using activated sludge with ages of 21 days. for the bio-sorption test with 50 mg L\(^{-1}\) of Cr (VI) initial concentration, IPLT sludge, C/N 9, and C/N 43 used were in the ages of 17 days, while the C/N 21 was in the ages of 21 days. Figure 2 shows the effect of C/N ratio to the Cr (VI) removal in different initial Cr (VI) concentration.
all bio-sorption tests showed the higher Cr (VI) removal as the contact time increased. At the 5 mg L\(^{-1}\) and 50 mg L\(^{-1}\) of initial Cr (VI) concentration, each variation of activated sludge also showed different rate of Cr (VI) removal. Bio-sorption tests using 5 mg L\(^{-1}\) of Cr (VI) (Figure 2a) showed the best removal conducted by C/N 9, followed by C/N 21 with removal percentage of 93.12% and 91.65%, respectively. At the same time, Cr (VI) removal by C/N 43 only reached 72.35%, while the IPLT sludge reached 56.65%. After t=8 h, Cr (VI) removal increased slowly and variation of C/N ratio seemed to not giving a substantial effects on the removal. Cr (VI) removal at t=72 h reached 93.35%, 97.3%, 96.81% and 97.04% for IPLT sludge, C/N 9, C/N 21 and C/N 43, respectively.

Variation of C/N ratio also showed different rate of Cr (VI) removal at the t=0 h until t=8 h when 50 mg L\(^{-1}\) initial Cr (VI) concentration used in bio-sorption tests. After t=8 h, amount of Cr (VI) removal reached 36.42%, 12.26%, 48.81% and 30.72% for IPLT sludge, C/N 9, C/N 21 and C/N 43, respectively. Cr (VI) removal process began to slowed down and reached stable condition after t=24 h. After that, it tended to be constant. All variation of C/N ratio did not show a substantial effect on Cr (VI) removal after t=72 h, which are greater than 93%, i.e. 93.83%, 98.04%, 95.71%, and 99.73% for IPLT sludge, C/N 9, C/N 21 and C/N 43, respectively.

The rate of Cr (VI) sorption was higher at the beginning of contact time (t=0 h until t=8 h). It is due to the form of the bio-sorption mechanism by the sorption or precipitation process through cell surface that does not depend on the cell metabolism. According to Ahalya et al., (2003), this type of sorption process usually occurs rapidly through physical and chemical interaction between metal and functional groups that are available in the microorganism’s cell surface. The mechanism occurs such as physical adsorption, ion exchange or chemical sorption at the microorganism’s cell surfaces. This type of bio-sorption mechanism happened because at the beginning of contact time, a large number of active sites on the cell surfaces are still available for heavy metal sorption, so that the sorption process can occurs in a shorten time. The binding between EPS molecules and biomass also formed a large surface that possibly supported this mechanism.

In contrast to the bio-sorption test with initial Cr (VI) concentration of 5 and 50 mg L\(^{-1}\) Cr (VI), C/N ratio gives a significant effect to the Cr (VI) removal at 100 mg L\(^{-1}\) of initial Cr (VI) concentration (Figure 2b). At t=0 h, the amount of Cr (VI) removed i.e. 9.66%, 25.55%, 14.92% and 16.15% for C/N 9, C/N 21, C/N 43 and IPLT sludge, respectively. After t=0, bio-sorption test using C/N 9 did not show great increase in Cr (VI) removal, moreover it was constant at low value. Varied removal from 19.63-75.87% of Cr (VI) was showed after t=72 h. Highest removal was done by sludge with C/N 43, followed by C/N 21, IPLT sludge, and C/N 9 with removal percentage of 75.87%, 65.42%, 60.87% and 19.63%, respectively. However, it is indicated that bio-sorption process using 100 mg L\(^{-1}\) Cr (VI) occurred in this study was not a favourable process. It is possibly due to the high loading and toxicity of Cr (VI) that minimise the viability of activated sludge.

In line comparison between the increase of C/N ratio and the increase of Cr (VI) removal showed in this study due to the availability and ability of active sites on functional groups in the sludge and the amount of EPS produced. EPS is macromolecule that produced by metabolic activity, hydrolysis or microbial lysis, especially bacteria, outside the cell wall. One of its functions is to protect microorganism’s cell from harsh external environmental such as toxic and danger materials (Comte et al., 2008; Sheng et al., 2010). It is also believe to plays a key role on bio-sorption process of heavy metal. Highest amount of EPS produced occurred in line with the increase of C/N ratio in medium, otherwise, protein based wastewater showed the lowest amount of EPS produced (Miqueleto et al., 2010). Moreover, higher C/N ratio will increase the stability of polymer (EPS) produced (Rudd et al., 1984). When the C/N ratio is high, cellular growth could be modified into EPS production by bacteria that caused by the nitrogen deficiency to make protein synthesis (Miqueleto et al., 2010). Despite of that, the increase of MLSS and MLVSS value during the adjustment process in this study indicated that the protein amount was quiet much for cellular synthesis process. However, the higher EPS production was believed to occur at the higher C/N ratio. Stasinakis et al. (2003) also found that higher Cr (VI) reduction occurred at the higher concentration of substrate in the medium. It was shown that the limited Cr (VI) reduction occurred at the lowest carbon contained due to limited substrate as the donor electron for Cr (VI) reduction. According to the bio-sorption tests conducted by IPLT sludge, it is also indicated that C/N ratio adjustment gave an effect to the value of Cr (VI) removed.
In this study, sludge with C/N 21 showed a higher removal of Cr (VI) at the beginning of contact time compared to the other variation of sludge at 5, 50 and 100 mg L\(^{-1}\) of Cr (VI) concentration. This indicates the physical and chemical sorption mechanism performed dominantly in bio-sorption tests using this sludge. Higher potential of physical sorption that C/N 21 have may be the reason for this phenomenon, considering that sludge bulking and foaming have occurred before to this sludge. Abundant filamentous bacteria contained in this sludge which caused sludge bulking and foaming gave a higher amount of active site and functional groups contained in the sludge. Kim et al. (2002) found higher metal sorption capacity at the higher number of Nocardia amarae (one kind of filamentous bacterium which is commonly found in sludge bulking and foaming) present in the mixed liquor. It was also found that pure culture of N. amarae exhibit a considerably higher sorption capacity of metal than the activated sludge had. N. amarae cells can acts as an effective bio-polymer for heavy metal sorption through physical-chemical bio-sorption due to the greater specific surface area that available for metal sorption. However, the occurrence of sludge bulking and foaming may cause the true ability of this sludge as bio-sorbent material are not well represented. They may cause a decreased sludge’s ability of metabolism dependent sorption mechanism.

After providing physical-chemical sorption at the beginning of contact time, Cr (VI) removal by C/N 21 only slightly increased. This occurred at the 5, 50 as well as 100 mg L\(^{-1}\) of Cr (VI) concentration. It may occur due to the active site at bio-sorbent surface which has started to fill, while the physico-chemical sorption was probably the dominant mechanism. Stasinakis et al. (2003) said that Cr (VI) could be absorbed through specific adsorption at bacteria surface and then reduced in the activated sludge’s flocks, especially inside of bacteria cells to determine the fate of Cr (VI) removed, concentration of total chromium was analysed after t=72 h for some various reactors to be compared. The result of total chromium analysis (Table 2) shows that there was total chromium reduction which conducted by sludge with C/N 21 and C/N 43, with the highest removal was conducted by C/N 43. The difference between the concentration of total chromium and Cr (VI) removed showed the existence of another chromium form which is seemed to be Cr (III). Conversely, this analysis also shows that Cr (VI) removal conducted by IPLT sludge and C/N 9 with 100 mg L\(^{-1}\) of Cr (VI) concentration was only a reduction process of Cr (VI). This is probably due to the limited amount and ability of specific active sites and EPS produced for Cr (VI) binding and sorption process in the sludge that caused the removal process stopped on the reduction process of Cr (VI) into Cr (III). Cr (III) was then separated again and entered the liquid form due to the weak bonding of sorption occurred so that total chromium concentration was not reduced.

Generally, the process of metal ion sorption occurs in two stage (Ahalya et al., 2003; Durraz and Sanin, 2001; Stasinakis et al., 2003). First one is binding/sorption process of a large number of metal ions which occurs rapidly, while the second stage is intracellular diffusion which occurs slower and depends on the sludge’s viability. At this stage, metal ions are transferred through cell membrane and will cause intracellular accumulation. Shock loading which possibly caused by the high toxicity of Cr (VI) in the media can damage the microorganisms’ viability in the sludge. It led to the decrease of metal removal mechanism through intracellular accumulation as well as specific molecules production by microorganisms which then drive to formation of complex and precipitation processes.

**Table 2. Total Chromium Analysis**

<table>
<thead>
<tr>
<th>Initial Cr (VI) Concentration (mg L(^{-1}))</th>
<th>Total Chromium (mg L(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IPLT Sludge</td>
</tr>
<tr>
<td>0</td>
<td>n.a</td>
</tr>
<tr>
<td>5</td>
<td>n.a</td>
</tr>
<tr>
<td>50</td>
<td>n.a</td>
</tr>
<tr>
<td>100</td>
<td>113.1</td>
</tr>
</tbody>
</table>

Note: u.d = undetectable n.a = not available

Total chromium analysis for C/N 9 and C/N 43 with 50 mg L\(^{-1}\) initial Cr (VI) concentration shows that the removal of Cr (VI) was not only being reduced into the other form of chromium. It may occur due to the large surface of functional groups in the activated sludge, so that it has a high capacity to removal metal, or through the multilayer sorption process due to the increase of driving force in the medium which is in line with the increase of initial Cr (VI) concentration. According to the result of total chromium analysis with 50 mg L\(^{-1}\) Cr (VI), it was believed that all the Cr (VI) removed at bio-sorption test using 5 mg L\(^{-1}\) Cr (VI) also fully removed through precipitation along the chemical interaction between metal and functional groups on the microorganism surface and interaction with specific molecules produced by microorganism due to the existence of toxic metal in media.

**Conclusions**

The results obtained in this study led to these following conclusions:

- The increase of C/N ratio was in line with the amount of Cr (VI) removed.
- Regularly adjustment of C/N ratio gave effect to removal of Cr (VI)
- C/N 43 seemed to be an optimum value for Cr (VI) removal with 97.04%, 99.73% and 75.87% of Cr (VI) removed from initial Cr (VI) concentration of 5, 50 and 100 mg L\(^{-1}\), respectively.
Generally, the increase of initial Cr (VI) concentration led to increase of Cr (VI) removal in this study, an exception occurred at biosorption tests using C/N 9 with 100 mg L\(^{-1}\) of initial Cr (VI) concentration. Maximum Cr (VI) concentration that could be removed by C/N 43 was 100 mg L\(^{-1}\) with total amount of Cr (VI) removed was 85.36 mg L\(^{-1}\) after 72 hours of operational time.

References


