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1 **Title of manuscript**

2 Comparison study of biosorption and coagulation/air flotation methods for chromium  
3 removal from wastewater: experiments and neural network modeling

4 **Running title**

5 Removal of chromium by biosorption vs. coagulation-DAF systems

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18 Number of text pages: 14

19 Tables: 03

20 Figures: 04

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25 **Comparison study of biosorption and coagulation/air flotation methods for chromium**  
26 **removal from wastewater: experiments and neural network modeling**

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33 **Abstract**

34 This work aims to compare a biosorption method (BM) and a coagulation–dissolved air  
35 flotation method (C/DAFM) as inexpensive and effective means of eliminating hexavalent  
36 chromium (Cr[VI]) from industrial wastewater. Synthetic wastewater containing 1000 mg L<sup>-1</sup>  
37 chromium was used for the experiments. The effect of different parameters (initial pH,  
38 amount of adsorbent, and contact time) was investigated for the BM. At optimal conditions  
39 (initial pH 3, 7 g adsorbent, and contact time 120 min) maximum Cr(VI) removal was  
40 estimated to reach 68.1%. For the C/DAFM, poly aluminum chloride (PAC), and FeCl<sub>3</sub> were  
41 used as coagulants and the dose was determined by jar test. In optimal conditions of pH 7.5,  
42 pressure of 3 bars, and flotation time of 5 min, a maximum of 85% of chromium was  
43 extracted. In a comparison of C/DAFM and BM, C/DAFM showed higher ability and greater  
44 potential for Cr(VI) removal. Process optimization was carried out using an artificial neural  
45 network (ANN) to predict the most favorable conditions of operation for maximum  
46 percentage of Cr(VI) removal from wastewater.

47 **Keywords:** Removal, biosorption method, coagulation–dissolved air flotation method,  
48 optimization, artificial neural network.

49 **1. Introduction**

50 A toxic metal, Cr(VI) enters the environment through such industrial processes as  
51 electroplating, chromate preparation, and leather tanning<sup>1, 2</sup>. One approach to treatment of  
52 Cr(VI)-laden wastewater is reduction of Cr(VI) to Cr(III) to form a solid hydroxide<sup>1</sup>. Ion  
53 exchange<sup>3</sup>, solvent extraction<sup>4</sup>, reduction<sup>5</sup>, electrochemical precipitation<sup>6</sup>, and adsorption<sup>7-</sup>  
54<sup>10</sup> may also be utilized for Cr(VI) reduction, but such treatment methods present  
55 disadvantages such as high cost involved with initial investment in equipment, as well as  
56 operational costs and costs for disposal of the residual metal sludge<sup>11, 12</sup>. The pursuit of  
57 efficacious yet cost-effective means of Cr(VI) removal is called for. Contemporary research  
58 has focused on biomasses derived from algae, fungi, or yeast, with a view toward the various  
59 advantages of each, including cost effectiveness, high selectivity, and eco-friendliness<sup>13</sup>.  
60 Brown algae, which form a diverse class of organisms found mainly in temperate to subpolar  
61 intertidal areas of the marine environment, have shown promise in a number of investigations  
62<sup>14</sup>. *Sargassum bevanom*, for example, is a species of brown algae that has a superior metal-  
63 adsorption capacity as compared to other biosorbents due to the powerful functional groups  
64 on its surface<sup>15</sup>.

65 The technology offered by the C/DAFM has potential for removal of heavy metals and other  
66 particulate matter from wastewater and offers a simple and cost-effective method for Cr(VI)  
67 removal. Once adequate flocculation of the particles in the solution to be treated has been  
68 achieved, the C/DAFM makes use of solid/liquid separation by attaching microscopic air  
69 bubbles to flocs suspended in an aqueous solution and floating the particles to the surface,  
70 where they can be skimmed off. The bubbles are formed by a reduction of pressure in a water  
71 stream saturated with air at higher than 3 bars<sup>16</sup>. Air introduced at the bottom of the container  
72 of water being treated forms small bubbles that collect on the suspended matter, and float it to  
73 the surface. The particulate matter may then be skimmed from the surface. Through this  
74 means particles having a higher density than the aqueous solution suspending them can be

75 made to float. The removed particles can be further processed, and any residuals in the  
76 treated water may be filtered out<sup>17</sup>. Process variables that control the C/DAFM, including the  
77 saturation pressure, air-to-solids ratio, and the hydraulic surface-loading rate, depend on the  
78 properties of the wastewater and can be adjusted to meet specific effluent quality standards<sup>18</sup>.  
79 The primary purpose of this study was to compare the effectiveness of two environmentally  
80 friendly technologies characterized by their ability to remove heavy metals from solutions  
81 without introducing pollution into the environment, as specifically applied to eliminating  
82 Cr(VI) from wastewater. Removal of chromium from wastewater using C/DAFM in  
83 comparison with BM has not been studied previously. In this study the BM was used to  
84 evaluate the potential of the brown alga *S. bevanom* as an adsorbent. Various factors were  
85 varied for each method and their effects observed; based on this, optimal conditions for both  
86 methods were established. The two methods were then compared to determine their relative  
87 effectiveness under optimal conditions.

## 88 **2. Materials and methods**

### 89 **2.1. Materials**

90 Potassium dichromate ( $K_2Cr_2O_7$ ) was dissolved in distilled water to make a  
91 stock solution of Cr(VI) (1000 mg L<sup>-1</sup>). Distilled water was added to dilute the solution as  
92 needed for each experiment. HCl (1 M) and NaOH (1 M) were used to adjust the pH as called  
93 for.

### 94 **2.2. BM study**

#### 95 **2.2.1. Biomass preparation**

96 In the BM study, *S. bevanom* collected along the Persian Gulf, Bushehr, Iran, was used as the  
97 biosorbent in all experiments. To obtain a clean biomass, the alga was initially washed three  
98 times with deionized water. Next, the biosorbent was placed in an oven to dry for 24 h at 70  
99 °C. The dried biosorbent was ground and then sifted to obtain a mesh size of 200–300.

### 100 **2.2.2. Batch experiment**

101 All experiments were performed using 250-mL Erlenmeyer flasks kept at room temperature  
102 and agitated occasionally at 300 rpm. Various parameters, including initial pH, adsorbent  
103 dosage, and contact time, were evaluated in the batch experiments. Also, in this study, the  
104 changing of initial pH, adsorbent dosage and contact time is from 2 to 8, from 1 to 10 g and  
105 from 15 to 150 min, respectively.

### 106 **2.2.3. Continuous experiments**

107 A glass column with an ID of 2 cm and 25 cm in length was used to carry out the continuous-  
108 flow sorption experiments. The column was fitted with an adjustable plunger and 0.5-mm  
109 stainless sieves at the base and head. The bottom 2 cm of the column were filled with a layer  
110 of 1.5-mm glass spheres in order to achieve a uniform intake of solution. *S. bevanom* was  
111 placed on top of the glass beads at the selected sorbent bed height. The flow rate of the  
112 Cr(VI) solution was regulated by a Miclins PP 40 peristaltic pump and forced up through the  
113 column at 5 mL/min. Sampling was done from the outlet flow at designated intervals of time  
114 and analyzed for presence of Cr(VI). After elution, the bed was rinsed using distilled water  
115 until the wash-effluent pH had stabilized near 7. It should be noted that, at each stage, 200 ml  
116 samples were taken. A diagram of the BM system used is shown in Figure 1a.

### 117 **2.3. C/DAFM study**

118 A diagram of the C/DAFM system used is shown in Figure 1b. The C/DAFM was carried out  
119 in six stages: (1) a sample solution at the desired pH was placed in the flotation tank, (2) PAC  
120 was added as a coagulant, (3) the chromium solution and PAC were mixed rapidly, (4)  
121 compressed air was injected into the flotation tank using a compressor, (5) flotation was  
122 continued for 30 min, and (6) samples were collected from the sampling point.

### 123 **2.4. Analytical methods**

124 Analysis of the concentration of Cr(VI) in the samples was carried out using a Unicam 929  
125 atomic absorption spectrometer (AAS). The following equation was used to calculate the  
126 removal percentage:

$$127 \text{ Removal efficiency } \% = \frac{(C_0 - C_f)}{C_0} \times 100 \quad (1)$$

128 where  $C_0$  is the initial chromium concentration (mg/L) and  $C_f$  is the final chromium  
129 concentration (mg/L).

130 The sorption capacity was computed as follows:

$$131 q_t(\text{mg/g}) = (C_i - C_t)(\text{mg/L}) \times \frac{V(\text{L})}{m(\text{g})} \quad (2)$$

132 where  $q$  is the amount of metal adsorbed at time  $t$ ,  $C_i$  was the liquid-phase concentration of  
133 the solute at the initial time,  $C_t$  was the liquid-phase concentration of the solute at a given  
134 time,  $V$  was the solution volume, and  $m$  was the mass of the adsorbent.

135 The amount of adsorption at equilibrium was computed as follows:

$$136 q_e(\text{mg/g}) = (C_i - C_e)(\text{mg/L}) \times \frac{V(\text{L})}{m(\text{g})} \quad (3)$$

137 where  $q_e$  is the amount of adsorption at equilibrium and  $C_e$  is the ion concentration (mg/L) at  
138 equilibrium.

## 139 2.5. ANN process

140 An ANN is a system that employs numerous elements to form a computational model. The  
141 elements, or neurons, are interconnected by weight coefficients that can be used for training  
142 the ANN to solve a particular problem in a set. In most ANN systems the neurons are  
143 separated into layers, with each layer performing a specific function. The network  
144 architecture of a given ANN consists of the configuration of the layers and the patterns

145 among them. In general, the neurons within a given layer will either be connected or not. In a  
146 feedforward neural network architecture, neurons connect to an output layer through an input  
147 signal. The weighted connections among neurons are adjusted using backpropagation, the  
148 error between the input data and the predicted values is minimized using Widrow-Hoff  
149 learning<sup>19</sup>. As ANN architecture is founded on neurons, transfer functions, layers, and their  
150 connections, designing a specific ANN consists of configuring the number of neurons, their  
151 arrangement layers, the number of layers, how the layers interconnect, the input weights, and  
152 the transfer functions. Trial and error is used to establish the number of layers and the number  
153 of neurons in each layer. This investigation focused on pH, amount of adsorbent, and contact  
154 time as the input variables for the first network, whereas pressure, flotation time, and bed  
155 height were the input variables for the second network. The experimental values for  
156 percentages of chromium removal with BM and C/DAFM were introduced as network output  
157 variables (network response). MATLAB software was used<sup>20</sup>.

### 158 **3. Results and discussion**

#### 159 **3.1. ANN**

160 Network training was used to determine the ANN weights. In much the same way as a  
161 mathematical model is calibrated, 75% of the data were used for data-collection training to  
162 establish the percentage of chromium eliminated from wastewater. For both the BM and the  
163 C/DAFM, 20 data sets comprised the training data. Figures 2a and 2b contrast the  
164 experimental data against the values predicted by the models. The  $R^2$  values obtained indicate  
165 the models to be acceptable. The optimal number of neurons in the hidden layer was found to  
166 be 9 neurons for both the BM and the C/DAFM (Tables 1 and 2). The root-mean-square  
167 errors for the training algorithms tested are presented in Table 3. The Levenberg-Marquardt  
168 (LM) algorithm was found to work best, and the LM-trained network chosen as the best  
169 predictor of process effectiveness.

170 In this study, typology of chromium based on reduction of  $\text{Cr}^{6+}$  to  $\text{Cr}^{3+}$  in acidic media with  
171 low pH was occurred.  $2\text{HCrO}^- + 6\text{I}^- + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{I}_2 + 8\text{H}_2\text{O}$ .

172 Iodide ion was used as a reducing agent to react with chromium (VI) and produce  $\text{I}^{3-}$  and  
173 Cr(III) ions. Due to low concentration of chromium in the sample, cloud point method was  
174 used for pre-concentration to  $\text{I}^-$  will react with cetyl trimethyl ammonium bromide and forms a  
175 negatively charged complex. Ammonium cerium sulfate (IV)  $[\text{Ce}(\text{NH}_4)_4(\text{SO}_4)_4]$  are used to  
176 oxidization of all Cr(III) to Cr(VI) and following reaction occurred:  $3\text{Ce}^{4+} + \text{Cr}^{3+} \rightarrow \text{Cr}^{6+} +$   
177  $\text{Ce}^{3+ 21}$ .

178  $\text{Cr}^{6+}$  sample was passed through the column that coated with strong acidic resin and samples  
179 from its bottom collected and then pre-concentration and extraction with UV-Vis device  
180 carried out and finally, absorption of Cr(VI) occurred.

### 181 3.2. BM result

#### 182 3.2.1. Initial pH

183 Usually pH is the most important factor in effectiveness of adsorption processes. The effect  
184 of initial pH was observed when varied from 2 to 8 at the initial chromium concentration of  
185  $1000 \text{ mg L}^{-1}$ , amount of adsorbent 7 g and amount of adsorbent 10 g, and contact time of 150  
186 min (Figure 2c). Above pH 3, chromium removal decreased when pH was increased. The  
187 maximum removal obtained was 70% at pH 3. Therefore, *S. bevanom* was the most stable in  
188 acidic or alkaline pH conditions. The greater sorption capacity at lower pH is possibly due to  
189 the breaking up of functional sites on the sorbent. In the higher pH ranges, where the  
190 chromium primarily takes the form of  $\text{HCrO}_4^-$ , removal decreased exponentially as pH  
191 increased, due to the greater attraction between the  $\text{HCrO}_4^-$  ions and the  $\text{H}^+$  ions on the algal  
192 surface. Equilibrium for various chromium ions is shown below<sup>14,22</sup>:





196 For discussion at low pH,

197 Adsorption of Cr<sup>6+</sup> below pH 3.0 suggests that bind of the negatively charged chromium  
198 species occurred through electrostatic attraction to the positively charged functional groups  
199 on the surface of sorbent cell wall due to the presence of more functional groups carrying  
200 positive charge at pH < 3. While at pH > 3 the sorbent cell wall possesses more group  
201 carrying net negative charge which repulses the metal anions. However, there is a removal at  
202 pH > 3.0 but the rate of removal was reduced, which could be considered the presence of  
203 physical adsorption on the surface of the sorbent<sup>23</sup>. At low pH, on the other hand, Cr (VI)  
204 had a higher redox potential and favored Cr (VI) bioreduction<sup>24, 25</sup>. Acidic pH biomass  
205 contains the positive oxidation state of chromium due to protonation and Chromium remains  
206 in the anionic form (i.e. HCrO<sup>4-</sup> or Cr<sub>2</sub>O<sub>7</sub><sup>2-</sup>), hence sorbed optimally onto the active sites of  
207 the biomass.

### 208 **3.2.2. Contact time**

209 Effect of contact time on chromium sorption by *S. bevanom* (initial pH = 3, initial chromium  
210 concentration 1000 mg/L, 7 g adsorbent) is shown in Figure 2a. Chromium sorption rate  
211 reached a maximum of 65.97% with a contact time of 120 min, with little variation in the  
212 sorption rate thereafter. Based on this observation, a 120-min contact time was used in  
213 subsequent experiments.

### 214 **3.2.3. Amount of adsorbent**

215 The effects of *S. bevanom* doses between 1 g and 10 g (in 500 mL aqueous solution, pH = 3,  
216 contact time 120 min, initial chromium ion concentration 1000 mg/L) were compared. The  
217 maximum percentage of chromium ions adsorbed was yielded with an adsorbent dose of 7 g.

218 As the adsorbent dose increased from 1 to 7 g, the percentage of chromium ions adsorbed  
219 increased from 6.82% to 65.82%. Doses above 7 g did not result in any significant increase in  
220 removal of chromium. As can be seen in Figure 2b, increase in adsorbent concentration  
221 resulted in a marked increase in the adsorption percentage of chromium onto the biosorbent,  
222 which can be attributed to that fact that the increased amount of adsorbent provides greater  
223 surface area. Based on these observations, a concentration of 7 g of *S. bevanom* in the 500-  
224 mL solution was chosen as an optimal amount of adsorbent.

225 Globally, it would be of relevance increasing the knowledge on Cr(VI) retention processes  
226 when this pollutant interacts with sorbent materials. In this way, Fernández-Pazos et al.<sup>26</sup>  
227 studied quantitative and kinetic aspects regarding Cr(VI) adsorption/desorption on various  
228 solid media (fine and coarse mussel shell, un-amended and mussel shell-amended forest and  
229 vineyard soils, slate processing fines and pyritic material). In addition to the kinetic  
230 characterization, it would be interesting to elucidate complementary aspects, such as the  
231 effects on Cr(VI) retention caused by changing pH, or the fractions where the retained Cr(VI)  
232 was bound, which can aid to estimate the degree of stability of that retention.

#### 233 **3.2.4. Cr(VI) adsorption/desorption as a function of pH**

234 To study adsorption, triplicate samples (1 g) of mussel shell were added with 10 mL of  
235 solutions containing 5 mg L<sup>-1</sup> Cr(VI) and different concentrations of HNO<sub>3</sub> (0.0025 M,  
236 0.0038 M, 0.005 M, 0.0075 M) or NaOH (0.0025 M, 0.0038 M, 0.005 M, 0.0075 M), also  
237 including NaNO<sub>3</sub> 0.01M. Control samples were constituted by each of the solid materials  
238 added with 10 mL of solutions containing NaNO<sub>3</sub> 0.01M and 5 mg L<sup>-1</sup> Cr(VI), but without  
239 HNO<sub>3</sub> or NaOH. After shaking for 24 h, all samples were centrifuged for 15 min at 4000 rpm,  
240 and filtered through acid-washed paper. The resulting liquid was analyzed for pH and Cr(VI).  
241 Adsorbed Cr(VI) was calculated as the difference between added Cr(VI) concentration and  
242 that remaining in the equilibrium solution. Desorption was studied using triplicate samples (1

243 g each) of the same solid materials than in the adsorption trials, that were added with 10 mL  
244 of solutions containing 100 mg L<sup>-1</sup> Cr(VI), also including NaNO<sub>3</sub> 0.01M as background  
245 electrolyte. After shaking for 24 h, all samples were centrifuged for 15 min at 4000 rpm, and  
246 filtered through acid-washed paper, discarding the liquid phase. The remaining solid phase  
247 was then subjected to a desorption procedure, adding 30 mL of solutions containing NaNO<sub>3</sub>  
248 0.01 M and diverse HNO<sub>3</sub> or NaOH concentrations aiming to provide a wide pH range, then  
249 being different for the various solid samples. After shaking for 24 h, all samples were  
250 centrifuged for 15 min at 4000 rpm, and filtered through acid-washed paper. The resulting  
251 liquid was analyzed for pH and Cr(VI). Desorbed Cr(VI) was calculated as the difference  
252 between the amount retained in the adsorption phase and that released to the equilibrium  
253 solution in the desorption phase, and it was expressed as percentage of the total amount  
254 adsorbed<sup>27</sup>.

### 255 3.2.5. Bed height

256 Figure 3a shows how bed heights of 10 cm, 15 cm, and 20 cm with initial Cr(VI)  
257 concentration of 1000 mg/L and flow rate of 5 mL/min affected chromium removal. When  
258 bed height was increased from 10 cm to 20 cm, the volume of the treated solution increased  
259 due to increasing diffusion of the chromium ions into the sorbent, correlated to decreasing  
260 axial dispersion in the mass transfer. This allowed sufficient time for the solute to diffuse into  
261 the biosorbent, remaining in the column for a longer period of time and treating a greater  
262 quantity of effluent. The increased sorption capacity achieved with increased bed height is  
263 attributable to the greater adsorbent concentration in larger beds. With more sorption sites  
264 available, the uptake of chromium ions in the column increased. The greatest Cr(VI) removal  
265 (85.09%) was achieved with the maximum bed height of 20 cm. It should be noted that as the

266 bed height increased from 10 to 20 cm the breakthrough time also increased. Also, it should  
267 be noted that, the range of 10 to 20 cm is range for sampling.

### 268 **3.3. C/DAFM system**

269 In C/DAFM systems, the liquid to be treated is first placed in a container and pressurized by  
270 dissolving air in it at approximately 1.5–3 bars. The supersaturated solution is conducted into  
271 a flotation tank, allowing the pressure to be released. Air precipitates out of the solution,  
272 forming small 30–120 mm gas bubbles, which cling to the particulate matter in the solution  
273 and raise it to the surface, allowing it to be eliminated. In this investigation, the effects of  
274 flotation time, pressure, and bed height on the C/DAFM system were investigated.

#### 275 **3.3.1. Flotation time and pressure**

276 The effect of varying pressures from 1.5 to 3 bars on the chromium removal percentage at a  
277 constant flotation time of 1–6 min and bed height of 1 m in the presence of PAC as a  
278 coagulant were measured (Figure 4b). The removal of Cr(VI) increased over the first 5 min,  
279 gradually leveling off until it reached equilibrium. The chromium removal reached 85% at a  
280 constant pressure of 3 bars.

281 The effects of pressure are dependent on the solubility of gases in liquids. At higher  
282 pressures, more gas is soluble in any given liquid than at lower pressures; the extra gas  
283 dissolved at higher pressure evaporates from the solution when the pressure is reduced. In  
284 this study maximum chromium removal was obtained at a pressure of 3 bars, and therefore  
285 this pressure was selected as the optimal value in the following experiments.

#### 286 **3.3.2. Bed height**

287 Two different bed heights, 1 m and 2 m, at a constant pressure of 3 bars and flotation time 5  
288 min, were tested. The amount of chromium removal decreased when bed height increased  
289 from 1 m to 2 m. The maximum chromium removal obtained at a bed height of 1 m was 85%.  
290 This bed height was thus selected as the optimal value for chromium removal.

### 291 3.4. Comparison between C/DAFM and BM

292 In this study a higher percentage of chromium removal was achieved using the C/DAFM than  
293 with the BM. The maximum chromium removal obtained with the BM was about 65% when  
294 carried out using the optimal conditions of initial pH 3, contact time 120 min, and adsorbent  
295 dose of 7g at the initial chromium concentration of 1000 mg/L, whereas with the C/DAFM,  
296 maximum chromium removal reached 85% at a pressure of 3 bars, bed height of 1 m, and  
297 flotation time 5 min.

### 298 4. Conclusion

299 The comparative effectiveness of the C/DAFM vs. the BM for removal of Cr(VI) from a  
300 solution was studied. With the BM, using dried *S. bevanom* as the biomass, 65% removal was  
301 achieved under optimal conditions including initial pH 3, contact time 120 min, and amount  
302 of adsorbent 7 g in 500 mL solution. In the C/DAFM system, maximum chromium removal  
303 achieved was 85% at optimal conditions including pressure of 3 bars and flotation time of 5  
304 min. Comparison of the two methods demonstrated that for an initial chromium concentration  
305 of 1000 mg L<sup>-1</sup>, the C/DAFM is more effective than the BM.

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346

347 **Figure captions**

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349 **Fig. 1.** Schematic diagram of experimental setup for (a) Schematics of experimental  
350 bioreactor designed for removal of MEG from gas-refinery wastewater: (a) air pump, (b)  
351 wastewater pump, (c) feed tank, (d) packed bed, and (b) dissolved air flotation method

352 **Fig. 2.** (a) Actual measured values vs. those predicted by ANN for Cr(VI) removal,  
353 biosorption method; (b) Actual measured values vs. those predicted by ANN for Cr(VI)  
354 removal, coagulation–dissolved air flotation method; (c) Effect of initial pH on Cr(VI)  
355 removal, constant contact time 150 min, amount of adsorbent 10 g, and Cr (VI) concentration  
356  $1000 \text{ mg L}^{-1}$

357 **Fig.3.** (a) Effect of contact time on Cr(VI) removal, initial pH 3, amount of adsorbent 10 g,  
358 and Cr(VI) concentration  $1000 \text{ mg L}^{-1}$ . (b) Effect of amount of adsorbent on Cr(VI) removal,  
359 initial pH 3, contact time 120 min, initial Cr(VI) concentration  $1000 \text{ mg L}^{-1}$

360 **Fig. 4. (a)** Breakthrough curves for Cr(VI) sorption onto *S. bevanom* at different bed heights.  
361 (b) Effect of flotation time on the C/DAFM at constant pressure of 3 bars and height 20 cm

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364 **Tables and figures**

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366 **Table 1: Effect of number of neurons in hidden layer on performance of neural network for Cr(VI)**  
367 **removal by biosorption method**

Number of neurons in hidden layer	RMSE	R <sup>2</sup>
2	1.362	0.996
3	2.183	0.989
4	2.013	0.991
5	1.548	0.994
6	1.536	0.995
7	2.322	0.988
8	6.445	0.902
9	0.884	0.998
10	1.002	0.997

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384 **Table 2: Effect of number of neurons in hidden layer on performance of neural network for Cr(VI) by**  
385 **C/DAFM**

Number of neurons in hidden layer	RMSE	R <sup>2</sup>
2	1.029	0.959
3	1.453	0.909
4	4.678	0.631
5	2.79	0.838
6	9.600	0.605
7	2.090	0.750
8	1.933	0.771
9	0.823	0.971
10	9.23	0.654

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404 **Table 3: Root-mean-square errors for training algorithms for 9 neurons in hidden layer of ANN for**  
 405 **Cr(VI) removal by BM and C/DAFM**

Algorithm No.	Algorithm	Transfer Function		RMSE (BM)	RMSE (C/DAFM)	R <sup>2</sup> (BM)	R <sup>2</sup> (C/DAFM)
		Hidden Layer	Output Layer				
1	BFG	Tansig	Purelin	7.641	2.038	0.859	0.786
2	CGB	Tansig	Purelin	2.376	0.842	0.985	0.970
3	CGF	Tansig	Purelin	1.724	2.262	0.993	0.725
4	CGP	Tansig	Purelin	1.287	2.423	0.996	0.700
5	GDA	Tansig	Purelin	4.549	2.599	0.947	0.688
6	LM	Tansig	Purelin	0.884	0.823	0.998	0.971
7	OSS	Tansig	Purelin	2.072	2.412	0.991	0.759
8	RP	Tansig	Purelin	2.427	2.093	0.986	0.720
9	SCG	Tansig	Purelin	1.461	2.058	0.995	0.771

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Figure 1a

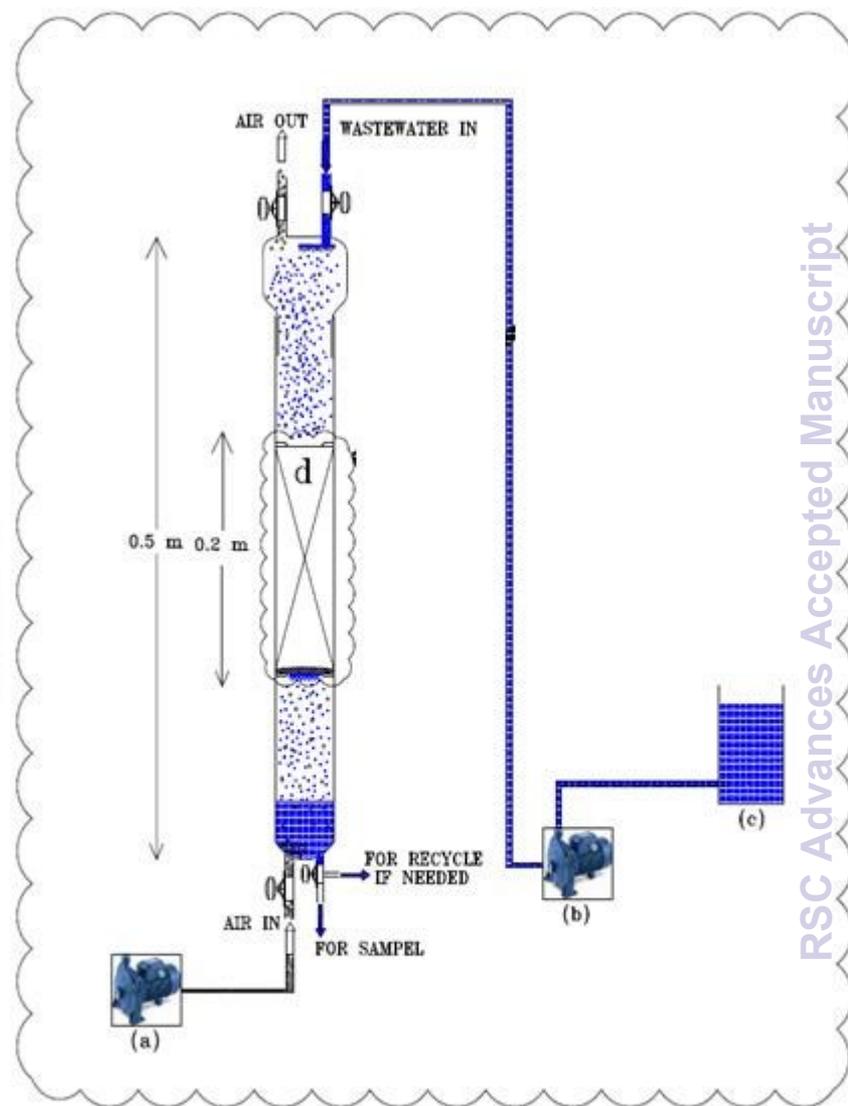
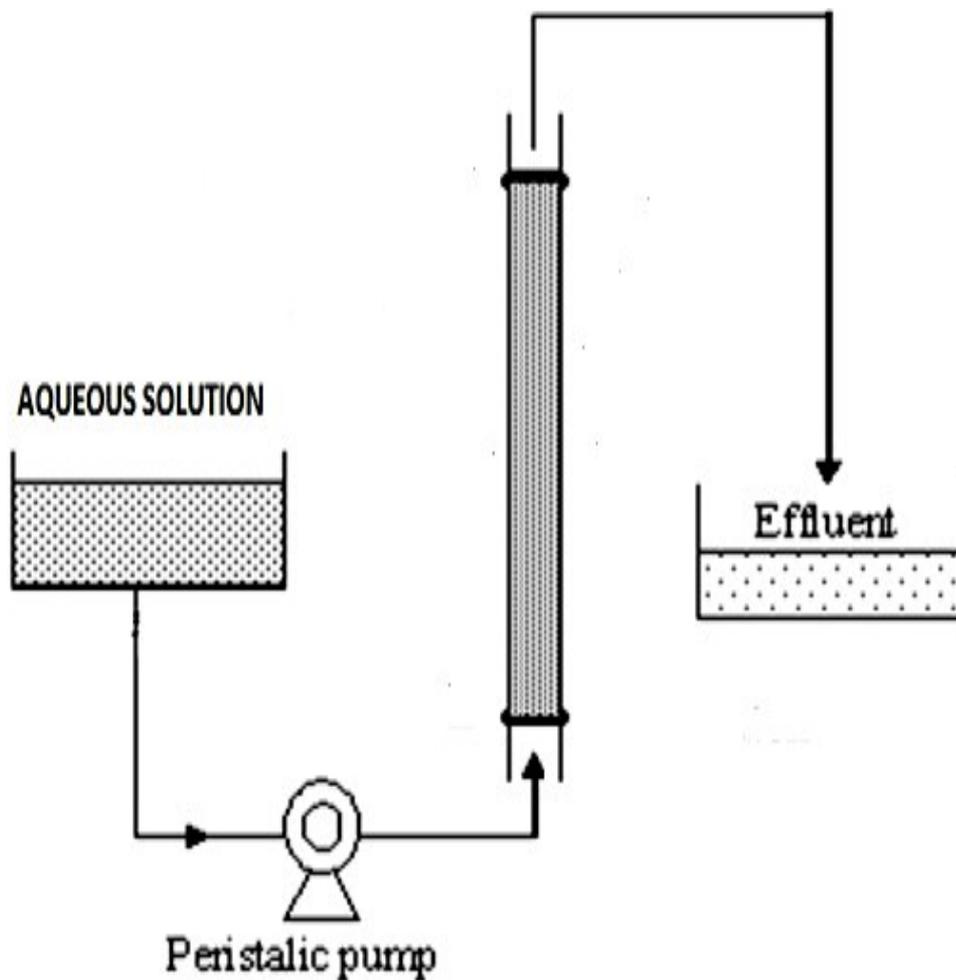


Figure 1b

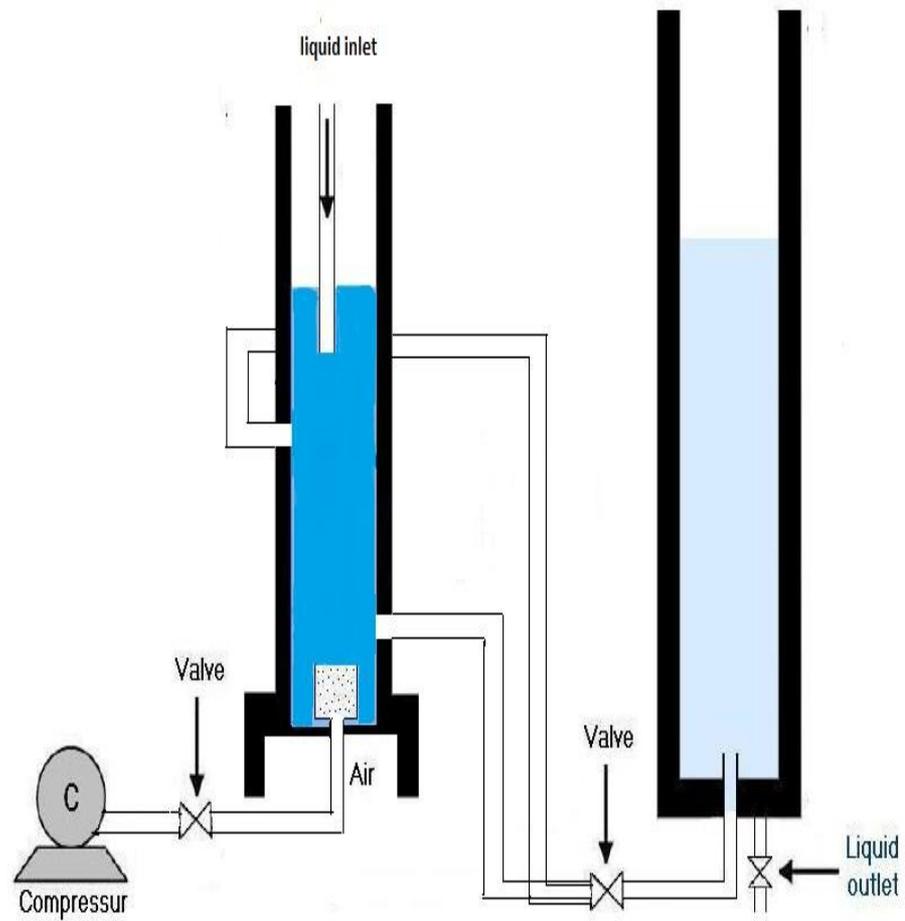


Figure 2a

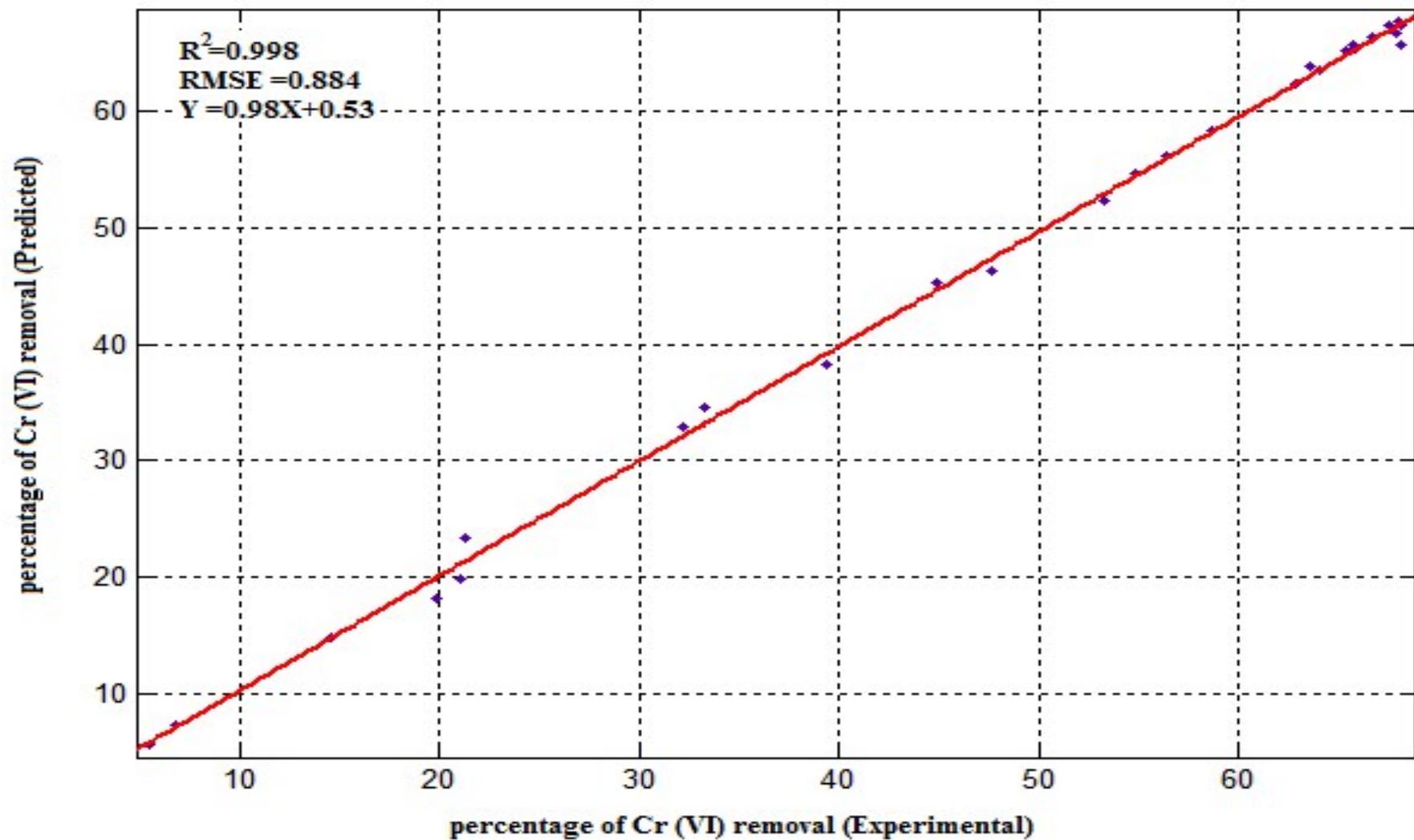


Figure 2b

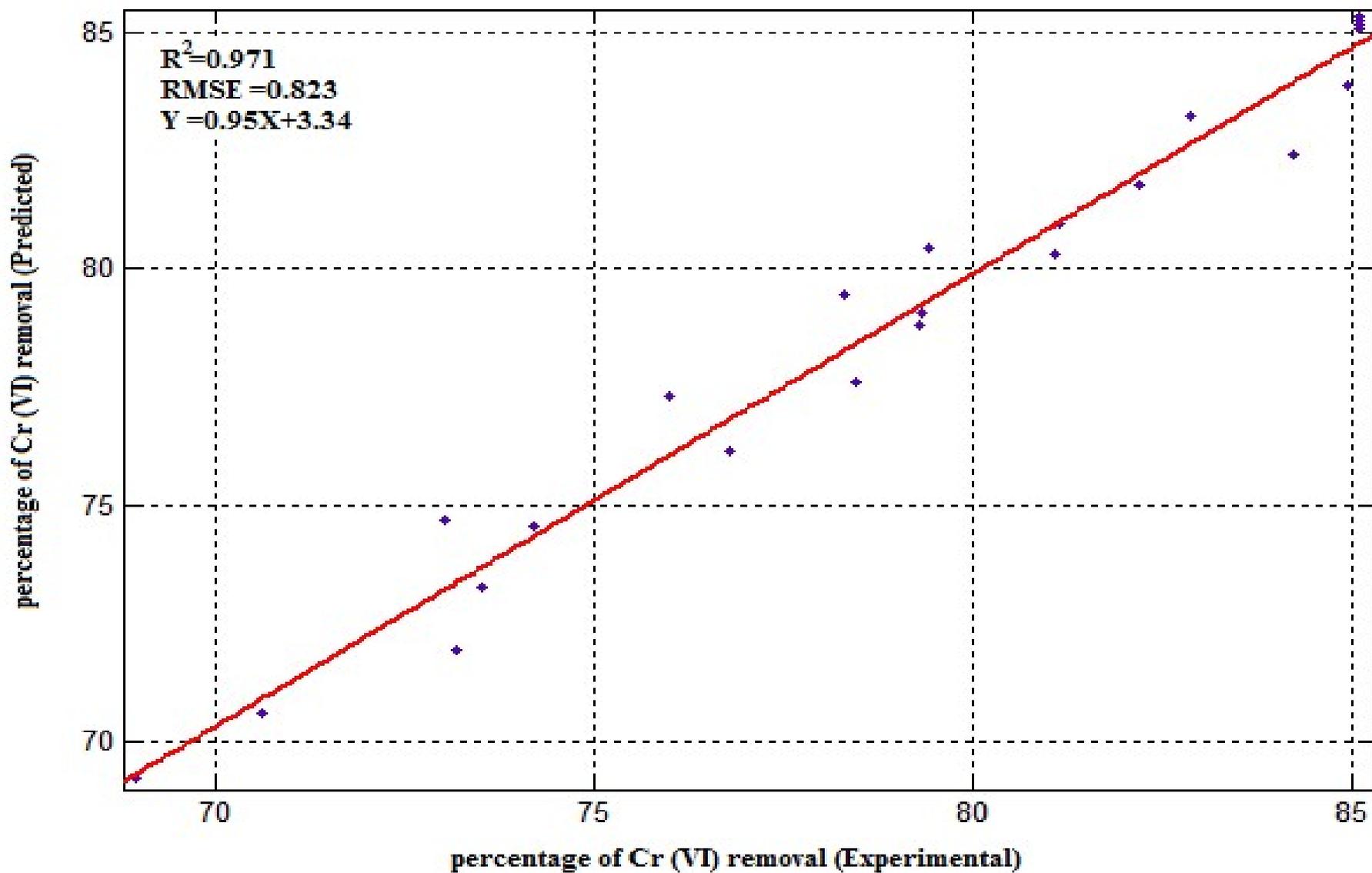


Figure 2c

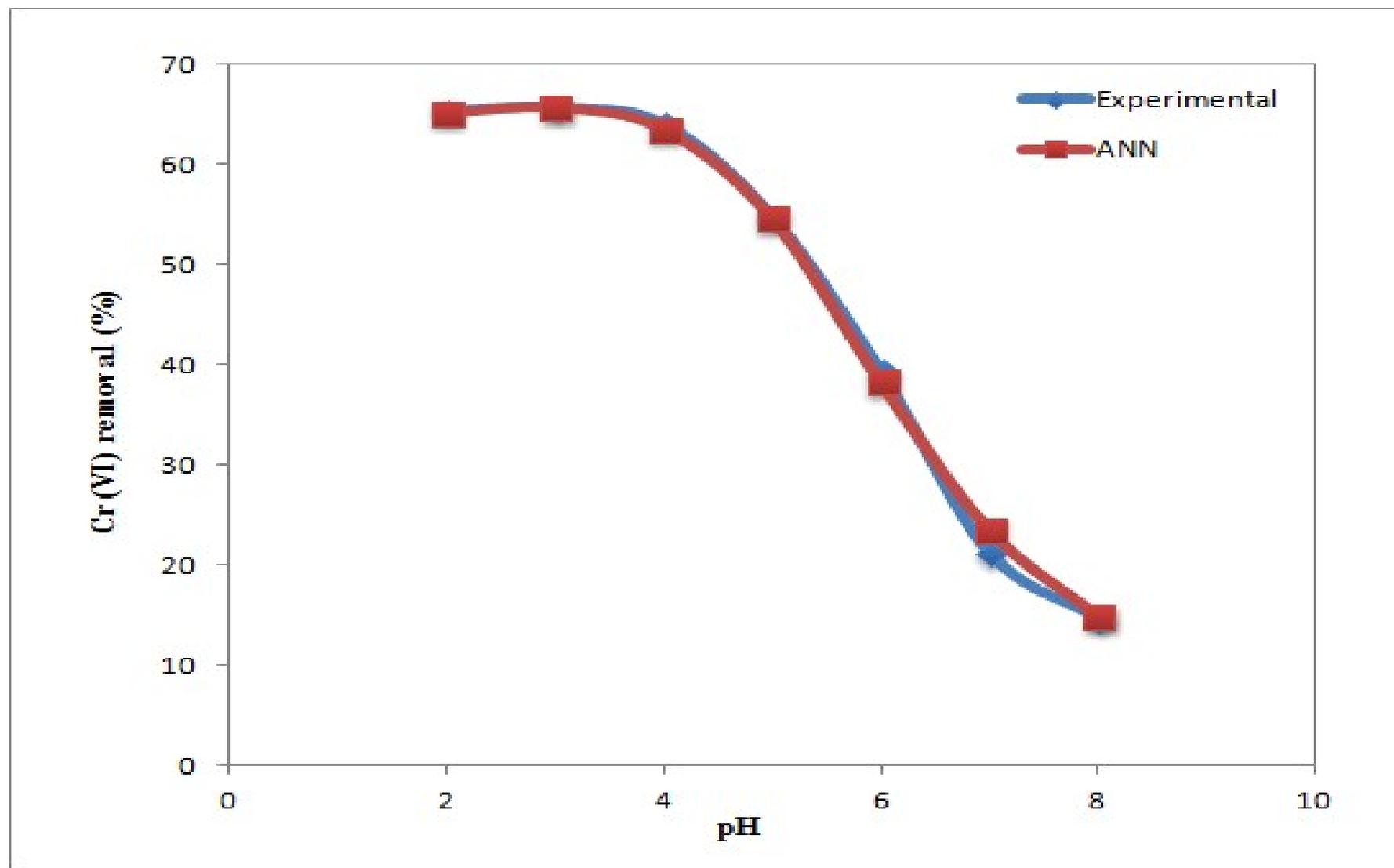


Figure 3a

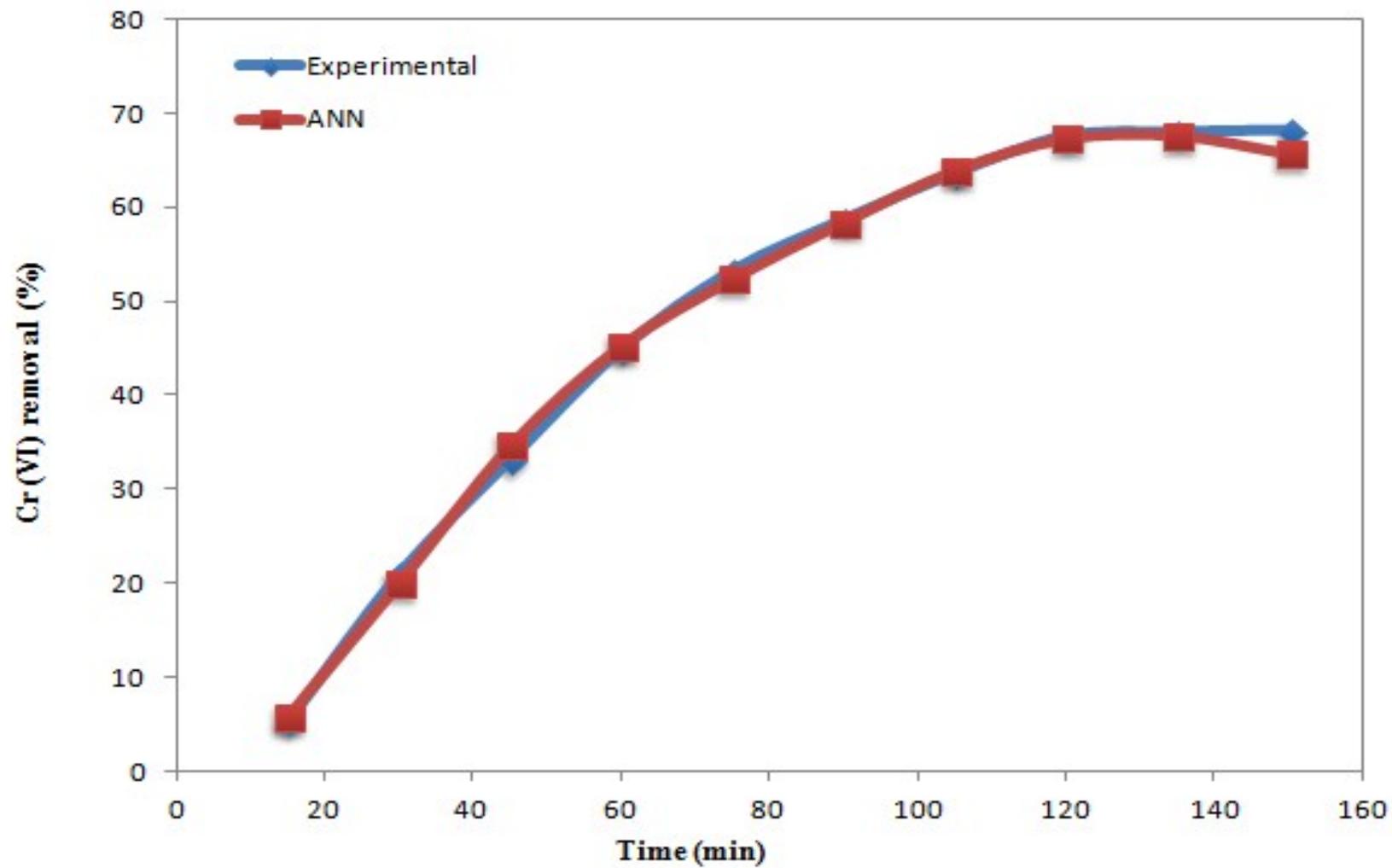


Figure 3b

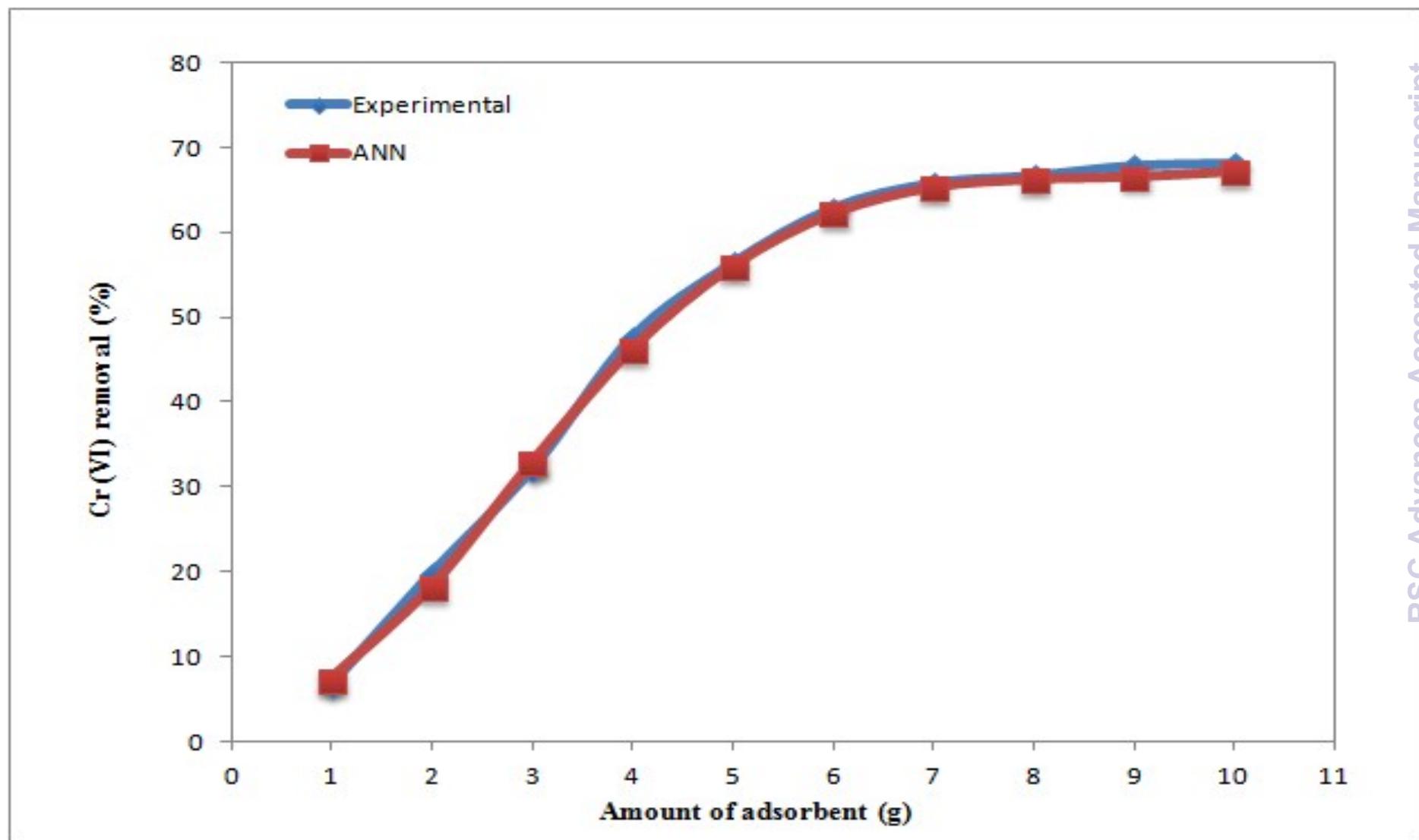


Figure 4a

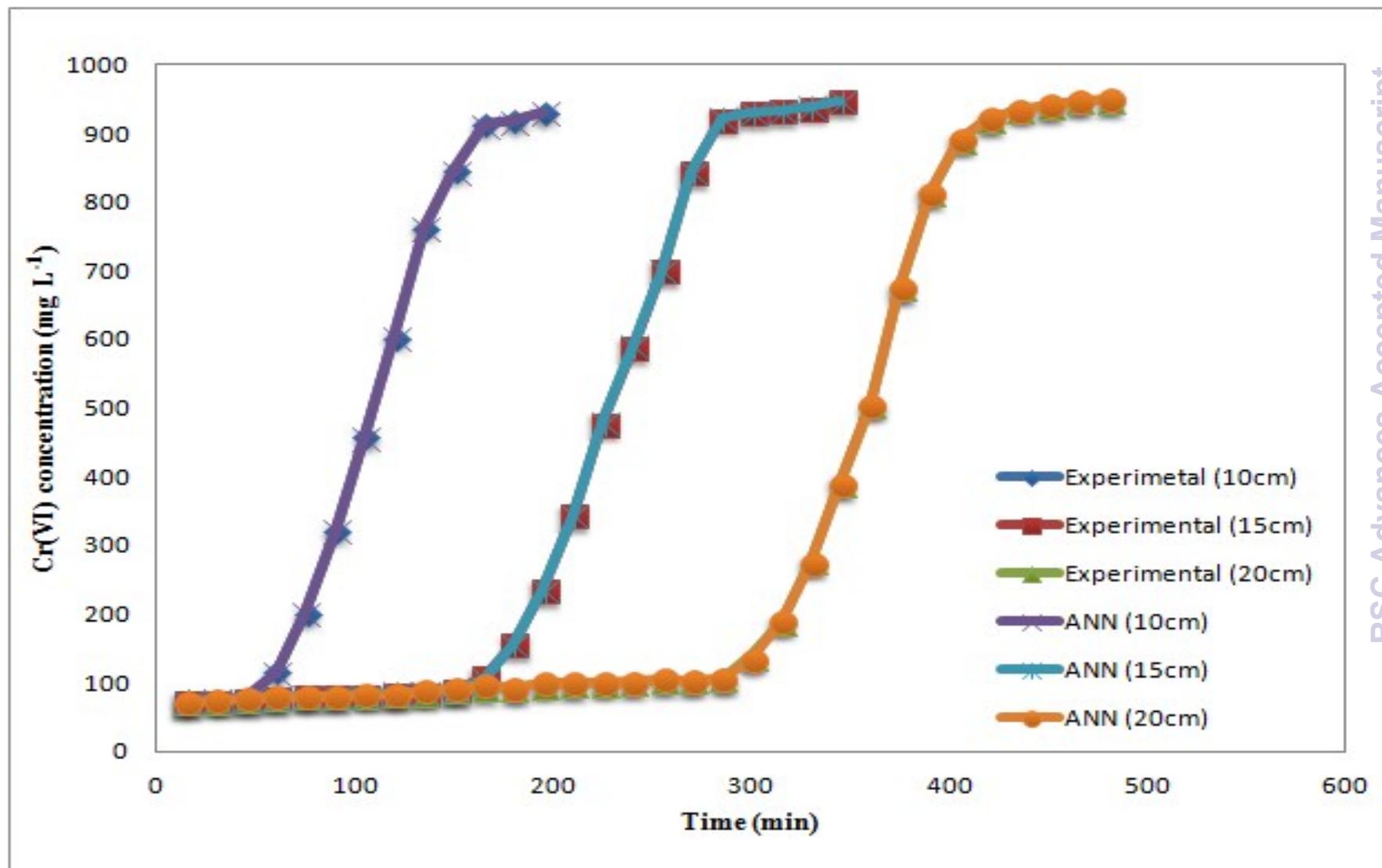
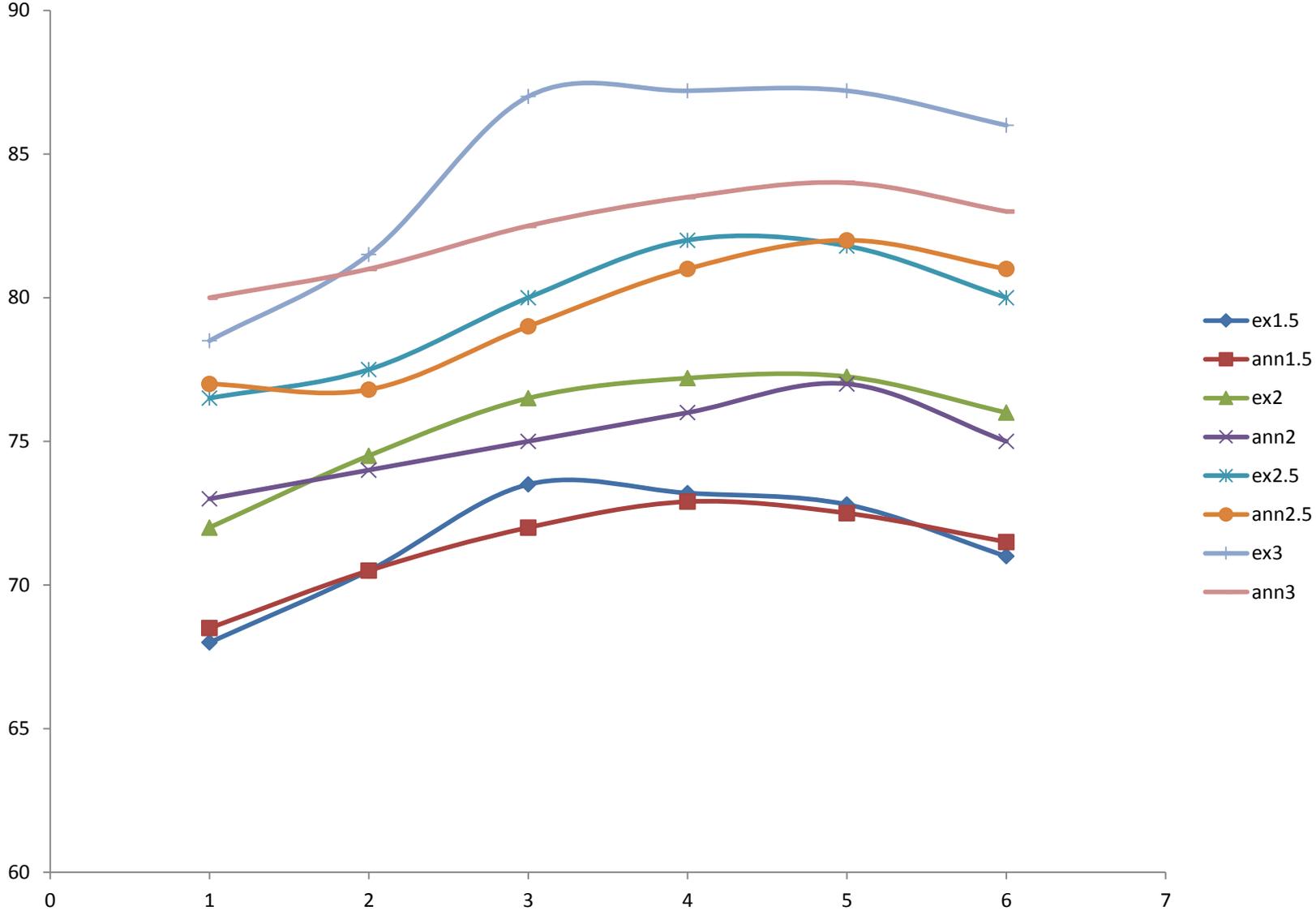


Figure 4b



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