

# Performance of Four Low Cost Adsorbents Produced From Agro-Waste in Removal of Cd (II) and Cr (VI)

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**Abstract**— The overall performance of four low cost adsorbents which have been produced in the laboratory having four different grades for each adsorbents depending on the activation temperature used during this manufacture, has been evaluated critically. The basis for the critical evaluation of the performance of the adsorbents is parametrical studies. It is interesting to note that the performance of all four adsorbents under consideration appear to be comparable.

**Key words:** PAC, GAC, activation, agro-waste, low cost adsorbents, removal of Cd (II) and Cr (VI)

## I. INTRODUCTION

The most serious chronic effect of cadmium Cd (II) is renal toxicity.[1] The dietary intake of cadmium has also been implicated in osteomalacia, osteoporosis and spontaneous fractures conditions, collectively termed as “itai-itai” (ouch-ouch). This is an originally documented in post-menopausal women in cadmium contaminated areas of Japan. Cadmium is more efficiently absorbed from the lungs than from the gastro intestinal tract. The absorption efficiency is a function of the specific cadmium compounds as well as its exposure concentration and route. Cadmium is transported in the blood by RBC and high molecular weight protein such as albumin accumulates mostly in the kidney and liver. [2] Renal and hepatic toxicity may occur if toxic cadmium levels in these organs occur even during the sub- chronic exposure. A number of health hazards due to chromium pollution have been reported in the literature. [3]

Cr (VI) causes skin irritation resulting in ulcer formation, dermatitis, over exposure to Cr (VI) leads to liver damage, pulmonary congestion and edema. It also causes perforations in nasal septum and malignant growth in respiratory tract. [4] The tolerance limits for Cd II and Cr (VI) for discharge into the inland surface waters are 2.0 mg/L and 0.10 mg/L, respectively. The maximum tolerance limit for the Total Cr (VI) has been fixed at 0.05 mg/L and 0.1 mg/L in the drinking and inland surface water respectively. Therefore studies on the removal of heavy metal pollution are increasing. [5]

Activated carbon adsorption is one of the most promising dependable and efficient processes to remove the heavy metals from the waste water to an acceptable limit. Unit operation -adsorption consists of collecting soluble substances that are in solution on a suitable interface. This process can occur at an interface between two phases- liquid-liquid, gas-liquid, gas solid and liquid-solid. [6]

Activated carbon is widely used as an adsorbent in industry due to its high adsorption capacity. This capacity is related to the pore structure and chemical nature of the carbon surface in connection with the preparation conditions. [7] The commercially available Powdered Activated Carbon (PAC)

and Granular Activated Carbon (GAC) which have been used successfully in removal of dissolved solids are costly. [8] Hence, there is a pressing need of manufacturing a low cost activated carbon. Such type of study will be useful to chemical manufacturers especially the small and medium scale enterprises having limited resources in resolving water pollution problems economically. [9]

## II. LITERATURE OVERVIEW

### A. Production of Adsorbents from Agro Wastes

The basic objective of the present study is to produce in the lab the adsorbents from agro based waste materials which are often disposed of by non-sustainable methods. This can be done by carbonization and activation.

- The production of activated carbon depends upon
- Nature and type of raw material
- Desired physical form of the carbon and
- Characteristics required for the intended application.

A typical activation technique includes chemical and steam activation. The porosity of the activated carbons especially the micro porosity is developed during the activation process. [10]

Chemical activation is generally carried out by impregnating the precursor with a chemical activation agent typically phosphoric acid or zinc chloride and the blend is heated to a temperature of 300 ° C to 400 ° C. Chemical activation agents reduce the formation of tar and other byproducts thereby increase carbon yield. The type of pores formed depends on the temperature and time of activation, the activating gas and the catalyst used if any. Chemically activated carbon generally exhibits a very open pore structure ideal for adsorption of large molecules. [11]

Thermal activation occurs in two stages, thermal decomposition or carbonization of precursor and controlled gasification or activation of crude char. During carbonization elements such as hydrogen and oxygen are eliminated from the precursor to produce a carbon skeleton possessing a latent pore structure. During gasification the char is exposed to an oxidizing atmosphere that greatly increases the pore volume and surface area of the product through elimination of volatile pyrolysis products and from carbon burn off. [12]

Steam activation is also used for activation for coal and coconut shell raw material which is usually processed in a carbonized form, activation takes place at temperatures of 800 ° C to 1100 ° C in presence of steam. Steam activated carbon generally exhibits a fine pore structure ideal for adsorption of compounds in both liquid as well as vapor phase application. Activated carbon produced by carbon dioxide activation had lower nitrogen surface area and micro pore volume than those of steam – activated carbon. [13]

Further these agro based waste adsorbents can be characterized to determine their suitability for removal of

single as well as multi solutes. It can be demonstrated that the activated adsorbents produced can be usefully applied to the treatment of aqueous waste streams by conducting studies of the influence of the operational parameters such as contact time, dose of adsorbents, initial concentrations of the single solute and multi solutes, activation temperature and results can be expressed as removal efficiency (%  $\eta$ ) of each of the adsorbent. [14]

### III. MATERIALS AND METHODS

The production of the adsorbents from agro waste in the Environmental Engineering laboratory of B V M Engineering College, Vallabh Vidyanagar (Gujarat) followed the three steps procedure for production of adsorbents. [15]

#### A. Step I: Natural Drying and Grinding

The agro-based waste materials utilized for producing adsorbents – activated carbon are potato peels (PP), mung husk (MH), banana peels (BP) and corn cob (CC).

The agro based waste materials were allowed for sun drying for 4 to 14 days. The time required for sun drying varies with the type of agro based waste material selected for investigation. During the drying care was taken against dust and other impurities. The dried samples were then shredded and ground thoroughly using chopper/grinder and screened through standard sieves available with Sophisticated Instrument Centre for Applied Research and Testing (SICART) of 20 meshes to get uniform particle size for the preparation of powdered charcoal.

#### B. Step II: Oven Drying and Chemical Impregnation

The uniformly ground powder prepared from all the waste materials were first washed with distilled water in the laboratory to remove soluble impurities, if any. The samples were then placed in an oven for drying at 105°C for 30 minutes. This is done to avoid any adsorption of moisture of the air on the surface of the waste powdered materials.

The powdered potato peels, powdered mung husk, powdered banana peels and powdered corn cob, 20 mesh sieve, were then taken for chemical activation.

The dried powdered material were mixed with acidulated zinc chloride and added more distilled water to make the bulk fluid. The mass was slowly heated in an evaporating basin on a sand bath keeping the mixture continuously stirred. With rise in temperature the powdered materials appeared to dissolve in the solution. The mass was heated to thick paste and was then dried at 105 °C in an air oven. The dried mass then was taken for carbonization.

Thus In the process of chemical activation strong dehydrating agent Zinc chloride was used as impregnating agent. The ratio of zinc chloride to the powder used was 1.33. On addition of such dehydrating agents pores are opened and more receptive sites are created. For the present investigation the impregnation time allowed was 12 hours. The recommended time is 12-36 hours.

#### C. Step III: Carbonization and Activation of Impregnated Samples

The impregnated samples were then placed in a muffle furnace for carbonization. The crucibles were covered. This

was done so as to exclude the air from the furnace to prevent the oxidation.

During carbonization, solid residue, char coal and volatile gases is produced. During this process pores i.e. void between graphite crystals are formed. Activation occurs immediately after carbonization. Activation may be chemical or physical the intermediate product is removed and graphite crystals become exposed to the activating agent. This increases the number and the dimension of the pores during activation.

In the present investigation, the carbonization was carried out at different temperatures 400°C, 500°C, 600°C and 700°C for a period of 5 hours. After 5 hours, the carbonized products were then cooled up to room temperature by introducing the crucibles into desiccators.

The product is then again crushed to extremely fine particles. This is activated carbon at 400 °C. This carbon contains considerable amount of zinc chloride which was used for impregnation. The samples were, therefore, washed with concentrated H<sub>2</sub>SO<sub>4</sub> till practically all the traces of Zinc chloride were dissolved. Zinc chloride is basic in its characteristics. The acid wash process was followed by distilled water till the pH of filtrate liquor was found to be neutral. The washed activated carbon products were then dried in the hot air oven at 103°C for 2 hours. Grinding the material followed by sieving to 20 meshes gave the uniform particle size of the adsorbent. [16]

This was the carbon prepared at 400 °C and was labeled as under:

- Potato peels Activated Carbon PPAC - 400 °C
- Mung husk Activated Carbon MHAC - 400 °C
- Banana Peels Activated Carbon BPAC - 400 °C
- Corncob Activated Carbon CCAC - 400 °C
- Similarly the activated carbons at 500°C, 600°C and 700°C were also produced in the laboratory and were given label accordingly

### IV. RESULTS AND DISCUSSIONS

#### A. Performance of Four Low Cost Adsorbents

The overall performance of four low cost adsorbents which have been prepared in the laboratory having four different grades for each adsorbents depending on the activation temperature used during this manufacture, has been evaluated critically. The basis for the critical evaluation of the performance of the adsorbents is parametrical studies.

#### B. Four Different Adsorbents and % Removal of Cd

##### 1) Performance of Adsorbent- MHAC

##### a) % Removal of Cadmium (Cd)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Cadmium (Cd) remains in the range of 67.8 to 71.2.

##### b) % Removal of Chromium (Cr)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Chromium (Cr) remains in the range of 66.8 to 71.7.

2) Performance of Adsorbent PPAC

a) % Removal of Cadmium (Cd)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Cadmium (Cd) remains in the range of 73.0 to 78.3.

b) % Removal of Chromium (Cr)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Chromium (Cr) remains in the range of 70.0 to 72.4.

3) Performance of Adsorbent BPAC

a) % Removal of Cadmium (Cd)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Cadmium (Cd) remains in the range of 76.3 to 76.8.

b) % Removal of Chromium (Cr)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Chromium (Cr) remains in the range of 70.0 to 64.0.

4) Performance of Adsorbent CCAC

a) % Removal of Cadmium (Cd)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Cadmium (Cd) remains in the range of 67.8 to 71.2.

b) % Removal of Chromium (Cr)

Under otherwise identical conditions of optimum dose (d) = 50 mg/50mL and contact time (Ct) = 45 min. of the adsorbent prepared at activation temperature = 600 °C., the value of the % removal of Chromium (Cr) remains in the range of 66.3 to 75.9.

Sr. No.	Te mp.	Cd i	Ct	η <sub>I</sub> MHA C	η <sub>II</sub> PPAC	η <sub>III</sub> BPAC	η <sub>IV</sub> CCAC
	°C	mg /L	mi n.	%	%	%	%
1	400	2.5	10	41.04	43.00	46.00	41.04
		2.5	20	61.32	62.74	68.12	61.68
		2.5	30	61.80	62.87	68.19	61.80
		2.5	45	63.84	64.25	72.67	63.83
2	400	3.5	10	50.77	45.37	46.03	42.86
		3.5	20	63.11	68.22	70.00	63.11
		3.5	30	62.12	68.45	70.62	63.12
		3.5	45	65.54	70.19	75.25	65.54
3	400	4.5	10	43.42	45.40	41.33	43.36
		4.5	20	64.18	67.51	62.82	65.33
		4.5	30	65.35	67.72	62.83	65.35
		4.5	45	68.59	70.73	68.47	68.59
4	400	5.5	10	45.07	47.25	44.56	45.07
		5.5	20	67.60	69.25	67.82	67.60
		5.5	30	68.21	69.36	68.59	68.21
		5.5	45	70.15	71.28	73.20	70.15

Table 1: Comparison

Sr No	Te mp	Cdi	Ct	η <sub>I</sub> MHA C	η <sub>II</sub> PPAC	η <sub>III</sub> BPAC	η <sub>IV</sub> CCAC
	°C	mg /L	mi n.	%	%	%	%
1	600	2.5	10	42.36	45.68	46.80	42.36
		2.5	20	63.24	68.72	71.20	63.24
		2.5	30	63.79	69.23	72.04	63.79
		2.5	45	67.83	73.00	76.33	67.83
2	600	3.5	10	47.37	46.74	47.49	43.37
		3.5	20	64.82	71.06	72.00	64.82
		3.5	30	64.84	71.08	72.62	64.84
		3.5	45	67.92	75.32	77.10	67.92
3	600	4.5	10	44.69	45.36	44.98	44.67
		4.5	20	64.69	69.20	68.00	67.11
		4.5	30	67.17	69.23	68.25	67.17
		4.5	45	70.52	73.00	71.46	70.52
4	600	5.5	10	45.80	50.16	46.93	45.65
		5.5	20	67.96	75.09	71.45	67.96
		5.5	30	68.64	75.59	72.08	68.64
		5.5	45	71.15	78.34	76.80	71.15

Table 2: Comparison

Sr. No	Te mp.	Cri	Ct	η <sub>I</sub> MHA C	η <sub>II</sub> PPAC	η <sub>III</sub> BPAC	η <sub>IV</sub> CCAC
	°C	mg /L	mi n.	%	%	%	%
1	400	0.25	10	38.28	37.60		38.00
		0.25	20	56.80	58.00		56.88
		0.25	30	57.08	60.72		58.69
		0.25	45	61.36	62.12		60.61
2	400	0.5	10	40.36	40.00	50.00	42.20
		0.5	20	58.19	64.22	73.00	63.24
		0.5	30	60.00	64.88	76.00	63.56
		0.5	45	64.40	67.34	76.00	65.58
3	400	0.75	10	42.93	45.33	42.93	44.15
		0.75	20	64.20	65.20	65.73	65.73
		0.75	30	64.21	66.03	70.67	65.79
		0.75	45	68.07	66.87	73.33	67.72
4	400	1	10	43.79	44.30	43.79	43.79
		1	20	64.76	66.90	65.80	65.80
		1	30	65.73	67.01	70.00	66.38
		1	45	67.27	68.35	74.00	70.13

Table 3: Comparison

Sr. No	Te mp.	Cri	Ct	η <sub>I</sub> MHAC	η <sub>II</sub> PPAC	η <sub>III</sub> BPAC	η <sub>IV</sub> CCAC
	°C	mg /L	mi n.	%	%	%	%
1	600	0.25	10	40.32	46.04		41.60

		0.2 5	20	61.16	70.00		62.80
		0.2 5	30	61.20	70.04		65.55
		0.2 5	45	66.80	70.04		66.30
2	600	0.5	10	41.24	48.60	44.60	44.60
		0.5	20	63.00	70.64	66.50	66.50
		0.5	30	63.24	71.10	72.00	66.54
		0.5	45	69.42	71.84	70.00	71.15
3	600	0.7 5	10	47.99	49.47	42.67	46.40
		0.7 5	20	69.15	72.00	64.00	70.00
		0.7 5	30	71.69	71.87	65.33	70.53
		0.7 5	45	72.00	72.19	69.33	72.63
4	600	1	10	45.90	48.70	39.10	44.60
		1	20	69.07	72.10	58.70	67.90
		1	30	69.36	72.41	60.00	68.33
		1	45	71.70	72.35	64.00	72.85

Table 4: Comparison

## V. CONCLUSIONS - COMPARISON OF PERFORMANCE OF FOUR ADSORBENTS

### A. Comparison for Removal of Cadmium (Cd)

From the exhaustive data obtained in the present investigation on % removal of Cadmium (Cd) using four different adsorbents some selected data under some selected different sets of conditions have been compared in Comparison Table – 1 and Comparison Table-2 from the above tables, the following are the interesting observations and conclusions.

- 1) Under otherwise identical conditions of Ct = 45 min., Cdi = 2.5 mg/L and activated temperature = 600 ° C, the value of the % removal for Cd for four different adsorbents under consideration namely adsorbent 1 – MHAC, adsorbent 2 – PPAC, adsorbent 3 – BPAC and adsorbent 4 – CCAC are 67.8,73.0,76.3 and 67.8 respectively.
- 2) Further under otherwise identical conditions of Ct = 45 min., Cdi = 5.5 mg/L and activated temperature = 600 ° C, the value of the % removal for Cd for four different adsorbents under consideration namely adsorbent 1 – MHAC, adsorbent 2 – PPAC, adsorbent 3 – BPAC and adsorbent 4 – CCAC are 71.1,78.3,76.8 and 71.1 respectively.
- 3) Thus, performance of adsorbent 2 – PPAC and adsorbent 3 – BPAC with respect to removal of Cadmium (Cd) appears to be comparable. Further performance of the adsorbent 1 – MHAC and adsorbent 4 – CCAC also appears to be comparable.
- 4) At activation temperature = 400 ° C, Cdi = 3.5 mg/L and Contact time (Ct) = 30 min. the values of the % removal of Cd for four different adsorbents, adsorbent 1 – MHAC, adsorbent 2 – PPAC, adsorbent 3 – BPAC and adsorbent 4 – CCAC are 62.1,68.5,70.6 and 63.1 respectively.

Thus performances of the adsorbents 1 –MHAC and adsorbent 4 – CCAC and adsorbent 2 – PPAC and

adsorbent 3 – BPAC with respect to removal of Cadmium (Cd) appears to be comparable at 400 ° C also.

- 5) However, at remaining activation temperatures and concentration of Cdi all the four adsorbents under consideration appear to have comparable performance.

For example, for activation temperature 400 ° C, Ct = 30 min. and Cdi = 5.5 mg/L, the value of % $\eta$  for all four adsorbents remain in the range of 68.0 % to 69.0 %. I.e. the value remains practically the same also for temperature 400 ° C, Contact time (Ct) and Cdi = 4.5 mg/L, the value of the % adsorption of Cadmium (Cd) remains in the range of 68.6 % to 70.7 % i.e. the value remains practically the same.

### B. Comparison for Removal of Chromium (Cr)

From the exhaustive data obtained in the present investigation on % removal of chromium (Cr) using four different adsorbents some selected data under some selected different sets of conditions have been compared in Comparison Table – 3 and Comparison Table-4

From the above tables, following are the interesting observations and conclusions:

- 1) At activation temperature = 400 ° C, Cri = 0.25 mg/L and Contact time (Ct) = 45 min., the values of the % removal of Cr for three different adsorbents, adsorbent 1 – MHAC, adsorbent 2 – PPAC and adsorbent 4 – CCAC are in the range of 60.6 to 61.4 i.e. the values practically remain the same.
- 2) At activation temperature = 400 ° C, Cri = 0.5 mg/L and Contact time (Ct) = 45 min, the values of the % removal of Cr for three different adsorbents, adsorbent 1 – MHAC, adsorbent 2 – PPAC and adsorbent 4 – CCAC are in the range of 64.4 to 66.6 i.e. the values practically remain the same.
- 3) At activation temperature = 400 ° C, Cri = 0.75 mg/L and Contact time (Ct) = 45 min., the values of the % removal of Cr for three different adsorbents, adsorbent 1 – MHAC, adsorbent 2 – PPAC and adsorbent 4 – CCAC are in the range of 67.7 to 68.0 i.e. the values practically remain the same.
- 4) At activation temperature = 400 ° C, Cri = 1 mg/L and Contact time (Ct) = 45 min., the values of the % removal of Cr for three different adsorbents, adsorbent 1 – MHAC, adsorbent 2 – PPAC and adsorbent 4 – CCAC are in the range of 67.3 to 70.1 i.e. the values practically remain the same.
- 5) At activation temperature = 600 ° C, Cri = 0.5 mg/L and Contact time (Ct) = 45 min., the values of the % removal of Cr for four different adsorbents, adsorbent 1 – MHAC, adsorbent 2 – PPAC, adsorbent 3 – BPAC and adsorbent 4 – CCAC are in the range of 69.4 to 71.2 for all the adsorbents i.e. the values practically remain the same.
- 6) At activation temperature = 600 ° C, Cri = 0.75 mg/L and Contact time (Ct) = 45 min., the values of the % removal of Cr for four different adsorbents, adsorbent 1 – MHAC, adsorbent 2 – PPAC, adsorbent 3 – BPAC and adsorbent 4 – CCAC are in the range of 69.3 to 72.6 for all the adsorbents i.e. the values practically remain the same.

- 7) At activation temperature = 500 ° C , Cri = 1 mg/L and Contact time (Ct) = 45 min., the values of the % removal of Cr for four different adsorbents , adsorbent 1 – MHAC, adsorbent 2 – PPAC, adsorbent 3 – BPAC and adsorbent 4 – CCAC are in the range of 69.0 to 72.9 for all the adsorbents i.e. the values practically remain the same.
- 8) At activation temperature = 500 ° C , Cri = 1 mg/L and Contact time (Ct) = 20 min., the values of the % removal of Cr for four different adsorbents , adsorbent 1 – MHAC, adsorbent 2 – PPAC, adsorbent 3 – BPAC and adsorbent 4 – CCAC are in the range of 66.1 to 69.0 for all the adsorbents i.e. the values practically remain the same.
- 9) However, at other operating conditions excluding above cited data, the adsorbent BPAC appears to have higher values of % adsorption of Chromium (Cr). For example, at activation temperature 400 ° C, Contact time (Ct) = 45 min. Cri = 0.5 mg/L and Cri = 0.75 mg/L, the value of %  $\eta$  is in the range of 76.0 and 73.3. However at activation temperature 400 ° C, Contact time (Ct) = 30 min. Cri = 0.5 mg/L and Cri = 0.75 mg/L the value of %  $\eta$  is in the range of 70.7 to 76.0. These observations made for BPAC at temperature 400 ° C for Cri values 0.5 mg/L and 0.75 mg/L may be considered as exception to general observations.
- 10) Hence in the case of % adsorption of Cr in different adsorbents, it can be concluded that the performance of all four adsorbents under consideration appear to be comparable.

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