A NOVEL POROUS ACTIVATED CARBON COMPOUND PREPARED FOR ADSORPTION OF COBALT (CO (II)) FROM AQUEOUS SOLUTION FOR ENVIRONMENTAL POLLUTION MITIGATION

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ABSTRACT

The eco-friendly and sustainable technique was developed to resolve the problem of heavy metal pollution. In the present study, the removal of cobalt (Co (II)) was carried out using the activated carbon (AC). Activated carbon compound was prepared using selected plants such as *Ficus benghalensis* (FB), *Mangifera indica* (MI), *Tamarindus indica* (TI), *Azadirachta indica* (AI) and *Syzygium cumini* (SC). The characterization of the products was done by using the scanning electronic microscope (SEM) in order to know the microstructure of AC. It shows that prepared activated carbons (PACs) are porous in nature having the elevated surface area for effective adsorption and applicable for the mitigation of heavy metals. The study involves the effect of dose, concentration and contact time for removal of Co (II) and to assess the efficiency of PACs. The results reveal that the adsorption of Co (II) observed to be highest at 5g PAC-AI, PAC-MI and 6g for PAC-TI, PAC-FB, PAC-SC dose, respectively. Maximum adsorption was exhibited in a solution containing 25 mg/L concentration of Co (II) after addition of a mixed dose of PACs. The comparable adsorption was observed at contact time for PAC-AI, PAC-TI, PAC-FB, PAC-SC at 120 minutes and PAC-MI for 30 minutes respectively. Moreover, it is a need for continuous monitoring and further research for the development of an eco-friendly and advanced method to remove heavy metals.

Keywords: Cobalt (Co (II)), Porous activated carbon, Bio-adsorbent, Plant material

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INTRODUCTION

Anthropogenic activities are mostly responsible for causing serious threats to environmental spheres such as air, land, and water. The rapid industrial development is the main cause of increase in concentration of heavy metals and their disposal into the environment. It is important to mention that more than 20 heavy metals are considered lethal, and fifty percent of these are discharged into the environment in a huge quantity and that can pose dire consequences on human health.¹ The numbers of conventional methods have been developed over the last few years for the removal of heavy metals from industrial wastewater. The predominant methods are coagulation and flocculation.² Other traditional techniques were used for removal of heavy metal ions from aqueous solutions are chemical precipitation, ion exchange, chemical oxidation/reduction, reverse osmosis, electrodialysis, ultrafiltration, etc. However, these methods have their own limitations such as less efficiency, sensitive operating conditions, production of secondary sludge and also the disposal is a costly affair.³ The precipitation, ion exchange, electrochemical processes, and membrane technology are well-known chemical methods that are economically not feasible and less competent than the biosorption process.⁴ Moreover, these methods create environmental pollution by increasing the pollution load of heavy metals through the disposal of byproduct.¹

The cost-effective and non-conventional adsorbents such as agriculture byproducts such as nutshells, wood, bone, peat coconut shells have converted into activated carbons and biomass like *Aspergillus terreus*, *Rhizopus aehizus*.^{1,5,6} However, these materials can be used as effective adsorbents for the

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removal of heavy metals and the organic toxic compound from municipal and industrial wastewater.^{1,5} Although the lethal heavy metals ions are discharged into the aquatic streams through the various anthropogenic activities such as mining, refining ores, fertilizer industries, tanneries, batteries, smelting industries, metal plating, tanneries paper industries, pesticides, etc. creating dire consequences to the environment.^{7,8} The major toxic metals ions hazardous to humans as well as other forms of life are Cr, Fe, Se, V, Cu, Co, Ni, Cd, As, Pb, Zn, etc.^{7,8} and most of them bear the carcinogenic property when present in an excess amount.⁹ The heavy metals are naturally found in the earth's environment and ecosystem.¹⁰ Anthropogenic activities are mainly responsible for the increase in their concentration in environment and they can enter into the plant, animal, and human tissues via inhalation, diet, and rough handling.¹⁰ They can bind and interfere with the functioning of vital cellular components.¹⁰ Research-based on the treatment of effluent containing heavy metals has indicated that adsorption is considered and widely used method, for the mitigation of heavy metals from the waste watercourse. Activated carbon has been well-known adsorbent and it has been widely used for the removal of heavy metal and purification of the wastewater. However, activated carbon remains costly stuff.^{10,11}

Hence, it is necessary to develop safe and economic feasible methods for the removal of heavy metals from industrial contaminated waters.¹⁰ Thus, it is essential to carry out further research to produce low cost activated carbon from agricultural leftover by-products.^{10,11} In general, an adsorbent can be considered as a cost-effective adsorbent.¹²⁻¹³ However, the porous material can decide the efficiency of adsorption of metal on prepared activated carbon (PACs).^{6,14} The porosity of activated carbon increases the surface area for better adsorption.⁶

With this backdrop, the objective of our study was to develop the feasibility using porous carbonized plant material for the removal of Co (II) from the prepared aqueous solution. Although many studies have been carried out on this topic, no study has been made on different plant material which is easily available and mixed PACs dose effect on the concentration of Co (II). Activated carbon is widely used and applicable for removal of heavy metal from the aquatic environment due to its porous quality.¹⁵⁻¹⁷ Cobalt is an important trace element and actively participates in the vitamin B12 formation process. The requirement of Cobalt (Co) for human health is in micro quantity i.e. 1 mg/l. Cobalt salts small dose can be helpful to overcome with the problem of mineral deficiencies in certain animals. Cobalt is also bearing a carcinogenic property if given in large doses, and as a good reducing agent; it seldom appears in pure forms.¹⁸

EXPERIMENTAL

Materials

Plant bark of *Ficus benghalensis*, *Syzygium cumini*, *Azadirachta indica*, *Tamarindus indica*, *Mangifera indica* were collected from Savitribai Phule Pune University campus, Alice Garden located at a latitude of 18.52° North, the longitude of 73.85° East at an altitude of 560 meters (1,837 feet) above sea level. The average annual precipitation is about 722 mm and the average temperature in Pune is 25 °C. The average annual relative humidity is 59 to 64%.

Collection of Raw Material for Production of Coal

The Method develops by Nwabanne and Igbokwe,¹⁹ were followed for the production of porous activated carbon. In the present study, plant barks were cut into small pieces of 2-3 cm size, dried in sunlight, then grounded using the grinder, and passed into 2 mm mesh size sieve. The dried material was then soaked in a hot solution of 10% Phosphoric acid for an hour and dried at room temperature for 24 hr.^{10,20} Carbonization and activation of the material was carried out in a muffle furnace at 400 °C for 1 hr and subsequently washed with distilled water. The residual char was also ground using mortar and pestle to make powder. A subsequently powdered content was again heated at 600° C in a muffle furnace for 10 min for getting the product^{10,20} (Fig.-1).

Ash content

Ash percentage was determined according to Kamble et al.,¹⁹

Moisture content

It was determined by according to Kamble et al.¹⁹

SEM (Scanning Electron Microscope) Analysis

In order to know the size distribution of micropores of activated carbon and to understand its important characteristics to estimate its applicability as an adsorbent,^{6,21} SEM analysis was carried out. The microstructure of all PACs has been studied using SEM instrument (JEOL model no. JSM-6360 Microscope).

Fig.-1: Experimental Design

Experimental Setup and Methodology

Preparation of Stock Solution

The stock solution of Co (II) (100 mg/L) was prepared in the laboratory by dissolving 3.10 mg of cobalt nitrate in 1000 ml distilled water. The stock solution was stored in a sample bottle at room temperature.^{10,20}

Batch Study

In the present experiments, Batch adsorption study was conducted. The porous activated carbon obtained from locally available plant materials such as *Ficus benghalensis* (PAC- FB), *Syzygium cumini* (PAC- SC), *Azadirachta indica* (PAC- AI), *Tamarindus indica* (PAC- TI) and *Mangifera indica* (PAC- MI), has been used in order to study removal of Co (II) from aqueous solution. A batch adsorption study was conducted at various doses (1, 2, 3, 4, 5, and 6), concentration (25, 50, 75, 100 mg/ L) and contact time (30, 60, 90, 120 min). The contents were kept in separate conical flasks of 250 ml capacity. Contents of the flasks were well mixed using control shaking for 2 h and subsequently filtered through whatman 42 and finally taken for analysis of Co (II) using atomic absorption spectrometer (Shimadzu AA-7000).^{10,20}

Effect of Doses on Adsorption

Various doses of the adsorbent PACs were added at the various rate of 1g, 2g, 3g, 4g, 5g, 6g to each conical flask respectively and kept on the shaker for 2 h. Co (II) solution of 100 mg/L was added in the flasks.²⁰

Effect of Co (II) Concentration on Adsorption

100 ml solution of Co (II) of different concentrations of 25 mg/L, 50 mg/L, 75 mg/L, and 100 mg/L of Co (II) solution was taken in 5 different flasks in duplicate. The adsorbent optimum dose of activated carbon 1g, 2g, 3g, 4g, 5g, 6g, of PAC-FB, PAC-SC, PAC-AI, PAC-TI, and PAC-MI was added respectively into each conical flask containing the solution and subsequently treated for 2 h.²⁰

Effect of Contact Time on Adsorption

The adsorbent dose of activated carbon 1g, 2g, 3g, 4g, 5g, 6g of (PAC-FB), (PAC-SC), (PAC-AI), (PAC-TI), (PAC-MI) respectively were added in replicate to the metal solution and kept for 30, 60, 90 and 120 min interval to see the impact of contact time.²⁰

Statistical Analysis

The average values and standard errors have been calculated using statistical methods.

RESULTS AND DISCUSSION

Scanning Electron Microscope Analysis

Figure-1 showed the observed microstructure for PAC-TI and PAC-AI are heterogeneity in nature and showed porous nature having approximately 5 μm pore size (Fig.-1C and D). The activated carbon had an irregular porous surface, indicating relatively high surface areas.^{6,21} PAC-FB has shown no aggregation of particles, no symmetrical aggregation and was porous in nature (Fig.-1A). In the case of PAC-MI it has shown heterogeneity, 5 μm pore size, and porous nature and symmetrical aggregation (Fig.-1E). PAC-SC has shown aggregation in layers and heterogeneity (Fig.-1B). All the PACs are effective for removal of cobalt (Co (II)) from aqueous solution.

Fig.-1: (A) SEM image of PAC-FB, (B) SEM image of PAC-SC, (C) SEM image of PAC-AI, (D) SEM image of PAC-TI and (E) SEM image of PAC-MI

Characterization of Activated Carbon Compound

The moisture content of PAC-FB, PAC-SC, PAC-AI, PAC-TI, and PAC-MI observed to be 45.1%, 14.03%, 12.14%, 3%, 8.8% respectively (Table-1). The moisture content is one of the very important parameters and plays a very crucial role in maintaining the adsorption efficiency of activated carbon. It is necessary to have enough dried activated carbon for adsorption of any material.²² Several authors have argued that the excess moisture content fills the micropores or active adsorption sites, which led to decrease in adsorption capacity of prepared activated carbon.²³⁻²⁶ Ash content of PAC-FB, PAC-SC, PAC-AI, PAC-TI, and PAC-MI observed to be 67.69%, 31.64%, 59.7%, 72.30% and 66.6% (Table-1) respectively. It has been stated that the amount of carbon content is inversely proportional to the ash content of the any prepared activated carbon.²⁷

Effect of Dose on Adsorption of Co (II)

In case of different dosage, after treatment the concentration of Co (II) with PAC-FB at 1, 2, 3, 4, 5 and 6g / 100 ml was 62.06 (± 1.8), 49.04 (± 3.8), 41.46 (± 5.4), 44.81 (± 2.1), 42.42 (± 3.8), 40.26 (± 0.3) mg/l respectively. The optimum dose for removal of cobalt was 6 g. However, in case of PAC-SC the residual concentration was found to be 67.85 (± 4.3), 53.55 (± 2.6), 62.24 (± 1.5), 56.56 (± 1.4), 69.1 (± 3.3) mg/l (Table-3). The optimum dose was found to be 2 g. In case of PAC-AI it was 59.6 (± 4.3), 52.18 (± 2.6), 51.01 (± 1.5), 41.17 (± 5.3), 31.08 (± 1.4), 35.6 (± 3.3) mg/l. The optimum dose was found to be 5g. In case of (PAC-TI) it was 74.38 (± 1.7), 59.27 (± 0.1), 46.56 (± 8.8), 54.42 (± 8.2) 45.56 (± 7.5), 36.84 (± 0.4) mg/l. The optimum dose was found to be 5 g. In case of (PAC-MI) it was 65.61 (± 4), 63.41 (± 2.6), 62.84

(± 3.2), 56.77 (± 5.9), 51.15 (± 6.2), 61.4 (± 4.6) mg/l. Optimum dose was found to be 6 g (Table 3). The highest removal percentage of Co (II) was found at 6 g in PAC-FB (59.74% ± 0.76), PAC-SC (54.77% ± 1.68), PAC-TI (63.15% ± 0.42) while maximum efficiency was found at 5 g in PAC-AI (68.92% ± 1.68) and PAC-MI (48.85% ± 6.26) (Fig.-2A).

Table-1: Ash Content and Moisture Content

PACs	Ash Content	Moisture Contents
<i>Ficus benghalensis</i> (PAC-FB)	67.69%	45.1%
<i>Syzygium cumini</i> (PAC-SC)	31.64%	14.03 %
<i>Azadirachta Indica</i> (PAC-AI)	72.30%	12.14 %
<i>Tamarindus indica</i> (PAC-TA)	59.7%	3.00%
<i>Mangifera indica</i> (PAC-MI)	66.6%	8.8 %

However, the minimum residual concentration was observed after addition of PAC-AI and PAC-TI at 6 g of optimum dose. The possible explanation could be that the SEM analysis data had shown higher porosity, heterogeneity nature and symmetrical aggregation in PAC-AI and PAC-TI than that of other PACs. Moreover, the increasing amount of doses from 1 to 6 g showed increase in CO (II) adsorption in almost all PACs. The possible explanation could be for this was due to increasing the adsorptive surface area and the availability of extra adsorption sites to adsorb Co (II).²⁸⁻²⁹ The results of the present investigation support the above explanation.

Table-2: Residual Concentration of Co (II) in mg/L after Treatment at Different Doses of Activated Carbon

Name of Adsorbent	Initial Concentration of Co 100 mg/L					
	1g	2g	3g	4g	5g	6g
PAC-FB	62.06(± 1.8)	49.04(± 3.8)	41.46(± 5.4)	44.81(± 2.1)	42.42(± 3.8)	40.26(± 0.3)
PAC-SC	67.85(± 4.3)	53.55(± 2.6)	62.24(± 1.5)	59.26(± 5.3)	56.56(± 1.4)	6.91(± 3.3)
PAC-AI	59.6(± 4.3)	52.18(± 2.6)	51.01(± 1.5)	41.17(± 5.3)	31.08(± 1.4)	35.6(± 3.3)
PAC-TI	74.38(± 1.7)	59.27(± 0.1)	46.56(± 8.8)	54.42(± 8.2)	45.56(± 7.5)	36.84(± 0.4)
PAC-MI	65.61(± 4)	63.41(± 2.6)	62.84(± 3.2)	56.77(± 5.9)	51.15(± 6.2)	61.4(± 4.6)

Effect of Contact Time on Adsorption of Co (II)

Four different time intervals were used i. e. 30, 60, 90 and 120 minutes. In the case of (PAC-FB), it was 70.13 (± 3.3) 73.67 (± 0.5), 74.21 (± 0.7), 67.57 (± 0.9) mg/l. In the case of (PAC-SC), it was 67.27 (± 0.6), 68.9 (± 0.9), 67.27 (± 1.0), 54.33 (± 9.7) mg/l. In case of (PAC-AI) it was 72.5 (± 0.4), 68.7 (± 1.5), 67 (± 0.8), 66.7 (± 1.6) In case of (PAC-TI), it was 52.10 (± 1.3), 64.64 (± 3.8), 53.97 (± 1.5), 42.8 (± 10.8) mg/l. In the case of (PAC-MI), it was 61.70 (± 9.9), 71.23 (± 0.1), 70.69 (± 0.5), 67.31 (± 1.8) mg/l (Table-4). Optimum time was found to be 120 min in PAC-FB (32.42% ± 0.9), PAC-SC (32.42% ± 0.9), for PAC-TI (57.1% ± 10.85). In the case of PAC-AI (32.97% ± 0.80), it was 90 min while in case of PAC-MI (32.42% ± 0.9) it was 30 min (Fig.-2B). However, many studies revealed that the increasing contact time has led to increase in adsorption of metal^{30,20} but remains stable with a further increase in contact time.²⁹ Our results had shown the same trend for contact time.

Effect of Concentration on Adsorption of CO (II)

After treatment, the residual concentration of Co (II) with mixed all plants (PAC-TI), (PAC-MI), (PAC-AI), (PAC-FB), (PAC-SC) was 13.47 (± 3.8), 17.84 (± 0.9), 31.04 (± 0.1), 33.16 (± 2.1) (Table-4). Optimum concentration was found to be 25 mg/l. However, the mixed treatment of all PAC has resulted in highest removal efficiency and it was found to be 86.53 (± 3.86), 82.10 (± 0.90), 68.96 (± 0.14) and 66.83% (± 2.15) at 25, 50, 75 and 100 mg/l respectively. The maximum removal capacity was found at 25 mg/l of concentration (Fig.-2D). However many studies have been made and revealed that maximum adsorption of metal occurred at a low concentration of metal.^{30,31} In the present case, it was 25 mg/l while in case of Karnib et al¹⁵ was 30 mg/l. Same results has been observed by Kamble et al.²⁰ adsorption was maximum at PACC (90.5%) > PACB (87.5%) > CAC (85.5%) in a solution containing 25 mg/l concentration of Cu for all PACs.²⁰ The possible explanation could be that the adsorption efficiency has decreased with increasing concentration of metal in solution.^{32,33} Moreover, it could be because of low concentration of

metals are being absorbed by explicit sites and with increasing metal concentrations the explicit sites became saturated and the exchange sites of PACs got filled, which ultimately resulted in very less adsorption efficiency.³⁴

Fig.-2: (A) Effect of Dose on Co (II) Removal on Adsorbent, (B) Effect of Contact Time on Removal of Co (II) on Adsorbent, (C) Effect of Concentration on Co (II) Removal on Adsorbent, (D) Effect of Concentration on Co (II) Removal on Mixed Adsorbent

Table-3: Residual Concentration of Co (II) in mg/L after Treatment with Different Time

Name of Adsorbent	Initial Concentration 100 mg/L			
	30 min	60 min	90 min	120 min
PAC-FB	70.13(±3.3)	73.67(±0.5)	74.21(±0.7)	67.57(±0.9)
PAC-SC	67.27(±0.6)	68.9(±0.9)	67.27(±1.0)	54.33(±9.7)
PAC-AI	72.5(±0.4)	68.7(±1.5)	67(±0.8)	66.7(±1.6)
PAC-TI	52.10(±1.3)	64.64(±3.8)	53.97(±1.5)	42.8(±10.8)
PAC-MI	61.70(±9.9)	71.23(±0.1)	70.69(±0.5)	67.31(±1.8)

Table-4: Residual Concentration of Co (II) in mg/L after Treatment with increasing Concentration of Co (II)

Name of Adsorbent	Concentration of Co (II)			
	25 mg/L	50mg/L	75mg/L	100mg/L
Mixed all plants	13.47(±3.8)	17.84(±0.9)	31.04(±0.1)	33.16(±2.1)

CONCLUSION

Several techniques may be employed for the treatment of wastewater and the removal of Cobalt. It is crucial to choose the most appropriate treatment for metal, which is based on basic concentration, contact time and amount of adsorbent. There is a strong need for eco-friendly or bio-treatment methods for removal of the harmful environmental impact of heavy metal. The best optimum contact time for the

cobalt removal was 120 min for PAC-AI, PAC-TI, PAC-FB, PAC- SC and 30 min for PAC-MI. The best optimum concentrations for the Co (II) removal were 25 mg/l and 5g (PAC-AI), (PAC-MI), 6g (PAC- TI), (PAC- FB), (PAC-SC) of dose of activated carbon. However, the combination of all PACs showed higher efficiency than individual treatment. The use of activated carbon is a promising and innovative technique for clean and efficient treatment.

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REFERENCES

1. O. S. Amuda, A. Giwa, Bello I.A., *Biochem. Eng. J.*, **36**,174(2007), DOI: 10.1016/j.bej.2007.02.013
2. P. Rajasulochana and V. Preethy, *Reso.-Effici. Technol.*, **2**, 175(2016), DOI:10.1016/j.reffit.2016.09.004
3. A. Azimi, A. Azari, M. Rezakazemi, M. Ansarpour, *Chem. Bio. Eng. Review.*, **4**, 1(2017), DOI:10.1002/cben.201600010
4. F. Fu, Q. Wang, *J. Environ. Manage.*, **92**, 407(2011), DOI:10.1016/j.jenvman.2010.11.011
5. A. A. Oladipo, M. A. Abureesh, M. Gaz, *Int. J. Biol. Macromol.*, **90**, 89(2016), DOI:10.1016/j.ijbiomac.2015.08.054
6. E. Yagmur, M. Ozmak, Z. Aktas, *Fuel*, **87**, 3278(2008), DOI:10.1016/j.fuel.2008.05.005
7. Y. Maa, X. Lia, H. Mao, B. Wanga, P. Wang, *Chem. Eng. J.*, **353**,410(2018), DOI:10.1016/j.cej.2018.07.131
8. El. El-Shafey, M. Cox, A.A. Pichugin, Q. Appleton, *J. Chem. Technol. Biotechnol.*, **77**(4), 429 (2002), DOI:10.1002/jctb.577
9. A. Singh, S.M. Prasad, *Int. J. Environ.Sci. Technol.*, **12**,353(2015), DOI:10.1007/s13762-014-0542-y
10. H.A. Hegazi, *HBRC J.*, **9**, 276 (2013), DOI:10.1016/j.hbrj.2013.08.004
11. M. Saifuddin and P. Kumaran, *Elect. J. Biotech.*, **8**, 43 (2005).
12. K. Kadirvelu, Thamaraiselvi, K. Namasivayam, *Bioresour. Technol.*, **76**(1), 63(2001), DOI:10.1016/S0960-8524(00)00072-9
13. V.K. Gupta, Suhas, *J. Environ. Manage.*, **90**, 2313 (2009), DOI:10.1016/j.jenvman.2008.11.017
14. J. Li, L. Zheng, H. Liu, *J. Porous. Mater.*, **24**, 1575 (2017), DOI:10.1007/s10934-017-0397-y
15. M. Karnib, A. Kabbani, H. Holail, Z. Olama, *Energy Proce.*, **50**, 113(2014), DOI:10.1016/j.egypro.2014.06.014
16. A. Bhatnagar, W. Hogland, M.Marques, M. Sillanpaa, *Chem. Eng. J.*, **219**, 499(2013), DOI:10.1016/j.cej.2012.12.038
17. Q. Liu, T. Zheng, P. Wang, J. Jiang, N. Li, *Chem. Eng. J.*, **157**, 348(2010), DOI:10.1016/j.cej.2009.11.013
18. K. P. Singh, D. Mohan, S. Sinha, G.S. Tondon, D. Gosh, *Ind. Eng. Chem. Res.*, **42**(9),1965 (2003), DOI:10.1021/ie020800d
19. J.T. Nwabanne and P.K. Igbokwe, *Inter. J. Multi. Sci. Eng.*, **3**, 46 (2012).
20. P. N. Kamble, R.G. Bodade, A.K. Sagar, G.M. Pondhe, V.B. Gaikwad, A.V. Mane, *Natur. Environ. Pollut. Tech.*, **17**, 215(2018).
21. M. Kobyas and E. Demirbas Senturk, M. Ince, *Bioresour. Technol.*, **96**, 1581(2005), DOI:10.1016/j.biortech.2004.12.005
22. H.M. Boehm, *Carbon*, **32**,759 (1994), DOI:10.1016/0008-6223(94)90031-0
23. H. Abiko, M. Furuse, T. Takano, *Indus Health*, **48**, 427 (2010), DOI:10.2486/indhealth.ms1041
24. Y. H. Yoon, J.H. Nelson, *Am. Ind. Hyg. Assoc. J.*, **45**, 509(1984a), DOI:10.1080/15298668491400205
25. Y. H. Yoon, J. H. Nelson, *Am. Ind. Hyg. Assoc. J.*, **45**, 517(1984b), DOI:10.1080/15298668491400197
26. L. Zhou, M. Li, Y. Sun, Y. Zhou, *Carbon*, **39**,771 (2001), DOI:10.1016/S0008-6223(01)00025-2.

27. S. Rengaraj, M. Seung-Hyeon, R. Sivabalan, B. Arabindoo, V. Murugesan, *Waste Manag.*, **22**, 543 (2002), DOI:10.1016/S0956-053X(01)00016-2
28. G.O. El-Sayed, *Desalination*, **272**, 225(2011), DOI:10.1016/j.desal.2011.01.025
29. A. K. Kushwaha, N. Gupta, M.C. Chattopadhyaya, *Arab. J. Chem.*, **10**, 51645(2017), DOI:10.1016/j.arabjc.2013.06.007
30. B. Shrestha, J. Kour, K.N. Ghimire, *Adv. Chem. Eng. Sc.*, **6**, 525(2016), DOI:10.3126/njst.v13i2.7722
31. M. B. Desta, *J. Therm.*, 1(2013), DOI:10.1155/2013/375830
32. E. Erdem, N. Karapinar, R. Donat, *J. Colloid. Interface Sci.*, **280**, 309(2004), DOI:10.1016/j.jcis.2004.08.028
33. X. Wu, F. Zhao, M. Chen, Y. Zhang, C. Zhao, H. Zhou, *Adso. Scie. Tech.*, **26**, 145(2008), DOI:10.1260%2F026361708786036115
34. E. El-Ashtoukhy, N. Amin, O. Abdelwahab, *Desalination*, **223**, 162(2008), DOI:10.1016/j.desal.2007.01.206

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