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Integrated Management of Industrial Wastewater Treatment and its Reuse Options for Sustainable Developments A Green Technology Concept

Singanan Malairajan

Water Research Laboratory PG and Research Department of Chemistry
Presidency College (Autonomous), Chennai – 600005, Tamil Nadu, India

Corresponding Author Email: swethasinganan1966@gmail.com

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Abstract* — Water is an essential life-sustaining element of daily life. The water crisis in both quantity and quality apparently becomes inevitable in such a changing world in terms of global environmental changes, the ever-growing population and pressures on global freshwater resources. The water scarcity and misuse of fresh water resources leads to serious concern on the sustainable economic development, food security and protection of the environment in combination with the climate change. The adverse effects that the human race has exerted on water sources have in turn threatened human health either by limiting good hygiene or by impairing drinking water safety. Further, many industries are using large amount of fresh water for the production activities. It is also releasing large volume of wastewater into the environment and causes ecosystem damages. In the concept of environmental and economic sustainability, a proper wastewater management and water reuse system can help to a greater extent in the development of national economy. To cope with the water crisis, innovative approaches to source water management as well as reuse of treated wastewater have been proposed all around the world from a holistic perspective, based on integration of multidisciplinary framework. In the current research, a green technology concept has been introduced to the treatment on industrial wastewater using a novel biocarbon technology. In this research, Hibiscus rosa sinensis L. plant leaves were used for the production of the biocarbon. It is an indigenous medicinal plant, widely available in nature, the leaves have rich carbon content. In this research protocol, three stages were involved. In the first stage, the metal adsorption capacity (pollutant removal), of the biocarbon was evaluated using Cr (VI) ions as model pollutant. The adsorption experiments were carried out in a batch reactor system with pre-determined experimental conditions. In the second stage, leather industry wastewater was subjected for treatment with biocarbon. In the third stage, the treated wastewater was used for the growth of certain plant species in a pilot scale farming land. The current experimental research, leather industry wastewater containing total dissolved solids of 15200 mg/L were introduced in the reactor system, after the equilibrium time of 3hrs; the concentration of TDS in outlet water was 995 mg/L. The color of the leather industry wastewater was reduced to 98.25% and the level of COD was reduced to 98.35% with optimum biocarbon dose of 3.0 g/100mL. In addition, a pilot scale farming practice was carried out in 12 x 12 sq. ft field for the growth of Fodder grass, Sataria clauca and Sorghum. The productivity results show faster growth of the species and 6.8 kg of biomass/sq. ft. The results indicates that, *Hibiscus rosa - sinensis* L. plant leaves biocarbon has excellent adsorption capacity in pollutant removal in the wastewater. Further, the wastewater can be reused for the growth of plants for may farming practice.

***Keywords* — Integrated water management, wastewater treatment, reuse options, heavy metal removal, biocarbon, adsorption technique**

I. INTRODUCTION

The clean water-food-energy nexus are emerging as an important and dynamic issue for the sustainable development in our society [1. Water stress has become a perennial concern in most cities globally. The quality and quantity of fresh water is of vital concern for mankind and is directly linked with human welfare and inhabitants. Increasing demand for food, fiber and fodder will place great stresses on the land, water, energy and other resources. This is also greatly impacting on climate change.

The population growth, urbanization of new cites and other modernization activities, are ultimately accelerating the demand and supply of fresh water. It is also causing misappropriation of available fresh water resources and leading to grater water scarcity and pollution. Pollutants, such as heavy metals, are serious threats to the environment. They are getting introduced to aquatic streams due to various industrial activities [2], [3].

Water pollution affects human health and ecosystems, as well as aquatic plants and animals. The water pollution associated with heavy metal resulting from industrial and urban activities is a serious global issue due to its high toxicity, low biodegradability, and accumulation in the food chain [4]. The commonly released toxic heavy metals are zinc, thallium, copper, nickel, mercury, cadmium, lead, and chromium [5]. These heavy metals are mostly deleterious for humans, animals and the environment.

Notably, chromium is a toxic heavy metal and added into the environment by electroplating, leather processing, mining and pigment manufacturing processes [6]. Chromium exists in several oxidation states, but the most stable and common forms are Cr (0), the trivalent Cr (III), and the hexavalent Cr (VI) species. Cr (VI) in the forms of chromate (CrO_4^{2-}), dichromate ($Cr_2O_7^{2-}$) are considered the most toxic forms of chromium and are the largest threats to the environment [7]. Due to mutagenic and carcinogenic effects, Cr (VI) is more toxic for human health as compared to Cr (III) [8]. The permissible concentration of chromium in drinking water suggested by USEPA is 0.1 mg/L [9]. The WHO sets the limit of chromium in wastewater at 0.05 mg/L [10].

Wastewaters, regardless of their type, are a serious problem in both environmental and economic perspective. On the other hand, it can be viewed as a potential resource not just for water but as energy and nutrient. The energy potential of wastewater is ten times more than the energy used to treat it. Safe disposal of wastewater is essential which should not pose any threat to human life or health and the environment. Hence, proper wastewater management is of great importance in achieving sustainable development.

Numerous remediation techniques have been discovered and applied in the treatment of industrial wastewater particularly removal and recovery heavy metals. The well-known wastewater treatment methodologies are ion-exchange, phase extraction, chemical precipitation, membrane separations, biological treatments and electrochemical methods [11]–[14]. However, the above-stated methodologies commonly suffer from a number of inherent limitations, such as low efficiency, long period, high operational cost, complex operation and generation of secondary pollution, which make them difficult to obtain satisfactory results in practical application [15]. Comparatively, adsorption method has received extensive attention and began to play a crucial role for the remediation of heavy metal pollution, due to its cost-effectiveness, high efficiency, simple operation as well as considerable choice for adsorbents [16].

In the current research, a green technology concept has been introduced to the treatment on industrial wastewater using a novel biocarbon technology. In this research, *Hibiscus rosa - sinensis* L. plant leaves were used for the production of the biocarbon. The advent of treated wastewater reuse changes the sector to one generating a valuable product - safe and reliable water supply.

II. METHODS

A. *Preparation of biocarbon*

Hibiscus rosa - sinensis L. is an important medicinal plant widely available in agricultural fields. The plant leaves were collected and air dried for 48 hours. The dried leaves were grounded in ball mills and the screened homogeneous powder was used for the preparation of biocarbon. The biocarbon was prepared by treating the leaves powder with the concentrated sulphuric acid (Sp. gr.1.84) in a weight ratio of 1:1.8 (biomaterial: acid). The resulting black product was kept in an air-free oven, maintained at 160 ± 5 ºC for 6 hours followed by washing with distilled water until free of excess acid, then dried at 105 ± 5 ºC. The particle size of carbon between 100 and 120 µm was used [17]. The process of preparation of biocarbon was presented in the Fig. 1.

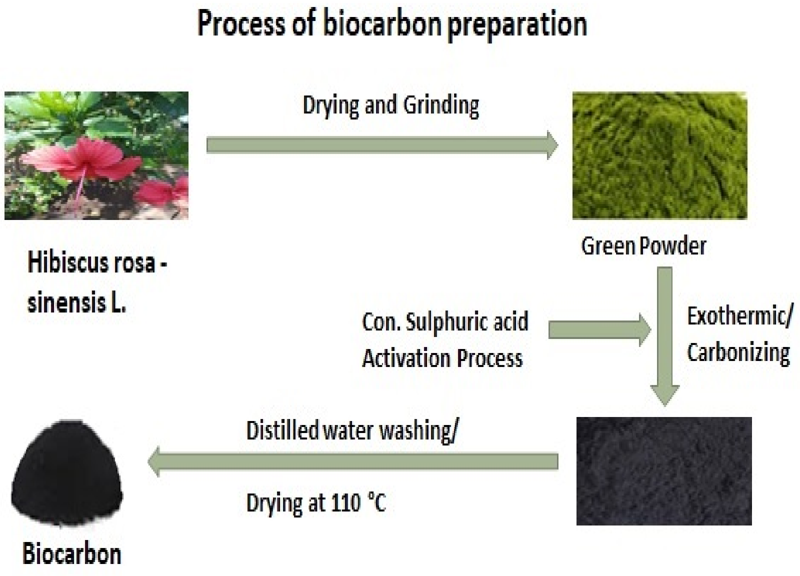

Fig. 1: The process of preparation of biocarbon

B. Evaluation of adsorption capacity biocarbon

The metal adsorption capacity of the prepared biocarbon should be estimated before using in any wastewater treatment process. In these aspects, the metal uptake capacity of the biocarbon was determined using Cr (VI) ions as model pollutant in these experimental studies. For this purpose, the batch-wise adsorption experiments were conducted in a series of 250 mL of Erlenmeyer flasks. The adsorption experiments were carried out in a batch reactor system with pre-determined experimental conditions including, the effect of pH, contact time, amount of biocarbon dose and temperature using an initial metal ion concentration of 100 mg/L with a volume of 100 mL.

Importantly, the amount of biocarbon dose was optimized using different amount of biocarbon dose such as 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 g separately with 4.5 pH test solutions. The adsorption experiments were performed at 30 ± 2 °C. The experimental flasks were constantly agitated at 250 rpm for a time period of 180 min to determine the equilibrium condition. Samples were collected at the end of the pre-determined time interval (30 min) and the concentration of metal ions was estimated using the AAS technique. Percent removal of chromium (VI) ions and the quantity of metal ions adsorbed from the wastewater system was calculated using the equations described by Dada et al., [18]:

$$q_e = \left(\frac{C_o - C_e}{w} \right) \times V \quad (1)$$

$$\% \text{ Removal} = \left(\frac{C_o - C_e}{C_o} \right) \times 100 \quad (2)$$

Where C_o and C_e are the initial and equilibrium concentrations of the metal ions (mg/L), w is mass of biocarbon (g) and V is the volume of the metal containing wastewater (mL) respectively.

C. Treatment of leather industry wastewater

The wastewater collected from leather industry was passed through the specific screening system for the removal any dirt materials. A dirt-free wastewater samples were collected in clean polythene containers and subjected to batch adsorption process with pre-defined equilibrium data. The biosorption process was carried out at the room temperature of 30 ± 2º C in a series of six 250 mL capacity Erlenmeyer flask. Each flask is loaded with 100 mL of wastewater and subjected to equilibrium process. The wastewater treatment process and reuse for cultivation operation was illustrated in the Fig. 2.

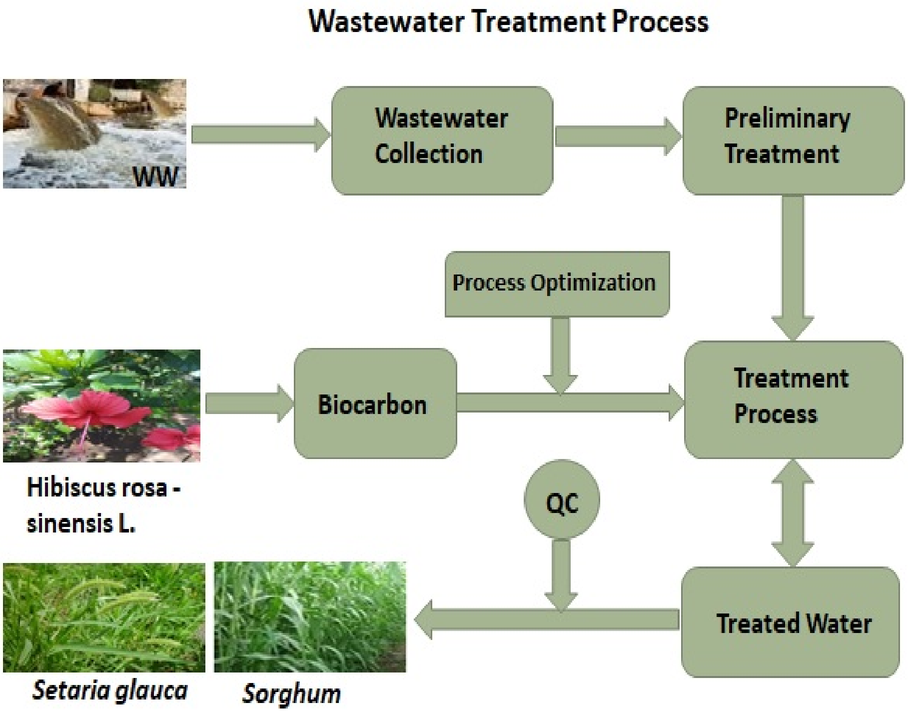

Fig. 2. Wastewater treatment process

III. RESULTS AND DISCUSSION

A. Characterization of biocarbon

The characterization of biocarbon is absolutely necessary to ascertain the nature of surface area and the evaluation of adsorption capability of the adsorbent in any metal particle removal studies in bulk solution. The necessary physico-chemical properties of the *Hibiscus rosa - sinensis* L. plant leaves biocarbon were shown in Table 1.

Table 1.
Characteristics of the Biocarbon

S.No.	**Parameters**	**Values**
1.	Moisture content (%)	42.10 ± 1.05
2.	Bulk density (g/ml)	1.26 ± 0.06
3.	Ash content (%)	28.25 ± 1.12
4.	Total organic components (%)	88.56 ± 1.30
5.	Insoluble components (%)	13.25 ± 1.72
6.	Surface area (BET) (m^2/g)	255 ± 0.08
7.	C content (%)	85.65 ± 1.08
8.	H content (%)	9.25 ± 0.05
9.	Ion exchange capacity (meq/gm)	0.85 ± 0.02
10.	Phenol Number	85.50 ± 0.05

B. Surface morphology

Scanning electron microscopy (SEM) is an important technique used to analyse the surface characteristics of the biocarbon (Fig. 3). The sample was scanned by using JSM 6701F JEOL, Japan. The SEM micrograph of biocarbon shows that, some leaf like structures and large numbers of nanograins were present. Most probably, the presence of nanograins and cavities ae responsible for the adsorption of heavy metal ions on different parts of the biocarbon. The SEM image illustrates the surface texture and porosity of biocarbon with cavities and grains significantly increased the contact area for the metal uptake process [19].

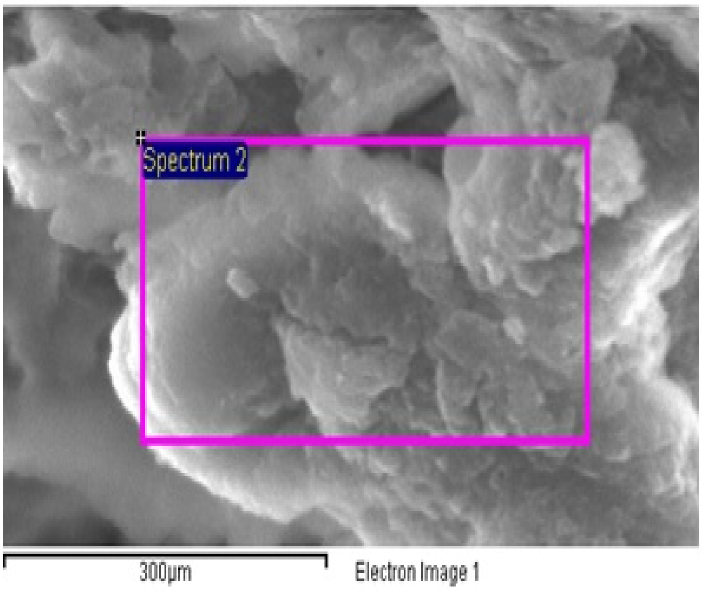

Fig 3. SEM photograph of the biocarbon

C. Adsorption process of Cr (VI)

The effect of contact time on Cr (VI) removal was investigated by varying the contact time (30 - 240 min), while keeping the solution pH at 4.5, biocarbon dose of 3.3 g/100 mL and the initial metal ion concentration of 100 mg/L. The results are presented in Fig. 4. It is observed that, the maximum removal efficiency of Cr (VI) is 98.65 %. This removal process is progressively increased with an increasing in contact time. After the equilibrium level reached, the removal efficiency was constant. It seems that, the adsorption process happening in two stages. The first stage was rapid. This is due to the presence of large number of vacant surface site readily available for adsorption process. In the second stage, a slower progressive adsorption was represented. Since, the remaining vacant surface sites may be exhausted due to repulsive forces between the solute molecules of solid and bulk phase [20]. The mechanism of solute transfer to the solid includes diffusion through the fluid film around the adsorbent particle and through the pores to the internal adsorption sites [21].

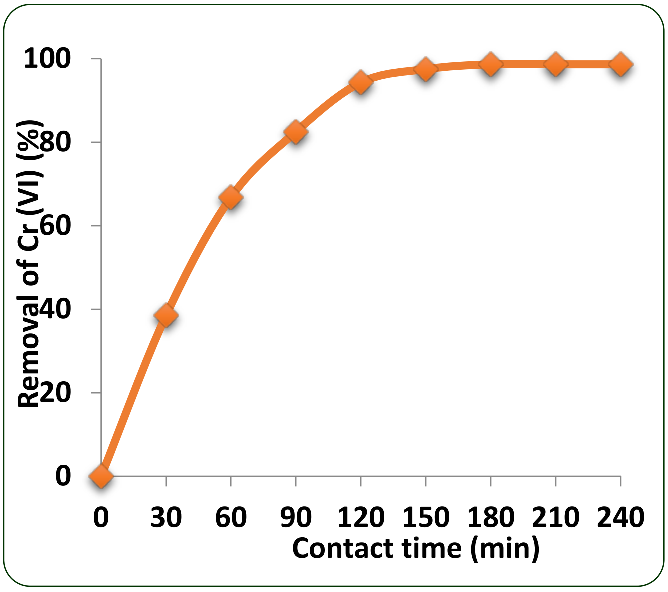

Fig. 4: Adsorption process of Cr (VI)

D. Treatment of leather industry wastewater

The leather industry wastewater was collected from the industrial area situated in Northern districts of Tamil Nadu, India and analysed for the essential physico-chemical parameters and selected heavy metals and the results were reported in Table 2.

Table 2: Treatment of leather industry wastewater

Sl.No	**Characteristics of leather industry wastewater**	**Quality leather industry wastewater (mg/L)**		**Removal result (%)**
		Before Treatment	**After Treatment**	
1.	pH	5.45	4.15	--
2.	EC (µmhos/cm)	23390	1545	93.40
3.	TDS	15200	995	93.45
4.	TSS	1855	155	91.64
5.	TH	2530	358	85.85
6.	BOD	2885	55	98.09
7.	COD	11520	190	98.35
8.	Calcium	495	90	81.81
9.	Magnesium	368	65	82.33
10.	Chloride	420	72	52.86
11.	Sulphate	1450	135	90.69
12.	Nitrate	190	25	86.84

The analytical results clearly indicate that, in leather industry wastewater all the wastewater quality parameter reduced significantly. It is observed that, the level of BOD and COD is reduced to 98.09 and 98.35 % respectively. Since, BOD and COD are the main pollution parameters and includes the biodegradable and non-biodegradable organic matter in the wastewater. Similarly, chloride, sulphate and nitrate also well reduced in all the wastewater. All the parameters indicates that, the treated wastewater is well meeting the agriculture quality of wastewater normally used for the cultivation of different crops.

E. Heavy metals removal in leather industry wastewater

Presence of heavy metals in wastewater is very much dangerous and may create health hazardous to human beings as well as to aquatic animals. Heavy metals are highly toxic and non-biodegradable in nature. It tends to bioaccumulate in aquatic organisms [22]. Heavy metals such cadmium, copper, lead, nickel and chromium are very much toxic even at low concentrations. In the present research work, the leather industry wastewater samples subjected to treatment process involving various steps and finally with adsorption process. The heavy metal removal results in leather industry wastewater indicates that, Cu (II) was 85.31 %, Cd (II) was 92.86 %, Pb (II) was 90.85 %, Ni (II) was 85.48 % and Cr (VI) was 95.54 % respectively. The results were presented in the Fig. 5. It is further noted that, all other pollutants present in the wastewaters are also significantly reduced. It also well supported that Hibiscus rosa sinensis L. plant leaves based biocarbon is a good and cheap adsorbent and can be used for the removal of all inorganic and organic pollutants in wastewater system.

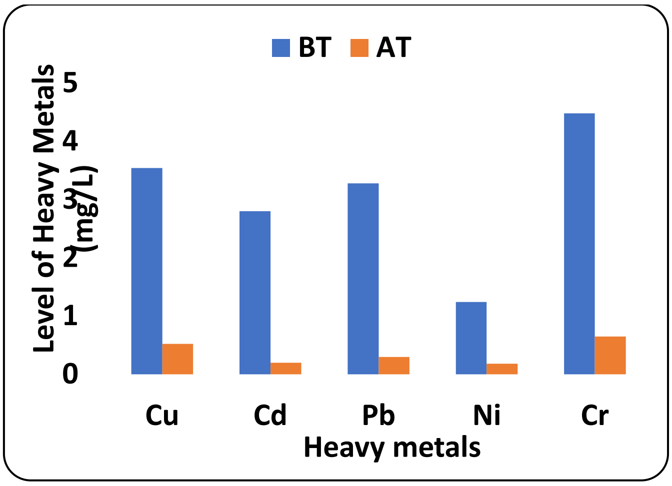

Fig. 5: Removal of heavy metals in leather industry wastewater

F. Reuse of treated wastewater in agriculture practice

The treated leather industry wastewater was utilized in pilot scale irrigation process for cultivation of Setaria glauca, a fodder grass for livestock applications, and Sorghum for small-scale shown in Fig. 6. The productive results are presented in Table 3. The results demonstrated that the treated leather industry wastewater has good nutrient capacity and hence, the species is steadily grown well and produced good yield.

Table 3: Growth Characteristics of Setaria Glauca and Sorghum

S. No.	Parameters	Setaria glauca	Sorghum
1.	Field size	12 x 12 sq. ft	12 x 12 sq. ft.
2.	Growth period	120 days	120 days
3.	Total biomass	5.0 – 5.5 kg/sq. ft.	6.5 – 6.8 kg/sq. ft.

Fig. 6: Cultivation of Setaria glauca and Sorghum

IV. CONCLUSION

The biocarbon prepared using *Hibiscus rosa - sinensis* L. plant having higher potential for removal of Cr (VI) and other inorganic and organic pollutants in leather industry wastewater. The process of adsorption employed in this research work is cost effective, simple and highly efficient. The maximum uptake of Cr (VI) was observed at the pH of 4.5 with optimum biocarbon dose rate of 3.0 g/100mL at 180 minutes equilibrium time. The percentage of the removal of Cr (VI) in synthetic wastewater is 98.65 and the removal process was progressively increased with the increase of contact time. This result supports that, the biocarbon can be used for the treatment of any industrial wastewater. As an application part, leather industry wastewater was used for the batch adsorption process. It is observed that, BOD (98.09 %) and COD (98.35 %) is well reduced in the wastewater. Similarly, most of the heavy metals are significantly removed (Cu (II) was 85.31 %, Cd (II) was 92.86 %, Pb (II) was 90.85 %, Ni (II) was 85.48 % and Cr (VI) was 95.54 %). The results are very much promising for the use of the biocarbon for the treatment of leather industry wastewater. It has greater affinity to remove the metal pollutant particularly. These results demonstrate that, the greater potential for the application of biocarbon materials would be an effective method for economic treatment of wastewater. In the piolet scale farming practice nearly 6.8 kg biomass were cultivated. These results indicates that, the treated wastewater can be reused successfully for the cultivation of various of plants and definitely aids the sustainable water management.

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