

# Removal of arsenic from contaminated water utilizing tea waste

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Received: 7 March 2015 / Revised: 28 October 2015 / Accepted: 3 January 2016 / Published online: 20 January 2016  
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**Abstract** Activated carbon is the adsorbent commonly used to remove arsenic from contaminated water. However, the problem is that it is not always available everywhere and considered expensive in developing countries. An inexpensive alternative to activated carbon can therefore aid the adequate treatment of contaminated water. Tea waste, water hyacinth and banana peel are investigated extensively in this study as the inexpensive alternative. Tea waste treated with a right proportion of aqueous  $\text{FeCl}_3$  reagent is found to have substantially higher arsenic removing capacity (which is quantified by arsenic concentrations measured employing Double Beam Atomic Absorption Spectrophotometer) than the other two. The comparison made subsequently between tea waste and activated carbon reveals the feasibility of the utilization of tea waste. The arsenic removing capacity of tea waste treated with the right proportion of aqueous  $\text{FeCl}_3$  reagent is found to be equal to that of the activated carbon treated with the same reagent over the continuous operative time of 2 h. The tea waste treated rightly with the same reagent also removes arsenic at acceptable capacities over extended operative times such as 4–6 h. It is therefore proposed to consider tea waste as the inexpensive alternative to activated carbon in treating arsenic contaminated water.

**Keywords** Tea waste · Arsenic · Water · Activated carbon · Adsorption · Water treatment

## Introduction

Arsenic poisoning can cause non-malignant skin alteration and skin cancer. It can also cause internal malignancies, peripheral vascular diseases and black foot disease. Because of these adverse health effects, the arsenic poisoning particularly through the use of water has been under special attention (Jain and Ali 2000; WHO 1993). International standards for arsenic have generally been 50 ppb for drinking water, but other countries are looking at lowering their standards (Ng et al. 2003). The World Health Organization (WHO) recommended a provisional guideline value of 10 ppb based on both estimated health risks and the practical detection limit in 1993. Recently the German standard for arsenic has been lowered to 10 ppb (Ng et al. 2003). The scenario of arsenic poisoning in Bangladesh can certainly be considered as the worst in the world (Chowdhury 2004). 18 % of the wells are having arsenic more than 50 ppb. Approximately 59 districts from the total 64 are currently affected at various extents in Bangladesh (Karim 2000).

Arsenic in water has generally been a global concern. Hence, there is a pressing demand for more innovation to maintain arsenic at the safe levels in water. There are a number of arsenic removal methods, which include coagulation followed by precipitation, membrane separation, anion exchange, and adsorption, etc. (Chowdhury et al. 1999; Gupta and Chen 1978; International et al. 2000; Mohan and Pittman 2007; Mondal et al. 2006). Adsorption is the most demanding one which has favorable economics, low installation and maintenance cost. It is also more energy efficient than the others. In adsorption, activated carbon is used commonly as the adsorbent but it is relatively expensive and not always available everywhere at sufficient quantities (Gupta and Chen 1978). Therefore, an

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inexpensive alternative to activated carbon can greatly increase the application of adsorption based method in various developing countries like Bangladesh. Materials such as tea waste, microbial biomass and straw etc., have already been tested generally as low-cost adsorbent (Aikpokpodion et al. 2010; Amarasinghe and Williams 2007; Bhaina and D'Souza 2001; Cay et al. 2004; Ingole and Bhole 2003; Kamsonlian et al. 2011; Mahavi et al. 2005; Wasewar 2010; Wasewar et al. 2008). The use of waste materials as inexpensive adsorbent can have several additional advantages. It is reported in general that tea waste is capable to trap heavy metals due to its highly porous structure with insoluble cell (Aikpokpodion et al. 2010; Amarasinghe and Williams 2007; Cay et al. 2004; Mahavi et al. 2005; Wasewar 2010; Wasewar et al. 2008). The functional groups present in tea waste also aid the trapping action. Hence, the arsenic removing capacities of tea waste and two more waste materials namely water hyacinth and banana peel are investigated extensively in this study with an objective to propose an inexpensive alternative to activated carbon.

## Materials and methods

Tea waste, water hyacinth and banana peel are chosen as the potential inexpensive alternative to activated carbon. In traditional practice, after leaching aromatic compounds from tea leaves, the residual solid is discarded as tea waste. The collected tea waste is washed with distilled water thoroughly to remove dirt and fine particles. The wet tea waste is then dried in air for 5 h at room temperature and heated in an oven at 60 °C for another 24 h to remove moisture. The dried tea waste is grinded and sieved. The tea waste particles of the size of 20-mesh are taken to be used for removing arsenic from water. The processed tea waste particles are shown in Fig. 1.

The collected water hyacinths are washed with distilled water to remove dirt and fine particles. The washed water

hyacinths are cut into small pieces and dried in sun-light for 5 h. To remove the moisture more, the small pieces are again dried in the same oven at 60 °C for another 24 h. The dried small pieces are pulverized in a laboratory blender to obtain fine particles of 20-mesh size as shown in Fig. 2. Similarly, the collected banana peels are cleaned by washing with distilled water and dried subsequently in the sun-light for 5 h. The sun-dried banana peels are dried again in the same oven at 60 °C for 24 h. The oven-dried peels are cut into small pieces and finally pulverized into 20-mesh size as shown in Fig. 3.

The schematic of experimental setup used to determine arsenic removing capacities is given in Fig. 4. The setup consists of a feed reservoir of 40 l, three acrylic made columns of 24 inches length and 1 inch diameter and a drain tank of 10 l. There is a regulating valve below the underneath of feed reservoir to control outgoing flow. Each column is also accompanied with a pair of in–out flow-regulating valves. The underneath of each column is equipped with a polymeric filter of 30-mesh size to prevent the flow of particles of 20-mesh size. The feed reservoir is charged with contaminated water having 100 ppb arsenic and 5.0 pH value. Each column is charged individually with 10 g of processed waste materials. It is known from basic inorganic chemistry that ferric cation ( $\text{Fe}^{+3}$ ) tends to react with soluble arsenate and arsenite anions and forms insoluble according to the stoichiometry:  $\text{Fe}^{+3} + \text{AsO}_4^{3-}/\text{AsO}_3^{3-} \rightarrow \text{FeAsO}_4/\text{FeAsO}_3\downarrow$  (Albert et al. 3rd edition). This action may accelerate the removal of arsenic from water. Therefore, 40 ml of 0–50 ppm aqueous  $\text{FeCl}_3$  solution is also added through top side-port as a reagent into the column charged with 10 g of waste material. A time of 30 min is subsequently allowed for charged waste materials to take up the added reagent sufficiently in order to form a waste-reagent porous matrix. Finally the contaminated water from the feed reservoir is passed continuously through the column. The water samples are then collected from the outlet of each column in 10-ml



**Fig. 1** Processed tea waste of 20-mesh size

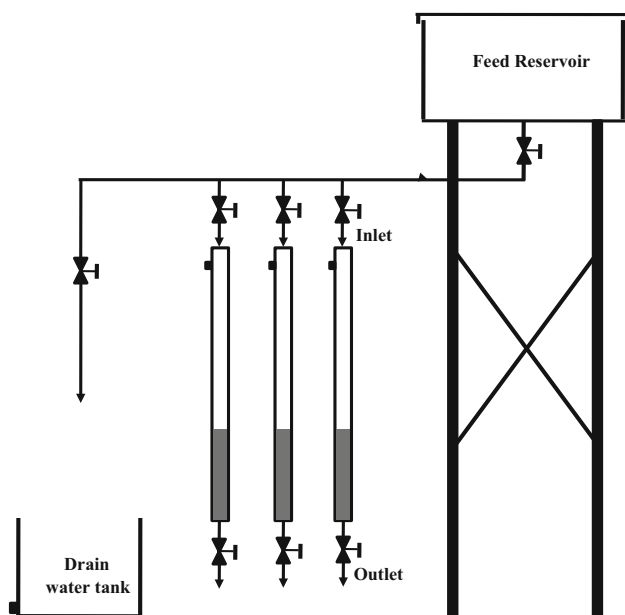


**Fig. 2** Processed water hyacinth of 20-mesh size





**Fig. 3** Processed banana peel of 20-mesh size



**Fig. 4** The scheme of experimental setup used to determine arsenic removing capacities

glass sampling bottles at various times. The arsenic concentrations in the collected water samples are measured using AA-6300 Shimadzu Double Beam Atomic Absorption Spectrophotometer. Each experiment is conducted three times very carefully to verify the reproducibility of each result. The difference of arsenic concentration between the inlet and outlet streams of the column is taken as the measure of the arsenic removing capacity of the respective waste material. The removing capacity is mathematically defined below:

$$\text{Arsenic removing capacity} = \frac{C_{As.Inlet} - C_{As.Outlet}}{C_{As.Inlet}} 100\%$$

where  $C_{As.Inlet}$  and  $C_{As.Outlet}$  are, respectively, the concentrations of arsenic in water at the inlet and outlet of the columns.

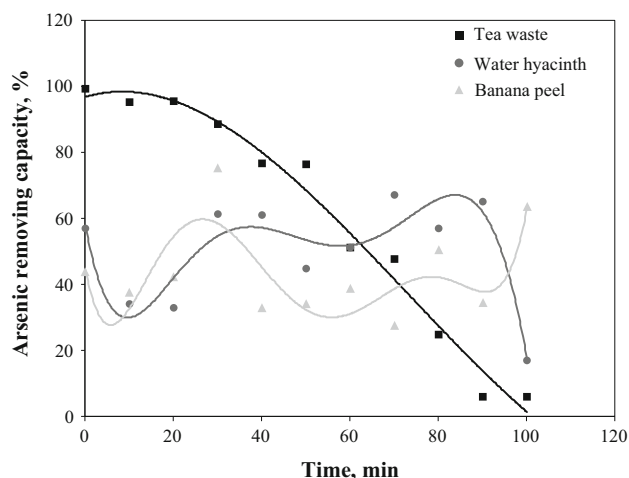
## Results and discussion

Arsenic removing capacities of processed tea waste, water hyacinth and banana peel of 20-mesh size are evaluated and compared at the absence and presence of  $\text{FeCl}_3$  reagent. A comparison is subsequently made with activated carbon. Each data presented in the following figures are the average of its three values with a deviation  $<4\%$ .

### Comparison among tea waste, water hyacinth and banana peel

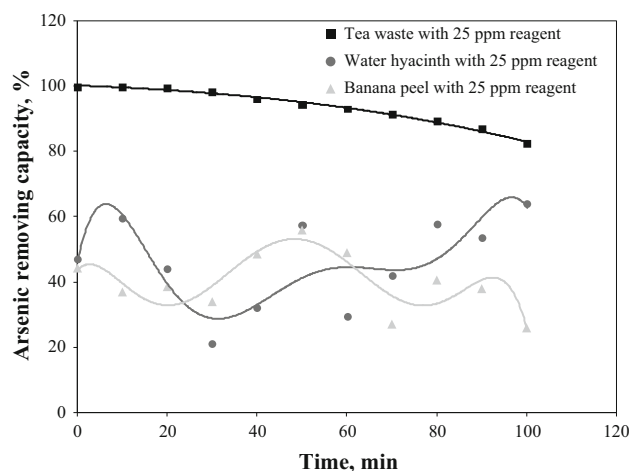
The arsenic removing capacities of processed tea waste, water hyacinth and banana peel of 20-mesh size at the absence of  $\text{FeCl}_3$  reagent are presented in Fig. 5. It can be seen from Fig. 5 that tea waste initially exhibits a removing capacity substantially higher (which is almost double) than that of water hyacinth and banana peel. Though the capacity of tea waste reduces monotonically to around 5 % by 100 min, it remains more than 90 % over the first 30 min. It is important to conclude here that tea waste is certainly more capable than both water hyacinth and banana peel to remove arsenic over the first 30 min. Hence, tea waste is better choice than the others two. However, it is surprising that though the capacity of tea waste decays clearly with time may be due to the reduction of active surface, the capacities of the other two fluctuate around the average with a small net lowering as can be seen from Fig. 5. This happens may be due to the irregular contact between flowing water and the active site of water hyacinth and banana peel.

The arsenic removing capacities of processed tea waste, water hyacinth and banana peel of 20-mesh size at the presences of 25 and 50 ppm  $\text{FeCl}_3$  reagent are shown in

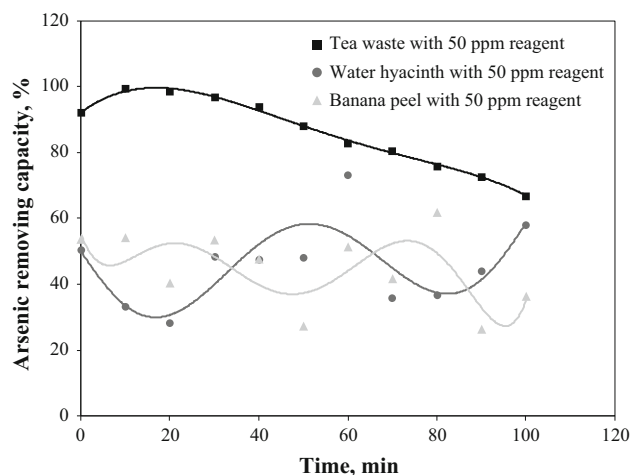


**Fig. 5** Comparison of arsenic removing capacity among tea waste, water hyacinth and banana peel at the absence of  $\text{FeCl}_3$  reagent





**Fig. 6** Comparison of arsenic removing capacity among tea waste, water hyacinth and banana peel treated with 25 ppm aqueous  $\text{FeCl}_3$  reagent

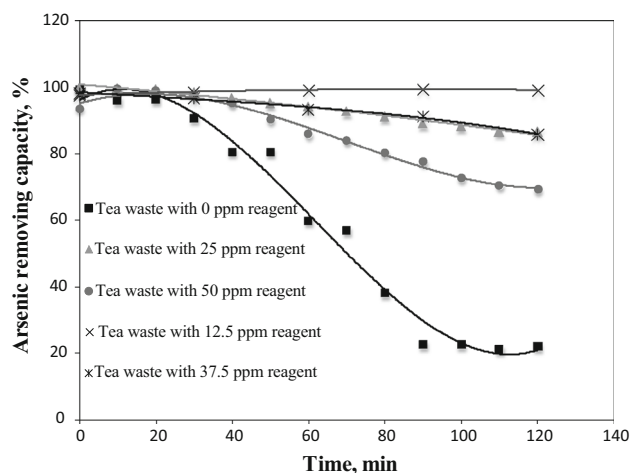


**Fig. 7** Comparison of arsenic removing capacity among tea waste, water hyacinth and banana peel treated with 50 ppm aqueous  $\text{FeCl}_3$  reagent

Figs. 6 and 7. Figures 6 and 7 reveal that the qualitative behavior of each waste material remains unchanged, while only the rate of decay with time reduces at the presences of reagent for tea waste. Hence, tea waste remains better choice than the water hyacinth and banana peel over the entire operative time of 100 min.

### Effect of reagent addition

To understand the effect of reagent on the arsenic removing capacity, the study is continued with tea waste only which has larger removing capacity than the other two. Arsenic removing capacity of processed 20-mesh size tea waste is tested at the reagent concentrations of 0.0, 12.5, 25.0, 37.5



**Fig. 8** Effect of the addition of  $\text{FeCl}_3$  reagent into processed tea waste

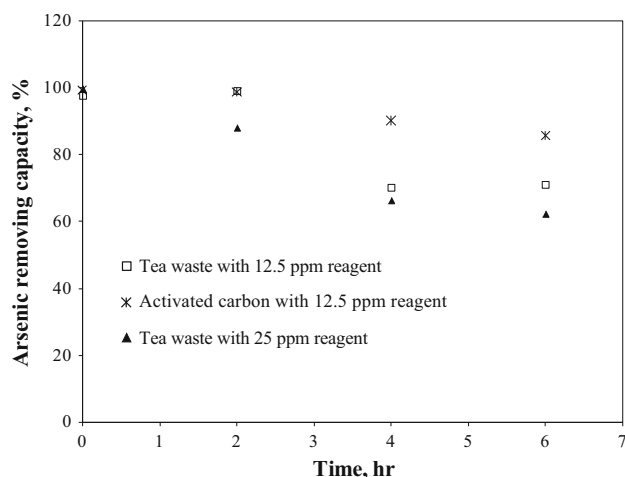
and 50.0 ppm. Figure 8 shows that when the reagent concentration is increased from 0.0 to 12.5 ppm, tea waste attains a unique characteristic. At this condition there is almost no change in arsenic removing capacity with time over the entire operative time of 120 min; the tea waste removes arsenic from water constantly. Figure 8 further shows that when the reagent concentration is increased from 12.5 to 25 ppm, the removing capacity again decays with time. However, the rate of decay with time at 25 ppm reagent concentration is substantially lower than that at 0.00 ppm reagent concentration. Consequently, the overall removing capacity is remarkably higher than that at 0.00 ppm. The effect remains same at 37.5 ppm reagent concentration. With the further increase in concentration to 50 ppm, the rate of decay with time increases more keeping the overall removing capacity larger than that at 0.0 ppm reagent concentration. Hence, it is generalized that the addition of reagent into the bare tea waste by a right proportion increases the overall arsenic removing capacity remarkably.

### Comparison with activated carbon

The experimental observations confirm that tea waste treated with a right proportion of  $\text{FeCl}_3$  reagent can give much better removal of arsenic from contaminated water than water hyacinth and banana peel do. Hence, a comparison between tea waste and activated carbon which is used conventionally is now required to determine the suitability of tea waste for commercial application. Figure 9 shows the arsenic removing capacities of activated carbon and tea waste treated with  $\text{FeCl}_3$  reagent over an operative time of 6 h. The size of both activated carbon and tea waste is kept at 20-mesh. It is found that over the first







**Fig. 9** Comparison of arsenic removing capacity between processed tea waste and activated carbon

2 h (120 min) activated carbon and tea waste both treated with 12.5 ppm reagent exhibit the same arsenic removing capacity. Hence, tea waste and activated carbon treated with 12.5 ppm reagent are equivalent to each other in terms of arsenic removal for shorter operative times such as 2 h. For this equal arsenic removal, a general economic analysis (incorporating the costs of tea waste collection, processing, and treating with reagent, etc.) reveals that using tea waste instead of activated carbon can give at least 50 % savings in monetary-value. On the other hand, over the operative time of 4–6 h, the arsenic removing capacity of tea waste treated with 12.5 ppm reagent lowers from that of the activated carbon by approximately 22 %. Nevertheless, the tea waste treated with 12.5 ppm reagent gives 70 % removing capacity over the 4–6 h. For this operative time, the monetary-savings from tea waste is reduced by 22 % lowering in the removing capacity. The arsenic removing capacity of tea waste treated with 25 ppm reagent in Fig. 9 further emphasizes the use of reagent at a right proportion.

## Conclusion

Arsenic poisoning through water is severely harmful for human being and deserves special attention from researchers for proper suppression. Numerous studies have already been under research. Activated carbon is mostly used as an adsorbent to remove arsenic from contaminated water. However, it is not always easily available everywhere at the right amount and also expensive especially for developing countries. Therefore, an inexpensive alternative to activated carbon can certainly contribute to the proper suppression of arsenic poisoning. To propose an inexpensive alternative to activated carbon, the arsenic removing

capacities of tea waste, water hyacinth and banana peel are investigated extensively in this study. It is observed that tea waste treated with a rational proportion of aqueous  $\text{FeCl}_3$  reagent exhibits substantially higher arsenic removing capacity than the other two. A comparison is subsequently made between tea waste and activated carbon. It is found that the arsenic removing capacity of tea waste treated with the rational proportion of aqueous  $\text{FeCl}_3$  reagent is equal to that of the activated carbon treated similarly with the same reagent over the continuous operative time of 2 h. Hence, for the operative times till 2 h, it can be concluded that tea waste treated rightly with reagent is equivalent to activated carbon in terms of arsenic removing capacity, while it is inexpensive than the latter. For the operative time of 2 h, the tea waste is expected to give a monetary-savings of minimum 50 %. The tea waste treated rightly with reagent also removes arsenic from contaminated water at reasonable capacities over extended operative times. Since the removing capacity is largely dependent on reagent proportion and operative time, it is proposed to consider both factors properly for practical application of tea waste as an inexpensive alternative to activated carbon.

**Acknowledgments** Supports from the Department of Chemical Engineering, Bangladesh University of Engineering and Technology, and Bangladesh Council of Scientific and Industrial Research are gratefully acknowledged.

## References

- Albert AC, Geoffrey W, Paul LG. Basic Inorganic Chemistry, 3rd Edition, ISBN-13: 978-0471505327
- Aikpokpodion PE, Ipinmoroti RR, Omotoso SM (2010) Bisorption of nickel (II) from aqueous solution using waste tea (*Camellia cinensis*) materials. Am Eurasian J Toxicol Sci 2(2):72–82
- Amarasinghe BMWPK, Williams AR (2007) Tea waste as a low cost adsorbent for the removal of Cu and Pb from wastewater. Chem Eng J 132:299–309
- Bhaina K, D'Souza S (2001) Uranium (VI) biosorption by dried roots of *Eichhornia crassipes* (water hyacinth). J Environ Sci Health Part A 36:1621–1631
- Cay S, Uyanik A, Ozasik A (2004) Single and binary component adsorption on copper (II) and cadmium (II) from aqueous solution using tea industry waste. Sep Purif Technol 38:273–280
- Chowdhury AMR (2004) Arsenic crisis in Bangladesh. Sci Am 291:86–91
- Chowdhury TR, Basu GK, Mandal BK, Biswas BK, Samanta G, Chowdhury UK, Chanda CR, Lodh D, Roy SL, Saha KC, Roy S, Kabir S, Quamruzzaman Q, Chakraborti D (1999) Arsenic poisoning in the Ganges delta. Nature 401:545–546
- Gupta SK, Chen KY (1978) Arsenic removal by adsorption. J Water Pollut Contr Fed 50(3):493–506
- Ingole NW, Bhole AG (2003) Removal of heavy metals from aqueous solution by water hyacinth (*Eichhornia crassipes*). J Water SRT Aqua 52:119–128
- International Consultants, Inc., Malcolm Pirnie, Inc., The Cadmus Group, Inc. (2000) Technologies and costs for removal of arsenic from drinking water. USEPA No. 68-C6-0039



- Jain CK, Ali I (2000) Arsenic: occurrence, toxicity and speciation techniques. *Water Resour* 34:4304–4312
- Kamsonlian S, Suresh S, Ramanaiah V, Majumder CB, Chand S, Kumar A (2011) Biosorptive behaviour of mango leaf powder and rick husk for arsenic (III) from aqueous solutions. *Int J Environ Sci Technol*. doi:[10.1007/s13762-012-0054-6](https://doi.org/10.1007/s13762-012-0054-6)
- Karim MM (2000) Arsenic in groundwater and health problems in Bangladesh. *Water Resour* 34(1):304–310
- Mahavi AH, Naghipour D, Vaezi F, Nazmara S (2005) Tea waste as an adsorbent for heavy metal removal from industrial wastewaters. *Am J Appl Sci* 2(1):372–375
- Mohan D, Pittman JC (2007) Arsenic removal from water/wastewater using adsorbents: a critical review. *J Hazard Mater* 142:1–53
- Mondal P, Majumder CB, Mohanty B (2006) Laboratory based approaches for arsenic remediation from contaminated water: recent developments. *J Hazard Mater* 137(1):464–479
- Ng JC, Wang J, Shraim A (2003) A global health problem caused by arsenic from natural sources. *Chemosphere* 52(9):1353–1359
- Wasewar KL (2010) Adsorption of metals onto tea factory waste: a review. *IJRRAS* 3(3):13
- Wasewar KL, Mohammad A, Prasad B, Mishra IM (2008) Adsorption of Zn using factory tea waste: kinetics, equilibrium and thermodynamics. *CLEAN Soil Water Air* 36(3):320–329
- WHO (1993) Guidelines for drinking water quality. World Health Organization, Geneva

