Desalination and Water Treatment
www.deswater.com
doi:10.5004/dwt.2017.20426

76 (2017) 225–231
May

High turbid water treatment by Kenaf fibers: a practical method for individual water supply and remote areas

Mokhtar Mahdavi[a,b], Amir Hossein Mahvi[c,d], Hamidreza Pourzamani[e,f], Ali Fatehizadeh[a,b,e,f], Afshin Ebrahimi[e,f,*]

[a]*Environment Research Center, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran*
[b]*Student Research Committee and Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran*
[c]*School of Public Health, Tehran University of Medical Sciences, Tehran, Iran, email: ahmahvi@yahoo.com*
[d]*Center for Solid Waste Research, Institute for Environmental Research, Tehran University of Medical Science, Tehran, Iran*
[e]*Environment Research Center, Research Institute for Primordial Prevention of Non-communicable disease, Isfahan University of Medical Sciences, Isfahan, Iran*
[f]*Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran, email: a_ebrahimi@hlth.mui.ac.ir*

Received 31 May 2016; Accepted 6 December 2016

ABSTRACT

Fast and easy access to simple methods for water treatment is one of the most important issues in the field of environmental health, water, and wastewater engineering. The aim of this study was to investigate the application of kenaf fibers for the fast treatment of high turbid water. To evaluate its ability, a pilot plant with various lengths (17.5, 35 and 70 cm) and weight (35 and 70 g) of fibers was used. A synthetic high turbid water (700 NTU) was prepared by mixing the kaolin and riverbed sediments. A samples were analyzed for residual turbidity, true colour, UV_{254} absorbance and total organic carbon (TOC).The findings showed that at the optimum condition, the removal efficiency of turbidity, true colour, and UV_{254} by kenaf fibers with 35 cm length was 99.93, 95.09 and 71.43%, respectively. Also, the quantity of produced water was 0.00368 L/g kenaf/h. This study showed that kenaf fibers can be used for high turbid water and fast treatment by a very simple and easy manner without any energy and chemical addition.

Keywords: High turbid water; Fast water treatment; Kenaf fibers; Emergency condition

1. Introduction

Many countries in the world are experiencing water stress or water scarcity, and water quality assessment is important to use the best quality of water for drinking [1]. Access to safe water is a right for all of the people in the world because it has a very important role in health, sustainable development, and economical growth. Today, despite the technological advancement in water treatment supply systems, a major challenge facing many developing countries is the lack of clean, safe and enough quantity of drinking water for their citizens **[2]**.

The primary aims of all water treatment technologies are to remove physical, chemical and biological contaminants from raw water in the most affordable and efficient manner. The consumption of contaminated water may lead to waterborne disease outbreaks or other illnesses that endanger human health [3]. Therefore, the purification of water is essential in order to make it safe for human

*Corresponding author.

consumption. For many developing countries, rural and remote areas, conventional and newly membrane technologies are very expensive, complex or unavailable [4,5]. Today, many researchers and scientists are looking for simple and inexpensive methods for treating water in remote and deprived areas. However, to achieve these goals physical processes such as coagulation, sedimentation, filtration, and adsorption area priority [6]. Recently, there is growing interest to use agricultural by products as an adsorbent to remove pollutants from water and wastewater. It has been widely investigated that raw and natural agricultural wastes can be alternatives to the current costly methods of water or wastewater treatment [7,8]. There are a few other advanced water treatment processes which are very costly [9–11].

Kenaf fiber is a good example for this matter that some recent studies have addressed. Kenaf is one of the members of hibiscus family (*Hibiscus cannabinus* L.). It is a fibrous herbaceous plant with large biomass production and fast growth rate [12,13]. Kenaf processing factory produces waste which can be used for other applications. Kenaf plant contains three types of fiber include bast, core, and pith. Bast refers to the outer section of the stalks and core is the inner part. They represent about 30 and 70% of the dry weight of the stalks, respectively. The pithconsists exclusively of parenchymatous cells [14]. Bast fibers have attractive mechanical properties that enable their use as alternatives to glass fibers as reinforcing elements in polymer composites [15,16]. Adsorption process is the most practical application of kenaf fibers that has been used in other studies for water and wastewater treatment process. Kenaf has shown a good capacity to bioremediation and heavy metals removal from wastewater and aqueous solutions [17–19].

The main purpose of this study was to investigate the ability of the kenaf fibers as a natural cellulosic micro filter to remove turbidity, colour and organic matter from aqueous solutions and to determine its capacity to produce clean water. And finally, the aim of this project was to produce an effective and efficient method for water purification with minimal cost, complexity and simple structure for remote and deprived areas.

2. Materials and methods

2.1. Chemical soaking and preparation of kenaf fibers

In this study, Iranian kenaf fibers were used. The long fibers were cut into 35 and 60 cm in length. For comparison of fiber performance, a constant weight of 75 g was selected for both pieces. Kenaf fibers were washed with distilled water several times, to remove debris and impurities. After that, kenaf fibers were kept for 24 h in distilled water. Again, they were kept for 24 h in 0.01 molar NaOH and 24 h in 0.01 molar HCl. Then, the fibers were washed with distilled water several times until the pH reached 7.

2.2. Preparation of water samples

For the preparation of the turbid stock solution, 10 g of kaolin, heavy grade (BDH Chemicals) was added to 2 L distilled water. Separately, 2 kg of riverbed sediment was added into 2 L of distilled water and mixed for 1 h. Then, settling of about 60 min, the suspended solution was added to prepared kaolin solution. Total volume was made up to 3.5 L. The suspension was stirred slowly at 30 rpm for 24 h for hydration of the particles and uniform dispersion [20,21]. Then, the stock solution was used in the preparation of water samples with turbidity of 700 NTU by serial dilution.

2.3. Analytical methods

All samples were analyzed for residual turbidity, true colour, total coliforms, UV_{254} absorbance, and TOC. All experiments were conducted according to the Standard Method for the Examination of Water and Wastewater. Turbidity, colour, TDS, EC and pH of the samples were measured by TN-100 (EUTECH) Turbidimeter, DR 5000-HACH LANGE, EC meter SENSION5 (HACH LANGE) and pH-meter model CG 824, respectively. For true colour and UV absorbance at 254 nm analysis, treated water was already filtered using a 0.45-μm filter.

2.4. Pilot plant and its components

In this study, a pilot plant was used which consists of 3 sections: 1) raw water tank, 2) treated water tank and 3) flexible tubular pipe with prepared fiber being placed in it (Fig. 1A and B). About 3 L of turbid water sample (700 NTU) entered to the raw water tank. Water passed through the hollow fiber of kenaf without any external energy and reached to treated water tank. The duration and the amount of water passing through the kenaf fibers were recorded at different time intervals. The weight and length variation of kenaf fibers were also investigated for water transfer. These variations include 70 g of kenaf fibers with 35 cm length, 35 g of kenaf fibers with 35 cm length, 35 g of kenaf fibers with 17.5 cm length and 35 g of kenaf fibers with 70 cm length. For each experiment, first 50 ml of produced water was discarded, and then analysis conducted on later outputs. All experiments were conducted in 3 h interval until the kenaf output reached to zero.

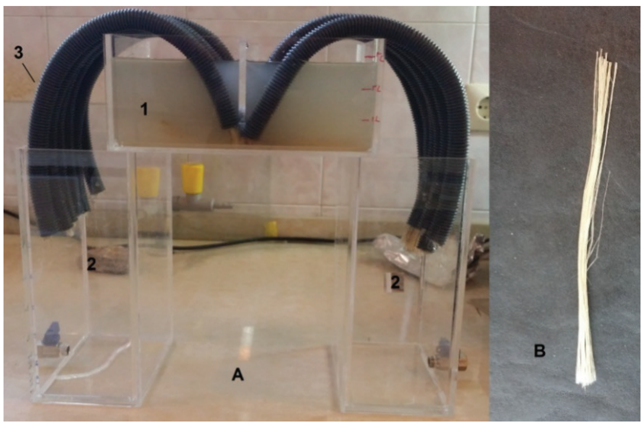

Fig. 1. (A) A pilot plant of natural cellulosic micro filtration. (B) Kenaf fibers.

3. Results and discussion

3.1. Preparation of kenaf fibers

Table 1 shows the characteristics of fiber hemp extracts that have been soaked in extraction solutions (NaOH, HCl and distilled water solution). At first they had impurities that could interfere with the quality of treated water. Therefore, for removal of all impurities and dirty attached material to kenaf fibres they placed in it. It can be seen that large amount of colour, turbidity and organic matter of kenaf fibres structure repelled to extraction solutions. After this process (Table 1) kenaf fibres were washed with distilled water several times and used in this study.

3.2. Quality of synthetic water

In this study, to simulate the actual condition of water in the environment and to test the ability of kenaf fibers, a high turbid and colour water sample was prepared. Table 2 shows the characteristics of synthetic water for the experiment.

3.3. Water production by kenaf

Most cellulosic materials have a tendency to absorb fluid owing to their chemical structure and the hydroxyl groups available in their chain. The hydrogen and oxygen bonds are at the outer surface and immediately absorb any amount of water forming a hydrogen bond. In kenaf fibers, the capillary force would be the major contribution to the adhesion force owning to its hydrophilic nature, so condensation of water from the environment resulted in the formation of a capillary bridge between the tip and fiber during contact, and it contributed to the origin of capillary force. Capillary condensation occurred easily on a hydrophilic surface such as the surface of natural fiber [22–24]. To determine the effect of fiber weight on water productivity, 35 g of kenaf fibers were used in the experiments. The quantities of produced water by these kenafs are illustrated in Fig. 2. For 70 and 35 g of kenaf, the volume of water produced was about 0.25, 0.125 L during the first 30 min and 1.35, 0.68 L after 3 h, respectively. Finally, they produced 13.15- and 5 L of the clean water after 48 h. From Fig. 2, it can be concluded that water productivity with 70 g of kenaf is almost twice in contrast with 35 g ones.

To determine the effect of kenaf length on water production, three different lengths of fiber with equal weight (35 g), including 17.5, 35 and 70 cm were selected and used in our pilot plant. The results of these experiments are presented in Fig. 3.

The results showed that in the first 30 min, the volumes of produced water for 17.5, 35 and 70 cm fibers of kenaf were 0.32, 0.125 and 0.035 L, respectively (Fig. 3). Also, in the next 3 h, the produced water volumes reached to 0.88, 0.68 and 0.2 L, respectively. After 48 h operation, the kenaf fibers hadn't any water transmission and their final water productions were 5.2, 5 and 1.71 L. One of the reasons for low water production by 17.5 cm kenaf that more near to 35 cm results is related to the amount of kenaf length that situated under surface of the water in the raw water tank. For kenaf with 17.5 cm length, 5 cm of it was placed in raw water tank and about 10 cm was set

Table 2
Feed water characteristics before treatment with kenaf fiber

Parameter	Value (± SD)
Turbidity (NTU)	700 (±2)
Colour (Pt. Co)	265 (±1)
pH	8 (±0.1)
Temperature °C	21
UVA_{254}nm (cm^{-1})	0.35 (±002)
TOC (mg/L)	45 (±.06)

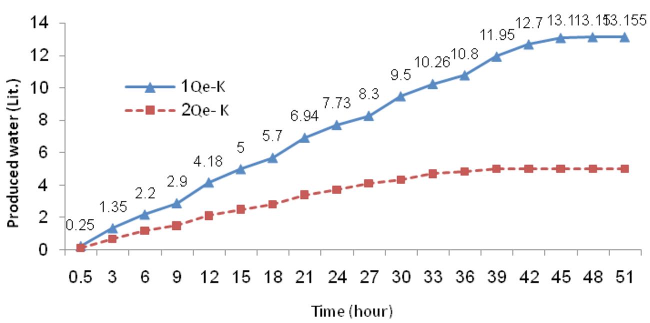

Fig. 2. Water production by 35 cm kenaf length: Qe-k1; 70 g, Qe-k2; 35 g.

Table 1
Some specifications of treated kenaf by acid, base and distilled water

Status	Turbidity (NTU)	Colour (Pt. Co Units)	UV254 (1/cm)	pH
Specification of distilled water after 24 h exposure to kenaf fibers	2	33	0.36	6.5
Specification of discarded 0.01 molar NaOH solution after 24 h exposure to kenaf fibers	1.71	300	0.942	10
Specification of discarded 0.01 molar HCl solution after 24 h exposure to kenaf fibers	1.5	27	0.047	3
Specification of distilled water after 24 h exposure to kenaf fibers that soaked in both 0.01 molar NaOH and HCl	1.4	25	0.03	7

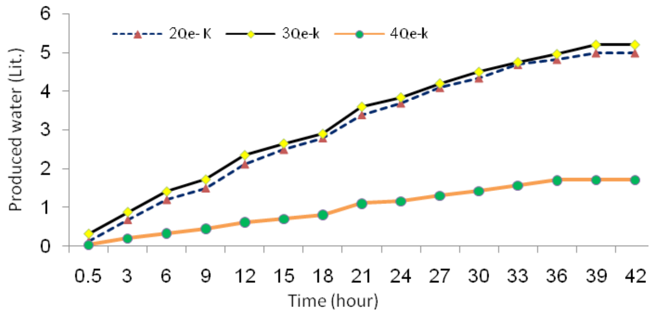

Fig. 3. Water production by different length of the fibers and an equal weight of 35 g: Qe-k2 35 cm, Qe-k3; 17.5 cm and Qe-k4; 70 cm.

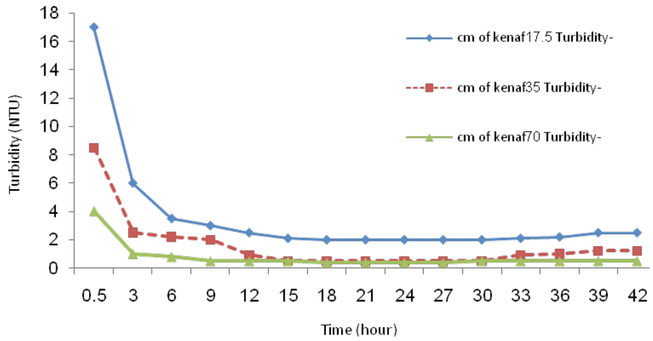

Fig 4. Turbidity variation of produced water by different length of the fiber and an equal weight of 35 g.

to above of the siphon; therefore, only 2.5 cm of the fibers was placed under siphon section. In contrast, for kenaf fibers with 35 cm, about 20 cm of the fibers was placed below the raw water surface or siphon section, thus, there was more gravity force, adhesion and surface tension that causes more water to be transfer and to be produced. In our study, it was found that length of kenaf under raw water surface or siphon section has limited effect on water transfer. Our claim can be seen in Fig. 3. In fact, for kenaf fibers with 70 cm length, about 55 cm of fiber was placed under raw water surface or siphon section, so it is mandatory for water to pass through 55 cm porous way. This action reduced water velocity and transfer of it during pass way. Eventually, kenaf fibers with 17.5 cm length produced more water than 35 or 70 cm of kenaf fibers. In this study, kenaf fibers with 35 cm length can produce an optimum 0.00368 L. water/g kenaf·h.

3.3. Quality of treated water

3.3.1. Turbidity removal

The main mechanisms for turbidity removal by kenaf fibers are screening and enmeshment by very tiny pore and porous structures. In fact, all particles larger than kenaf fibers pore cannot pass through the pores, so they are removed from water, effectively. Another mechanism that was found in this study is when water passes from kenaf fibers by capillary action; the suspended particles remain in raw water while water molecules pass the fibers easily. Here, results showed that by increasing kenaf fibers length, the turbidity of produced water was decreased. From Fig. 4, it can be seen that for kenaf with 17.5 cm length, initial turbidity of 700 NTU reached to 17 and 6 NTU, during the first 30 min and after 3 h, respectively. Finally, after 15 h it reached a constant value of 2 NTU. However, for kenaf with 35 cm length, the initial 700 NTU turbidity decreased to 8.5 NTU during the first 30 min and 2.5 NTU after 3 h. Finally, after 15 h it reached a constant value of 0.5 NTU. Kenaf fibers with 70 cm length reveal effective results, so they produced water with 4, 1 and 0.4 NTU during the first 30 min, 3 h and 15 h, respectively. Alfred et al. used crude seed powder of kenaf as a coagulant for high turbid water purification. Results showed that it was very effective in removing turbidity, with an efficiency of 96.0% [25]. In our study, without any energy consumption for coagulation and flocculation, 99.93% removal efficiency for turbidity was attained by 35 cm kenaf with 70 g weight.

The chlorination process is less effective in turbid water. Ideally, the turbidity of water should be less than 5 NTU or even 1 NTU. Turbidity can provide food and shelter for pathogens so it causes poor disinfection.

3.3.2. Colour removal

Suspended and dissolved particles influence colour of water. Soil runoff produces a variety of yellow, red, brown and gray colours. In our raw samples, the colour of samples was mainly brown and yellow. The mechanism that removes colour from raw water includes screening, enmeshment through fibers strain and adsorption. The first two mechanisms predominantly conducted by particulate removal or colour related to suspended particles. But, latest mechanism (adsorption) deal to dissolve colour removal. Other study showed that acid treated kenaf fiber is an effective adsorbent for the removal of Methylene blue dye (MB) from aqueous solutions [26]. Fig. 5 shows the colour removal by the studied kenaf fibers. It can be seen that with an increase in kenaf length, colour removal efficiency was increased. For kenaf fibers with 17.5 cm lengths, the final colour of treated water reached to 110 Pt.Co units from 265 Pt.Co during the first 30 min. Also, the colour unit reached 68 Pt.Co after 3 h and finally after 18 h reached a constant value of 32 Pt.Co units. For kenaf fibers with 35 cm length, colour in treated water reached 70, 23 and 13 Pt.Co units after 30 min, 3 h and 15 h, respectively. Finally, for kenaf fibers with 70 cm length, colour in treated water reached to 25, 10 and 4 Pt.Co units after 30 min, 3 h and 15 h, respectively. From these, it can be concluded that by increasing kenaf length, colour removal efficiencies were increased. The probable reason for this phenomenonis related to additional time for adsorption and enmeshment through porous kenaf fibers. Also, results by Gharehchahi et al., on the application of kenaf fibers for water hardness reduction showed that kenaf has a considerable potential in water softening. They indicated that the length of kenaf has a dominant positive effect on water hardness removal, while time has a negative effect [27]. Our results showed that the removal efficiencies of colour by 17.5, 35 and 70 cm of kenaf were 87.92, 95.09 and 98.49%, respectively. In comparison with a previous study on water treatment by newly coag-

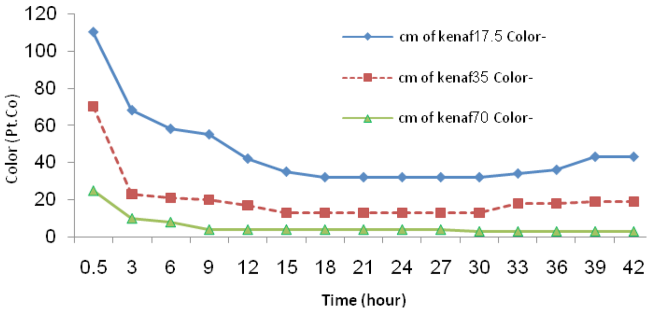

Fig. 5. Residual colour in treated water by different length of the fiber and an equal weight of 35 g.

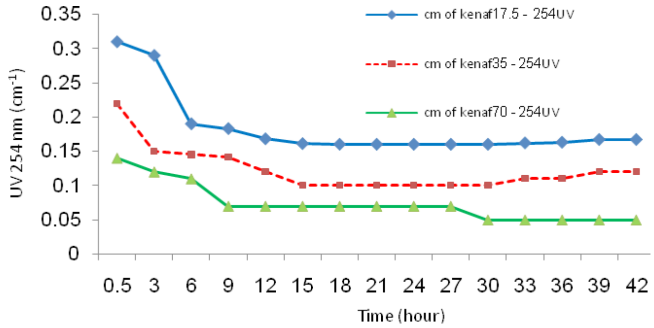

Fig. 6. Organic matter variation in treated water by different length of the fiber and equal weight of 35 g.

ulant [9,20,21], it can be concluded that water treatment by kenaf fibers has a good and nearly equal efficiency.

3.3.3. Organic matter removal

Natural organic matter (NOM) has a significant impact on drinking water quality. This impact is very important when disinfection of drinking water is compulsory in all situations. During disinfection process, chlorine can react with natural organic matter [28] and consequently form disinfection by-products (DBPs), which may be of concern due to potential health risks associated with consumption and exposure [29]. TOC concentration and UV_{245}nm absorption of raw sample were about 45 mg/L and 0.35 cm^{-1}, respectively. Fig. 6 shows the variation of UV_{254} during water treatment by different length of kenaf fibers.

Results showed that for 17.5 cm kenaf length, UV_{254} value reached 0.31, 0.29 and 0.16 cm^{-1} after 0.5, 3 and 15 h, respectively. After 15 h it remained constant until 42 h. However, for kenaf fibers with 35 cm length, UV_{254} value reached to 0.22, 0.15 and 0.1 cm^{-1} after the same above operation times, respectively. Also for 70 cm kenaf, UV_{254} value decreased to 0.14, 0.12 and 0.07 cm^{-1}, respectively. The removal efficiencies of UV_{254} by these fibers were 54.29, 71.43 and 80%, respectively. In the removal process, several mechanisms are responsible for the removal of organic matter by kenaf; one might be adsorption. Another study showed that the usage of core and bast fibers of kenaf improve adsorption [30]. The $^{-}$OH group on the surface of kenaf will attract the organic matter by attraction forces and trap them on the porous of the kenaf. Organic matter present as a suspended or dissolved in water. It is obvious that the suspended fraction is removed by enmeshment among very tiny branch and tissues of the fibers (Fig. 7).

Functionally, the organic material is predominantly phenolic and carboxylic in nature, but also contains alcohol, purine, amine and ketone groups and is often described as a weak anionic polymer [31]. So, most of the organic matter or turbidity in water bodies has negatively charged functional groups [32]. On the other hand, most natural fiber contains three hydroxyls (OH) groups. These hydroxyl groups can form hydrogen bonds inside the macromolecule itself (intra-molecular) and between other cellulose macromolecule (inter-molecular). This is the reason why all natural fibers are hydrophilic in nature. However, the negative charge of kenaf fibers repels particle and organic matter that has a negative charge. Thus when water molecules pass through kenaf with hydrogen bonds, defense force between them, blocks the suspended particles or other particles to pass through kenaf fibers. According to this information, it is hypothesized that repulsion force between negative functional groups in kenaf fibers and negative charge of organic molecules such as humic and fulvic acid prevent the transmission of organic matter during the passage of water across kenaf fibers. Results of this study showed that TOC concentration in treated water reached to 22, 8 and 6 mg/L for kenaf fibers with 17.5, 35 and 70 cm length, respectively.

3.3. Scanning electron microscopy (SEM)

To study the surface and adsorption behavior of kenaf fibers, the scanning electron microscopy (SEM) analysis was carried out before and after high turbid water contact (Fig. 7A and B). It can be seen, the morphology of the kenaf fibers surface before high turbid water treatment was clean, rough and porous (Fig. 7A). These specifications provide a high possibility for colour, particle and organic matter to be trapped and adsorbed to the inner and outer surface of pores. After these actions, it can be seen that the surface of kenaf is covered by a thick layer of removed material from water (Fig. 7B).

3.4. Fourier transform infrared (FTIR) spectroscopy

Fourier transform infrared spectroscopy was performed to characterize the chemical functional groups in kenaf fibers before and after high turbidity water treatment. The FTIR spectra of kenaf fibers are shown in Fig. 8. Both spectra are dominated by the three peaks at 1030, 2354 and 3333 cm^{-1}. The band at 3333 is assigned to hydroxyl stretching which belongs to cellulose [33]. This band undergoes some shift after the adsorption of some organic matter or other pollution in raw water due to the interaction between O–H and another functional group of pollutants.

The band at 1030 cm^{-1} corresponds to the stretching which belongs to C–O in hemicelluloses, cellulose or lignin [34,35]. Another small peak of 1423 cm^{-1} is related to carbonate anion. The FTIR investigation showed that acidic functional groups (hydroxyl and carboxylic) of used kenaf mainly contribute to the adsorption of organic matter that has negative functional group. The application of kenaf fibers in water treatment as an unconventional water treat-

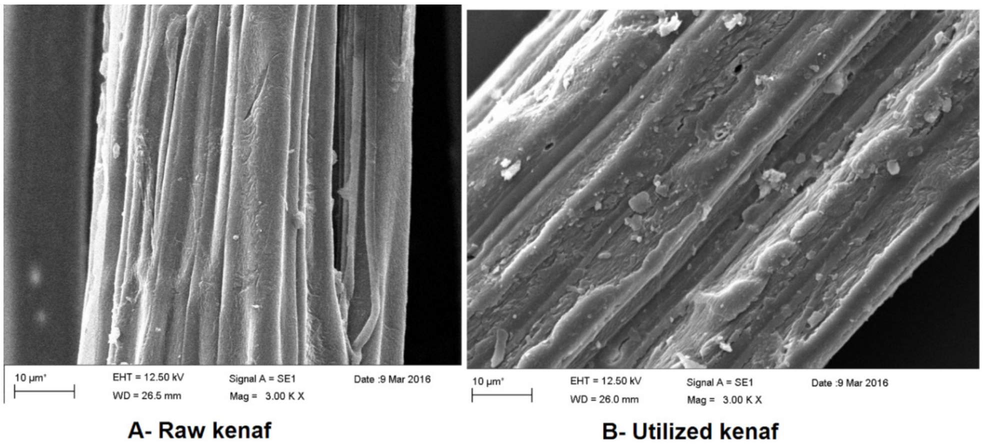

Fig. 7. SEM micrograph (magnification: 3.00 k) of (A) raw kenaf fibers before water treatment, (B) used kenaf fibers after high turbid water treatment.

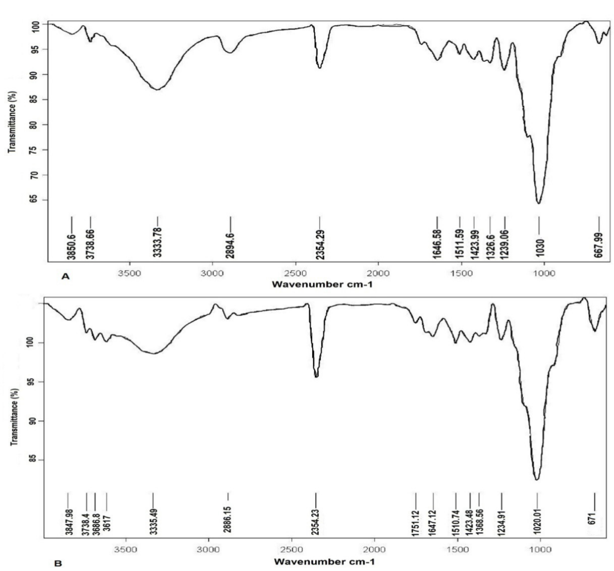

Fig. 8. FTIR spectra of the kenaf fibers, (A): raw fibers;(B): fibers after water treatment.

ment process is a very useful method with respect to other unconventional processes presented so far [36–40].

4. Conclusion

Results of this study showed that kenaf fibers have very good efficiency to produce drinking water from high turbid water. It can be concluded that kenaf with 35 cm length has better efficiency than 17.5 and 70 cm length in water production. However, with increasing length of kenaf, produced water had a better quality. The 70 g of kenaf with 35 cm length could produce 0.00368 L/g kenaf·h. The removal efficiency of turbidity, colour, and UV_{254} by 35 cm kenaf fibers were 99.93, 95.09 and 71.43%, respectively. These results achieved without any energy and chemical matter consumption. On the other hand, kenaf fibers are very inexpensive, simple and easily portable by everyone and anywhere. Also, it is easily stored and is stable in most conditions.

Fast and easy access to simple methods for water purification is one of the most important issues in the field of environment, and water and wastewater engineering. This subject becomes more attractive when the water supply to individual or remote areas encounters some limitations like energy consumption, the complexity of instruments or method and chemical matter for the treatment of water. Therefore, kenaf fibers can be used as a very simple, cheap and effective method for water treatment.

Acknowledgements

The authors acknowledge funding provided by the Isfahan University of Medical Science, School of Health, Environmental Health Engineering Department, Isfahan, Iran for this approved project with 194202 code number. The authors gratefully acknowledge the student research committee, school of health, Isfahan University of Medical Science, Isfahan, Iran. Also from Dr. Mohammah Ghasemian, Dr. Ensieh Taheri, Eng. Hossein Farokhzadeh and Mrs. Asrin Pashaee for their assistance. This article is dedicated to my father and mother.

References

[1] H. Gharibi, A.H. Mahvi, R. Nabizadeh, H. Arabalibeik, M. Yunesian, M.H. Sowlat, A novel approach in water quality assessment based on fuzzy logic, J. Environ. Manage., 112 (2012) 87–95.

[2] A. Ebrahimi, M. Mahdavi, A. Ghasemian, P. Poursafa, F. Sharifi, R. Mohammadi, M. Nejatifar, M.M. Amin, H. Asayesh, S. Safiri, Trends in health burden of untreated water and insanitary environments in Iran, 1990–2010: Findings from the global burden of disease study 2010, M.J.I.R.I, 30 (2016) 899–907.

[3] S. Khan, M. Shahnaz, N. Jehan, S. Rehman, M.T. Shah, I. Din, Drinking water quality and human health risk in Charsadda district, Pakistan, J. Cleaner. Production, 60 (2013) 93–101.

[4] S.M. Avvannavar, M. Mani, N. Kumar, An integrated assessment of the suitability of domestic solar still as a viable safe water technology for India, Environ. Eng Manage. J., 7 (2008) 667–85.

[5] K.A. Ghebremichael, Moringa seed and pumice as natural alternative materials for drinking water treatment, PhD, KTH land and water resources engineering 2004.
[6] W.H.O, Household Water Treatment and Safe Storage: Manual for the Trainer, 2013.
[7] A.H. Mahvi, F. Gholami, S. Nazmara, Cadmium biosorption from wastewater by Ulmus leaves and their ash, Eur. J. Sci. Res., 23 (2008) 197–203.
[8] A. Maleki, A.H. Mahvi, M.A. Zazouli, H. Izanloo, A.H. Barati, Aqueous cadmium removal by adsorption on barley hull and barley hull ash, Asian J. Chem., 23 (2011) 1373–1376.
[9] M. Mahdavi, M. M. Amin, Y. Hajizadeh, H. Farrokhzadeh, A. Ebrahimi, Removal of different NOM fractions from spent filter backwash water by polyaluminum ferric chloride and ferric chloride, Arab J Sci Eng., (2016), DOI 10.1007/s13369-016-2364-3.
[10] A.H. Mahvi, A. Maleki, R. Rezaee, M. Safari, Reduction of humic substances in water by application of ultrasound waves and ultraviolet irradiation, Iran. J. Environ. Health Sci. Eng., 6 (2009) 233–240.
[11] E. Bazrafshan, A.H. Mahvi, S. Nasseri, M. Shaieghi, Performance evaluation of electro coagulation process for diazinon removal from aqueous environments by using iron electrodes, Iran. J. Environ. Health Sci. Eng., 4 (2007) 127–132.
[12] S. Irmak, I. Öztürk, Hydrogen rich gas production by thermocatalytic decomposition of kenaf biomass, Int. J. Hydrogen Energy., 35 (2010) 5312–5317.
[13] H.P.S.A. Khalil, A.F.I. Yusra, A.H. Bhat, M. Jawaid, Cell wall ultrastructure, anatomy, lignin distribution, and chemical composition of Malaysian cultivated kenaf fiber, Ind. Crops Prod., 31 (2010) 113–121.
[14] M.T. Paridah, A.B. Basher, S. SaifulAzry, Z. Ahmed, Retting process of some bast plant fibres and its effect on fibre quality: A review, Bio Resour., 6 (2011) 5260–5281.
[15] O. Faruk, A.K. Bledzki, H.-P. Fink, M. Sain, Biocomposites reinforced with natural fibers: 2000–2010, Prog. Polym. Sci., 37 (2012) 1552–1596.
[16] M. Tajvidi, R.H. Falk, J.C. Hermanson, Time–temperature superposition principle applied to a kenaf-fiber/high-density polyethylene composite, J. Appl. Polym. Sci., 97 (2005) 1995–2004.
[17] C.M. Hasfalina, R.Z. Maryam, C.A. Luqman, M. Rashid, The potential use of kenaf as a bioadsorbent for the removal of copper and nickel from single and binary aqueous solution, J. Nat. Fibers., 7 (2010) 267–275.
[18] C.M. Hasfalina, R.Z. Maryam, C.A. Luqman, M. Rashid, Adsorption of copper (II) from aqueous medium in fixed-bed column by kenaf fibres, APCBEE, Procedia., 3 (2012) 255–263.
[19] Y.C. Wong, S.H. Lim, N.A. Atiqah, Remediation of industry wastewater effluent by using kenaf as waxes absorbent, Prese. Environ. Sustainable. Dev., 7 (2013).
[20] A. Ebrahimi, E. Taheri, A. Pashaee, M. Mahdavi, Effectiveness of poly aluminium ferric chloride for turbidity and colour removal from low to medium turbid water, Arch. Hyg. Sci., 3 (2014) 175–183.
[21] A. Ebrahimi, E. Taheri, A. Pashaee, M. Mahdavi, The effectiveness of polyaluminum ferric chloride (PAFCl) for turbidity and colour removal from Isfahan raw water, Desal. Water Treat., 55 (2015) 1966–1972.
[22] Z. Mitul, Absorbency characteristics of kenaf-core particles, Ph.D. thesis, North Carolina State University, USA, 2004.
[23] D.L. Sedin, K.L. Rowlen, Adhesion forces measured by atomic force microscopy in humid air, Anal. Chem., 72 (2000) 2183–2189.
[24] B. Bhushan, S. Sundararajan, Micro/nanoscale friction and wear mechanisms of thin films using atomic force and friction force microscopy, Acta Mater., 46 (1998) 3793–3804.
[25] J.N. Alfred, A.Y. Sangodoyin, Efficacy of Hibiscus cannabinus L. (kenaf) crude seed powder and its methanol extract in water purification, Civil. Environ. Res., 3 (2013).
[26] D.K. Mahmoud, M.A.M. Salleh, W.A.W.A. Karim, A. Idris, Z.Z. Abidin, Batch adsorption of basic dye using acid treated kenaf fibre char: equilibrium, kinetic and thermodynamic studies, Chem, Eng, J., 181 (2012) 449–457.
[27] E. Gharehchahi, A.H. Mahvi, S.M.T. Shahri, R. Davani, Possibility of application of kenaf fibers (*Hibiscus cannabinus* L.) in water hardness reduction, Desal. Water Treat., 52 (2014) 6257–6262.
[28] A. Matilainen, M. Vepsalainen, M. Sillanpaa, Natural organic matter removal by coagulation during drinking water treatment: A review, Adv. Colloid. Interface. Sci., 159 (2010) 189–197.
[29] S.D. Richardson, C. Postigo, Drinking water disinfection by-products, Emerging organic contaminants and human health, Springer, New York, 2011, pp. 93–137.
[30] M.S. Sajab, C.H. Chia, S. Zakaria, S.M. Jani, M.K. Ayob, K.L. Chee, P.S. Khiew, W.S. Chiu, Citric acid modified kenaf core fibers for removal of methylene blue from aqueous solution, Biores. Technol., 102 (2011) 7237–7243.
[31] K.E. Dennett, A. Amirtharajah, A. Studstill, T.F. Moran, J.P. Gould, Humic substance removal and minimization of trihalomethanes by ferric chloride coagulation, AWWA, 1995.
[32] Y.H. Shen, T.-H. Chaung, Removal of dissolved organic carbon by coagulation and adsorption from polluted source water in Southern Taiwan, Environ. Inter., 24 (1998) 497–503.
[33] M.S.U. Rehman, I. Kim, J.-I. Han, Adsorption of methylene blue dye from aqueous solution by sugar extracted spent rice biomass, Carbohydr. Polym., 90 (2012) 1314–1322.
[34] H. Sosiati, Harsojo, Effect of combined treatment methods on the crystalinity and surface morphology of kenaf bast fibers, Cellul. Chem., Technol., 48 (2014) 33–43.
[35] A. Kardam, K.R. Raj, S. Srivastava, M.M. Srivastava, Nanocellulose fibers for biosorption of cadmium, nickel, and lead ions from aqueous solution, Clean. Technol. Environ. Policy., 16 (2014) 385–393.
[36] A.H. Mahvi, V. Alipour, L. Rezaei, Atmospheric moisture condensation to water recovery by home air conditioners, Amer. J. Appl. Sci., 10 (2013) 917–923.
[37] M. Mahdavi, A.H. Mahvi, S. Nasseri, M. Yunesian, Application of freezing to the desalination of saline water, Arab. J. Sci. Eng., 36 (2011) 1171–1177.
[38] E. Bazrafshan, F.K. Mostafapour, M. Ahmadabadi, A.H. Mahvi, Turbidity removal from aqueous environments by Pistacia atlantica (Baneh) seed extract as a natural organic coagulant aid, Desal. Water Treat., 56 (2015) 977–983.
[39] A. Dalvand, E. Gholibegloo, M.R. Ganjali, N. Golchinpoor, M. Khazaei, H. Kamani, S.S. Hosseini, A.H. Mahvi, Comparison of Moringa stenopetala seed extract as a clean coagulant with alum and Moringa stenopetala-Alum hybrid coagulant to remove direct dye from textile wastewater, Environ. Sci. Pollut. Res., 23 (2016) 16396–16405.
[40] A. Jafari, A.H. Mahvi, Reactive dyes (R. Blue 19 and R. Red 120) removal by a natural coagulant: Moringa oleifera, Environ. Eng. Manage. J., 14 (2015) 2393–2398.