Journal of Applied Science and Engineering, Vol. 23, No. 1, pp. 61–68 (2020) DOI: 10.6180/jase.202003_23(1).0008

Preparation of Household Water Filter

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Abstract

There is an urgent need to identify cheaper and efficient methods of removing contaminants as the demand for clean water rises. In this study, the household water filters were prepared from low-cost materials based on kaolin powder and combustible materials as palm fronds powder which acts as pore creating agent. The filter samples with different content (0, 10, 20, 30) wt% of palm fronds powder were fabricated using a dry pressing method and fired at 1250 °C. Thereafter, the porous ceramic filter samples were carbonized at 950 °C for 6 hrs. The ceramic filters were characterized by X-ray diffraction and SEM. Physical properties (linear shrinkage (L.Sh.), apparent porosity (A.P.), water absorption (W. A.), apparent solid density (A.S.D.), permeability and diametrical compression strength) before and after carbonization was also studied. The total dissolved solids (TDS), turbidity (Tur.), pH, conductivity (Ec), free Cl, and salt percentage (sal %) of water from both household water filters with and without activated carbon was also examined before and after filtration. The presence of heavy metals from the water was analyzed before and after filtration.

***Key Words*: Porous Ceramic Household Water Filter, Kaolin Powder, Carbonization**

1. Introduction

Water is important for human; it contains around 60% of the weight of human body. The water we drink daily must be free from any pollution such as organisms or chemical substances that may affect health and quality of life [1]. There are two types of drinking water including pure water and safe water. Pure water may be defined as water that is free of extraneous substances whether harmless or not. While safe water may have some contaminants but these contaminants will not effect human health, and must be at an acceptable range [2]. Water is media for thousands of microorganisms, some of which cause disease. Pathogens (e.g., bacteria, viruses, protozoa, and helminthes) in water cause a variety of diarrhea-related diseases, such as cholera [3].

Drinking water contains not only microbial contaminants, but also chemical contaminants that range from organic (benzenes, polychlorinated) to inorganic (chloride, nitrates, magnesium, phosphate, iron) compounds [4].

Ceramics are the most compatible products with their qualities of being resistant to corrosion, erosion, and abrasion, thermal shocks and inert [5]. Ceramics filter has shown to be an excellent tool in water treatment as materials are locally available and the method of production is simple to all [6], it can be manufactured easily in different shapes like a flower pot, disc, and candle [7]. Ceramic water filters proved to be one of the five best treatment options available for reducing turbidity and bacteria [8]. Kaolin ($Al_2O_3.2SiO_2.2H_2O$) is a naturally hydrated aluminum silicate mineral, has a high Si and Al content, which has colors ranging from white to red due to the amounts of iron oxide presence [9].

Some investigations reported many technologies used for water treatment such as reverse osmosis process by using ceramic membrane, chemical addition to drinking

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water such as Chlorine, ozonitation, and adsorption by using activated carbon [10].

Unfortunately, ceramic membrane fabrication, even though commercially available, still remains highly expensive from a technical and economic point of view due to the use of expensive powders such as α, γ alumina, zirconia, titanium oxide, and silica [11].

Chlorine or chloramines were added for drinking water disinfection. The reaction of chlorine with organic matter can produce products such as trihalomethanes, that may increase the risk of cancers [12].

For many years activated carbon (AC) has been used as water filtering medium for purification of drinking water. It is widely used to remove contaminants from water due to their high capacity for adsorption of such compound, because of their large surface area, surface charge and porosity. These contaminants cause bad tastes and odors, and also cause infection. Activated carbon can remove the tastes and odors, and the biological oxygen demand (BOD) and also the total suspended solids (TSS) from the drinking water [13].

Adsorption can be defined as a physicochemical process that occurs at the interface of solid-liquid [12,14]. The factors that effect on adsorption are: (a) the physical and chemical properties of the absorbent such as pore size, surface area and chemical composition; (b) the physical and chemical properties of the adsorbate such as, molecular size, molecular polarity, chemical composition and the adsorbate concentration in the solution; (c) the time of residence in the system and (d) liquid phase properties such as temperature and pH [15].

Kaolinite is considered as a good adsorption material for toxic heavy metals removal and is used as liner in water treatment plants, as shown in reported results [16–18].

No one piece of treatment equipment manages all contaminants. All treatment methods have limitations and often a combination of treatment processes is required to effectively treat the water. Different types of carbon remove different contaminants and no one type of carbon removes all contaminants at maximum efficiency [19].

Numerous studied have been carried out on using porous ceramic filter alone or using activated carbon filter for filtering. To date, no investigations were made that use porous ceramic filter with activated carbon at the same filter to get safe water. In the present work we offer a low-cost water treatment filter manufactured from kaolin powder with palm fronds powder as pore forming agent to reach to the recent needs for safe and tasty tap water.

2. Materials and Methods

2.1 Samples Preparation

Kaolin sample was collected from the west desert (Dwekhla) in Iraq. The clay was grounded by using a ball mill to get particle diameter less than or equal to 75 µm. The composition of kaolin powder was determined by wet chemical analysis technique as illustrated in Table 1.

Palm fronds powder that was used as a pore former was obtained from palm fronds. It was dried in the sun and then ground and sieved to get particle of diameter between 106–400 µm.

Sieved kaolin powder and combustible material were mixed in the selected proportion as illustrated in Table 2. The mixtures were then molded into disk shape (25 mm diameter and 3 mm thickness) by dry pressing method at 5 Tons.

Table 2. The Composition of kaolin and palm fronds powders

Samples number	Kaolin powder wt%	Palm fronds powder wt%	Samples number after carbonization
1A	100	0	1B
2A	90	10	2B
3A	80	20	3B
4A	70	30	4B

Table 1. The Composition of kaolin powder

Kaolin contents	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	CaO	SO_3	K_2O	Na_2O
Composition %	49.38	32.72	1.08	2.07	0.18	1.19	0.05	0.44	0.22

The filters were air-dried at room temperature for 1 day and then fired in a programmable furnace. Three stages have been determined: (1) the temperature was increased from room temperature to 700 °C at 3 hrs. and 1 hr. as soaking time, (2) the temperature increased to 1000 °C at 2 hrs., and soaked for 2 hrs., and (3) the temperature increased to 1250 °C at 1 hr., holding the final temperature for 2 hrs.

2.2 Carbonization Process

The diffusion of active carbon in sintered porous ceramic was carried out by carbonization process. Sintered ceramic filters were impeded in sealed box containing a mixture of grounded coal with heat treated at 950 °C for 6 hrs. Figure 1 shows the samples after firing (before and after carbonization).

2.3 Ceramic filter Properties

2.3.1 Microstructural Properties

XRD analysis was performed to identify crystalline phases. (SHIMADZU 6000) diffractometer with CuKα radiation ($\lambda = 1.5406$ Å), was used. Microstructural and surface porosity of the cross section samples were investigated by SEM type (FEI Quanta 450).

2.3.2. Physical Properties

2.3.2.1 Linear Shrinkage (L.Sh.)

The linear shrinkage of all samples was determined by measuring the differences in disk diameters before and after sintering as shown in Eq. (1) according to ASTM.

$$\text{Linear Shrinkage (L. S.\%)} = \frac{L_o - L}{L_o} \times 100 \tag{1}$$

where (L_o) length of test specimen before firing and (L) fired length of test specimen.

2.3.2.2 Apparent Porosity (A.P.) and Water Absorption (W.A.) Test

The apparent porosity and water absorption of the fired samples was determined by Archimedes principle. The percentage of apparent porosity and water absorption are calculated according to the ASTM (C373–72) as shown in Eqs. (2) and (3) respectively.

$$\text{Apprent Porosity (\%)} = \frac{S - D}{S - I} \times 100 \tag{2}$$

$$\text{Water Absorption (\%)} = \frac{S - D}{D} \times 100 \tag{3}$$

where: S = soaked mass (g), D = dry mass (g), I = suspended mass (g).

2.3.2.3 Apparent Solid Density (A.S.D.)

The apparent solid density of all the fired samples was determined by Archimedes principle and given in terms of masses as shown in Eq. (4) according to the ASTM (C373–72):

$$\text{Apparent solid density} = \frac{D}{D - I} \times \frac{\text{lg}}{\text{cm}^3} \tag{4}$$

2.3.2.4 Permeability Test

In this method a constant pressure of water is applied over the porous ceramic sample. The permeability of all samples is calculated according to Darcy law as follows:

$$K = \frac{TV}{APt}$$

where: (K) permeability (cm^2/bar. Sec), (V) collected volume of water (cm^3), (T) thickness of the sample (cm), (A) cross sectional area of the sample (cm^2), (P) pressure (bar) and (t) time required to collect the volume of water (sec).

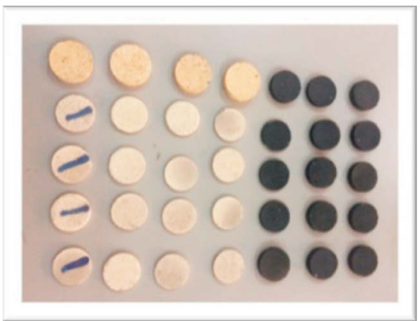

Figure 1. Samples after firing (before and after carbonization).

2.3.2.5 Diametrical Strength Test

The mechanical resistance test was performed using diametrical compressive strength, and calculated by using the equation:

$$\delta = \frac{2F}{\pi D t}$$

where: (δ) diametrical compressive strength (Pascal), (F) applied load (N), (D) sample diameter (m) and (t) sample thickness (m).

2.4 Water Analysis

Water samples was collected from domestic taps (Baghdad-Al-Resafa) using cleaned sterile plastic container and refrigerated. Several tests were used to examine water before and after filtration as turbidity, pH, Ec, TDS, salt percentage, and free chloride ion.

2.4.1 Adsorption of Heavy Metals

The evaluation of each filter performance to heavy metals was done. Chromium, nickel, cobalt, cooper, and manganese chlorides were used at 5% concentration as a source of heavy metal ions. Adsorption of Cr (III), Ni (II), Co (II), Cu (II), and Mn (II) was investigated by using atomic absorption.

3. Results and Discussion

3.1 Powder Characterization

The chemical composition of used kaolin is given in Table 1. It reveals that the dominant component were silica (SiO_2: 49.38) and alumina (Al_2O_3: 32.72). The main impurities are TiO_2, Fe_2O_3, MgO, CaO, SO_3, K_2O and Na_2O. Figure 2 shows the XRD patterns of raw materials before and after sintering and carbonization. It can be seen from the figure that kaolinite with quartz (as a trace) are the mineral component of the sample in pattern (a). While the major phase obtained after sintering is mullite and cristoballite is a minor phase as shown in Figure 2b. Mullite and activated carbon are observed in XRD pattern after carbonization process as shown in Figure 2c. The peaks in the patterns of XRD appears at $2\theta = 25.26$ and 44.65 that correspond to the (002) and (100) planes of the graphitic structures.

Figures 3, 4, 5 showed the SEM images of the fractured sintered samples with two different magnifications. All the images of fractured filters showed a surface with rough morphological structure. The pure ceramic

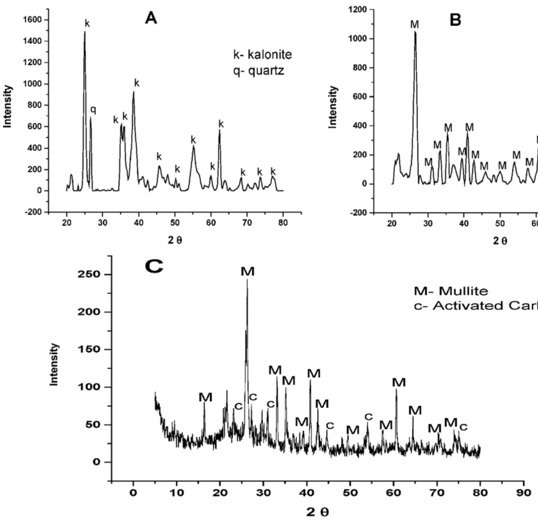

Figure 2. XRD pattern of samples (a) green body, (b) after sintering, (c) after carbonization.

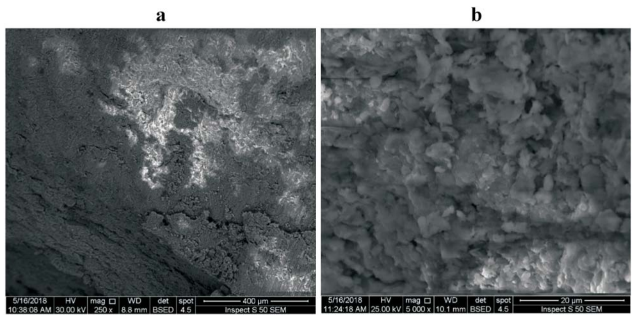

Figure 3. SEM images of 1A sample a (magnification×250), b (magnification×5000).

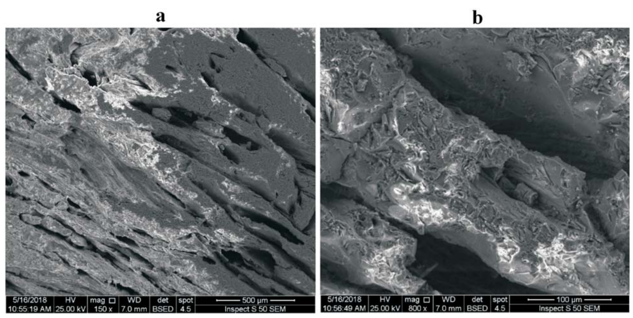

Figure 4. SEM images of 3A sample before carbonization a (magnification×150), b (magnification×800).

a b

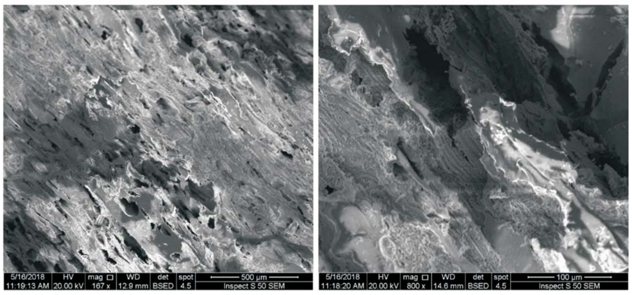

Figure 5. SEM images of 3A sample after carbonization a (magnification×167), b (magnification×800).

filter (1A) (without addition) has small surface area with dense microstructure of apparent porosity equal to 11.12%. It can be seen from Figure 3 that small pores with different sizes are distributed throughout the filter texture. After addition 20 wt% of combustible material there is an increment in porosity as shown in Figure 4. As it is seen from sample 3A, the pores are larger than pure sample with longitudinal shape with different sizes which randomly distributed on the surface of sample. While after carbonization the porosity decreased, the varieties of pores with different shapes could also be clearly identified from Figure 5. This can be attributed to that carbon atoms are settled in the open pores and on the surface of the samples.

3.2 Physical Properties

3.2.1 Linear Shrinkage

The results obtained for linear shrinkage of samples before and after addition of combustible material are shown in Table 3. It is quite clear that linear shrinkage decrease with increase in palm fronds powder. This may be attributed to increase in sample porosity. Linear shrinkage was carried out after the first heat treatment (sintering), so the same values are obtained from samples with and without carbonization.

3.2.2 Apparent Porosity and Water Absorption

The apparent porosity and water absorption of the prepared filters before and after carbonization were examined and the results are shown in Table 3. The apparent porosity and water absorption increased as the percent weight of combustible materialin samples increased. This is due to the higher percentage of burn-out material in the composition.

Ceramic filters with similar percentages of kaolin and palm fronds powder but without and with carbonization have different porosity. The values decreased because the carbon atoms pass through continues pore and reduced the pore diameter and thus the apparent porosity and water absorption as shown in SEM images.

3.2.3 Apparent Solid Density

The apparent solid density of the fabricated household filters decreased from samples 1A to 5A and from 1B to 5B for household filters prepared after carbonization as shown in Table 3. This measurement is related to porosity, so A.S.D. after carbonization is higher than before.

3.2.4 Permeability Test

The permeability obtained for each sample during the study was recorded in Table 3. The permeability in-

Table 3. The results of physical and mechanical properties of prepared filters

Samples number	L.SH.%	A.P.% (Average)	W.A.% (Average)	A.D. g/cm^3 (Average)	Permeability (cm^2/bar. S)	Diametrical strength (MPa) (Average)
1A	10.0	11.12	5.56	2	1.27	12.2
2A	9.3	19.06	7.22	1.72	1.41	11.45
3A	9.2	29.66	18.2	1.63	3.38	8.3
4A	8.9	41.44	28	1.48	4.73	7
1B	10.0	7.47	4.2	2.76	0.85	13
2B	9.3	17.44	6.32	2.33	1.02	12.25
3B	9.2	29.53	17.21	1.71	3.3	11.85
4B	8.9	37.02	23.14	1.6	4.23	7.78

creased as the weight percent of combustible material increased as shown in Table 3. This increment is due to continues pore creation that increased with additive. Samples without carbonization have slightly larger values as compare to samples after carbonization; these results are compatible with SEM results.

3.2.5 Diametrical Compressive Strength

Diametrical compressive strength values decreased with increasing combustible material content as observed in Table 3. After carbonization, D.C.S. was higher than before. The pores may act as stress concentrations, and they decreased the density of the material and the cross-section area to which the load is applied on and thus the compressive strength.

3.3 Water Analysis

3.3.1 Physical Properties Test

The ability of porous ceramic water filter to reduce various contaminants from drinking water is recognized. The results of physical properties for water obtained before and after filtration were illustrated in Table 4. After using the filter (before and after carbonization) the pH has increased and their concentration was within the range of the WHO standard for drinking water (6.50 to 8.50) as shown in Table 4. Lower values of pH may cause corrosion in the pipes which release metal ions like lead that may cause human health risks [20]. TDS is an essential factor in the drinking water quality. It is also observed from Table 4 that the initial value of TDS in the raw water was 478 mg/L. This value of TDS dropped to within the range of 102 to 114 mg/L and from 97 to 62 mg/L before and after the carbonation process respectively as shown in Table 4. These concentration levels were within the range of standard drinking water reported by EPA (500 mg/L). The turbidity measurement results shown in the Table 4 proved that the filter is effective in reducing the turbidity of raw. If the turbidity values are used as a measure of efficiency of filters the results were 71, 65, and 57% for samples 2A, 3A, and 4A respectively, while after carbonization the efficiency increased to 71.5, 74, and 76% respectively. Before carbonization, continuous pores pass residual suspended and colloidal matter through it, and with increasing porosity the quantity of these matters increased. After carbonization the quantity of carbon atoms increased, and the adsorption of dislike matter increased. The reduction in conductivity was observed in Table 4, and the effect of carbon atoms after carbonization on the total soluble salts contained within filtered water was also clear. The salt and free Cl was removed by prepared filters in all samples.

Table 4. The results of physical properties of filtered water

Sample no.	pH	TDS mg/L	Turbidity (NTU)	Sal %	Ec (μs/cm)	Free Cl
1	6.75	478	4.22	0.2	843	0.03
1A	7.9	99	1.19	0	168	0
2A	7.8	102	1.22	0	173	0
3A	7.6	109	1.46	0	180	0
4A	6.76	114	1.8	0	185	0
1B	7.8	98	1.16	0	164	0
2B	7.65	97	1.2	0	160	0
3B	7.59	93	1.1	0	155	0
4B	6.97	62	1	0	141	0

3.3.2 Adsorption of Heavy Metals

From Table 5 it can be seen that ion concentration in water has lower values as compared to the starting concentration. It is also apparent that after carbonization, the filter was more effective in reducing heavy metals due to carbon atoms adsorbtion.

Table 5. Ion concentration before and after filtering with and without carbonization

Ions	Ion concentration before filtering (mg/L)	Ion concentration before carbonization (mg/L)	Ion concentration after carbonization (mg/L)	Drinking water standards (mg/L)
Cu	5	0.08	0.02	1
Cr	5	0.103	0.04	0.1
Ni	5	0.096	0.03	0.1
Mn	5	0.166	0.025	0.1

4. Conclusion

This study demonstrated that porous ceramic filter prepared from different content of palm fronds powder by a dry pressure method then covered by a layer of activated carbon through the carbonization process can be efficiently eliminating impurities in tap water. The pores and activated carbon trapped and adsorbed water contaminants during the water filtering process and lowering impurities to recommended levels making the treated water suitable for human consumption.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] World Health Organization (WHO) (1971) *International Standards for Drinking-Water*, 3rd Edition., Geneva, Switzerland, p. 9.

[2] Whipple, G. C. (1907) *The Value of Pure Water*, John Wiley and Sons, New York, p. 58.

[3] Das, C., and S. Bose (2017) *Advanced Ceramic Membranes and Applications*, Taylor and Francis Group.

[4] Mwabi, J. K., F. E. Adeyemo, T. O. Mahlangu, B. B. Mamba, B. M. Brouckaert, C. D. Swartz, G. Offringa, L. Mpenyana-Monyatsi, and M. N. B. Momba (2011) Household water treatment systems: a solution to the production of safe drinking water by the low-income communities of Southern Africa, *Physics and Chemistry of the Earth* 36, 1120–1128. doi: 10.1016/j.pce.2011.07.078

[5] Kingery, W., H. Bowen, and D. Uhlmann (1976) *Introduction to Ceramics*, 2nd ed., New York: Wiley.

[6] Agbo, S. C., E. U. Ekpunobi, C. C. Onu, and K. G. Akpomie (2015) Development of ceramic filter candle from NSU (kaolinite clay) for household water treatment, *International Journal of Multidisciplinary Sciences and Engineering* 6(10), 18–23.

[7] Eze, K. A., J. O. Nwadiogbu, and E. T. Nwankere (2012) Effect of acid treatment on the physicochemical properties of kaolin clay, *Archives of Applied Science Research* 4(2), 792–794.

[8] Simonis, J. J., and A. K. Basson (2011) Evaluation of a low cost ceramic micro-porous filter for elimination of common disease microorganisms, *Physics and Chemistry of the Earth* 36, 1129–1134. doi: 10.1016/j.pce.2011.07.064

[9] Yahaya, S., S. S. Jikan, N. A. Badarulzaman, and A. D. Adamu (2017) Chemical composition and particle size analysis of kaolin, *Path of Science* 3(10), 1001–1004. doi: 10.22178/pos.27-1

[10] Fatimah, I., U. A. Hasanah, and H. P. Putra (2014) Preparation of bifunctional ceramic membrane based on TiO^2/kaolinite for water disinfection, *J. Mater. Environ. Sci*. 5(6), 1976–1981.

[11] Tsuru, T. (2001) Inorganic porous membranes for liquid phase separation, *Separation and Purification Methods* 30(2), 191–220. doi: 10.1081/SPM-100108159

[12] Metcalf, and Eddy (2003) *Waste Water Engineering, Treatment and Reuse*, 4^{th} edition, McGraw-Hill, New York, Singapore, p. 1219.

[13] March, H., and F. R. Reinoso (2006) *Activated Carbon*, 1^{st} edition Elsevier Ltd., Great Britain, p. 425–428.

[14] Talaat, H. A., N. M. ElDefrawy, A. G. Abulnour, and H. A. Hani (2011) Evaluation of heavy metals removal using some Egyptian clays, 2^{nd} International Conference on Environmental Science and Technology, 37–42.

[15] Karapinar, N., and R. Donat (2009) Adsorption behavior of Cu2+ and Cd2+ onto natural bentonite, *Desalination* 249, 123–129. doi: 10.1016/j.desal.2008.12.046

[16] Yauvz, O., Y. Altunkaynak, and F. Guzel (2003) Removal of copper, nickel, cobalt and manganese from aqueous solution by kaolinite, *Water Research* 37, 948–952. doi: 10.1016/S0043-1354(02)00409-8

[17] Bhttacharyya, K., and S. Gupta (2008) Adsorption of a few heavy metals on natural and modified kaolinite and montmorillonite: a review, *Advance in Colloid and Interface Science* 140, 114–131. doi: 10.1016/j.cis.2007.12.008

[18] Veli, S., and B. Alyuz (2007) Adsorption of cooper and

zinc from aqueous solution by using natural clay, *Journal of Hazardous Materials* 149, 226–233. doi: 10.1016/j.jhazmat.2007.04.109

[19] Dastgheib, S. A., T. Karanfil, and W. Cheng (2004) Tailoring activated carbons for enhanced removal of natural organic matter from natural waters, *Carbon* 42(3), 547–557. doi: 10.1016/j.carbon.2003.12.062

[20] Spellman, F. R., and J. Drinan (1999) *The Drinking Water Handbook*, Technomic Publishing Co, Inc. United States of America, pp. 151–152.

Manuscript Received: May 13, 2019
Accepted: Oct. 24, 2019