CHEMISTRY & CHEMICAL TECHNOLOGY

Chem. Chem. Technol., 2021,
Vol. 15, No. 2, pp. 291–298

Chemical Technology

CELLULOSE ACETATE HOLLOW FIBER MEMBRANES FROM BANANA STEM FIBERS COATED BY TiO_2 FOR DEGRADATION OF WASTE TEXTILE DYE

Siti Wafiroh[1, ✉], Abdulloh Abdulloh[1], Alfa Akustia Widati[1]

https://doi.org/10.23939/chcht15.02.291

Abstract. Cellulose acetate hollow fiber membrane from banana stem fibers coated by TiO_2 (CAHFMT) was prepared and characterized as an alternative material for degradation of waste textile dye. Its applicability was demonstrated by mechanical properties, FTIR, SEM, thermal resistance, performance, and degradation efficiency. Cellulose acetate (CA) was synthesized from banana stem fibers by swelling stage, acetylation reaction, and hydrolysis reaction. CA was modified using TiO_2 of various concentrations. CAHFMT with 22 % w/v dope concentration has the optimum mechanical properties (stress, strain and Young's modulus), as well as hydrophilic properties. The performances of CAHFMT with Congo red were determined. The SEM results showed that the membrane had rigid pores. Moreover, this research stated that CAHFMT could be a solution to overcome economical and effective problems.

Keywords: membrane, hollow fiber, cellulose acetate, TiO_2, waste textile dye.

1. Introduction

The development of the textile industry is quite rapid in Indonesia. According to data from Ministry of Industry, the national textile industry absorbed about 1.4 million workers in 2016, contributing non-oil/non-gas exports of US$ 9.26 billion in 2018 and increased to US$ 11.22 billion last year. However, the improvement in this industry is not accompanied by adequate awareness of environmental management as a result of the industry's progress. The textile industry is an important contributor to environmental pollution, particularly the aquatic environment due to the produced dye waste. Disposal of waste water into rivers from dye-producing industries will cause serious environmental problems. In addition, most dyes are mutagenic and carcinogenic [1].

Generally, the waste which is produced by the textile industry is non-biodegradable organic compound dye waste, which can cause environmental pollution, especially the aquatic environment [2]. Textile dyes are generally made of about 60–70 % of azo compounds and derivatives, which degrade with great difficulties. Moreover, the long stay of azo compounds in the environment causes the diseases because of their carcinogen and mutagenic nature [3]. Dye waste disrupts aquatic ecosystems, retards photosynthesis activity, and inhibits the growth of aquatic biota. Nowadays there are many various ways to remove Congo red dye waste, including adsorption.

Fatimah *et al.* [4] degraded Congo red by using a modified TiO_2 natural zeolite. This method successfully degraded Congo red by 40 % in 1 h. Tapalad *et al.* [5] used ozone technology to degrade Congo red by 39 % within 120 min. But these methods have shortcomings. The adsorption method is a fairly inexpensive method, but it is less effective. The textile dyestuff adsorbed by the zeolite is still accumulating in the adsorbent which will, someday, create new problems. The ozone technology simply removes pollutants from one phase to another and the separation is simple [6]. Zao *et al.* [7] processed the textile dyestuff by using microfiltration membranes [7]. However, processing with membrane often undergoes fouling, so antifouling material is needed. TiO_2 is an antifouling material with high activity, but it often coagulates and cannot be used continuously. To solve this problem, the membrane and TiO_2 were combined and the method was called as photocatalytic membrane technology [8].

Currently, photocatalytic membrane technology becomes a promising technology and has been applied to degrade textile dye waste. Mozia *et al.* [9] compared the results of blue methylene degradation in photocatalytic membrane reactor using pure TiO_2 and carbon-coated TiO_2. The carbon-coated TiO_2 photocatalytic membrane reactor provides higher blue methylene degradation

---

[1] Faculty of Science and Technology, Universitas Airlangga,
Campus C Mulyorejo, 60115 Surabaya, East Java, Indonesia
✉*sitiwafiroh@fst.unair.ac.id*

activity than those using pure TiO_2 of 86 %. Essawy *et al.* [10] applied membrane copolymer-TiO_2 to degrade two types of textile waste:remazol red RB-133 (RR RB 133) and reactive blue 2 (RB2). The results show that the presence of TiO_2 causes both pollutants to be degraded better compared to the absence of TiO_2 in the copolymer membrane. Damzel *et al.* [11] used a hybrid photocatalytic nanofiltration membrane of polysulfone and polystyrene with TiO_2 to degraded three types of dyestuff. The membrane degraded red 18, direct green 99 and yellow acid 36 by 100, 94 and 91.9 %, respectively.

The advantages of the photocatalytic membrane technology are the control of time particle retention and separation process simultaneously and continuously. However, this technology is quite expensive because the membrane base material (synthetic polymer) needs to be imported from abroad and it is not biodegradable. Therefore, it is necessary to find other sources of available and cheap materials. In addition, modern technological advances cause global warming which adversely affects human survival. Given the danger that will be made, it is necessary to make efforts to prevent it. One that can be done is to start reducing the use of technology that is not environmentally friendly and start switching to green technology [12]. One example of green technology is a membrane derived from a natural polymer.

The basic ingredients of membrane production from natural polymers are cellulose acetate. Cellulose is a natural polymer with a strong bonding structure due to its crystallinity, compactness and very well order. Cellulose is a major part of both wood and non-wood. One source of cellulose is fiber of banana stem. Banana stem fiber contains about 60–65 % of high cellulose, so it can be used as an alternative material membrane [13].

The development of membrane technology produces various types of membranes, including plate-and-frame membrane, tubular, spiral-wound and hollow fibers. Compared to other membrane modules, hollow fiber geometry provides greater membrane effectiveness. In addition, hollow fiber forms provide good mechanical support and are easily treated during fabrication and operational processes [14]. Hollow fiber membrane is more desirable than flat membrane, because the latter has many shortcomings, *e.g.* frequent fouling, so membrane performance becomes less effective [15].

Membrane is a thin layer needed to be composed with other compounds so that the membrane will have strong and durable mechanical properties [16]. Composites which are often used in membrane modifications include TiO_2 inorganic compounds. TiO_2 most often attracts attention because of its stability, availability and applications in the fields of medicine, catalysis, photocatalysis, energy and others [17].

Therefore, in this research cellulose acetate (CA) synthesized from banana stem fibers was used as the material to produce hollow fiber membrane which was then coated with TiO_2 (CAHFMT) and applied for degradation of waste textile dye. The phase inversion method, used for the CAHFMT production, is a process of changing the polymer shape from the liquid phase into a solid phase under controlled conditions. Dope concentrations were 21, 21.5, 22, 22.5 and 23 %. The mechanical properties of CAHFMT (strain, stress, Young's modulus) were determined, as well as membrane flux and rejection value. The membrane morphology was confirmed with SEM, FTIR and DSC techniques.

2. Experimental

2.1. Materials and Instruments

All chemicals were of analytical grade and used as received without further purification. Hydrochloric acid, sodium hydroxide, glacial acetic acid, sulfuric acid, NaOCl, $Ca(OH)_2$, glacial acetic acid, acetic anhydride, commercial TiO_2 (anatase, d = 4.26 g/ml, MW = = 79.87 g/mol), H_2SO_4, formamide, acetone and phenolphthalein indicator were obtained from Merck. The instruments used were the tensile test equipment AG-1S 50 KN Autograph, SEM JEOL JSM-8360LA, FTIR Shimadzu 8400S, JEOL JDX-3530, UV-1800 Shimadzu spectrophotometer and differential scanning calorimeter.

2.2. Synthesis and Characterization of CA from Banana Stem Fiber

CA from banana stem fiber was synthesized through three steps: pulp making, pulp bleaching, and cellulose acetate synthesis.

Preparation of banana fiber pulp: 20 g of prepared banana stems were immersed in 200 ml of $Ca(OH)_2$(2.5 % w/v) for about 1 week until they became soft. The mixture was washed with water until it was free from bases (tested using red litmus).The obtained fibers were loaded into a flask filled with 150 ml of NaOH (17.5 % w/v) and then heated in reflux for 4 h. Next, the mixture was blended to obtain finer fiber and cooled at room temperature. After this it was washed with water until the neutral pH, molded in a baking dish and dried in an oven at ≤333 K until pulp was generated.

Pulp bleaching: 10 g of dried pulp were added to 88 ml of water into a beaker glass. The mixture was stirred under heating to 333 K to form slurry. The slurry was cooled to room temperature, about 100 ml of NaOCl (5 % v/v) were added and the mixture was continuously stirred for 30 min. The pulp was rinsed with water, soaked in NaOH (2 % w/v) and kept for 30 min. The mixture was again rinsed with water until neutral pH and dried in the open air until a white pulp was formed [13].

CA synthesis: 10 g of bleached pulp were added to 24 ml of glacial acetic acid (99.9 %) in the Erlenmeyer tube and stirred in the shaker at 313 K for1 h. Then 60 ml of glacial acetic acid and 0.5 ml of concentrated H_2SO_4 were added, the mixture was again stirred for 45 min and cooled to 291 K. Next, 27 ml of acetic anhydride, which was previously cooled to 288 K, were added and stirred for 3 h at room temperature. After adding 30 ml of acetic acid (67 %) dropwise for 3 h at 313 K and stirring for 15 h, the solution was precipitated with the dropwise addition of water and stirring to obtain a powdered precipitate. The obtained precipitate was filtered, washed with water until neutral pH and dried in an oven at 333–343 K. The dried precipitate was crushed using mortar and stored in desiccators [13]. CA was characterized by determining *Mv* using viscometry, acetyl content and FTIR.

2.3. Production and Characterization of CAHFMT

The synthetic CA powder was dissolved bit by bit with acetone at room temperature. The mixing of the dope solution was carried out in a closed Erlenmeyer to avoid solvent evaporation. The dope compositions were 21, 21.5, 22, 22.5 and 23 % w/v; the membranes were coated with 0.2 % w/v of TiO_2. The formamide was added after all cellulose acetate has dissolved in acetone. The dope solution was stirred for several hours until the mixture became homogenous then sterilized overnight to remove air bubbles. The dope solution was ready to be molded into a hollow fiber membrane using the inversion method. The formed hollow fiber membrane was washed with running water to remove the residual solvent and transferred into a tub containing the sodium azide solution until the hollow fiber membrane was characterized. Before modulated, the membrane was coated with TiO_2.

CAHFMT performance was tested using cross-flow cells. Flux J was defined as the quantity permeated per unit of area and per unit of time (Eq. 1).

$$J = \frac{V}{A \cdot t} \tag{1}$$

where J is flux, $l \cdot m^{-2} \cdot h^{-1}$; V is the permeate volume, l; A is a membrane surface area, m^2 and t is the time, h.

Rejection coefficient R was calculated according to Eq. (2).

$$R = \left(1 - \frac{C_p}{C_f}\right) \cdot 100\% \tag{2}$$

where C_p and C_f are the concentrations of permeate and feed, respectively. Feed is Congo red and waste textile dye.

The mechanical properties of the CAHFMT, including stress, strain and Young' modulus, were measured by means of an AG-1S 50 KN Autograph test unit. Each sample was stretched unidirectional at a constant rate of 5 mm/min; the initial distance between the clamps was 50 mm. Three specimens were tested for each sample.

The membrane morphology was determined with SEM and thermal resistance with DSC.

3. Results and Discussion

3.1. Synthesis and Characterization of CA from Banana Stem Fiber

As a result of reflux, the color of the solution was brown, indicating the dissolved lignin and hemicellulose. Lignin and hemicellulose are macromolecules which have a large molecular weight, but they are easily degraded by alkaline solutions due to an amorphous structure [18].

Pulp bleaching was aimed to degrade remaining lignin in the pulp. The peak of cellulose absorption (Fig. 1) occurs in –OH (3365.78 cm^{-1}) and C–O groups (1099.43–1251.80 cm^{-1}). These clusters show the presence of a glycoside bond and C–O bond in the cellulose ring. C–H with vibration occurs at wave number of 2920.23–2850.79 cm^{-1}, C–H with bending vibration appears at wave numbers of 1539.20–1462.04 cm^{-1} [19].

The CA synthesis was performed by three stages: inflation stage, acetylation stage and hydrolysis stage. In the inflation stage, a glacial acetic acid, which acts as a swelling agent, was added to the cellulose from the banana stem fiber pulp. In addition, glacial acetic acid can increase the reactivity of cellulose so that cellulose is more reactive with acetic anhydride. At the acetylation stage, an acetic anhydride and sulfuric acid as a catalyst were added to the activated cellulose. The reaction was carried out at low temperatures because of an exothermic reaction. Sulfuric acid reacts rapidly with acetic anhydride to form acetyl sulfate and acetic acid. Acetyl sulfate reacts with cellulose to form cellulose sulfate ester. Three –OH groups in the cellulose substituted with the acetyl group form a solution of cellulose triacetate *via* acetylation reaction. The acetylation of bio fiber pulp from banana tree waste requires optimal acetylation time of 3.5 h and temperature of 313 K. These conditions greatly determine the quality of cellulose acetate produced as the membrane base material. Non-optimal acetylation conditions will result in a low quality of membrane. The hydrolysis reaction is aimed to deacetylate the cellulose triacetate solution into CA. In addition, the water in acetic acid will bind the remaining acetic anhydride to acetic acid. Characterization of CA produced in this study include: functional group analysis, determination of relative molecular mass, and determination of acetyl content. The FTIR results are shown in Fig 1.

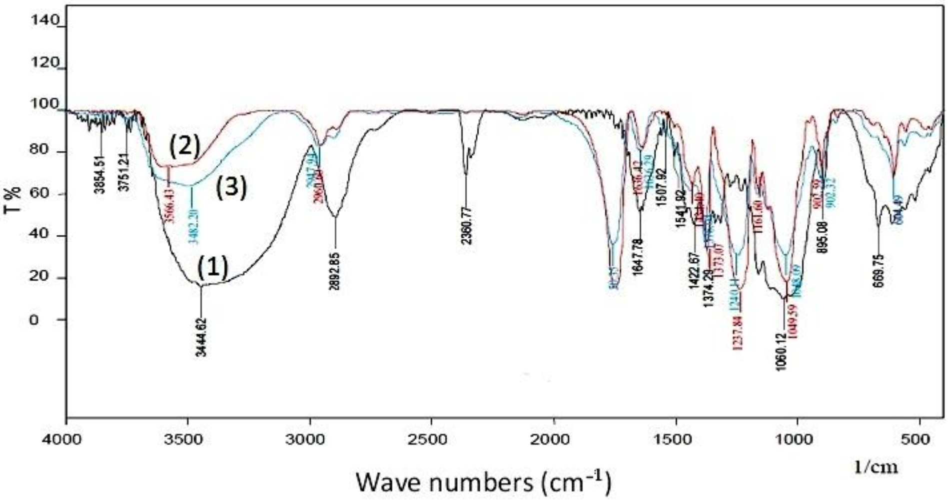

Fig. 1. FTIR spectra of cellulose (1), synthesized CA (2) and commercial CA (3)

The absorption spectra of CA banana stem fiber and commercial CA are similar. The typical absorption peaks occur in the carbonyl (1751.36 cm^{-1}) and acetyl group (1049.28 cm^{-1}); –COC– bond, which is the bond between the monosaccharide, appears at wave numbers of 1234.44 cm^{-1} and is very sharp. If we compare FTIR results for cellulose, CA biofiber pulp and commercial CA, the –OH group of cellulose is replaced with acetyl group in CA so that we observe its decrease, while the intensity of peak absorption of acetyl group increased and carbonyl group appeared. This proved that the cellulose converts into CA *via* acetylation.

Determination of *Mv* by means of the viscometry method shows the value of 51.15 kDa for the synthesized CA, while *Mv* of commercial CA is 50.36 kDa. The greater value of the synthesized CA is due to several factors determined the relative molecular mass of CA: the fiber length of the cellulose or the base material, the bleaching process, the acetylation time and the hydrolysis time. It is also determined by the composition of the materials used for CA manufacture. Determination of acetyl content is useful for determining the type of CA obtained from the acetylation of banana pulp cellulose. The cellulose monoacetate has acetyl content less than 35 %, cellulose diacetate 35–43.5 % and cellulose triacetate 43.5–44.8 % [20]. A good performance membrane can be obtained by selecting the membrane base material. The greater the degree of polymerization (DP) of CA polymer material, the greater the amount of the H and OH groups available, such that the physical interaction between acetone as the solvent and formamide as a pore-swelling ingredient in the printing solution become larger, which will affect pore size and membrane strength. Meanwhile, when the degree of substitution (DS) of polymer material is higher, it will increase the space barrier and lower the amount of hydroxyl group, such that the membrane flux becomes smaller. Acetyl content of the synthesized CA is 40.23 % while for commercial CA this value is 40.40 % [21]. The degree of substitution of acetyl groups in CA preferably ranges from 37.5 to 40.1 %. The amount of acetyl groups depends on hydrolysis time. The greater the hydrolysis time, the longer the deacetylation process.

3.2. Production and Characterization of CAHFMT

The production of CAHFMT uses a phase inversion technique in which the polymer in the form of a solution is converted into a controlled solid form. The dope solution has a very high viscosity requiring a thrust force to exit through the spinneret of the printer so that nitrogen gas is applied at a pressure of 506.6 kPa. Nitrogen gas also serves to remove air bubbles from dope solutions that have been made before exit through the spinneret of the printer. The dope solution comes out of the spinneret and enters the tub of coagulation. During the process of membrane molding the solvent evaporation determines the morphology of the membrane so that the optimum water gap of 25 cm is used [13]. The process continues to the coagulation stage that occurs when the membrane enters the coagulation bath containing water with a temperature of 278 K. The low temperatures used can form a hollow fiber membrane that has an asymmetrical side. The formed CAHFMT are stored in sodium azide solution to prevent membrane bacterial degradation. Prior to characterization, hollow fiber membrane was coated with TiO_2 (0.2 % w/v).

The characteristics of CAHFMT are necessary to determine the quality of the resulting membrane. CAHFMT characterization includes the thickness measurement, mechanical properties test (stress, strain and Young's modulus), membrane morphological analysis with SEM and membrane application for degradation of textile dye.

The measurement of CAHFMT thickness was carried out using a screw micrometer which had an accuracy of 0.01 mm. Hollow fiber membranes were cut longitudinally and stretched. The average thickness of hollow fiber membrane was found to be 0.14–0.15 mm.

The stress values obtained at each variation of the CAHFMT are shown in Fig. 2. High stress values indicate that the material has strength, *i.e.,* the ability to resist deformation. Therefore, a membrane with great strength is strong and non-fragile. The increase in the weight percentage concentration of CA also increased the intermolecular spacing. Through this phenomenon, the stress value of a higher weight percentage concentration of CA is better than that of a smaller weight percentage concentration. The molecular density of the membrane reduces the pore size thus making the tensile strength even greater [22]. However, there is a deviation at the dope concentration of 23 %.The homogenous dope solution is not formed. This is caused by the solubility of CA with a solvent that has been saturated at 22 %. Furthermore, the dope solution cannot be molded, so it reduces the bond strength at the membrane and causes the membrane to have a small stress value.

The strain value (often called elasticity) indicates a material's ability to increase its length before breaking. An ideal membrane has a small and evenly distributed pore size and excellent mechanical strength. In this research, we determined that the CAHFMT strain tended to decrease when the dope concentration was increased (Fig. 3). When the membrane presents high elasticity, it is deformedat high pressure easily. The deformation process increases the pore size, where a larger pore size and higher elasticity can decrease membrane performance.

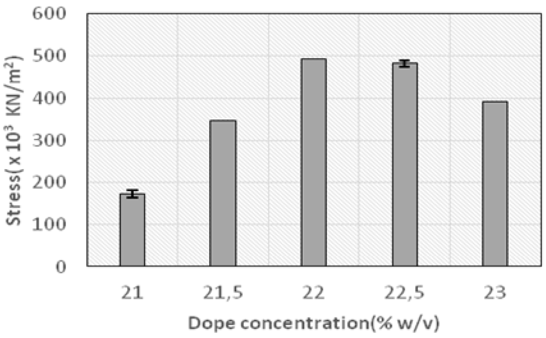

Fig. 2. Stress *vs*. dope concentration

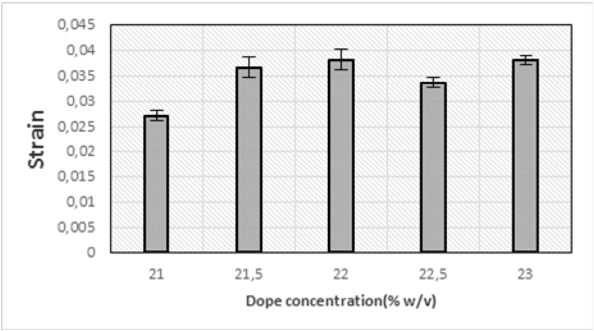

Fig. 3. Strain *vs*. dope concentration

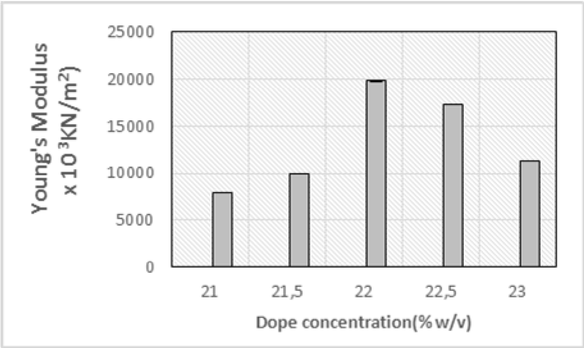

Fig. 4. Young's modulus *vs*. dope concentration

Increasing the concentration of dope solution creates more intermolecular bonds and decreases the elasticity value. In the graph, there is a deviation in the value at the 22.5 % and 23 % concentrations, whereas there is an increase in the membrane strain when the concentration is increased. This is due to the lack of a homogeneous dope solution, resulting in unevenly distributed pores and a non-constant membrane elasticity [20].

Young's modulus value shows the elastic strain of a material. If the membrane's Young's modulus value is large, then the membrane can maintain its pore size when applied to large pressure [17]. The Young's modulus value of CAHFMT is shown in Fig. 4.

Young's modulus is derived from the strain on the stress value, so that if there are large voltage values, then Young's modulus is greater; meanwhile, if the values are small, Young's modulus increases. Thus, Young's modulus is influenced by tension and the CAHFMT strain. The graph shows the largest Young's modulus value at the 22 % concentration, because the CAHFMT concentration has an ideal ratio of stress to strain so that the Young's modulus value obtained is also large. Therefore, in this research, the optimum condition is obtained at the dope concentration of 22 % with a stress of 452 MN/m^2, strain of 0.0228, and Young's modulus value of $19.8\cdot10^3$ MN/m^2. The CAHFMT performance can be shown by the flux value and its rejection coefficient. The flux value shows the ability of flow to pass through the membrane, whereas the rejection coefficient indicates the membrane's ability to hold the solute molecule [20]. The obtained CAHFMT are formed into modules [14]. Before the performance test, the membrane module was first compacted by passing the flow of water over the membrane to open the membrane pores until a constant flux value was obtained. To calculate the concentration during the test, a UV-Vis spectrophotometer was used. In this test, one type of textile dye, that is, Congo red, was used as a bait. The Congo red solution produced a standard curve with a maximum wavelength of 498 nm. In this research a membrane flux of 73.33 l/m^2·h and rejection coefficient value of 93.4 % were obtained. The hollow fiber membrane module has a large flux value because the membrane performance uses a cross-flow that minimizes the occurrence of fouling on the membrane. In addition, a large rejection value means that the hollow fiber membrane is effective in holding the permeate particles so that only a few part of the particles are passed.

FTIR was performed for the CAHFMT to determine the bonds occurring in the membrane and whether there is any change in the functional group after the membrane is printed. The infra red spectra of CAHFMT are shown in Fig. 5. The character of the –OH group, which is still visible in the 3600–2800 cm^{-1} region, has board bands at 3450.77 cm^{-1} and a CO stretch vibration in the range of 1300–1000 cm^{-1}, characterized by sharp bands at 1045 cm^{-1}. This indicates no cluster change with the addition of TiO_2. The absorption of TiO_2 is usually seen at 556 cm^{-1} wave number. However, the results of the analysis are not visible, thus proving whether the bonds that occur between TiO_2 and the membrane are physical bonds only.

The morphological analysis of CAHFMT was done using SEM, which aimed to determine the cross section and pore distribution and pore size on the surface of the resulting membrane. The SEM test was performed on a hollow fiber membrane with an optimal dope concentration. The SEM results of the cross section of the hollow fiber membrane are shown in Fig. 6.

The SEM results also show that the inner surface of the membrane had a denser pore than the outer surface, meaning the membrane had asymmetric pores. The pores of the inner membrane surface averaged 23.9 μm and the pore size of the outer surface of the outer membrane averaged 99.56 μm. The inner diameter of the hollow fiber membrane was 964.6 μm and the outer diameter was 1331 mm, as shown in Fig. 7. The pore distribution of the CAHFMT was uniform.

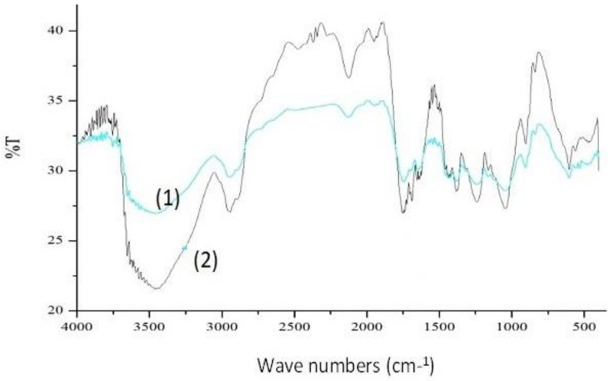

Fig. 5. FTIR spectra of CAHFM (1) and CAHFMT (2)

The DSC thermal test results are shown in Fig. 8, demonstrating that the melting point of CAHFMT is 500.6 K, while the glass temperature is 359.37 K. In this study, CAHFMT was coated with TiO_2 by an immersion method, so an exceptionally large TiO_2 was suitable on the outer surface of the membrane, which would be effective for the degradation of waste textile dye. Photocatalytic degradation was carried out under UV exposure in a chamber with a 50 W UV lamp, with a wavelength of 254 nm. Each sample was located at 25 cm from the lamp and exposed for 1 h. The temperature during photo degradation was maintained at 303 K. In this study, the application of three days repetitive dye degradation in the CAHFMT remained relatively unchanged. This shows that the membrane material is still stable and the dye is degraded. The mechanism of the degradation reaction is that the wavelength is shorter than the band gap energy, for example, TiO_2, which is 380 nm (equivalent to 3.2 eV). This means that the energy of the UV lamp can excite the electrons, e$^-$, from the valence band to the conduction band and produce a hole, h$^+$, at the valence band. The holes will react with H_2O to produce hydroxy radicals [23]. The degradation reaction is proposed in Eqs. (3-5).

$$TiO_2 + h\nu \rightarrow \text{hole}^+ + e^- \quad (3)$$

$$H_2O + \text{hole}^+ \rightarrow OH\bullet + H^+ \quad (4)$$

$$OH\bullet + \text{Congo red} \rightarrow$$
$$\rightarrow \text{product (simpler molecules than Congo red)} \quad (5)$$

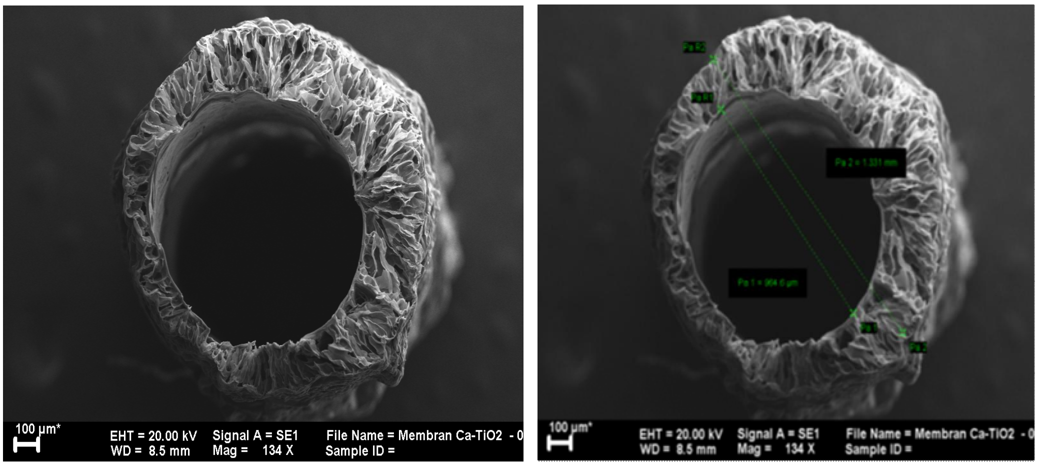

Fig. 6. Cross section SEM images of CAHFMT

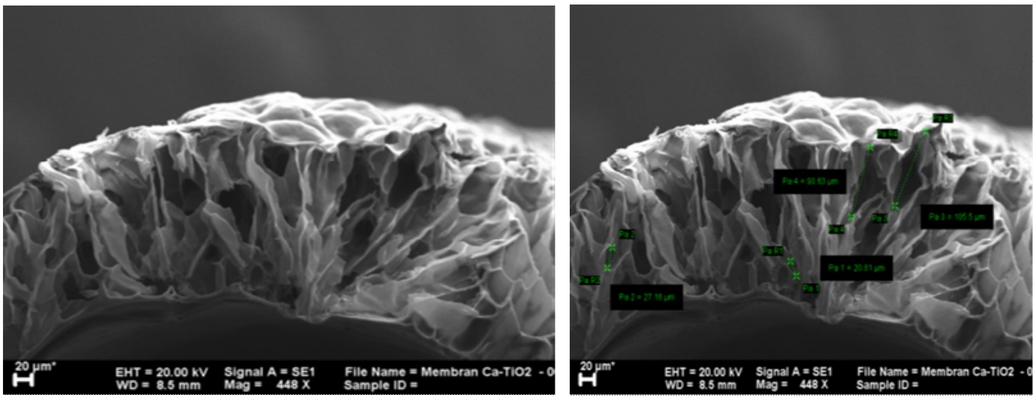

Fig. 7. A view of inner and outer diameter of CAHFMT

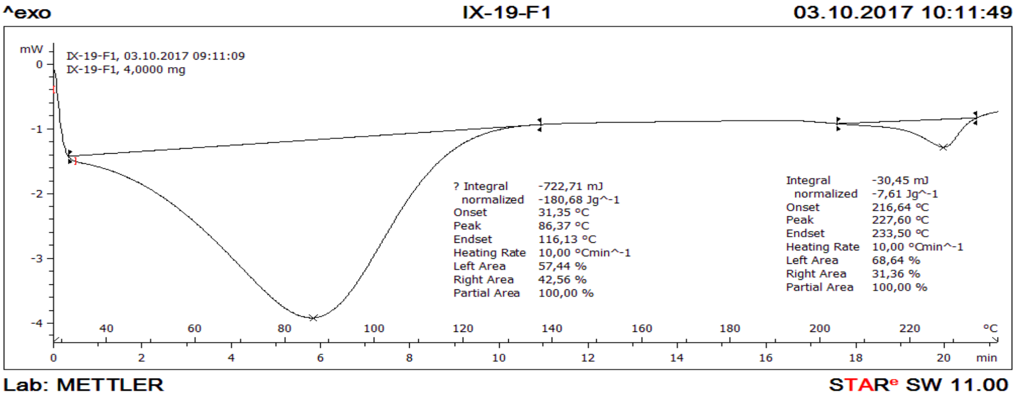

Fig. 8. DSC thermogram of CAHFMT

At first, one example of a dye textile solution, called Congo red, at 622 ppm was degraded by TiO_2 under UV irradiation. Degradation was done by immersing TiO_2 into 150 ml of Congo red solution using UV light and stirring for 1 h. So, TiO_2 reacts with UV rays to degrade Congo red. Then, the Congo red degradation solution was measured with a UV spectrophotometer to determine the residual concentration. The degradation result obtained 100 % degradation efficiency and the degraded Congo red was colorless. In the same procedure, the CAHFMT was used to degrade the dye waste textile and Congo red. The resulting effectiveness of textile waste degradation was 94.2 % while the Congo red degradation efficiency was 96.96 %.

4. Conclusions

CAHFMT was successfully produced with an optimum concentration of 22 % dope solution by mixing or blending a dope solution of cellulose acetate, acetone solvent, and formamide as a pore-forming additive and coating with TiO_2 0.2 % (w/v). The dope concentration affects the mechanical properties of CAHFMT, where CAHFMT with a 22 % dope concentration has optimum mechanical properties, *i.e.,* stress of 452 MN/m^2, strain of 0.0228, and Young's modulus value of 19.8·10^3 MN/m^2. The performance of CAHFMT with Congo red is as following: flux 73.33 l/m^2·h, rejection 93.4 %, degradation efficiency of waste textile dye 94.2 %, degradation efficiency of Congo red 96.96 % and thermal resistance 500.6 K.

Acknowledgements

This reseach was suppoted by funding of Ministry of Research and Techonology, Republic of Indonesia.

References

[1] Gupta V., Pathania D., Agarwal S., Singh P.: J. Hazard. Mater., 2012, **243**, 179. https://doi.org/10.1016/j.jhazmat.2012.10.018

[2] Verma A., Dash R., Bhunia P.: J. Environ. Manage. 2012, **93**, 154. https://doi.org/10.1016/j.jenvman.2011.09.012

[3] Anjaneya O., Yogesh Souche S., Santhoshkumar M., Karegoudar T.: J. Hazard. Mater., 2011, **190**, 351. https://doi.org/10.1016/j.jhazmat.2011.03.044

[4] Fatimah I., Sugiharto E., Wijaya K. *et al.*: Indones. J. Chem, 2006, **6**, 38. https://doi.org/10.22146/ijc.21770

[5] Tapalad T., Neramittagapong A., Neramittagapong S., Boonme M.: Chiang Mai J. Sci., 2008, **35**, 63.

[6] Zhang H., Quan Z., Chen S. *et al.*: Sep. Purif. Technol., 2006, **50**, 147. https://doi.org/10.1016/j.seppur.2005.11.018

[7] Zhao C., Xue J., Ran F., Sun S.: Progr. Mater. Sci., 2013, **58**, 76. https://doi.org/10.1016/j.pmatsci.2012.07.002

[8] Zhang X., Wang D., Lopez D., da Costa J.: J. Chem. Eng, 2014, **236**, 314. https://doi.org/10.1016/j.cej.2013.09.059

[9] Mozia S., Toyoda M., Tsumura T. *et al.*: Desalination, 2007, **212,** 141. https://doi.org/10.1016/j.desal.2006.10.007

[10] Essawy A., A.El-Hag A., Abdel-Mottaleb M. *et al.*: J. Hazard. Mater., 2008, **157,** 547. https://doi.org/10.1016/j.jhazmat.2008.01.072

[11] Grzechulska-Damsel J., Tomaszewska M., Morawski A.: Desalination, 2009, **241**, 118. https://doi.org/10.1016/j.desal.2007.11.084

[12] Kutti L.: Cellulose, Starch and Their Derivatives for Industrial Applications. Doctoral thesis. VTT Technical Research Centre of Finland, Helsinki 2013.

[13] Wafiroh S., Harsasi S., Puji L.: Mal. J. Fund. Appl. Sci., 2014, **10,** 119. https://doi.org/10.11113/mjfas.v10n3.264

[14] Jiangfeng Y., Wang K., Ren M. Jefferson *et al.*: J. Membr. Sci., 2012, **421**, 8. https://doi.org/10.1016/j.memsci.2012.03.069

[15] Drioli E., Giorno L.: Membrane Operations Innovative Separations and Transformations. Wiley-VCH Verlag GmbH & Co, Weinheim 2009. https://doi.org/10.1002/9783527626779

[16] Jayakumar R., Ramachandran R., Divyarani V. *et al.*: Int. J. Biol. Macromol., 2011, **48**, 336. https://doi.org/10.1016/j.ijbiomac.2010.12.010

[17] Abedini R., Mousavi S., Aminzadeh R.: Chem. Ind. Chem. Eng. Q., 2012, **18**, 385. https://doi.org/10.2298/CICEQ111202014A

[18] Zugenmaier P.: Crystalline Cellulose and Derivates, Characterization and Structures. Wood Science, Verlag Berlin Heidelberg 2009. https://doi.org/10.1007/978-3-540-73934-0

[19] Nikolić G.: Fourier Transforms - New Analytical Approaches and FTIR Strategies, InTech, Croatia 2011. https://doi.org/10.5772/2040

[20] Baker R.: Membrane Technology and Applications, 2nd edn. John Wiley & Sons Ltd., Chinister 2004.

[21] Granstrom M.: Cellulose Derivate: Synthesis, Properties and Applications. Academic Dissertation. University of Helsinki, Helsinki 2009.

[22] Zhang X., Wen Y., Yang Y., Liu L.: J. Macromol. Sci. B, 2008, **47**, 1039. https://doi.org/10.1080/00222340802266298

[23] Rahmawati F., Fadillah I., Mudjijono M.: J. Mater. Environ. Sci., 2017, **8**, 389.

Received: January 31, 2019 / Revised: July 01, 2019 / Accepted: November 12, 2019

АЦЕТАТ-ЦЕЛЮЛОЗНІ ПОРОЖНИСТІ МЕМБРАНИ З ВОЛОКОН БАНАНОВИХ СТЕБЕЛ З НАНЕСЕНИМ TiO_2 ДЛЯ РОЗКЛАДУ ВІДПРАЦЬОВАНИХ ТЕКСТИЛЬНИХ БАРВНИКІВ

Анотація. *Синтезовано і досліджено ацетат-целюлозні порожнисті мембрани з волокон бананових стебел з нанесеним* TiO_2 *(АЦПМТ) як альтернативний матеріал для розкладу відпрацьованого текстильного барвника. Визначено механічні властивості, термостійкість, продуктивність та ефективність розкладу синтезованих мембран, проведені спектроскопічні та мікроскопічні дослідження. Ацетат целюлози (АЦ) одержано з волокон стебла банана через стадію набухання, реакцію ацетилювання та реакцію гідролізу з подальшим модифікуванням* TiO_2 *різних концентрацій. Встановлено, що найкращі механічні властивості (напруження, деформація та модуль Юнга), а також гідрофільні властивості виявляє АЦПМТ з концентрацією додатку 22 % мас. Досліджено поведінку АЦПМТ з Конго червоним. За допомогою SEM аналізу встановлено, що мембрана мала жорсткі пори. Показано, що застосування АЦПМТ може бути вирішенням економічних та екологічних проблем.*

Ключові слова*: мембрана, порожнисте волокно, ацетат целюлози,* TiO_2*, відпрацьований текстильний барвник.*