CHEMICAL ENGINEERING TRANSACTIONS

VOL. 63, 2018

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Jeng Shiun Lim, Wai Shin Ho, Jiří J. Klemeš

ISBN 978-88-95608-61-7; **ISSN** 2283-9216

DOI: 10.3303/CET1863077

Development of Tea Waste/Kapok Fiber Composite Paper

Rohah A. Majid[a,*], Zurina Mohamad[a], Rafidah Rusman[a], Ainur A. Zulkornain[b], Nurshaleeza A. Halim[b], Mohammad Abdullah[b], Jiun H. Low[c]

[a]Department of Bioprocess and Polymer Engineering, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.
[b]Fakulti Kejuruteraan Kimia Kampus Pasir Gudang, Universiti Teknologi MARA (UiTM) Johor, 81750 Masai Johor, Malaysia.
[c]School of Engineering, Taylor's University, Taylor's Lakeside Campus, No.1 Jalan Taylor's, 47500 Subang Jaya, Selangor, Malaysia.
r-rohah@utm.my

An awareness to sustain world's green environment have triggered many efforts to use agricultural wastes as sources of fibres in pulp and paper making industries. In this research, tea waste/kapok fibre composite papers at various amounts of kapok contents were prepared. Tea waste, a by-product from tea industry, was treated with sodium hydroxide (NaOH) solution to remove non-cellulosic substances such as lignin, wax and hemicellulose. It was found that the tea waste papers treated with 15 wt% - 25 wt% NaOH solutions exhibited good tear indexes. Addition of kapok fibre into the tea waste had reduced the tear indexes of the composite papers. Higher kapok contents caused the entanglement of their long fibres, resulting in agglomeration of the fibres throughout the tea waste matrix. This was proven by the images of scanning electron microscopy. However, the water repellent properties of the composite papers were improved at an average of 52.3 % with respect to that of pure tea waste paper. The hydrophobic nature of the kapok fibre was responsible for the results. Overall, tea waste/kapok fibre composite has offered an improved paper property, where each fibre compensated the weakness of its counterpart. This indicates with agrowastes can be manipulated in such way to meet the requirements for pulp and paper making industries.

1. Introduction

High consumptions on paper-based products such as corrugated cardboards, packaging, books and wallpapers have indirectly reflected on the number of trees need to be chopped to meet the demands. Woods are the primary sources of fibres for pulp and paper productions worldwide (Low et al., 2017). Owing to the environmental concerns, deforestation and shortage of fibres, extensive researches had been conducted to use agrowastes such as pineapple crown leaves (Tran, A. V., 2006), corn stalk and napier grass (Zawawi et al., 2014) and oil palm mesocarp (Syed-Hassan et al, 2014) as the alternative raw materials for pulp and paper productions. Tea waste is another type of agrowaste coming from tea industries. Tea waste had been used as adsorbent of metal traces in wastewater (Amarasinghe and Williams, 2007), bio-oil, bio-char and bio-diesel (Nagaraja et al., 2013), casing materials in mushroom cultivation (Gulser et al., 2003) and handmade tea waste paper (Tutus et al., 2015). From the latter, the paper shows poor physical strengths such as low tear index, burst index and double fold resistance. These are due to the fibre morphology and chemical components such as low cellulose content and low elasticity coefficient. To solve the problem, a high cellulose secondary fibre is introduced into the weak primary fibre system to form a composite. Tutus et al. (2015) had added a strong Turkish pine pulp that has high cellulose content into the tea waste mixture to produce a composite paper. The composite paper showed a remarkable improvement in breaking length, tear index and burst index. Batiancela et al. (2014) had mixed tea waste with 20 wt% to 50 wt% wood dust of Paraserianthes falcataria (Batai wood) to produce particleboards with satisfactory thickness swelling, water repellent, internal bond and stiffness properties. Malaysia is also known for its highland tea productions such as BOH, Bharat and Sabah tea (World Tea news, 2013). Some of the tea wastes are converted into composts but most of them are burned or discarded in landfill. Open burning practiced by many tea farmers in Malaysia has

Please cite this article as: Rohah A. Majid, Zurina Mohamad, Rafidah Rusman, Ainur Asyikin Zulkornain, Nurshaleeza Abdul Halim, Mohammad Abdullah, Jiun Hor Low, 2018, Development of tea waste/kapok fiber composite paper, Chemical Engineering Transactions, 63, 457-462 DOI:10.3303/CET1863077

negatively affected the environment. By adopting the concept of composite fibre system, an effort was made to produce the tea waste composite paper by introducing a secondary fibre from a local plant. A strong kapok fibre that high in cellulose was selected as a composite counterpart to form a new tea waste/kapok composite paper.

Kapok fibre is a silky plant fibre that clothes the seeds of kapok tree (Ceiba pentandra). The plant is widely cultivated in Southeast Asia and Africa where the fibre is traditionally used as a stuffing material for beds and pillows. Kapok fibre contains a waxy cutin on the fibre surface which imparts good water repellent and oil absorbent (Chaiarrekij et al., 2011). Kapok fibre was used as a filter medium for oil-water separation where the oil removal efficiencies consistently exceeded 99 %. However, by treating the kapok fibre with sodium hydroxide (NaOH) had reduced the efficiency of oil adsorption due to the removal of cutin wax from the surface of the fibre (Lim et al., 2007). Chaiarrekij et al. (2011) used kapok fibre as wood substitution material in recycled paper mixture. They found that the addition of kapok fibre had improved the hydrophobicity, tensile strength and burst index of recycled paper/kapok composite paper. The increase in opacity, density and tensile index of were also observed. However, due to brittleness and inelasticity nature of kapok fibre, tear index and elongation at break of the composite paper were reduced (Chaiarrekij et al., 2012). These drawbacks were improved by adding stronger fibre such as sisal into the kapok/polyester composite system where the compressive properties of the composite had been tremendously increased (Reddy and Naidu, 2009).

With regard to the aforementioned, the aim of this study is to explore the fabrication of tea waste/kapok composite paper. Effects of fibre ratio (tea waste: kapok fibre) on the tear index, water absorbency and surface morphology of the composite paper were investigated.

2. Methods

2.1 Preparation of Tea Waste Paper

Tea waste was obtained from Cameron Highland tea plantation, Malaysia. Sodium hydroxide (NaOH) was purchased from Fisher Scientific. Kapok fibre was collected from a local village in Kuala Terengganu, Malaysia. Tea waste was treated at various concentrations of NaOH (10 %, 15 %, 20 %, 25 % and 30 %) to remove non-cellulosic materials such as lignin, wax and hemicelluloses. Tea waste was soaked with NaOH solution and cooked for 30 min. The cooked tea waste (pulp) was washed with a copious amount of tap water to remove the traces of non-cellulosic materials and NaOH. Later, the wet pulp was blended into the slurry prior to screening with a strainer to remove excess water. The pulp was dispersed into a paper mould and dried under sunlight. The dried paper was carefully removed from the mould and underwent tear index test. The formulation that gave the highest tear index was selected to be mixed with kapok fibre to make composite paper.

2.2 Preparation of Tea Waste/Kapok Fibre Composite Paper

The freshly dried kapok fibre was grounded using a Grinding Machine Model FFC-23 into a fine dust (500 microns). This was to assist the dispersion of fibre in the tea waste matrix. The fibre was not treated with alkali to retain its waxy-hydrophobic nature (Lim et al, 2007). The ground kapok fibre was mixed with the tea waste slurry and blended with a stainless-steel blender. The mixture of tea waste/kapok fibre was screened with a strainer to remove the excess water. The pulp was dispersed into a mould, dried under sunlight. The dried paper was carefully removed from the mould. The ratio of tea waste : kapok fibre was varied as follows; 100 : 0 wt%, 90 : 10 wt%, 75 : 15 wt%, 80 : 20 wt% and 70 : 30 wt%.

2.3 Tear Index Test

The tear test of was performed using mechanical Elmendorf ProTear test machine. The tear strength of paper is extremely important. The tear strength refer to the force required to cause a cut in a paper sheet to propagate across the paper sheet.The test was conducted to study the tearing resistance of specimens according to ASTM D 686. Tear Index was calculated according to Eq(1) - Eq(3).

$$\text{Average tearing force, mN} = \frac{16 \times 9.81 \times \text{average scale reading}}{\text{number of plies}} \qquad (1)$$

$$\text{Average grammage, g.m}^{-2} = \frac{\text{weight}}{\text{area}}, \text{ where area} = 3.1856 \times 10^{-3}\ \text{m}^2 \qquad (2)$$

$$\text{Tear index} = \frac{\text{average tearing force (mN)}}{\text{average grammage (g.m}^{-2}\text{)}} \qquad (3)$$

2.4 Scanning Electron Microscopy

Scanning Electron Microscopy (SEM) was used to analyse the surface morphology of the composite paper. A sample was mounted onto a sample holder and was sputtered-coating with thin films of gold. The opening voltage was set at 10 kV and the sample was analysed using a Hitachi TM3000 Tabletop Microscope.

2.5 Water Absorption Test

The test was carried out according to ASTM D 570. Specimens were sampled at regular intervals and weighted immediately after wiping away water from the surface. The percentage of water absorption was calculated by using Eq(4). An average of four samples was taken for each formulation.

$$\text{Percentage of water absorption} = \frac{W_2 - W_1}{W_1} \times 100\ \% \quad (4)$$

where W_1 and W_2 are the weight of specimens before and after soaking in the water for 1 min.

3. Results and Discussion

3.1 Tear Index

The tear indices (tear resistance/grammage) of the tea waste papers at various NaOH concentrations were shown in Figure 1. In this analysis, the untreated tea waste paper was omitted from the discussion due to the poor paper formation. The presence of impurities such as lignin and wax on the surface of untreated fibres have prevented the fibres from closely packed, thus, the fibres fall into pieces during the paper making process (Natalie et al., 2001). Tutus et al. (2015) had reported that tea waste consisted of higher lignin (36.9 %) but lower cellulose (29.4 %) when compared to the softwoods and the hardwoods. It can be seen that by increasing NaOH concentration had increased the tear index of the tea waste paper. The alkali treatment had improved the hydrophobicity, surface roughness and wettability of the fibre (Hashim et al., 2012). In return, the interfacial bonding between the tea waste fibres were also improved. However, further increased the NaOH concentration at 30 % had reduced the tear index. Higher NaOH concentration has damaged the fibre, weakening the strength of natural fibre (Li et al., 2007). The same result was obtained when excess NaOH was used to treat oil palm and sisal fibres (John and Anandjiwala, 2008). From the finding, tea waste treated with 20 % NaOH was selected to be mixed with kapok fibre to produce the composite paper.

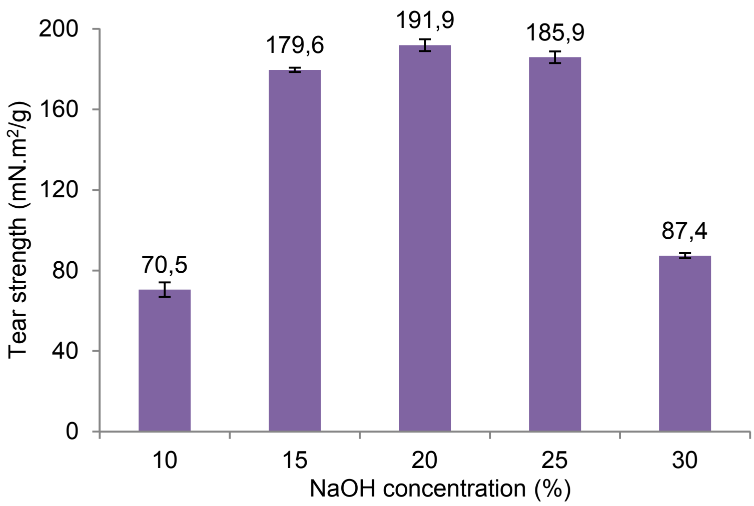

Figure 1: Tear index of composite paper at NaOH concentrations

The tear indices (tear resistance/grammage) of the composite papers at various kapok fiber contents were shown in Figure 2. It can be seen the addition of the kapok fiber had reduced the tear index of the composite paper. The reason for this reduction was thought as follows; higher kapok fiber had caused more kapok fiber to entangle due to its long fibre nature and tended to agglomerate throughout the tea waste matrix. The claims were proven with SEM images as discussed in the next section. The agglomerated kapok fiber gave poor paper formation, negatively affected the tear index of the composite paper. Chaiarrekij et al. (2012) had reported a slight improvement on the tear index of recycled paper-kapok composite paper, although an alkali-treated kapok fibre was used in their system. They found that the brittleness and inelasticity nature of kapok fibre affected the tear of the paper. Another reason was related to higher lignin content in the tea waste. Although the tea waste had been treated with NaOH, study showed only 90 % of lignin was dissolved in NaOH while another 10 % was remaining in the fiber (Tutus et al., 2015).

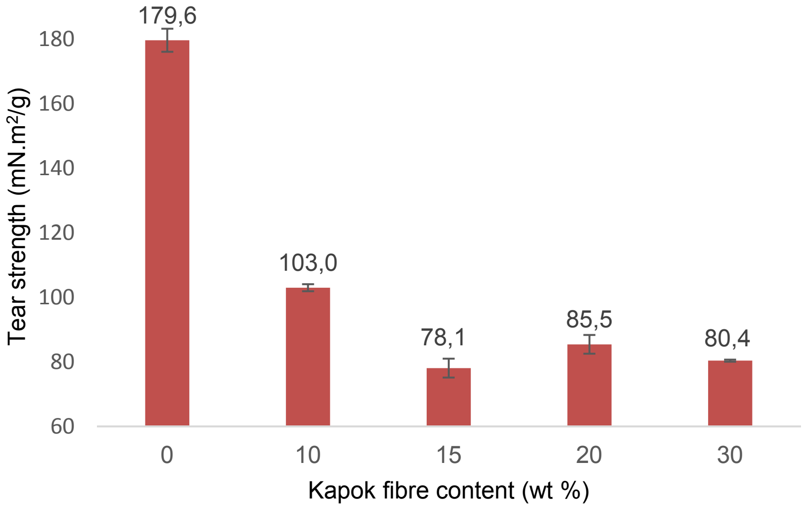

Figure 2: Tear index of composite paper at various kapok fibre contents

3.2 Scanning Electron Microscopy

Figure 3 shows the SEM images of the composite paper at various kapok fibre contents. The increase of kapok content had disturbed the continuity phase of the tea waste matrix. Kapok fibre was entangled to each other due to long fibre nature, forming a patch or lump in the matrix. Further increased the kapok content (Figure 4b) caused the formation of more kapok lumps, thus covering more the tea waste matrix. As discussed in the previous results, these lumps blocked the exit of the water passage and reduced the interfacial adhesion between both fibres. Consequently, the lumps negatively affected the tear index and the water repellent of the composite paper.

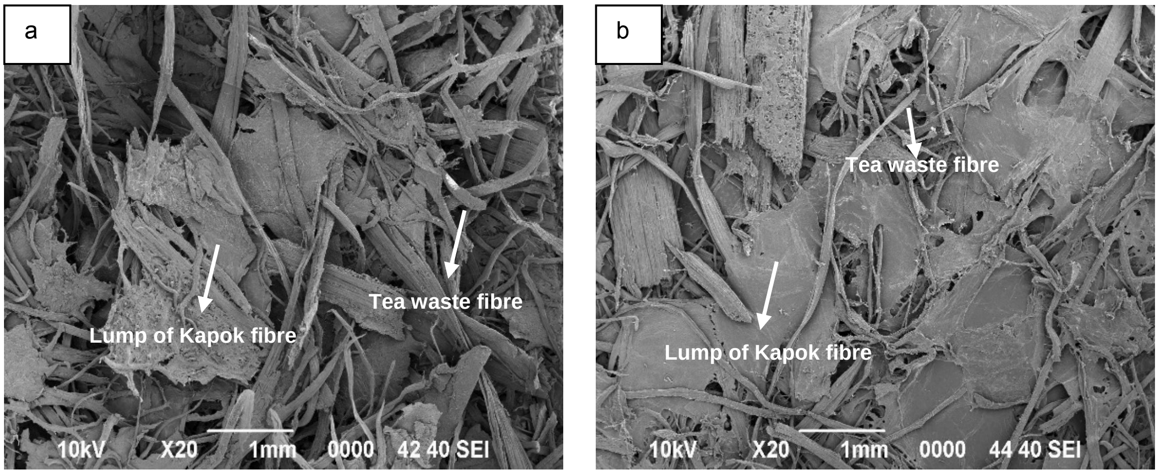

Figure 3: SEM images of composite paper (a) 90 : 10 tea waste : kapok fiber; (b) 70 : 30 tea *waste : kapok fiber*

3.3 Water Absorption

The percentages of water absorptions of all samples containing various amount of kapok fibres were shown in Figure 4.

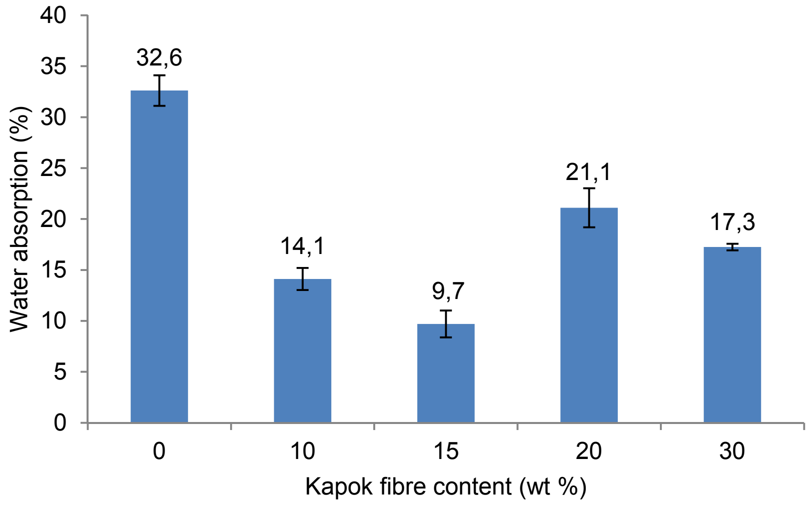

Figure 4: Effect of kapok fibre content on the water absorbency *of the composite paper*

It can be seen that tea waste paper absorbed the highest amount of water at the saturation point (i.e. the weight of sample remaining constant). The addition of kapok fibre had lowered the water absorption due to the hydrophobic nature of kapok fibre (Zheng et al. (2015). Further increased the fibre content had increased the water absorbency. When water was in contact with the composite paper, the water was repelled by the waxy surface of kapok fibre and was channelled into the pore spaces (passages) between the fibres (Lim et al., 2007). By increasing the kapok fibre content, the fibre tended to entangle and agglomerated due to its long chain nature. The agglomerated kapok fibre formed a lump which blocked the exit of the passage, thus preventing the water to flow out from the pores. Further increased the kapok fibre had caused more water to be trapped in the pores. As a result, the percentage of water absorbency increased.

4. Conclusions

Few findings can be outlined. NaOH-treated tea waste papers exhibited high tear index due to the improved interfacial adhesion between the tea waste fibres. During the treatment, non-cellulosic substances such as lignin, hemicellulose and wax were dissolved in NaOH and were removed upon washing with water. Further increased the NaOH concentration (30 %) had damaged the fibre, thus weakening the tear index. The addition of kapok fibre into the tea waste matrix had reduced the tear index of the composite paper, due to the agglomeration of long kapok fibre and the brittleness of kapok fibre. In contrast, the composite paper showed better water repellent than that of tea waste alone, owing to the hydrophobic cutin wax that coated the surface of the kapok fibre. By increasing the kapok fibre content had moderately increased the percentage of water absorption, although the values were still lowered than that of 100 % tea waste paper. The agglomerated kapok had formed more lumps in the matrix and blocked the exit passage of the water. Consequently, more water was trapped in the pores, thus increasing the water content in the paper. Images from SEM had supported arguments. Overall, it can be concluded that with the controlled process parameters such as NaOH concentration and fibre ratio, composite paper offers a promising alternative source for the pulp and paper productions in Malaysia. Both fibres could compensate the weakness of each, thus producing the composite paper with improved properties.

Acknowledgments

The authors would like to thank Universiti Teknologi Malaysia for furbishing the grant (GUP) to expedite the research work (Vot: Q.J130000.2546.14H38). Last, but not least, research colleagues for all the assistance granted throughout the research period.

References

Amarasinghe B.M.W.P.K., Williams R.A., 2007, Tea waste as a low cost adsorbent for the removal of Cu And Pb from wastewater, Chemical Engineering Journal, 132, 299–309.

Batiancela M.A., Acda M. N., Cabangon R.J., 2014, Particleboard from waste tea leaves and wood particles, Journal of Composite Materials, 48 (8) ,911–916.

Chaiarrekij S., Apirakchaiskul A., Suvarnakich K., Kiatkamjornwong S., 2011, Kapok I: Characteristics of kapok fiber as a potential pulp source for papermaking, BioResources, 7(1), 475−488.

Chaiarrekij S., Pattanapiyasup S., Lekhalawan S., Phiphatwitthay S., 2012, Use of kapok pulp to improve properties of recycled paper, The Journal of the Royal Institute of Thailand, 37(1), 1−9.

Gulser C., Peksen A., 2003, Using tea waste as a new casing material in mushroom (Agaricus bisporus (L.) Sing.) cultivation, Bioresource Technology, 88, 153–156.

Hashim M.Y., Roslan M. N., Mohd Amin A., Ahmad Zaidi A. M., Ariffin S., 2012, Mercerisation treatment parameter effect on natural fibre reinforced polymer matrix composite: A brief review. Journal of World Academy of Science, Engineering and Technology, 68, 1638-1644.

John M., Anandjiwala R., 2008, Recent developments in chemical modification and characterisation of natural fibre reinforced composites, Journal of Polymer Composites, 29, 187-207.

Li X., Tabil L. G., Panigrahi S., 2007, Chemical treatments of natural fibre for use in natural fibre-reinforced composites: A review, Journal of Polymer Environment, 15, 25-33.

Lim T-T., Huang X., 2007, Evaluation of hydrophobicity/oleophilicity of kapok and its performance in oily water filtration: Comparison of raw and solvent-treated fibers, Industrial Crops and Products, 26, 125−134.

Low J.H., Andenan N., Wan Abdul Rahman W.A., Rusman R., A. Majid R., 2017, Evaluation of rice straw as natural filler for injection molded high density polyethylene bio-composite materials, Chemical Engineering Transactions, 56, 1081-1086.

Nagaraja M., Charles I., Sundaresan R., Natarajan R., Srinivas T., 2013, Energy and byproducts recovery from tea waste, International Journal of Electrical Energy, 1 (1), 49−54.

Natalia M., Osterberg M., Stenius, P., 2001, Lignin adsorption on cellulose fiber surfaces: Effect on surface chemistry, surface morphology and paper strength. Cellulose, 81, 113-125.

Reddy G. V., Naidu S.V., 2009, Compressive, chemical resistance, and thermal studies on kapok/sisal fabrics polyester composites, Journal of Reinforced Plastics and Composites, 28 (12), 1485-1495.

Tran A. V., 2006, Chemical analysis and pulping study of pineapple crown leaves, Industrial Crops and Products, 24 (1), 66-74, DOI: 10.3303/CET1649022.

Tutus A., Kazaskeroglu Y., Cicekler M., 2015, Evaluation of tea wastes in usage pulp and paper production, BioResources, 10 (3), 5407−5416.

Syed-Hassan S.S.A, Nor-Azemi S.N.I., Fuadi F.A., 2014, Adsorption and dispersion of nickel on oil palm mesocarp fibre, Chemical Engineering Transactions, 37, 709-714, DOI: 10.3303/CET1437119.

Zawawi D., Mohd Z. M. H., Angzzas S. M. K., Halizah A., Ashuvila, M. A., 2014, Exploring of agro waste (pineapple leaf, corn stalk and napier grass) by chemical composition and morphological study, BioResources, 9 (1), 872-880.

Zheng Y., Wang J., Zhu Y.F., Wang, A., 2015, Research and application of kapok fiber as an absorbing material: A mini review, Journal of Environmental Sciences, 21-32.

World Tea News, 2013, Discovering tea Malaysia <http://worldteanews.com/tea-estate-and-garden-profiles/discovering-tea-malaysia> accessed 4.01.2018.