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AQ : 1 AQ : 2 AQ : 3 AQ : 4 The current issue and full text archive of this journal is available on Emerald Insight at: https://www.emerald.com/insight/0955-6222.htm A wicking measurement approach to evaluate the protection of non-medical face mask fabrics Giovanni Anggasta, Iwan Halim Sahputra and Debora Anne Yang Aysia Department of Industrial Engineering, Petra Christian University, Surabaya, Indonesia Abstract Purpose – The objective of this research is to systematically compare two methods of wicking test for evaluating the quality of the non-medical-mask fabric, i.e. its absorbency property at various conditions, using a design of experiment approach. This research also evaluates the suitability of several fabrics to be used for non-medical masks. Design/methodology/approach – Horizontal and vertical wicking tests were selected to evaluate the absorbency property of five fabrics commonly used for the non-medical mask. The tests were performed at three temperatures and using two types of liquid. The design of experiment approach was employed to determine the relationship between the path length of liquid movement in fabric and type of test method, temperature and type of liquid. Findings – Both vertical and horizontal wicking tests show the same order of fabrics according to their absorbency. The order is cotton twill, local cotton, Japanese cotton, Oxford and Scuba, where the first in the order has the lowest absorbency and the last has the highest absorbency. Based on the analysis of variance (ANOVA), the range of temperature and types of liquid employed in this research do not affect the path length of the liquid movement in the fabric. Originality/value – This research proposes horizontal and vertical wicking tests as a practical tool to evaluate absorbency property of fabric for the non-medical mask. This research also presents a design of experiment approach to evaluate the effect of the test method, temperature and type of liquid on the path length of the liquid movement in the fabric. Keywords Non–medical mask fabric, Wicking test, Experiment design Paper type Research paper Nofna-cmeemdiacsakl fabrics Received 9 September 2021 Revised 26 April 2022 18 July 2022 26 July 2022 Accepted 10 November 2022 1. Introduction AQ : 6 The ongoing COVID-19 pandemic has changed people's lifestyles. The term new normal, which is synonymous with a clean and healthy lifestyle, is now familiar to the public. Wearing a mask is a must for everyone when traveling outside the house or being indoors with people from outside of their household. Masks may reduce the spread of respiratory droplets from the user's mouth or nose to the surrounding people. On June 5, 2020, WHO recommends non- medical masks can be used ad hoc for specific activities (e.g. while on public transport when physical distancing cannot be maintained), and their use should always be accompanied by frequent hand hygiene and physical distancing (World Health Organization, 2020). A good non-medical mask must consist of several layers of fabric with a different function in each layer, be comfortable to use and be easy to breathe. For the outer layer, the material used must be waterproof or hydrophobic (Australian Government and Department of Health, 2020). This kind of fabric will repel droplets and moisture (NDTV, 2020). Low absorbency fabrics are suitable for this layer. Fabrics with high density or filtration capability to filter and inhibit the entry of droplets containing viruses into the inside of the mask are preferable for the middle layer. The inner layer is a hydrophilic layer or a layer that absorbs liquid easily (Bhattacharjee et al., 2021). This layer must absorb liquid very well so that the surface of the mask in contact with the wearer is always dry and comfortable to be used. Thus, a test InternatiSocniaelnJcoeuarnndalToefcChlnoothloinggy © Emerald Publishing Limited method is needed to measure liquid absorption by the non-medical mask fabric material. 0955-6222 DOI 10.1108/IJCST-09-2021-0124 IJCST In this study, five types of material, which are cotton twill, local cotton, Japanese cotton, Oxford and Scuba, will be investigated. The most popular material that is used in Indonesia for non- medical masks is cotton (Halodoc, 2021). Scuba masks are quite popular in Indonesia, because they are comfortable and cheap (Detikhealth, 2020). The rest of the materials are chosen because the composition meets WHO requirements for non-medical masks (World Health Organization, 2020). Several measurement methods have been developed to study liquid absorption in solid material. Some methods employ for example gravimetric sorption technique (Sarkar et al., 2007), direct height measurement (Harnett and Mehta, 1984), image analysis technique (Zhuang et al., 2002; Chinnadurai et al., 2020), magnetic induction technique (Mazloumpour et al., 2011), electrical conduction technique (Atasagun et al., 2016) and X-ray tomography (St€ampfli et al., 2013). Some of these techniques require more expensive equipment and sophisticated methods (Zhuang et al., 2002; Chinnadurai et al., 2020; Mazloumpour et al., 2011; Atasagun et al., 2016; St€ampfli et al., 2013). Wicking or spontaneous imbibition is the liquid absorption into a porous material due to capillary pressure (Pillai and Masoodi, 2012). Imbibition itself means the absorption of water by the surface of a hydrophilic material, which causes the material to expand after absorbing water. Wicking and fluid absorption are significant characteristics of textile materials (Patnaik et al., 2006). Capillarity (another name for wicking) is considered as the primary performance index of absorbent materials, such as wipes, diapers and commercial wicks (Masoodi et al., 2012). Several methods can be used to perform the wicking test, including vertical and horizontal wicking tests (Owens et al., 2012). The vertical wicking rate of fabric is measured according to AATCC 197 (American Association of Textile Chemists and Colorists, 2011a) and a typical setup is illustrated in Figure 1. The standard test method may be precise, but the test method fails to F1 take the effects of gravity into account. Most testing procedures that are based on upward wicking either ignore the effects of gravity or implicitly assume that it will have a similar proportional influence on all materials (Miller, 2000). The horizontal wicking property of a fabric is measured according to AATCC 198 (American Association of Textile Chemists and Colorists, 2011b) and its experimental setup is illustrated in Figure 2. In many common capillary systems, F2 which involve wicking in a substantially horizontal plane, the capillary pressure is much greater than the gravitational force that the latter may be ignored (Schwartz, 1969). Figure 1. Vertical wicking test IJCST ▪ IJCST-09-2021-0124_proof ▪ 21 November 2022 ▪ 11:04 pm The objective of this study is to perform a systematic comparison of those test methods using five types of fabrics widely used for non-medical masks at various conditions. The design of experiment approach is employed to evaluate factors affecting the wicking behavior and reproducibility of the experiment. This study proposes horizontal and vertical wicking tests as a practical tool to evaluate the absorbency property of five difference fabrics commonly used in Indonesia for the non-medical mask. From the absorbency properties, then the appropriate hydrophobic fabric for the outer layer and hydrophilic fabric for the inner layer can be selected for a non-medical mask. This research also presents a design of experiment approach to evaluate the effect of the test method, temperature and type of liquid on the path length of the liquid movement in the fabric. Non-medical face mask fabrics Figure 2. Horizontal wicking test 2. Experimental details 2.1 Vertical and horizontal wicking test The placement of the fabric sample along with the tools used for the vertical wicking test is shown in Figure 1. Length "h" represents the fluid propagation height at a certain time, to show the increase in length over a certain time. Length "Lc" represents the height of fluid propagation at equilibrium state, which is used to calculate the effective capillary radius of the fabric. The horizontal wicking test is a combination between vertical wicking and horizontal wicking. Vertical wicking in the horizontal wicking test occurs when the liquid creeps up toward "h", as presented in Figure 2. The effect of gravity on this test is very small because it only mainly affects when the fluid travels up on the vertical side of the fabric. The placement of the fabric sample along with the tools used for the horizontal wicking test can be seen in Figure 2. At the early stage of the test, the liquid will propagate up to a height of "h", then the liquid will propagate horizontally at the length of "L". 2.2 Pre-experiment The pre-experimental stage was performed to determine the vertical height of the fabric at the horizontal wicking test and the length of time for both experiments. The sample size of the fabric was 15 3 5 cm, based on the previous study (Simile and Beckham, 2012). The vertical height of the fabric at horizontal wicking or "h" can be seen in Figure 2. The vertical height of the fabric for each test must be at the same level so it does not raise a new factor in the experiment. The vertical heights of the fabric used in this test were 1.5, 2.0 and 2.5 cm. The factors that affect the difference in the vertical height of the fabric are the angle between the liquid surface and the vertical height of the fabric itself. The results of the change in height T1 and angle test can be seen in Table 1. Determining the length of time in this research is very important. If the duration of the experiment is too long, the liquid absorbed in the fabric may begin to evaporate. On the other hand, if the duration of the experiment is too short, the liquid may still move in the fabric. The appropriate time for this experiment is when the liquid is still propagating but starting to slow down. Determination of the length of time of the experiment was done by comparing the height of the water propagation at 10, 15 and 20 min. During the horizontal wicking experiment, the path length of the liquid movement on the Scuba fabric exceeds the fabric's horizontal length. Because of it, the sample size of the fabric length was extended from 15 cm to 20 cm. The results of the experiment that have been averaged can be seen in Table 2. T2 The difference in the path length between two subsequent measurements was calculated to evaluate the movement speed. It can be seen in Table 3 that the difference in propagation between T3 15 and 20 min is small. It means that the movement of the liquid in the fabric starts to slow down after 15 min. In the case of local cotton, Japanese cotton and cotton twill, liquid has stopped moving before 20 min in both methods. Therefore, the measurement time was set to be 15 min. 2.3 Experimental design An experimental design approach was employed to evaluate the ability of the fabric to absorb liquid in different conditions. The response variable of this study was the fluid movement path length. The sample size of the fabric was 15 3 5 cm, based on the previous study (Simile and Vertical height of the fabric Fabric type 1.5 cm 2 cm 2.5 cm Local cotton Table 1. Japanese cotton Contact angle between Cotton twill the liquid surface and Oxford the fabric Scuba 758 858 708 858 708 808 758 858 808 908 908 908 908 908 908 Vertical wicking Horizontal wicking Fabric type 10 min 15 min 20 min 10 min 15 min 20 min Local cotton Table 2. Japanese cotton Path length of the Cotton twill liquid movement in the Oxford fabric (in cm) Scuba 2.97 3.17 5.27 6.10 2.53 2.97 8.37 9.57 9.60 11.37 3.23 1.27 6.17 3.17 2.97 0.93 9.70 6.47 11.50 12.97 2.27 4.50 1.27 8.23 15.47 2.37 4.57 1.37 8.50 16.93 Vertical wicking Horizontal wicking Fabric type 10 and 15 min 15 and 20 min 10 and 15 min 15 and 20 min Table 3. Local cotton Difference in path Japanese cotton length between the two Cotton twill subsequent Oxford measurements (in cm) Scuba 0.20 0.06 0.83 0.07 0.44 0.00 1.20 0.13 1.77 0.13 1.00 0.10 1.33 0.07 0.34 0.10 1.76 0.27 2.50 1.46 T4 Beckham, 2012). The types of fabrics used in this study, as shown in Table 4, are the most common fabric types used for a non-medical mask in Indonesia. The samples were cut from new fabrics provided by the fabric suppliers. The measurement time, i.e. 15 min, was determined based on the result of the pre-experiment stage. In the pre-experiment stage, several measurement times were tested: 5 min, 10 min, 15 min and 20 min. The results show increasing in propagation height at 20 min begins to slow down and eventually stops. If the fluid stops moving, there is a possibility that the liquid on the cloth starts to evaporate thus data obtained becomes invalid. To measure other type of fabric, the measurement time must be re-evaluated and determined. The length of the fluid movement was measured after 5, 10, 15 min for both methods, and when the fluid stops moving, i.e. equilibrium state, for the vertical wicking test. At 15 min, measurements were done on three sides (left, center and right) of the sample to evaluate whether there is an effect of the edges on the propagation of liquid. Four factors used in this study were the type of fabric, room temperature, type of liquid and test method. These factors were assumed to have a significant effect on the response. The types of fabrics used in this study and their composition can be seen in Table 4. The room temperature used in this study refers to the Indonesian National Standard or SNI 03–6572 of T5 2001, which categorizes room temperature into three groups (Table 5). The types of fluid used in this study were water and salt solution. Water is the main substance of human body fluids. The salt solution is a liquid that can represent saliva or droplets. For this study, the concentration of the salt solution was 1.594 g/L (Sarkar et al., 2019). The experiment was conducted with three replications for each combination. Thus, the total run of the experiment was 180 for vertical and horizontal methods. The humidity was in the range between 45 and 65%. The experiments were conducted in a 30 3 30 3 40 cm closed transparent acrylic box inside an air-conditioned room. The experiments were carried out between 9.00 a.m. and 1.00 p.m.. During the experiments, the lights inside the room were on. The statistical test in the analysis stage was performed using the Minitab 2016 software. 3. Results and discussion The path lengths of the fluid movement in the fabric were averaged and then evaluated using the Identical, Independent, Normal Distribution (IIDN). The identical test used Bartlett's test, the independent test used Durbin Watson Statistics and the normality test used Anderson Darling. The alpha value selected in this study was 0.01. After all the IIDN conditions were satisfied, then the ANOVA test was performed on the experimental data. The averaged path F3; 4 lengths from the vertical and horizontal wicking test results are presented in Figures 3 and 4. Fabric type Composition Local cotton Japanese cotton Cotton twill Oxford Scuba 95% cotton, 5% polyester 90% cotton, 10% polyester 98% cotton, 2% spandex 65% cotton, 35% polyester 90% polyester, 10% spandex Table 4. Fabric composition Category Range of temperature Cool Comfort Warm 20.5 8C – 22.8 8C 22.8 8C – 25.8 8C 25.8 8C – 27.1 8C Table 5. Range of temperature Figure 3. Path length of the fluid movement measured from the vertical wicking test Figure 4. Path length of the fluid movement measured from the horizontal wicking test In Figures 3 and 4, it can be seen that the path length increases along the measurement time. However, at certain times, the liquid movement starts to slow down. The path length for the Scuba and Oxford fabrics is much longer than the other fabrics, where Scuba is the longest. It indicates that Scuba has the fastest wicking flow rate, thus, it has the best absorbency property. On the other hand, cotton twill has the shortest path length, thus, the slowest wicking flow rate. The order of the fabrics with the lowest to highest wicking rate is the same for both methods. The order is cotton twill, local cotton, Japanese cotton, Oxford and Scuba. Standard wicking methods are useful for determining the rate of advance of the liquid front (Owens et al., 2012; Tang et al., 2017). Hence the measured path length of these samples in a period of time indicates the wicking flow rate of the fabric. Moreover, there is evidence that for given water imbibition, the mass transfer rate and the rate of advance of the liquid front are directly related (Hollies et al., 1957a; Zhu et al., 2015). Cotton twill fabric which contains 98% cotton (the highest percentage of cotton compared to the rest fabrics in this study) has the slowest wicking rate and Scuba fabric containing 90% polyester (and no cotton) has the fastest wicking rate. This is in agreement with the other result, i.e. the absorption rate of polyester fabric has been measured to be faster than polyester/cotton blend fabric (El Messiry et al., 2015). The cotton twill fabric has been found to have a slower wicking rate than local (plain) cotton fabric in this study is also in agreement with the other result (Chowdhary and Rashedul, 2019; Mallick and De, 2021). The data used to calculate the effective capillary radius were the length of fluid propagation at 15 min for the horizontal wicking test and the length of fluid propagation when equilibrated for the vertical wicking. In vertical wicking, the requirement to calculate the effective capillary radius of the fabric is when it is in equilibrium or the fluid has stopped moving. The equation for calculating the effective capillary radius for vertical wicking is as follows (Simile and Beckham, 2012): R ¼ L2cpγg (1) where γ is the surface tension of the liquid, Lc is the path length of the liquid's movement at equilibrium, ρ is the density of the liquid and g is the acceleration due to gravity. The average T6 length of the liquid movement along with the effective capillary radius can be seen in Table 6. At the vertical wicking test, the smaller its effective capillary radius the longer the path length (Simile and Beckham, 2012). Under the theories of capillarity, if the radius is smaller, then the combination of surface tension and adhesive forces act to push the liquid is higher, thus the longer the path length. From Table 6, it can be seen that Scuba has the smallest capillary radius of 9.9 mm and the longest average fluid movement length of 11.43 cm. The effective hydraulic radius of the capillaries for horizontal wicking was calculated using the following equation (Tang et al., 2017): R ¼ pLffiffi 2 3 2 η t γ (2) coefficient (Kamath et al., 1994), η is the viscosity of the liquid and γ is the surface tension of where (L/√t) is the slope of the plot L (path length) vs square root of t (time) or the wicking the liquid. The path length data for the horizontal wicking test were also averaged. The averaged T7 path length and fabric effective capillary radius can be seen in Table 7. It can be seen that Scuba has the largest capillary radius of 43.70 mm and the longest average fluid movement Fabric type Average length (cm) Average effective capillary radius (μm) Cotton twill Local cotton Japanese cotton Oxford Scuba 3.04 44.6 3.20 40.8 6.25 20.5 9.51 12.3 11.43 9.9 Table 6. Average length and capillary radius of the fabric from the vertical wicking test result path of 15.88 cm compared to the rest. For horizontal wicking, the larger its pore size the longer the path length (Simile and Beckham, 2012), as can be seen in Eq. (2), as the larger the wicking coefficient (or the rate (Hollies et al., 1957b)) the larger the pore size. One reason Scuba appears to have the largest radius here due to the rate is more significantly affected by its structure and not pore size distribution, thus the driving force is not only force of capillarity (Minor and Schwartz, 1960). The analysis of variance (ANOVA) test was performed on the experimental data and the result is presented in Table 8. Four factors in this test are the type of fabric (factor A), room T8 temperature (factor B), type of liquid (factor C) and test method (factor D). It is found that only one factor has a significant effect on the path length, that is the type of fabric (factor A). As presented in Table 8, factor A has a p-value close to zero, i.e. less than alpha value (0.01). Room temperature, type of liquid and test method do not significantly affect the path length, as indicated by their p-value higher than alpha value. Different type of fabric significantly affects the path length of fluid movement, thus indicating each fabric has different absorbency property. The Tukey test was performed to statically evaluate the differences between the path lengths. The results from the test in Table 9 show that the path lengths of local cotton and T9 cotton twill are not significantly different, while the rest are significantly different. This is Fabric type Average length (cm) Average effective capillary radius (mm) Table 7. Cotton twill Average length and Local cotton capillary radius of the Japanese cotton fabric from the Oxford horizontal wicking test Scuba 1.41 0.28 2.34 0.79 4.62 3.39 8.63 12.15 15.88 43.70 Table 8. Result of the analysis of variance (ANOVA) Source DF Seq SS Adj MS F P D 1 0.54 0.54 A 4 3276.43 3276.43 B 2 5.67 5.67 C 1 0.00 0.00 A*B 8 0.73 0.73 A*C 4 0.02 0.02 B*C 2 0.00 0.00 A*B*C 8 0.01 0.01 Error 149 241.63 241.63 Total 179 3525.05 Total Note(s): S 5 1.27345 R-Sq 5 93.15% R-Sq (adj) 5 91.77% 0.54 0.34 819.11 505.10 2.83 1.75 0.00 0.00 0.09 0.06 0.01 0.00 0.00 0.00 0.00 0.00 1.62 0.563 0.000 0.178 0.977 1.000 1.000 0.999 1.000 Fabric type N Mean Grouping Scuba Oxford Japanese cotton Table 9. Local cotton Tukey test result Cotton twill 36 13.66 36 9.07 36 5.43 36 2.77 36 2.23 A B C D D indicated by the two fabrics being in the same group (group D). This means that the absorption capability of these two fabrics is statistically the same, while the other three fabrics have significantly different absorption capabilities. It can be seen that Scuba is the fabric with the highest absorbency with an average path length of 13.66 cm. On the other hand, local cotton and twill cotton are two types of fabrics with the lowest absorbency, where the path lengths are 2.77 cm and 2.23 cm, respectively. Therefore, the type of fabric suitable for the outer layer of the mask is twill cotton, with the second alternative being local cotton, because they are water-resistant or hydrophobic fabric. Meanwhile, the type of fabric suitable for the inner layer of the mask is Scuba, because it absorbs liquid easily. 4. Conclusion This research has been performed to evaluate the vertical and horizontal testing methods to determine the suitable fabric material for non-medical masks. A design of experiment approach has been employed to study the significant factors affecting the liquid absorption on fabrics. Five types of fabrics, the most commonly used in Indonesia for non-medical masks, have been

investigated in this study, i.e. Scuba, Oxford, Japanese cotton, local cotton and twill cotton. Measurements were performed at a range of temperatures in Indonesia, referring to the Indonesian National Standard (SNI) 03–6572 of 2001. From the results of both methods, the order of the types of fabric that have the highest to the lowest absorbency level is the same. Thus, both methods can be used to evaluate the quality of non-medical mask fabric. These methods can be alternatives to the ISO 11948–1 and EDANA 10.3.99 standards that have been employed to measure the absorption capacity of face masks using superabsorbent polymer containing nanofibers (Sivri, 2018). The fabric order from the highest to the lowest absorbency level is Scuba, Oxford, Japanese cotton, local cotton and twill cotton. Scuba is the fabric with the highest absorbency, having an average path length of 13.66 cm. Local cotton and twill cotton are two fabrics with the lowest absorbency, having path lengths of 2.77 cm and 2.23 cm, respectively. Therefore, the type of fabric suitable for the outer layer of the mask is twill cotton, with the second alternative being local cotton. Statistically, these two types of cotton are not significantly different in terms of their absorption capability. The results also present that the room temperature, type of liquid and test method used in this study do not significantly affect the absorption capability. References American Association of Textile Chemists and Colorists (2011), AATCC Technical Manual 197 Vertical Wicking of Textiles, American Association of Textile Chemists and Colorists, NC. American Association of Textile Chemists and Colorists (2011), AATCC 198 Horizontal Wicking of Textiles, American Association of Textile Chemists and Colorists, NC. Atasagun, H.G., Okur, A.Y.Ş.E., Akkan, T. and Akkan, L.O€. 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