DESIGN AND DEVELOPMENT OF PROFILE WICKING TESTER TO ANALYZE THE LIQUID DISTRIBUTION OF NURSING PAD IN ACTUAL USAGE CONDITION

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ABSTRACT

The present work aims at the study of fluid distribution in multi-direction on the wet-laid absorbent core prepared for the application of a nursing pad. A newly designed profile wicking tester was developed representing the actual usage condition considering the placement of nursing pad inside the brassier and the position of the liquid supply. Mapping of liquid distribution at different orientation of samples were done by testing 200 g/m2 wet-laid nonwoven samples in Profile, Vertical and Horizontal wicking testers. The effect of mass per unit area and thickness on the liquid transport was experimented using a profile wicking tester. The wicking distance was measured in multi-direction (0 - 360°) at an interval of 30° and the observation recorded using image processing technique. The data obtained was analyzed statistically using three-way ANOVA. The result and analysis showed a significant difference between three test methods and the liquid movement in the profile wicking tester was different. A further discussion on the interaction between independent variable and response variable on wicking distance was taken up. This newly developed profile wicking test method had the ability to provide information on the liquid distribution in actual usage condition which helped product development and further research to increase the utility of the absorbent core.

Keywords: Absorbent Core; Absorbency Behavior; Nursing Pad; Profile Wicking; Technical Textiles; Wet-Laid Nonwoven.

INTRODUCTION

Nursing pads used by the lactating mothers are placed inside the brassier to avoid any possible embarrassment caused by the leakage of milk during and after feeds [1, 2]. The general construction of the nursing pad consists of an innermost layer, an absorbent core, and the outer most layer [3]. The absorbent core of the commercially available nursing pad consists of wood pulp, superabsorbent polymer, and synthetic fibers manufactured by the air-laid web formation technique. The main function of the absorbent core is to absorb and retain the liquid to avoid any possible staining on the clothes [4-6]. There are various shapes and designs available commercially for the improvement of the performance of the nursing pad [7-11]. The drawback of the commercially available nursing pad is that only the lower portion of the nursing pad gets utilized and disintegrated during use. This does not help complete utilization of the pad [12]. But no systematic study has been reported so far in literature and patents on the subject of evaluation of the performance in actual usage condition.

The study of liquid transport in nonwovens is difficult due to the complexity of the porous networks [13]. Mapping of liquid transport in such fibrous network is of great importance for academics and industry due to its importance in the evaluation of its performance in many end application [14]. Generally, the liquid transport happens due to capillary action that occurs when the fibrous network is completely or partially immersed in a liquid or in contact with liquid from an infinite (unlimited) reservoir or finite (limited) reservoir [15]. Common test methods available so far for testing the absorbency behavior are vertical, horizontal, inclined, downward wicking and upward-downward-horizontal wicking tests [16-20]. Test results of these methods demonstrate the potential wickability or absorbency capacity of the sample but do not indicate the results of the performance behavior. The wicking test results depend on the material characteristics, namely pore structure, permeability, contact angle, test fluid characteristics, rate of liquid supply, apparatus used and test conditions [21].

In vertical wicking, samples are vertically positioned into an infinite liquid reservoir. The liquid enters from the bottom of the sample and its transport takes place due to capillary action which creates hydrostatic pressure to enable travel through the distance of the sample. The movement of the liquid stops at the equilibrium condition when the capillary action balances the hydrostatic pressure. Wicking results are influenced by gravity [16]. The rate of liquid spreading in horizontal wicking was determined, where the samples are positioned horizontally and the liquid is supplied from a definite distance [17]. In the downward wicking test, the downward movement of the liquid is measured following an initial upward movement of liquid from the infinite reservoir. This determines its capillary pressure (P_c) and permeability (K) [22]. Inclined wicking examines the influence of gravity on the spreading of liquid from a point source on an inclined sheet of sample [18].

The study of the liquid distribution in the absorbent material helps in evaluating the existing product and provide information for the design and development of the new product. Some of the technologies available for mapping the liquid distribution are direct observation of liquid movement through porous structure using colored liquid, discrete sensors based on conductance, temperature or optical measurements, optical imaging, gravimetric methods, X-ray imaging and magnetic resonance imaging [23].

The usage profile of the nursing pad differs from other absorbent pads used for hygiene purposes. Hence the above test methods do not represent the actual usage conditions and also the prediction of liquid movement through mathematical relations like Young-Dupre's, Lucas-Washburn equation, Darcy Law, Laplace equation, etc., is not possible [24]. Hence a need for the test method to simulate the actual in-use condition arises to enable a study of the absorbency behavior of the nursing pad. In this work, a new profile wicking method has been designed and developed. Wet-laid samples of 200 g/m^2, 300 g/m^2 and 400 g/m^2 were tested and the liquid movement was captured using a camera and the distance of the liquid movement was measured in multi-direction using image J software.

MATERIALS AND METHODS

Procurement and preparation of Wood pulp sample

Fully bleached single species softwood kraft pulp was procured in sheet form from Rajarajeswari Traders, Chennai. The procured pulp in sheet form was converted to fibrous form by soaking in distilled water for 12 hours and the disintegration was carried out using a Remi overhead stirrer RQ-122 at 3000 rpm for 10 min. Water was removed from the pulp after filtering the pulp through the sieve of ASTM mesh size 200, in order to avoid wastage of the fiber during filtering and the excess water, was squeezed out.

Pretreatment of wood pulp sample

Alkali treatment of wood pulp sample was carried out using 15% (w/v) NaOH solution for 10 minutes at 32ºC (room temperature) maintaining a Material: Liquor ratio of 1: 33. AR grade NaOH pellets was procured from Central Drug House, New Delhi. After treatment, the NaOH solution was removed from the wood pulp sample through a thorough washing several times using distilled water. The residual NaOH solution was removed by treating the washed pulp in 0.1% (w/v) AR grade Sulphuric acid solution and rinsed thoroughly in distilled water until it was neutral to pH. Drying was carried out in a hot air oven at 80°C till a constant weight was obtained. Conditioning of the pulp was carried out in an environment chamber at 25 ± 2° C and 65 ± 2% RH for 24 hours. The fiber length *L(w)* and fiber coarseness of the treated pulp were determined using fiber analyzer Kajaani FS-300 and found to be 2.24 mm and 0.366 mg/g respectively [25, 26].

Wet-laid web formation

Lab-scale wet-laid setup fabricated with reference to a Handsheet forming machine used in Tappi standard T205 SP-02 was used for the wet-laid nonwoven production. The alkali treated wood pulp was used as raw material for producing samples having a mass per unit area of 200 g/m^2, 300 g/m^2, and 400 g/m^2 .The web produced was compressed at a pressure of 120 kg/cm^2 using a compression molding machine. During compression, spacers made up of stainless steel of 1mm, 2 mm and 3 mm thickness were used for achieving the required thickness as shown in Table 1. The web characterization using parameters such as mass per unit area, thickness was done using standard methods ISO 9073-1:1995 and ISO 9073-2:1995. The porosity and air-permeability of the wet-laid nonwoven were found out by using a capillary flow porometer (CFP-1100A1, Porous materials Inc, USA) and digital air permeability tester (Frazier permeability tester, Model No. PM1-GP-100A-F, Porous materials Inc, USA) respectively. Porosity and air permeability tests were carried out according to the standard methods ASTM E 1294-89 and ISO-9237/7231 respectively. The constructional parameters of tested samples such as web density, theoretical web volume porosity% were calculated [27]. The liquid absorptive capacity of the web was determined using standard procedure NWSP 0.10.1RO and the values have been provided in table 2.

Table 1. Wet-laid nonwoven samples for wicking study

Mas per unit area (g/m^2)	**Original thickness (mm)**	**Compressed thickness (mm)**
200	2	1
300	3	2,1
400	4	3,2,1

Table 2. Constructional parameters of wet-laid nonwoven samples

Mass per unit area (g/m^2)	**Web thickness (mm)**	**Pore diameter (µm)**			**Air permeability (cm^3/sec/cm^2)**	**Calculated Web volume porosity (%)**	**Web density (g/ cm^3)**	**Total absorption capacity (g/g)**
		Smallest	Mean flow	Largest				
200±25	2.06	2.5087	36.4206	184.1589	38.08	81.10	0.1077239	20.5758
300±25	3.04	3.8663	33.6665	76.8696	29.75	81.11	0.1076965	30.05338
400±25	4.05	5.7544	32.3778	247.4088	22.86	81.64	0.1046530	36.02698

Materials preparation for wicking study

The specimen size used for the wicking study had 10 cm diameter. The liquid used during measurement was prepared by dissolving 0.5 g of Acid Fast red dye powder in 500 mL of distilled water. The test specimen was conditioned for at least 4h in an atmosphere of 25± 2^{o}C and 65 ± 2% RH. The topside of the nonwoven was marked for the identification of the placement of the sample in the sample holder. The center point of the sample was marked to facilitate the liquid supply at the center point. Sample handling was done using gloves to minimize the contamination. Five replication of each test was being carried out. The wicking experiments have been carried out at ambient room temperature.

EXPERIMENTAL SETUP

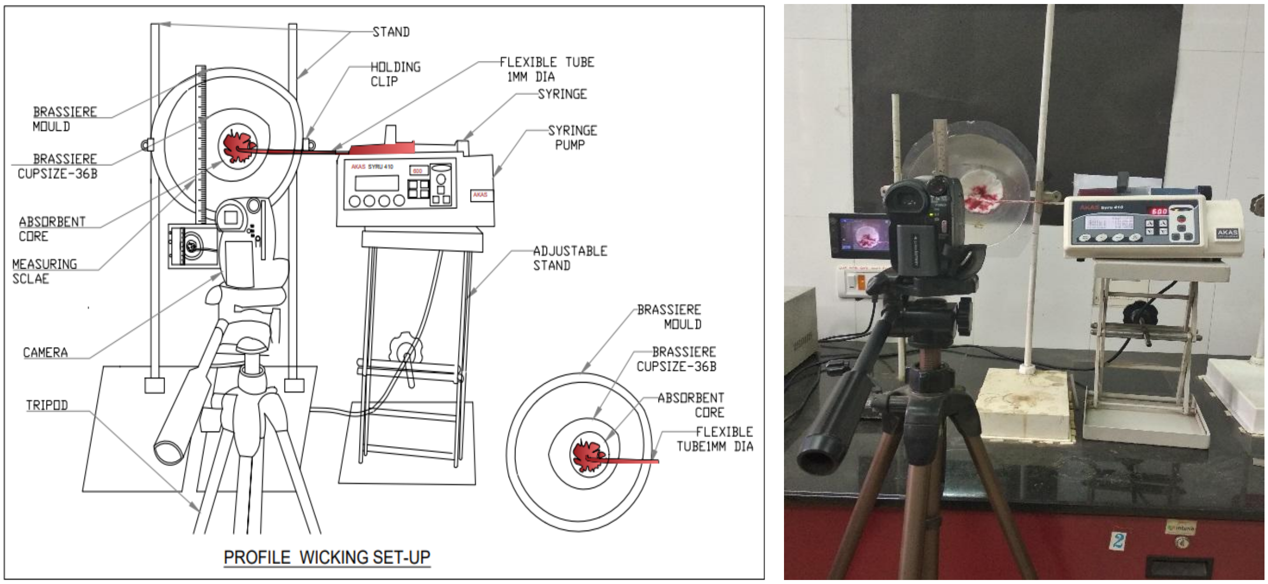
The profile wicking setup was designed and developed for the simulation of the actual usage condition for the assessment of liquid transport characteristics of the fibrous structure. The vertical and horizontal setup was designed to enable the study of variation in the physical placement condition of the absorbent core.

Liquid supply

The liquid supply was provided by injecting the fluid with the help of a 50 ml syringe. The end of the syringe needle was attached to a flexible tube of 1mm inner diameter and 3 mm outer diameter. The liquid was fed at a constant rate of 1mL/min through a syringe infusion pump, AKAS SYRU 410, supplied by Akash Medical Equipment, Chennai-25. The syringe was filled with a red dye solution. It was set in the slot for the syringe in the syringe infusion pump. The program was set for the flow rate of 1mL/min and the run switch was pressed for the liquid to flow into the pad. The flow of the liquid all through the tube is ensured before the supply was given to the sample. The liquid supply was provided at the center of a sample such that the flexible tube is in direct contact with the sample.

Description of Profile wicking setup

In profile wicking, the brassiere cup mould of size '36B' was used as the sample holder. The brassiere cup was fixed inside the brassier mould. The brassiere mould was held in position using two stands. The standard measuring scale was fixed on the master brassier mould for calibration during measurement. The profile wicking setup is shown in Figure 1. The sample was placed in position inside the brassiere cup.



a) b)

Figure 1 a) CAD diagram, b) photographic picture of profile wicking setup

EXPERIMENTAL PLAN

Effect of Profile, Vertical and Horizontal wicking on the wicking behavior of absorbent core

For the experimental plan, 200 g/m^2 wet-laid nonwoven samples of 1 mm and 2mm thickness were carefully chosen for a study of the effect of variation in the physical condition of the placement of the sample. The samples were tested in a profile wicking tester, a horizontal wicking tester, and a vertical wicking tester.

Effect of Mass per unit area on wicking behavior

The wet-laid samples of mass per unit area 200 g/m^2, 300 g/m^2 and 400 g/m^2 were chosen for the study of the effect of mass per unit area on the wicking behavior. The samples were tested in the profile wicking tester.

Effect of thickness on the wicking behavior

The samples of 300 g/m^2 1 mm thickness and 400 g/m^2 1 mm and 2 mm thickness were tested and the samples had the ability to absorb liquid only upto 6-8 mL and reach the endpoint by the dripping of the liquid. These samples were considered as not suitable for further analysis. Hence the samples of 200 g/m^2 (1 mm and 2 mm thickness), 300 g/m^2 (3 mm and 2 mm thickness) and 400 g/m^2 (4 mm and 3 mm thickness) was chosen for the study of the effect of different thicknesses in the same mass per unit area and the effect of same thickness in the different mass per unit area. The samples were tested in the profile wicking tester.

Absorption capacity of the web during the wicking study

The absorption capacity of the web during the wicking study is the capability of the web to hold the liquid until the liquid drops from the bottom of the pad.

$$\text{Utilization \%} = \frac{\text{Absorption capacity of the web during wicking study}}{\text{Total absorption capacity of the web}} \times 100 \quad (1)$$

DATA ANALYSIS

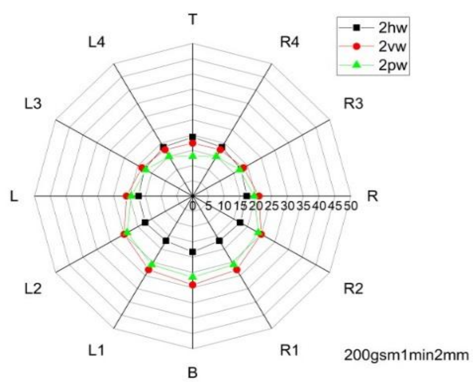
The distance traveled by the liquid (wicking distance) from the center point was measured from 12 different angles every minute. The observations were tabulated and recorded. The mean value of the five experimental results were carried out. A radial graph was drawn for all the samples used for comparison by pictorial representation so that the liquid movement in each direction was clearly visible using these data. Data analysis was carried out statistically using SPSS 21. Three-way ANOVA analysis was performed for locating any significant differences in the mean wicking height raised in a similar time at different levels of various factors. A p-value less than 0.01 was considered statistically significant at 99 % confidence level.

RESULTS AND DISCUSSION

Comparison of Profile, Horizontal and Vertical wicking

Radial Graph for wicking comparison

The radial graph depicts the distance traveled by each experiment for each minute by horizontal wicking (hw), vertical wicking (vw) and profile wicking (pw) respectively. The radial graph represents the absorbent pad size of 10 cm diameter. The center point is the liquid supply point, from the center point the liquid traveling distance at 12 different angles is measured at an angle 30° difference. The letter B indicates the bottom, T indicates the Top, R indicates the right and L indicates the left. The suffixes 1, 2 seen in R and L indicate the angles in down half. The suffixes 3, 4 seen in R and L indicate the angles in the top half. The liquid traveling profiles of 1 minute, 7 minutes and 14 minutes is shown in the figure it represent the starting, middle and final wicking stages.



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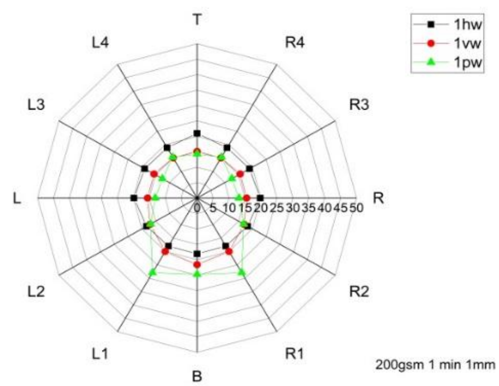

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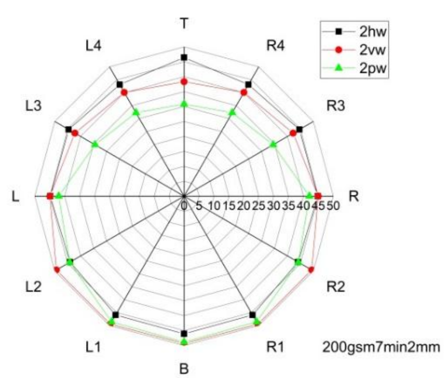

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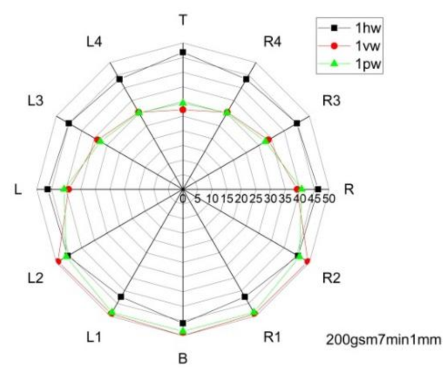

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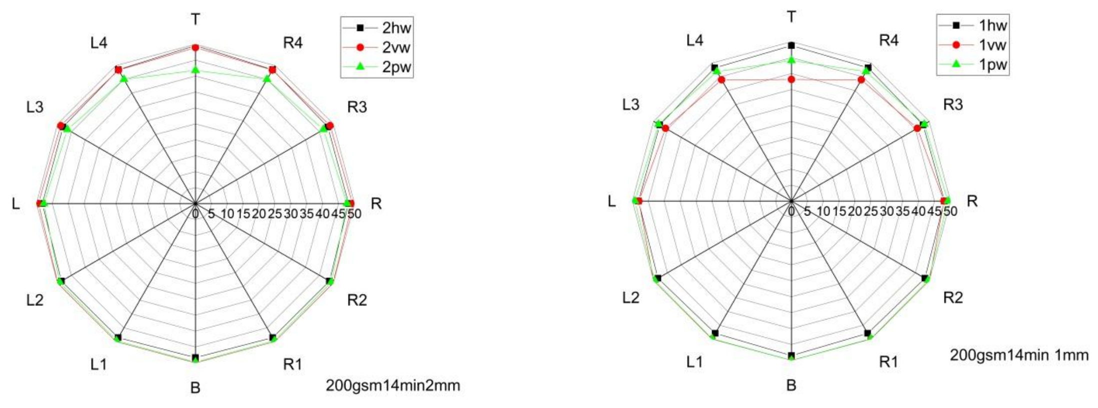

e) f)

Figure 4 Radial graph of Profile wicking (pw), Vertical wicking (vw) and Horizontal wicking (hw) test of a) 200 g/m^2 2 mm 1min, b) 200 g/m^2 1 mm 1min, c) 200 g/m^2 2 mm 7 min, d) 200 g/m^2 1 mm 7 min, e) 200 g/m^2 2 mm 14 min, f) 200 g/m^2 1 mm 14 min

From the above Figure 4, it is obvious that the movement of the liquid follows a different pattern in different angles for horizontal wicking, vertical wicking, and profile wicking when was observed for each minute for the same mass per unit area and the same thickness.

Three-way ANOVA Test for wicking comparison.

The three-way ANOVA utilized had the ability to test the effect size of the model, from which the effect of liquid transport (wicking distance) with respect to wicking method, angle and minute can be interpreted in Table 3 [30]. The ANOVA model that explained R^2 = 0.916 had 9l.6% and R^2 = 0.904 had 90.4% for 200 g/m^2 2 mm and 200 g/m^2 1 mm variability of the response variable (wicking distance). The variability in the significant difference was explained by a partial η^2 value shown in Table 3. The effect of profile wicking, vertical wicking and horizontal wicking among distance of liquid flow showed 24.5% variability in 200 g/m^2 1mm thickness and 31.1% in 200 g/m^2 2mm thickness. Interaction effect between wicking method, angle and minutes among distance of liquid flow was seen. 27.2% and 25% variability in distance of liquid flow for

200 g/m^2 1mm thickness and 200 g/m^2 2 mm thickness respectively were shown.

Table 3: Comparison of profile wicking, vertical wicking and horizontal wicking. Tests of Between-within Subject Effects

Sources of Variation	**200** g/m^2 **1 mm**			200 g/m^2 **2 mm**		
	F	**Significant p-value**	**Partial η^2**	**F**	**Significant p-value**	**Partial η^2**
R^2	0.904			0.916		
Within wicking	326.371	0.000	0.245	455.483	0.000	0.311
Within Angle	304.051	0.000	0.624	272.464	0.000	0.598
Within Minutes	1221.517	0.000	0.887	1576.158	0.000	0.910
Between Wicking and angle	101.969	0.000	0.527	73.280	0.000	0.444
Between wicking and Minutes	12.222	0.000	0.136	13.660	0.000	0.150
Between angle and Minutes	6.401	0.000	0.312	6.179	0.000	0.305
Between wicking and angle and Minutes	2.636	0.000	0.272	2.350	0.000	0.250

. Table 4 Correlation at 99% confidence level for wicking comparison

Correlation	Distance	Type of wicking	Angle	Minutes
Distance (p-value)	1.000	0.092 (0.000)	-0.307 (0.000)	0.745 (0.50)
Angle	(0.000)	(0.50)	-	(0.50)
Minutes	(0.000)	(0.50)	(0.50)	-

Adjusted R^2	0.658 (0.000)			

Correlation was tested at a 99% confidence level and values are tabulated in table 4. In this model, the independent variables were the wicking method, the angle and the minute which had effect on the response variable wicking distance that is 0.092 weak positive correlation between distance and wicking. When angle changed, there was 0.307 negative correlation with distance and when minute changed there was 0.745 strong positive correlation with distance. Here the adjusted R-value for 1 mm and 2 mm thickness was 0.658 that explains 66% variability by the independent variables minutes, angle and wicking included in the regression model together account for 66% variation in the distance of liquid flow.

Estimated marginal means for wicking comparison

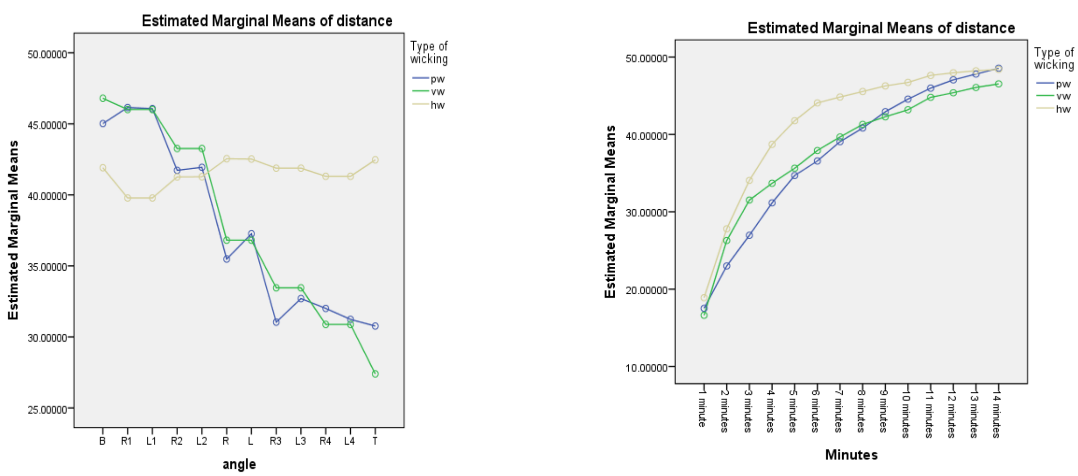

Figure 5 Estimated marginal means distance for wicking test on 200 g/m^2 with 1 mm thickness based on angle and Minute

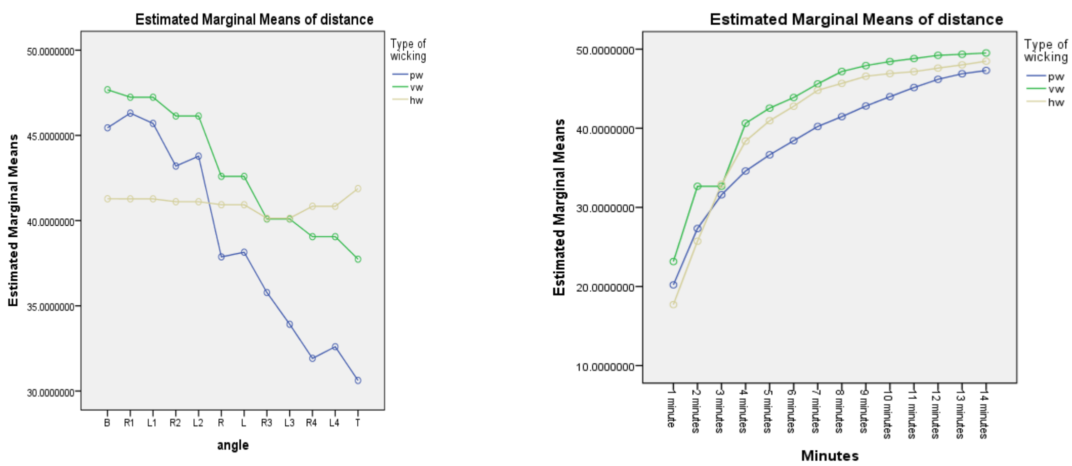

Figure 6 Estimated marginal means distance for wicking test on 200 g/m^2 with 2 mm thickness based on angle and Minute

REGRESSION EQUATION FOR FOR EFFECT OF THE SAME THICKNESS WITH DIFFERENT MASS PER UNIT AREA

Regression analysis was used for the values of the dependent variable (distance) from the values of the predictor variables that included as minutes, angle and thickness in the liquid flow as shown in Table 14.

Table 14 Regression table for 2 mm and 3 mm thickness profile wicking sample

Model	2 mm Thickness				3 mm Thickness			
	Unstandardi zed Coefficients		d Coefficients	Significant value	Unstandardi zed Coefficients		d Coefficients	Significant value
	B	Std. Erro	Beta		B	Std. Erro	Beta	

		r				r		
(Constant)	35.082	.604		.000	41.510	0.491		0.000
Thickness	-1.157	.293	-.050	.000	-7.488	0.238	-0.372	0.000
Angle	-1.606	.042	-.478	.000	-1.232	0.034	-0.422	0.000
Minutes	2.039	.036	.708	.000	1.676	0.030	0.671	0.000

The results shown in Table 14 reveal minutes, angle and thickness having a significant ($p<0.01$) influence on the distance of liquid flow. Angle has a negative influence on the distance of liquid flow with angle changes where there is a decrease 1.606 times in distance. Minute and thickness with a positive influence on distance revealed any increase in minute by one minute with 2.039 times increase in the distance of liquid flow. When thickness increased by 1mm there was 1.157 times increase in the distance of liquid flow. The inference is that controlling all the variables in the model, there is a significance increase in the distance of the liquid flow with increase in minutes and thickness. Regression analysis meant to test the **null hypothesis** that minutes, angle and thickness involved in liquid flow do not predict the distance. The Regression Model considered confirmed the relationship between Independent and Dependent Variable using the regression equation 2. The equations 7 & 8 are the regression equations obtained.

$$Y = 35.082 + (2.039)\ X_1 - (1.606)\ X_2 - 1.157\ X_3 \quad (7)$$

$$Y = 41.510 + (1.676)\ X_1 - (1.232)\ X_2 - 7.488\ X_3 \quad (8)$$

Where

Y = Distance of the liquid flow; a = Constant; X_1 = Minute; X_2 = angle; X_3 = thickness

6.5 Absorption capacity of the web during the wicking study

Table 15: Absorption capacity and utility during wicking studies

Wicking samples	Absorption capacity mL	Utilization% of the web
200 g/m^2 2 mm pw	15.35	74.6022
200 g/m^2 1 mm pw	14.56	70.76274
200 g/m^2 2 mm vw	15.58	75.72002
200 g/m^2 1 mm vw	13.38	65.02785
200 g/m^2 2 mm hw	18.96	92.14709
200 g/m^2 1 mm hw	17.65	85.78038
300 g/m^2 3 mm pw	22.4	74.53405
300 g/m^2 2 mm pw	19.8	65.88277
400 g/m^2 4 mm pw	27.6	76.60925
400 g/m^2 3 mm pw	24.0	66.61674

The liquid holding ability in the actual usage condition of the samples plays a very important role rather than the total absorption capacity. The utilization of the wet-laid nonwoven during the actual usage condition was evident when the total absorption capacity of the wet-laid web was analyzed and compared with that of absorption capacity during wicking studies. Though the web has the potential to absorb and retain the liquid, there were variation in the magnitude of the spreading of the liquid varies due to variations in the capillary pressure of the pores during the vertical and profile wicking tests and to the horizontal, vertical and profile orientation of the sample. When the samples were compressed, the pore size reduced with increased density, thereby reducing the amount of intertial space [37]. This approach causes a reduction in total absorption capacity. The result shows utility % of the web is higher for lower mass per unit area sample [38].

CONCLUSION

The newly designed “Profile wicking tester”, was developed to study the absorbency behavior of the nursing pad. The liquid supply was a point source discharged on the center of the wet-laid absorbent core samples. The liquid movement in multi-direction 360° angle was studied and results have been reported.

The general behavior of liquid movement was observed as initially the liquid tended to move towards gravity, reaching the bottom and then travelling upward against the gravity to the upper portion of the absorbent core from the point of liquid supply. This is presented in a radial graph. The absorbency results of 200 g/m^2, 300 g/m^2 and 400 g/m^2 found were 15.35 mL, 22.40 mL and 27.60 mL respectively, showed the mass per unit area are directly proportional to the absorbency capacity. The utility figures of 200 g/m^2, 300 $g/m^{2,}$ and 400 g/m^2 were 74.6%, 74.5%, and 76.6% respectively and utility was observed through the liquid spreading in all directions facilitating comfort during usage. This facilitates in deciding the suitability of the sample tested.

In each experiment the model was replicated five times with 5 individual samples. Readings were taken for each minute in 12 different directions until the experiment was completed. The results and the experimental model were validated through statistical analysis using a three-way ANOVA test. Various comparisons were made for testing the effect of liquid flow within and between wicking, mass per unit area, thickness in multi-direction from the point of supply of liquid in the absorbent core of the nursing pad. In this new test method, various analyses and interpretations of results were found possible with respect to liquid movement such as absorbency behavior, utility of the sample, comfort during usage, comparison between different parameter of the samples and selection of suitable samples.

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Conflict of Interest: The authors declares no conflict of Interest

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