Predicting Air Permeability of Nylon Parachute Fabrics

Mahmoud H. El Shakankery
Spinning and Weaving Engineering Dept., Textile Research Division, National Research Centre,
Mohmed H. Kasem
Spinning and Weaving Engineering Dept., Textile Research Division, National Research Centre,
Mostafa E. Al-Ebiary
Department of textile, spinning and knitting, Faculty of Applied Arts, Helwan University, Egypt

Abstract:

Parachute is used to slow the motion of an object through an atmosphere by creating drag. Its performance is considerably affected by the variation of fabric air permeability. Fabrics air permeability is affected by several factors such as porosity which depends mainly on the fabric and yarns construction. In this study , a theoretical model was formed to predict the air permeability of a parachute plain weave structure depending on the geometrical parameters, such as the yarn count, ends per cm, wefts per cm, fabric thickness, yarn diameter and fiber density. Furthermore, a theoretical model of porous systems is based on D'Arcy's lows was used. The experimental results were confirmed by examining 24 samples of 100% nylon plain fabrics produced with different yarn count and density. Linear Regression model was used to improve the theoretical model. The results revealed that, the proposed model is efficient for the calculation the air flow rate of nylon parachute fabrics.

Keywords:

Parachute
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1- Introduction

Nylon parachute fabric is one of the most often used tools for fighter plane pilots, landing aircrafts, or airdrops of heavy military tools. Polyamide 6 and polyamide 6.6 are commonly accepted fibers for manufacturing canopy and ribbon fabrics for parachutes. Starting from late 1970s Kevlar® 29 was used in parachute fabrics because of its superior resistant to strength degradation at elevated temperatures, light weight and less bulk. [1-4]

The performance of parachute is considerably affected by variation of fabric air permeability. Rate of the descent, stability and magnitude of opining shock are all affected on the parachute fabric air permeability. Air permeability is defined as the volume of air in liters which is passed through in one minute at a pressure difference of 10 mm head of water [5].

Air flow through textiles material is mainly affected by the pore characteristics of fabrics. It is clear that pore dimension and distribution is a function of fabric geometry. The yarn diameter, weave structure, surface formation techniques and the number of yarns per unit area are the main factors affecting the porosity of woven fabrics. The porosity of a fabric is connected with certain of its important features, such as air permeability, water permeability, dyeing properties etc. [6, 7].

When considering fluid flow through textiles, the shape arrangement and size distribution of voids through which the fluid flows are of great importance. The fabric thickness and differential pressure between the two fabric surfaces are the other dominant factors that affect permeability. The pressure gradient through a textile is a function of the viscosity, density, rate of fluid flow and porosity, as in the case of flow through a pipe [8] The dependence of the friction coefficient (*f)* on the Reynolds Number (*Re)* for laminar and turbulent flow is described by the Blasius equation (in Bayazitoglu's book)[9]:.

$$f = \lambda .\ Re^{-n} \qquad (1)$$

Where: λ is the coefficient of laminar or turbulent flow, and n is a coefficient indicating the flow regime. Laminar flow: $\lambda = 64$, $n = 1$ Turbulent flow: $\lambda = 0.3164$, $n = 0.251$. The type of flow depends on the Reynolds number. The Reynolds number represents the ratio of the inertia force to the viscous force [10]. The Reynolds number is calculated as f follows:

$$R_e = \frac{U_m D_h}{v} \qquad (2)$$

Where U_m is the mean flow velocity, (D_h) the hydraulic diameter of a pore, and v is the kinematic viscosity of the air [8, 10]. The pressure drop of the flow through a duct over the thickness of the fabric is related to the friction factor f through D'Arcy's formulation:

$$\Delta P = f \frac{t}{D_h} \rho \frac{U_m^2}{2} \quad (3)$$

Where (t) is the thickness of the fabric, and (ρ) is the air density [11]. A plain woven fabric structure of is shown in figure 1. During the air transport through woven fabric porous part of the air energy is used to overcome the fluid friction on the fabric and the rest to surmount the inertia forces. [12] For this reason, the air velocity in pores must be taken into consideration.

$$U = \frac{U_m}{\varepsilon} \quad (4)$$

Where (U) is the air velocity through pores, and (ε) is rate of the void area (porosity) which is defined by [13].

$$\varepsilon = 1 - \frac{Yarn\ volume}{Total\ volume} \quad (5)$$

By determined the ends per cm (E), wefts per cm (F), fabric thickness (t), ends yarn diameter (D_e) and weft yarn diameter (D_f) (which is illustrated in figure 1.1) the ends and weft yarn volume per one pore can be shown as follows

$$Yarns\ volume\ per\ one\ pore = \frac{\pi}{4}\left[\frac{D_e^2}{F} + \frac{D_f^2}{E}\right] \quad (6)$$

$$Total\ volume\ per\ one\ pore = \frac{1}{E.F}.t \quad (7)$$

Finally,

$$\epsilon = 1 - \frac{\pi}{4t}\left[E.D_e^2 + F.D_f^2\right] \quad (8)$$

The air velocity through the fabric does not usually have a high value. Therefore, the fluid flow in porous is laminar. According to kinetic theory, the Reynolds number is less 2320. [14] For this reason, the mean air velocity through one pore can be written from equation (1) and (3)

$$U_m = \left\{\frac{D_h^2}{32\,\eta t}\right\}.\Delta P \quad (9)$$

And (η) is the air dynamic viscosity, which equal at 20 C^o temperature 1.8205e-5 Kg/m. sec. [15and16]

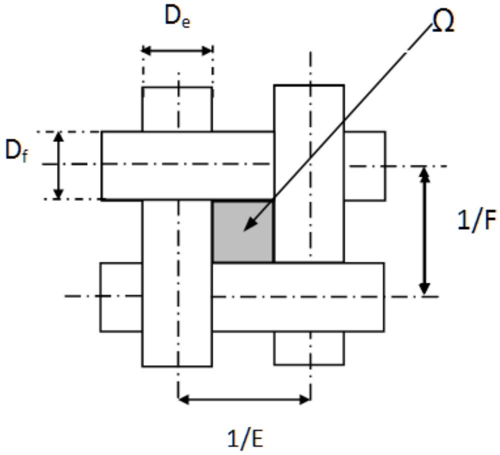

Figure 1.1. Plain woven fabric structure

The air velocity through pores can be written from equation (5) and (6)

$$\therefore\ U = \left\{\frac{D_h^2}{32\,\eta t}\right\}\frac{\Delta P}{\varepsilon} \quad (10)$$

The flow rate of air for a porous fabric material (Q) becomes

$$Q = m.A_1.U \quad (11)$$

Where (m) is number of pores, (A_1) is the cross section area of the pore and (U) is the air velocity through pores. The cross section area of the pore is given by [4].

$$A_1 = \pi\frac{D_h^2}{4} \quad (12)$$

Thus equation (11) can be rewritten as

$$Q = \frac{m}{\varepsilon}\pi\frac{D_h^4}{128\eta t}10^{-4}\Delta P \quad (13)$$

The woven fabrics Porous are not be found in the material mass but are formed by the warp yarns intersection with weft yarns. Theoretical model was created by considering one repeating unit cell of a weave structure. By determining the warp yarn denier (λ_e), the weft yarn denier (λ_f), the distance between two warp yarns (We) and the distance between two weft (W_f)

$$\therefore\ W_e = \frac{1}{E} - \frac{2}{3}\sqrt{\frac{\lambda_e}{10^5\pi\ell_e}} \quad (14)$$

And

$$W_f = \frac{1}{F} - \frac{2}{3}\sqrt{\frac{\lambda_f}{10^5 \pi \ell_f}} \qquad (15)$$

Where (ℓ) is the polymer specific weight (Nylon specific weight equal 1.14 g/cm^3) [16].

$$\therefore \Omega = W_e \cdot W_f \qquad (16)$$

In this study, diameter of the cross section of one pore is given by [12]

$$D_h = \frac{4\,\Omega}{S} \qquad (17)$$

Where (S) is the perimeter of the cross section which can be described by [17] :

$$S = 2\left[\left(\frac{1}{E} - D_e\right) + \left(\frac{1}{F} - D_f\right)\right] \qquad (18)$$

Substituting (8), (9), and (13) to obtain (D_h) the hydraulic diameter of a pore

$$\therefore D_h = 2\,\frac{\left((1/E) - \frac{2}{3}\sqrt{\frac{\lambda_e}{10^5\pi\ell}}\right)\left((1/F) - \frac{2}{3}\sqrt{\frac{\lambda_w}{10^5\pi\ell}}\right)}{\left((1/E) - \frac{2}{3}\sqrt{\frac{\lambda_e}{10^5\pi\ell}}\right) + \left((1/F) - \frac{2}{3}\sqrt{\frac{\lambda_w}{10^5\pi\ell}}\right)} \qquad (19)$$

The air permeability value (R) is calculated as follows

$$R = \frac{Q}{A_1} \qquad (20)$$

Where A_1 is the fabric area tested. [7]

Finally

$$R = \frac{10^{-4} m.\Delta P \left(\frac{\left((1/E) - \frac{2}{3}\sqrt{\frac{\lambda_e}{10^5\pi\ell}}\right)\left((1/F) - \frac{2}{3}\sqrt{\frac{\lambda_w}{10^5\pi\ell}}\right)}{\left((1/E) - \frac{2}{3}\sqrt{\frac{\lambda_e}{10^5\pi\ell}}\right) + \left((1/F) - \frac{2}{3}\sqrt{\frac{\lambda_w}{10^5\pi\ell}}\right)}\right)^4}{8\,\eta.t\left[1 - \frac{\pi}{4t}\left(E.\left(\frac{2}{3}\sqrt{\frac{\lambda_e}{10^5\pi\ell}}\right)^2 + F.\left(\frac{2}{3}\sqrt{\frac{\lambda_f}{10^5\pi\ell}}\right)^2\right)\right]} \qquad (21)$$

2- Materials and Methods

Twenty-four nylon woven fabrics were collected from SOUBHY for Synthetic Woven Fabrics Co., Egypt. The summary of the structural parameters is presented in table 2.1. The woven samples were conditioned for 24 hours in atmospheric conditions of 20 ± 2 °C temperature and 65 ± 5% relative humidity before the tests were performed.

The air permeability (R_t) of the samples in cm^3/cm^2.s was measured according to the method specified by Standard ASTM – D 737, using a Toyoseiki air permeability tester. The measurements were performed at a constant pressure drop at water gage 200 mm for 100 cm^2 test area. For each one of the twenty four fabric types, each sample was tested this measurement for five times, thus obtaining a body of (24 × 5 =) 120 measurements. Furthermore, the fabric thickness (t) was measured according to the method specified by Standard ASTM–D 1777. The experiments result data, theoretical values and liner regression model values of nylon woven samples air permeability are given in Table 2.

Table 2.1 Nylon parachute samples parameters.
(Weave structure: Plain weave)

Sample	Yarn count (denier)		Fabric Density		Thickness
	Ends yarn	Wefts yarn	Ends/cm	Wefts/cm	*cm*
S1	30	30	50	50	0.003
S2	30	30	48	48	0.0029
S3	30	30	48	45	0.0028
S4	30	70	52	36	0.0042
S5	30	70	46	40	0.0042
S6	40	40	50	46	0.0037
S7	40	40	48	44	0.0037
S8	40	50	54	36	0.0041
S9	40	70	50	36	0.0046

S10	45	45	44	42	0.0041
S11	50	50	45	38	0.0042
S12	54	54	42	36	0.0044
S13	70	70	38	32	0.0052
S14	90	70	30	42	0.0078
S15	80	60	30	42	0.005
S16	120	100	34	28	0.0084
S17	100	70	30	40	0.0078
S18	100	70	30	38	0.0077
S19	100	120	30	32	0.0085
S20	150	120	32	28	0.011
S21	150	125	36	24	0.012
S22	125	100	38	30	0.0084
S23	125	130	38	26	0.009
S24	125	70	40	38	0.0076

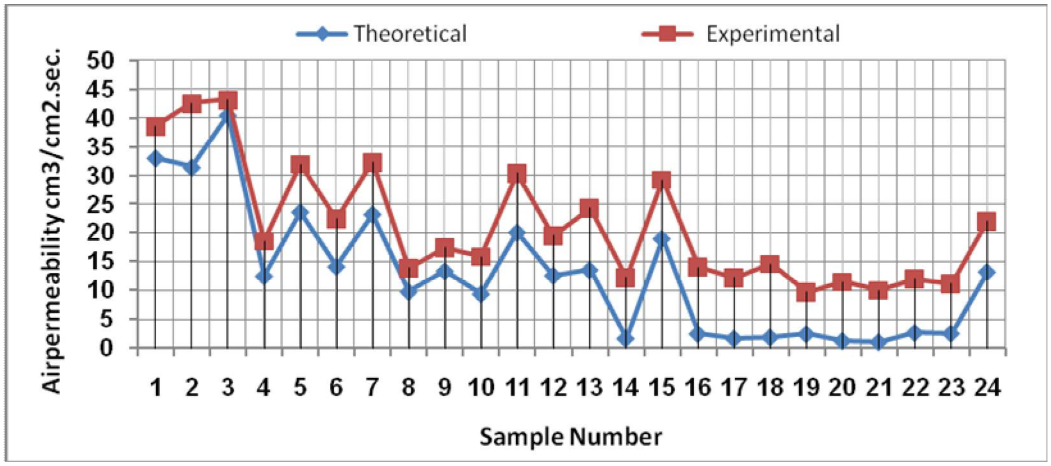

Figure 2.1. Comparison between the experimental and theoretical air permeability values.

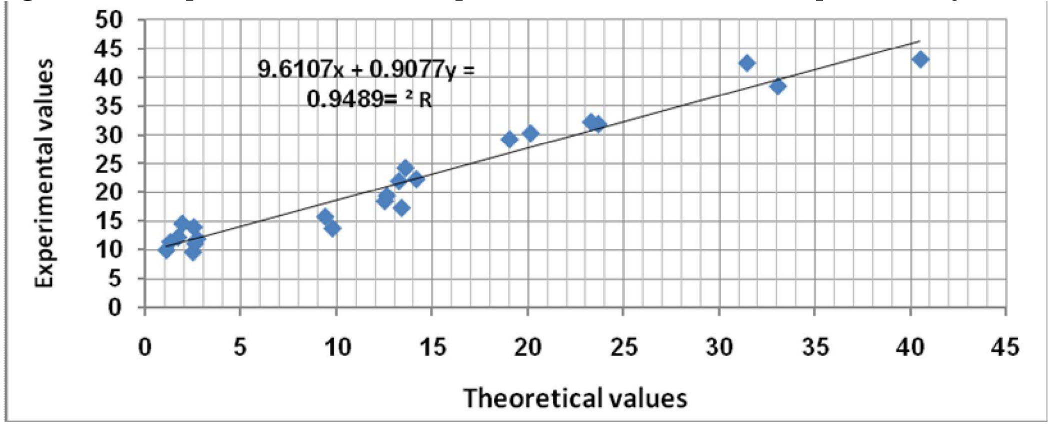

Figure 2.2. Regression plots for the theoretical and experimental air permeability values.

Table 2.2. Air permeability values of nylon parachute samples

ample code	Air permeability cm^3/cm^2.sec.			
	Theoretical	**Experimental**	**Liner regression model**	***Error***
S1	33.06	38.54	39.60	-2.74
S2	31.44	42.56	38.13	10.42

S3	40.51	43.2	46.35	-7.30
S4	12.51	18.59	20.96	-12.73
S5	23.67	31.95	31.08	2.73
S6	14.16	22.44	22.45	-0.06
S7	23.29	32.3	30.73	4.85
S8	9.78	13.87	18.48	-33.24
S9	13.39	17.42	21.75	-24.88
S10	9.4	15.88	18.14	-14.21
S11	20.13	30.36	27.87	8.21
S12	12.62	19.54	21.06	-7.76
S13	13.59	24.36	21.94	9.95
S14	1.71	12.29	11.16	9.19
S15	19.03	29.31	26.87	8.32
S16	2.53	14.07	11.90	15.39
S17	1.71	12.29	11.16	9.19
S18	1.93	14.68	11.36	22.61
S19	2.49	9.7	11.87	-22.35
S20	1.3	11.48	10.79	6.02
S21	1.1	10.04	10.61	-5.65
S22	2.72	12	12.08	-0.64
S23	2.6	11.17	11.97	-7.15
S24	13.25	22.11	21.63	2.18

3- Results and discussion

Comparing the experimental air permeability values and that using theoretical model method (Equation 21), it can be obtained the result shown in Figure 2.1 and 2.2. The air permeability value is same of trend, which is also indicated by the high values of regression (R^2= 0.948), obtained from the statistical analysis. From Figure 2.1, it can be seen that the experimental air permeability values is greater than theoretical model values. In order to air flow is not only through the pore size of fabrics but also through yarn filaments (inter yarn filaments) which increases fabric permeability. Furthermore, the cross section of pore size is not as assumed because the woven fabrics porous are formed by the warp yarns intersection with weft yarns. It is the different-like cross section that has been considered. On the other hand, the pores have different uniform distribution that makes error between experimental air permeability values and theoretical model method. Figure 2.2 shows regression plots between the predicted and experimental values (x axis predicted values, y axis measured or experimental values). Table 2.2 and figure 2.2 show that, the model can be successfully used for the prediction of the air permeability of nylon parachute fabrics. This theoretical model can be improved by add the liner regression model to equation (21) to be defined as:

$$R = 0.907 \times \left[\frac{10^{-4} m.\,\Delta P \left(\dfrac{\left((1/E) - \frac{2}{3}\sqrt{\frac{\lambda_e}{10^5 \pi \ell}} \right) \left((1/F) - \frac{2}{3}\sqrt{\frac{\lambda_w}{10^5 \pi \ell}} \right)}{\left(\left((1/E) - \frac{2}{3}\sqrt{\frac{\lambda_e}{10^5 \pi \ell}} \right) + \left((1/F) - \frac{2}{3}\sqrt{\frac{\lambda_w}{10^5 \pi \ell}} \right) \right)} \right)^4}{8\,\eta.\,t \left[1 - \frac{\pi}{4t} \left(E.\left(\frac{2}{3}\sqrt{\frac{\lambda_e}{10^5 \pi \ell}} \right)^2 + F.\left(\frac{2}{3}\sqrt{\frac{\lambda_f}{10^5 \pi \ell}} \right)^2 \right) \right]} \right] + 9.61 \quad (22)$$

Furthermore, from table 2.2 the error between experimental air permeability values and liner regression model values is defined as:

$$Error = \frac{experimental - result\ of\ liner\ regression}{experimental} \times 100\ \% \qquad (22)$$

From Table 2, it can be seen that except S8, S9, S16, S18 and S19 only have the error more than 15%, and the average error was 0.674%, (without result of samples have the error more 15%). That means that Equation (22) gives reasonably good predictions.

4- Conclusion

In this study, air permeability of nylon parachute fabrics with different fabric parameters was investigated. The measurements and the calculations of the permeability were modified. An experimental study was carried out to develop a theoretical and liner models to predict air permeability values for nylon parachute samples. The final theoretical model predicts the value of the air permeability using some fabric parameters before manufacturing. However, the closeness of the results of predictions based on calculated values from the theoretical model and the experimental values showed that, the proposed model can be successfully used for the prediction of air permeability of nylon parachute fabrics (R2 = 0.948) where it is simple and efficient.

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