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Optimizing comfort of single jersey fabric with 'good ultra violet ray protection' using preemptive goal programming

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Abstract:
Background: *Textiles clothing are engineered with an objective to make them comfortable as well as safe. Chemicals are used for value addition of fabrics but some of them are harmful. Regulations are imposed by government and various bodies to restrict these chemicals. Even though a textile is free from dangerous chemicals, UV light from sun may result erythema, skin cancer and other dermatological problems.). Therefore transmission of dangerous UV rays need to be restricted up to certain extend for safety. A compact fabric resists transmission of UV rays through it but it will also resist the air passage. Air permeability and thermal conductivity are the two prime parameters that control the physio thermal comfort of a fabric. An open fabric ensures high air permeability but lower thermal conductivity and high risk of UV ray transmission. So it is a challenging task to engineer a fabric for hot climate countries that ensure higher air permeability and thermal conductivity but more safety with respect to UV ray transmission. An attempt has been made to engineer a textile fabric with desired level of air permeability and thermal conductivity without compromising the safety with respect to UV ray transmission (with minimum UPF=15)*
Materials and Method:*Total thirty six single jersey fabrics are made with 100% cotton yarns of three different fineness as per as 4 factor 3 level orthogonal block Box and Behnken design. Four factors namely loop length, carriage speed, input yarn tension and yarn count are chosen and for each factor 3 levels are considered. The samples were relaxed, conditioned and tested for air permeability, thermal conductivity and UPF. Linear response surface equations are derived for air permeability, thermal conductivity and UPF.*
Results and Discussion:*Multi-objective optimization problem is formulated and preemptive goal programming is used to solve the program. The results show that desired level of UPF, air permeability and thermal conductivity are met. The optimization problem is validated by making new samples with the definite loop length and fineness obtained by solving the multi-objective optimization problem. The result shows that UPF and thermal conductivity are met at desired level. The air permeability is under achieved but the error is less than 10%.*
Conclusion:*Preemptive goal programming method is capable for finding the optimal solutions for production of single jersey knitted fabrics with target UPF, air permeability and thermal conductivity.*
Key Word: *Air-permeability, Optimization, Goal programming, UPF, Air permeability, Thermal-conductivity*

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I. Introduction

Engineering safe and comfortable textile has been always a challenge to the researchers and industry. There are various safety and comfort aspects of textile clothing and optimization of these factors has been experimented over time[1,2,3]. For casual and formal clothing, the major issues that challenge the safety are usageof restricted materials, chemicals and dyes during textile processing. Presence of these materials in textile clothing when used over time,consequences various health issues like cancer, respiratory problems, allergy, dermatological problems etc.[4,5,6]. Regulations are being imposed over usage of these materials by various government and bodies. However, textiles free from these restricted materials still may not resist certain health problems like erythema and skin cancer, if not engineered properly. The UV radiation from sun reaches earth surface all over the year and penetrates the deep into the dermis resulting erythema[7,8,9]. Textiles may resist this harmful UV rays and protect human skin to some extent. The protection against harmful UV rays extended by textiles is expressed by a terminology known as 'ultra violet protection factor' (UPF)[10,11,12]. A higher UPF value indicates more protection against UV rays and vice-versa. Based on the UPF values, textiles are classified into three categories. Textiles with UPF from 15 to 24 and 25 to 39 are known as 'good protection' and 'very good protection' respectively. Textiles with UPF equal or more than 40 are known as 'excellent protection'[13, 14].

It is desired therefore, to engineer a textile with a minimum safety against UV rays with UPF of 15 at least. Researchers have found that UPF of a textile depends on fibre type, porosity, fabric thickness, dyes, finishes etc.[15,16,17,18,19,20,21,22]. A non-porous, thick and compact fabric contributes higher UPF and vice-versa.

Engineering fabric for winter climate region is comparatively less challenging as a compact, thick and non-porous fabric is also desirable to resist heat transmission from body. However, a wearer may not feel comfortable in hot climate countries, if clothing is made of textiles with low porous and light weight fabric. A trade-off is required between the openness and closeness of a fabric that ensures both UPF and comfort at desired level. The physiological thermal comfort of a textile mainly depends on air permeability and thermal conductivity. A higher air permeability and thermal conductivity is desirable for better heat transmission to outer atmosphere from body. But, the air permeability and thermal conductivity are contradictive in nature. The porosity of a fabric results higher air-permeability but lowers thermal conductivity and vice-versa. Therefore, engineering a textile fabric for hot climate region with minimum safety level of UPF (UPF =15) with optimum comfort is a challenging task. An attempt has been taken to optimize the comfort of single jersey cotton fabric with 'good ultra violet ray protection' using preemptive goal programing.

II. Materials and methods

Hundred percent combed cotton yarns were used to preparethirty sixsingle jersey knitted fabric samples according to 4 factor 3 level orthogonal Box and Behnken designsof experiment[23](Figure 1). The samples were made in a computerized flat knitting machine, which has a special device that maintains loop length at desired level. The four factorsconsidered were loop length *(A)*, carriage speed *(B)*, yarn input tension *(C)* and yarn count *(D)* and for each of the controlled factors 3 levels were taken. The actual values of the factors corresponding to their coded levels are shown in Table 1.

$$\begin{bmatrix} -1 & -1 & -1 & 0 \\ -1 & -1 & +1 & 0 \\ -1 & +1 & -1 & 0 \\ -1 & +1 & +1 & 0 \\ +1 & -1 & -1 & 0 \\ +1 & -1 & +1 & 0 \\ +1 & +1 & -1 & 0 \\ +1 & +1 & +1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} -1 & -1 & 0 & -1 \\ -1 & -1 & 0 & +1 \\ -1 & +1 & 0 & -1 \\ -1 & +1 & 0 & +1 \\ +1 & -1 & 0 & -1 \\ +1 & -1 & 0 & +1 \\ +1 & +1 & 0 & -1 \\ +1 & +1 & 0 & +1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} -1 & 0 & -1 & -1 \\ -1 & 0 & -1 & +1 \\ -1 & 0 & +1 & -1 \\ -1 & 0 & +1 & +1 \\ +1 & 0 & -1 & -1 \\ +1 & 0 & -1 & +1 \\ +1 & 0 & +1 & -1 \\ +1 & 0 & +1 & +1 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & -1 & -1 & -1 \\ 0 & -1 & -1 & +1 \\ 0 & -1 & +1 & -1 \\ 0 & -1 & +1 & +1 \\ 0 & +1 & -1 & -1 \\ 0 & +1 & -1 & +1 \\ 0 & +1 & +1 & -1 \\ 0 & +1 & +1 & +1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Figure 1: Orthogomal Box and Behnkenexperimental design (4 factor 3 level)

Table 1: Actual values of the factors and their coded levels for single jersey fabric

Factors	**Coded level**		
	-1	**0**	**-1**
Loop-length *(A)*, mm	6.6	7.0	7.4
Carriage-speed *(B)*, m/s	0.25	0.6	0.95
Yarn-input-tension *(C)*, gf	6	8	10
Linear-density*(D)*, Ne	5	7.5	10

All 36 single jersey knitted samples were completely relaxed by washing them in a Washcator washing machine as per as EN ISO 6330 standard[24]. The washed fabric samples were then conditioned at standard temperature of 20±2ºC and 65±4% relative humidity for 48 hours. Air-permeability, thermal conductivity and UPF of these samples were evaluated. TEXTTEST FX3300 air-permeability tester and Alambeta instrument(Sensora, Liberac, Czech Republic) were used to evaluate air-permeability (as per as ASTM D737 standard)[25] and thermal conductivity (as per the standard ISO EN 31092)[26] of fabric samples respectively. UPF tests (in-vitro method) were determined using Labsphere 2000F as per AATCC 183: 2004 standard[27]. For each sample 10 readings for air-permeability, thermal conductivity and UPF were taken and their mean were considered.

Response surface equations of air-permeability, thermal-conductivity and UPF of fabrics

Every optimization problem requires equations (either linear or polynomial), that relate the independent controlled factors and the objective function. In this problem the objective functions are air permeability, thermal conductivity and UPF, whereas the controlled factors are loop length, carriage speed, yarn input tension and linear density of the yarns. Linear regressions equations are developed to relate these objective functions and controlled factors. The general form of the model is shown below:

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D \qquad (1)$$

where, *Y* is the response variable and *A*, *B*, *C* and *D* are the inputs to the model. $\beta_{0,}$ β_1,β_2,β_3 andβ_4 are regression coefficients. Regression coefficients which are significant at 95% confidence limit are only considered. The fitted linear regression models along with the co-efficient of determination (R^2) are given below:

$Air\ permeability\ (AP) = 154.86 + 22.29A + 111.49D \qquad (R^2 = 0.97) \qquad (2)$
$Thermal\ conductivity\ (TC) = 39.26 - 0.78A - 4.6D \qquad (R^2 = 0.93) \qquad (3)$
$Ultraviolet\ protection\ factor(UPF) = 11.39 - 1.69A - 7.69D \qquad (R^2 = 0.94) \qquad (4)$

It is evident from equations (2), (3) and (4) that, while the loop length and yarn count have significant effect on air permeability, thermal conductivity and UPF, yarn carriage speed and yarn input tension have no considerable influence on these response variables.

Goal programming

Goal programming (GP) is one of the classical optimization methods, which is effectively used when an optimization problem is multi-objective in nature[28,29,30]. Unlike linear programming, which has only one linear objective functions, a goal programming deals with more than linear objectives. A linear programming problem consists one objective function and one or more constraints. Therefore, in a linear programming problem the solution fulfills all the constraints prior to optimizing the objective function. In goal programming, each objective and constraintis considered as 'goal' and a target is fixed for each 'goal'. Each goal is then transformed into an equality constraint by introducing deviation variables $d_i^+$and d_i^-. These deviation variables define the degree of extend by which a targeted goal i is 'over achieved' or 'underachieved' respectively. Objective function is then formed comprising these deviation variables and is then optimized (minimize or maximize) to attain the solution.General model of a GP model is given below.

$$\text{Minimize} \quad Y = \sum_i^n w_i(d_i^+ + d_i^-) \qquad (5)$$
$$\text{Subject to} \quad \sum_{i=1}^k a_{ij}\,x_j + d_i^- - d_i^+ = b_i\ (i = 1,2,\dots k)$$
$$\begin{pmatrix} Valueofthe \\ objective \end{pmatrix} + \begin{pmatrix} Goal \\ underachived \end{pmatrix} - \begin{pmatrix} Goal \\ overachieved \end{pmatrix} = Goal$$
$$x_j, d_i^-, d_i^+ \geq 0\ foralli, j$$

wherex_j is decision variable j, w_i is the weightage attached to goal i, d_i^- is underachievement of goal i and d_i^+ is overachievement of goal i.

Now, based on the nature of problem or requirement, attaining all the targets of the goals may be attempted simultaneously or as per as hierarchy of interest. The goal programming in which there is no prioritization of goals are known as non-preemptive GP, whereas the GP in which the targets of the goals are attained one after another depending on their importance is known as preemptive GP.

III.Result and discussion

Formulation and evaluation of preemptive goal programming problem

As the primary objective of this problem is to initially achieve UPF of 15 and then optimize the air permeability and thermal conductivity, preemptive goal programming method is utilized to formulate the multi-objective optimization problem.

Goal 1: Minimum UPF of single jersey fabric (UPF) = 15
Goal 2: Minimum air permeability of single jersey fabric (AP) = 80 and minimum thermal conductivity of the fabric (TC) = 42

The goal programming model for Goal 1 is specified as follows:

$$\text{Minimize} \quad Z = d_1^-$$
$$\text{Subject to} \quad 11.39 - 1.69A - 7.69D + d_1^- - d_1^+ = 15$$
$$154.86 + 22.29A + 111.49D + d_2^- - d_2^+ = 80$$
$$39.26 - 0.78A - 4.6D + d_3^- - d_3^+ = 42$$
$$6.6 \geq A \geq 7.4$$
$$5 \geq D \geq 10$$
$$d_1^-, d_1^+, d_2^-, d_2^+, d_3^-, d_3^+ \geq 0$$

Linear programming problem solving method (LPP) is used to solve the above minimization problem and the solutions are given below:

$$A = -1\ (Coded\ value);\ D = -0.2497(coded\ value);\ d_1^- = 0;\ d_1^+ = 0;\ d_2^- = 75.266;\ d_2^+ = 100;\ d_3^- = 100;\ d_3^+ = 99.1885$$

Now, in the above part of the goal programming problem, goal 1 is accomplished but goal 2 is not yet achieved. Therefore, in order to achieve goal 2, the constraint (d_1^-) is added to keep the first goal at the value obtained earlier (d_1^-=0). Therefore, the goal programming model becomes,

Minimize $Z = d_2^- + d_3^-$

Subject to

$$11.39 - 1.69A - 7.69D + d_1^- - d_1^+ = 15$$
$$154.86 + 22.29A + 111.49D + d_2^- - d_2^+ = 80$$
$$39.26 - 0.78A - 4.6D + d_3^- - d_3^+ = 42$$
$$6.6 \geq A \geq 7.4$$
$$5 \geq D \geq 10$$
$$d_1^- = 0$$
$$d_1^-, d_1^+, d_2^-, d_2^+, d_3^-, d_3^+ \geq 0$$

This part of the goal programming is solved using linear programming problem solving method (LPP) and the solutions are,

$$A = 1\ (Actual\ value = 7.4\ mm);\ D = -0.87(Actual\ value = 5.5\ Ne);\ d_1^+ = 1.40;\ d_2^- = 0;\ d_2^+ = 0;\ d_3^- = 0;\ d_3^+ = 0.49;\ UPF = 16.4;\ AP = 80\ and\ TC = 42.49$$

The solution shows that the prime objective to design single jersey fabric with good UV protection (UPF≥15) is overachieved, whereas the other objectives i.e the air permeability is perfectly met and thermal conductivity is overachieved w.r.t the targets set.

Validation of optimization problem

To validate the optimization problem, single jersey fabric sample was made in the same computerized flat knitting machine (gauge = 12) using 100% cotton yarn with fineness of 5.5 Ne and loop length of 7.4 mm. The fabric sample was washed for complete relaxation as per the standard mentioned earlier. The fabric sample is then tested for UPF, air permeability and thermal conductivity. The achieved values and optimized values are compared. It is found that the achieved values are very close to the optimized values and is less than 4% for UPF and thermal conductivity and less than 10% for air permeability. It is obvious from Table 2, the primary target UPF = 15 has been attained that ensures 'good UV protection'. The secondary targets air permeability and thermal conductivity are conflicting in nature. The actual value of thermal conductivity exceeds the minimum target whereas the same of air permeability is underachieved but the error is less than 10% and may be acceptable.

Table 2: Optimized and achieved UPF, air permeability and thermal conductivity values of single jersey fabric

Fabric type	Optimized parameters	UPF			Air permeability			Thermal conductivity		
		O	A	Error %	O	A	Error %	O	A	Error %
Singlejersey	7.4 mm and 5.5 Ne	16.4	15.8	3.7	80	72.5	9.4	42.49	43.5	2.4%

O = Optimized value, A= Achieved value

IV. Conclusion

Preemptive goal programing is used to design a single jersey knitted fabric that ensures 'good ultra violet ray protection' with desired air permeability and thermal conductivity. As the porous structure of single jersey transmits more harmful UV rays through it, the prime objective was to attain the desired UV protection level and then achieve the desired comfort. Therefore, preemptive goal programming method for optimization has been used here. Initially linear equations for UPF, air permeability and thermal conductivity are developed for formulation of optimization problem. During formulation of the GP program, underachieved deviation variable for UPF is minimized and then the solution of deviation variable is added in the subsequent GP problem as constraint. In the second step of preemptive GP, the GP was formulated to attain the air permeability and thermal conductivity at desired level. This part of optimization is done simultaneously as air permeability and thermal conductivity are conflicting in nature. In this step of GP, the sum of underachieved deviation variable for air permeability and thermal conductivity were minimized. Optimum solutions of loop length and yarn count are evaluated for single jersey with at least 'good UV ray protection' and desired air permeability and thermal conductivity. The air permeability and thermal conductivity targets were met and are overachieved. Though the air permeability is underachieved but the error is less than 10% and is acceptable.

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