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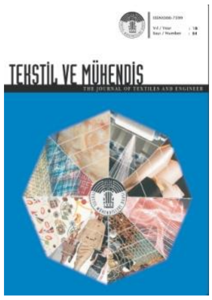

Process Optimization of Pad-Dry-Fixation and Foam Coating Methods for Flame Retardant Mattress Fabrics

Alev Geciktirici Yatak Kumaşları için Emdirme ve Köpük Kaplama Yöntemlerinin Proses Optimizasyonu

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Araştırma Makalesi / Research Article

PROCESS OPTIMIZATION OF PAD-DRY-FIXATION AND FOAM COATING METHODS FOR FLAME RETARDANT MATTRESS FABRICS

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ABSTRACT: The subject of flame retardancy is a dynamic area which is constantly developing in textile industry. Flame retardant chemicals are applied to many home textile products, including mattress fabrics, by different methods. In the paper, the parameters of the two different methods (pad-dry-fixation and foam coating) used in the application of the flame retardant chemicals to the mattress fabrics produced with 100% PET fibers were optimized by Response Surface Method. The flame retardant properties of the fabrics were evaluated by Limit oxygen index (LOI). The proposed models for LOI test results of both coating methods were found to be statistically significant. However, it was determined that the LOI value for the pad-dry-fixation method was better explained by the model's inputs than the foam coating method. R^2 (0.9619) and R^2 adjusted (0.9571) values of fitted model for the pad-dry-fixation demonstrated that there was an acceptable correlation between the predicted and actual LOI values. The optimum chemical quantity, squeezing pressure and fixing temperature for the pad-dry-fixation method were found to be 150 g/lt, 6 bar and 189.2 °C, respectively. Based on these optimum conditions, the predicted LOI value was found to be 41.92%.

Keywords*:* Mattress Fabric, Flame retardancy, Pad-dry-fixation, Foam coating, Limit oxygen index

ALEV GECİKTİRİCİ YATAK KUMAŞLARI İÇİN EMDİRME VE KÖPÜK KAPLAMA YÖNTEMLERİNİN PROSES OPTİMİZASYONU

ÖZET: Alev geciktiricilik konusu tekstil sektöründe sürekli gelişen dinamik bir alandır. Alev geciktirici kimyasallar, yatak kumaşları dâhil birçok ev tekstili ürününe farklı yöntemlerle uygulanmaktadır. Bu makalede, alev geciktirici kimyasalların % 100 PET filament ile üretilen yatak kumaşlarına uygulanmasında kullanılan iki farklı yöntemin (emdirme ve köpük kaplama) parametreleri Yanıt Yüzey Yöntemi ile optimize edilmiştir. Kumaşların alev geciktirme özellikleri Limit oksijen indeksi (LOI) ile değerlendirilmiştir. Her iki kaplama yönteminin LOI test sonuçları için önerilen modeller istatistiksel olarak anlamlı bulunmuştur. Bununla birlikte, emdirme yöntemi için LOI değerinin, modelin girdileri ile köpük kaplama yöntemine göre daha iyi açıklandığı belirlenmiştir. Emdirme yöntemi için geliştirilmiş modelin R^2 (0.9619) ve düzenlenmiş R^2 (0.9571) değerleri, tahmini ve gerçek LOI değerleri arasında kabul edilebilir bir kolelasyon olduğunu göstermiştir. Emdirme yöntemi için optimum kimyasal miktar, sıkma basıncı ve fiksaj sıcaklığı sırasıyla 150 g/lt, 6 bar ve 189.2 ◦C olarak bulunmuştur. Bu optimum koşullara göre öngörülen LOI değeri %41,92 olarak bulunmuştur.

Anahtar Kelimeler: Yatak kumaşı, Alev geciktirici, Emdirme yöntemi, Köpük kaplama, Limit oksijen indeksi

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1. INTRODUCTION

A large part of the natural or synthetic materials utilized in the production of home textiles, which comprise floor coverings used in home or indoor areas, curtains, linens, mattresses, quilts, and many other textile products, tend to ignite in air, if exposed to a flame or other heat source of adequate intensity for a sufficient period. Therefore, firefighting that has been going on for centuries is inevitable for the textile sector and the need for flame retardant home textile products is of great importance for protection from fire. Flame retardancy is defined as the non-continuation of combustion after removal of the flame source, but the physical and chemical changes of the material. Textile material is defined as flame retardant if it does not ignite when exposed to a flame source or if it extinguishes despite physical and chemical changes when the flame source is removed even if it ignites [1].

The mattress sector has shown a rapid development in recent years among the flame retardant home textile products. What people expect from the mattresses is that it has not only a good quality sleep but also protective features in the face of a negative situation such as fire. In order to provide the desired comfort and flame retardant properties to the mattress, all materials used in the production of mattresses must also be correctly identified and used in a compatible manner. In particular, the fabrics used on the outside of the mattress play an important role in the ignition and combustion. Flammability refers to temperature and to heat amount necessary to ignite a textile material with a certain chemical composition and a given configuration. Flammability characteristics of the mattress fabrics can be influenced different factors such as fiber content, yarn twist, fabric density, fabric construction, fabric weight and fabric finishes [2].

Fibers behave differently when exposed to heat or open flame due to differences in chemical structure. Accordingly, the fibers are divided into three groups: ready-to-burn fibers (cotton, stalk fibers, regenerated cellulose fibers and PAN), low-flammability fibers (wool, silk, polyester and polyamide) and non-flammable fibers (such as glass, mineral and asbestos) [3]. Poly(ethylene terephthalate) (PET) is extensively used in many areas, not only in the clothing industry but also in home furnishings such as drapery and matress fabrics due to its outstanding characteristics of high strength, good flexibility, resistance to shrinkage and stretch and thermal stability [4]. The distinguished properties of PET make these fibers an important material in the production of mattress fabrics [5]. However, they have substantial limits on account of their organic nature leading to a relatively poor fire behavior [6]. They are flammable fibers with a limiting oxygen index (LOI) of 21 % [7] and exhibits serious melt-dripping behavior during combustion [8, 9]. The melt-dripping behavior accelerates the spread of flame [10]. Hence, the research and development of flame retardant PET fibers and fabrics are of remarkable importance to reduce fire disasters [7]. The flowing three methods are mainly applied in order to impart the flame retardancy to PET fibers: copolymerization of PET with a reactive flame retardant monomer during the PET synthesis stage [11-14], addition of flame retardants to the PET matrix during the spinning stage [15-17] and depositing flame retardants on the PET fabric surface through flame-retardant finishing [7, 10, 18, 19]. Flame-retardant PET fibers obtained via copolymerization demonstrate better flame-retardant durability, however they require higher costs and more complicated operations. Adding flame retardants to PET matrix during spinning is a simple process, however, is limited due to high requirements (molecular structure, decomposition temperature, etc.) for additive flame retardant [7]. Among the various ways to impart flame retardancy to PET fibers or fabrics, the flame retardant finishing method has been widely utilized in many different areas, including the mattress industry, due to its relative suitability, many techniques available, cheapness and easy control compared to the other two ways [10]. In this method, flame retardants are commonly deposited onto the surface of fabrics including sol-gel process, solution-dipping method, spray coating, and layer-by-layer (LbL) assembly, and so forth [20]. Moreover, pad-dry-fixation and foam coating techniques are generally used to transfer flame-retardant chemicals to mattress fabrics.

In the literature, studies have generally focused on the use of different flame retardants (such as expandable graphite, phosphorus-containing siloxane, aluminium phosphinate, nanoclay, sulfur-containing aryl polyphosphonate, superhydrophobic bionic etc.) to add flame retardant properties to PET fibers or fabrics [21-25]. In this work, unlike the literature, it was aimed to optimize variable parameters of the two methods (pad-dry-fixation and foam coating) used in order to give the flame retardant properties to the mattresses produced from %100 PET fiber by Response Surface Method. The variable parameters were chemical quantity, squeezing pressure, and fixing temperature for the pad-dry-fixation method; were foam density and fixing temperature for the foam coating method. Commonly used chemicals were selected for both methods, thus focusing only on optimum production conditions for maximum flame retardant properties. The flame retardant properties have been evaluated by means of LOI (limited oxygen index) test.

2. MATERIAL AND METHOD

2.1 Material

Double-layer weft knitted fabric with a filling core, which comprises a surface layer and a rear layer, is most commonly used in the production of mattress fabric. Double-layer weft knitted fabrics are produced on double-bed circular knitting machines by feeding filling yarn between two needle beds. Generally, filling yarns having soft, bulky or textured structure are used for the production of mattress fabrics. In this work, double-layer weft knitted fabric samples were manufactured by OVJA 1.6 E Mayer & Cie. circular knitting machine (38 inch - 20E) in the rib knit structure. The surface and rear layers of fabrics were produced with 110 dtex polyester (PET) and also, 900 deniers PET filament were used as filling. The wales per cm (wales/cm) of the knitted fabric was 11.1, the course per cm (courses/cm) was 10.8 and the fabric weight was 230 g/m^2.

Two different coating solutions commonly used for foam coating method and pad-dry-fixation methods were determined to impart flame retardant properties to mattress fabrics. Flame retarder AD14 + Tubicoat CM 2T chemicals were used as flame retardants in foam coating method. The flame retarder AD14 chemical is a halogen-based additive that have been considered to be highly effective in improving the flame retardancy of fibers. The pH value of this chemical is 8.5 and it is a nonionic chemical. Halogen-based flame retardants are still widely used in the mattress industry, although in recent years there have been many concerns about the application of their due to the potential emission of toxic fumes and the bioaccumulation of bromine [26]. The Tubicoat CM 2T chemical used as a binder for foam coating is an acrylate-based anionic compound. The pH value of this chemical is between 7.5-8.5 and it has the ability to self-cross-link compounds.

Phosphonate derivatives Aflammit Pe Conc. chemical was used as flame retardants in pad-dry-fixation method. Aflammit Pe Conc. chemical is an organic phosphorus compound. The pH value of this chemical is between 2.5 and 3.5 and its density is 1.28 g/cm^3. Phosphorus-containing flame retardants have been applicable to many polymer matrices, due to their low toxicity, high efficiency, spinnability, durability and molecular diversity [9, 26].

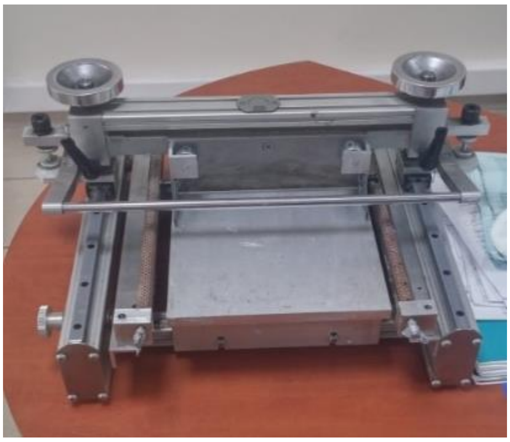
2.2 Methods

In this work, the full factorial experimental designs having three variables with three levels for the pad-dry-fixation method and two variables with three levels for the foam coating method were planned. The range of these variables and levels are given in Table 1. For pad-dry-fixation method, the independent variables were chemical quantity (X_1), squeezing pressure (X_2), and fixing temperature (X_3). 27 different coated mattress fabrics with a 3^3 factorial experimental design for pad-dry-fixation method were obtained. For foam coating method, foam density (X_4) and fixing temperature (X_5) were determined as the independent variables and 9 different fabrics were prepared with 3^2 factorial experimental design.

According to the determined experimental design, two different solutions were deposited on the surface of fabrics by pad-dry-fixation (Fig. 1-a) and foam coating (Fig. 1-b) techniques. Since the machines used for the application of the flame-retardant finishes were laboratory type, the fabric samples were cut to 30 x 35 cm dimensions according to the width and length of the machine. For both methods, machine parameters and fabric properties were kept constant, except for parameters that were changed in a controlled manner. The application prescriptions of the coating process for both methods used in the study are given in Table 2.

Table 1. Levels of factors used in the experimental design

Methods	Factors	Units	Code	Levels		
Pad-dry-fixation	Chemical quantity	(g/lt)	X_1	50	75	150
	Squeezing pressure	(bar)	X_2	4	5	6
	Fixing temperature	(°C)	X_3	110	140	190
Foam coating	Foam density	(g/cm^3)	X_4	200	350	700
	Fixing temperature	(°C)	X_5	110	140	190



(a) (b)

Figure 1. (a) Pad-dry-fixation machine; (b) Foam coating machine

Table 2. Application prescriptions of coating processes used in the study

Methods	Parameters	I	II	III
Pad-dry-fixation method	The concentrations (g/l)	50	75	150
	Squeezing pressure (bar)	4	5	6
	Fixing temperature (°C)/Time (dk)	110 °C 2’	140 °C/2’	190 °C/2’
	Pick-up (%)	96	77	62
	Drying temperature (°C)/Time (dk)	110 °C/15’		
Foam coating method	The concentrations (g/cm^3)	200	350	700
	Fixing temperature (°C)/Time (dk)	110 °C/2’	140 °C/2’	190 °C/2’
	Chemical / Binder Ratio (%)	50		
	Chemical Amount on Fabric (gr/m^2)	4.8	6.7	12.9
	Drying temperature (°C)/Time (dk)	110 °C/15’		

2.3 Flame retardancy analysis

The flame retardant efficiency of the sample fabrics was determined through the LOI (Limit Oxygen Index). LOI test was developed by Mark and Atlas to determine the burning behavior of different polymers [27]. The LOI test determines the minimum percentage of oxygen required to continue to burn of a material (ASTM D2863). The test is carried out by placing the sample vertically, igniting at its top edge with hydrogen flame in an oxygen-nitrogen atmosphere. The fabrics burn from top to bottom and, the oxygen (O^2) and nitrogen (N^2) streams are adjusted until the sample is completely and slowly burned. The test is repeated until consistent results are obtained. LOI test value is expressed by the following formula [28].

$$LOI\ \% = [O_2] / ([O_2] + [N_2]) \times 100 \quad (1)$$

Prior to the experimental study, the samples were conditioned for at least 24 hours under standard atmospheric conditions (20±2ºC temperature, 65±2% relative humidity).

2.4 Response analysis and optimization

Optimization is a technique used to determine the optimum working conditions of a system or a process in order to obtain the best possible response. Response surface methodology (RSM) has been quite popular for optimization of processes in which a response of interest is influenced by several variables [29]. RSM is essentially a particular set of mathematical and statistical methods for designing experiments, building models, evaluating the effects of variables, and searching optimum conditions of variables to predict targeted responses [30]. In this work, optimal application parameters of pad-dry-fixation and foam coating techniques used to add the flame retardancy properties to the mattress fabrics were estimated with RSM.

The application procedure of the RSM as an optimization technique comprises the following steps: (1) the determination of the variables and their levels; (2) the selection of the experimental design and carrying out the experiments according to the selected experimental matrix; (3) the developing a mathematical model of the second order response surface; (4) the evaluation of the model’s fitness; and (5) the obtaining the optimal experimental parameter set that produces a maximum or minimum response value; (6) the determination of the response surface plot and contour plot of the response as a function of the variables and determination of optimal points [29, 31].

In the optimization process of RSM, the response variables (y_i) can be simply related to independent variables (x_i) by linear or quadratic models [30]. In the study, experimental data with three-level were fitted to the polynomial function to contain quadratic terms. The polynomial functional relationship for a quadratic model, which also includes the linear model, with k independent variables is generally as follow:

$$y_i = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij}\, x_i x_j + e_i, \quad (2)$$

where y_i is the response (flame retardancy efficiency) used as a dependent variable; k is the number of independent variables, x_i and x_j are independent variables (factors); β_0 is the constant coefficient, and β_i, β_{ij} and β_{ii} are the regression coefficients of linear, quadratic term and interaction terms, respectively, and e_i is the error.

The developed mathematical models can sometimes not satisfactorily describe the experimental domain studied. The variance analysis (ANOVA) provides a more reliable way to identify the significant input variable in the developed model [31]. The ANOVA also gives the relative contribution that each input variable makes on the overall estimated response. In the study, the statistical analysis of the data was performed with Minitab 19 statistical software package. This software was used to determine the optimal application parameters, to observe the effect of application parameters on the response, and to estimate the coefficient of regression equation of the obtained data.

3. RESULTS AND DISCUSSION

3.1 Model development for the pad-dry-fixation method

The complete design matrix together with the experimental and the predicted response values for the pad-dry-fixation method is given in Table 3. F0 code in Table 3 refers to the raw mattress fabric without any flame retardant application. While the LOI value of untreated fabric is 29.5%, the overall average of the LOI values of treated fabrics is 39.1%. It is cleared that the LOI value of the fabrics increase by approximately 32.5% with the flame retardant chemical used in the study. In addition, it is seen that the F27 coded fabric, that produced with 150 g/lt chemical quantity, 6 bar squeezing pressure and 189.2 °C fixing temperature, has the highest flame retardant value with 41.8%.

The experimental responses (LOI) were correlated with the three factors (X_1: chemical quantity, X_2: squeezing pressure, X_3: fixing temperature) studied using the second order polynomial as represented by Eq. (2). The quadratic regression model for the LOI (Y) in terms of uncoded factors are given by Eq. (3):

$$Y = 30.46 + 0.0722\,X_1 + 0.001\,X_2 + 0.0312\,X_3 - 0.000231\,X_{12} + 0.0463\,X_{22} - 0.000055\,X_{32} + 0.00242\,X_1 X_2 - 0.000006\,X_1 X_3 - 0.00156\,X_2 X_3 \qquad (3)$$

The function describes how the factors and their interactions influence the flame retardancy properties of the mattress fabrics [32]. The positive sign in front of the terms in the model indicates the synergistic effect of the factors whereas the negative sign indicates the antagonistic effect of theirs [33].

Analysis of variance (ANOVA) is required to test the significance and adequacy of the model and to determine the statistical effect of factors on responses. ANOVA for the quadratic regression model of LOI are listed in Table 4. The statistical significance is evaluated by the P-value (probability) with 95% confidence level. Values of probability less than 0.05 indicate that the terms are significant. The quality of the polynomial model is specified by the coefficient of determination, namely R^2 and adj-R^2. R^2 coefficient is a statistical measure representing the proportion of the variance for a dependent variable that's explained by an independent variable or variables in a regression model.

Table 3. The fabric codes and the changed application parameters for the pad-dry-fixation method

Fabric codes	Uncoded factors			LOI	
	X_1	**X_2**	**X_3**	**Exp.[a]**	**Pred.[b]**
F0	-	-	-	29.5	-
F1	50	4	110	36.5	36.8
F2	50	4	140	37.1	37.1
F3	50	4	190	37.5	37.4
F4	50	5	110	37.1	37.1
F5	50	5	140	36.9	37.4
F6	50	5	190	37.4	37.7
F7	50	6	110	37.8	37.6
F8	50	6	140	38.3	37.8
F9	50	6	190	38.3	38.0
F10	75	4	110	38.4	38.1
F11	75	4	140	38.7	38.4
F12	75	4	190	38.9	38.7
F13	75	5	110	38.7	38.5
F14	75	5	140	39.1	38.8
F15	75	5	190	38.6	39.0
F16	75	6	110	38.7	39.0
F17	75	6	140	38.7	39.2
F18	75	6	190	39.5	39.4
F19	150	4	110	39.8	40.3
F20	150	4	140	40.5	40.6
F21	150	4	190	40.8	40.9
F22	150	5	110	41.1	40.9
F23	150	5	140	41.4	41.1
F24	150	5	190	41.6	41.3
F25	150	6	110	41.7	41.6
F26	150	6	140	41.7	41.8
F27	150	6	190	41.8	41.9

[a]Experimental
[b]Predicted

Table 4. ANOVA for the RSM model of LOI test

Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**	**Percent(%)**
Model	9	206.541	22.949	199.09	0.000	96.19
X_1	1	184.729	184.729	1602.58	0.000	86.03
X_2	1	11.490	11.490	99.68	0.000	5.35
X_3	1	3.201	3.201	27.07	0.000	1.49
X_1^2	1	3.120	3.120	27.07	0.000	1.45
X_2^2	1	0.039	0.039	0.33	0.565	0.02
X_3^2	1	0.121	0.121	1.05	0.309	0.06
X_1X_2	1	0.570	0.570	4.95	0.029	0.26
X_1X_3	1	0.006	0.006	0.05	0.824	0.00
X_2X_3	1	0.143	0.143	1.24	0.269	0.07
Residual error	71	8.184	0.115			3.81
Lack of fit	17	6.744	0.397	14.88	0.000	3.14
Pure error	54	1.440	0.027			0.67
Total	80	214.725				

The model's p value of 0.00 for in Table 4 implies that the model is significant for LOI value. The value of R^2 is obtained 96.19, which demonstrates a high correlation between the experimental and predicted data. Moreover, the value of adj-R^2 (0.9571) confirms the proposed model. The total residue is divided into lack of fit and pure error. The lack of fit (LOF) test usually indicates a missing one or more important terms or factors in the model. If the model does not fit the data well, the lack of fit will be significant [34]. It is mathematically possible to entirely eliminate the lack of fit of the model, however, the pure errors could never be avoided by any predictive equation. From the Table 4 for LOI value, it is clear that the LOF value is significant relative to pure error. However, the pure error F value is also quite low and close to F_{lof} value. Therefore, the significance of LOF value is considered to be negligible for the model.

The highest contribution percentage on the model proposed for LOI test belongs to the chemical quantity (X_1) with 86.03%. In terms of contribution percentage, the chemical quantity is followed by the squeezing pressure with a rate of 5.35%. Although the effect of fixing temperature on the model is significant, it is seen that the percentage is quite low compared to the other factors.

3.2 Response contours for the pad-dry-fixation method

The response contour plots are the graphical representation of the regression model utilized in order to visualize the relationship between the response and experimental levels of each variable [2]. Figure 2 show the 2-D contour plots for LOI responses. Figure 2 indicates that the increasing of chemical quantity remarkably ascends the LOI value. However, it is seen that the effect of squeezing pressure and fixing temperature on LOI value is rather insignificant compared to chemical quantity. It is also clear that the squeezing pressure positively affects the flame retardant property of the mattress fabric at a higher rate than the fixing temperature. With the increase in the squeezing pressure, the coating material is thought to penetrate in the fabric structure. Therefore, it is considered that the fixed coating material affects the flame retardancy properties of the mattress fabrics positively than the coating material retained on the surface. Although it is less than the other factors, it is obvious that the fixing temperature applied to fasten the coating material to the fabric increases the LOI value. As can be seen from the plots and Table 2, the best performance (41.8%) in terms of flame retardancy was obtained with 150 g/lt chemical quantity, 6 bar squeezing pressure and 190 °C fixing temperature.

3.3 Optimization of parameters for the pad-dry-fixation method

Response Surface Methodology was used to optimize the parameters affecting LOI. Table 5 shows the predicted parameter values to obtain the optimum LOI value and the response result to be obtained when these values are selected. The optimum LOI value which experimentally resulted in 41.92 % was obtained using application conditions as: 150 g/lt chemical quantity, 6 bar squeezing pressure and 189.2 ◦C fixing temperature. It was observed that the obtained experimental values were in good agreement with the values predicted from the models.

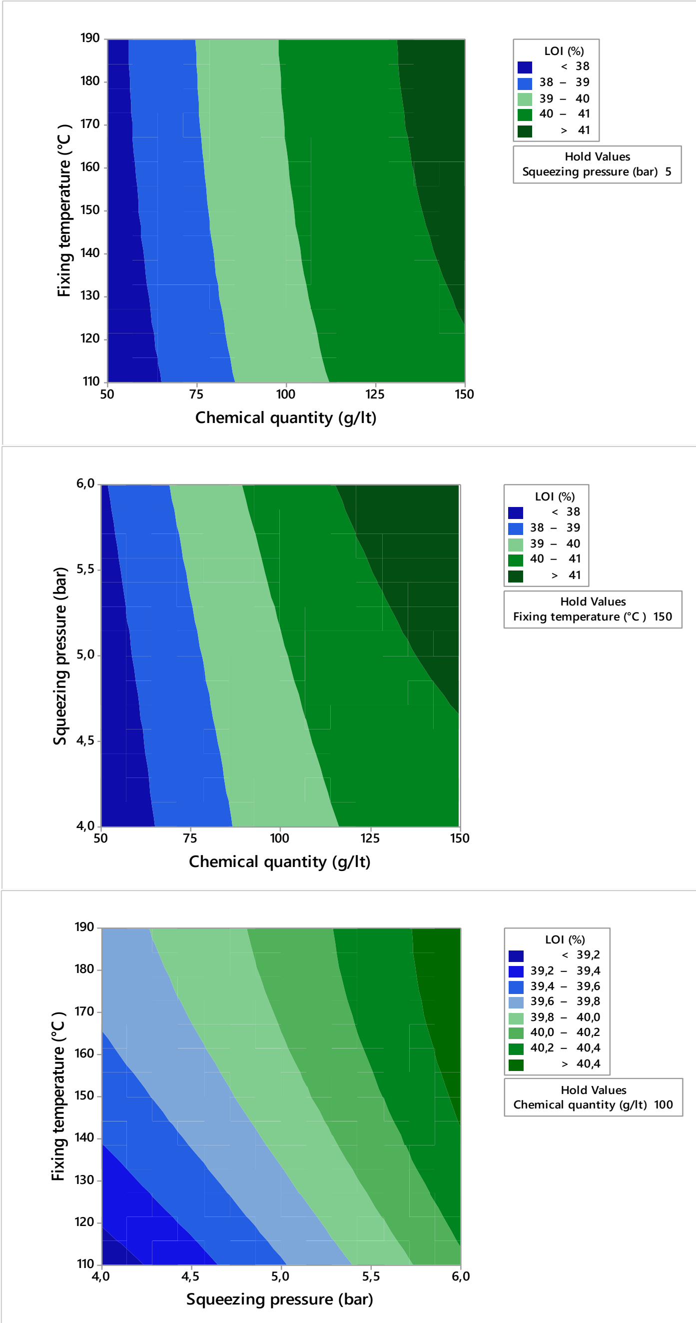


Figure 2. 2-D contour plots for LOI responses, (a) fixing temperature and chemical quantity; (b) squeezing pressure and chemical quantity; (c) fixing temperature and squeezing pressure.

Table 5. Optimum predicted parameters and responses for pad-dry-fixation method

	Factors			Response	CI
	X_1	X_2	X_3		
Y	150	6	189.2	41.92	41.63; 42.22

3.4 Model development for the foam coating method

The design matrix, the experimental and the predicted responses for 9 experiments are given in the Table 6. The LOI values of the fabrics covered by the foam coating method compared to the raw fabric increase by approximately 6.1%. In addition, the highest LOI value of % 32.7 was achieved with the F6 fabric (Table 6). The predicted responses for the foam coating method was obtained using Eq. (4). From Table 6, it is clear that the predicted responses are to be quite close to the experimental responses.

$$Y = 26.95 + 0.01091\ X_4 + 0.0160\ X_5 - 0.000004\ X_4^2 - 0.000024\ X_5^2 - 0.000018\ X_{45} \quad (4)$$

Table 6. The fabric codes and the changed application parameters for the foam coating process

Fabric codes	Uncoded factors		LOI	
	X_4	X_5	Exp.[a]	Pred.[b]
F0	-	-	29.5	-
F1	200	110	29.6	30.0
F2	200	140	30.8	30.2
F3	200	190	30.3	30.4
F4	350	110	31.3	31.0
F5	350	140	30.7	31.2
F6	350	190	31.3	32.6
F7	700	110	32.7	32.5
F8	700	140	32.3	32.3
F9	700	190	32.4	30.0

[a]Experimental
[b]Predicted

ANOVA results for the quadratic regression model obtained from RSM are given in Table 7. The model's p value of 0.00 for in Table 7 implies that the model is significant. Moreover, R^2 value of the model is 0.8675, which means that 86.75% variation can be explained by this model and only 13.25% of total variation cannot be explained (Adj-R^2=0.8360). However, it is clear that the lack of fit value is significant and it constitutes %10.68 of the model's error. This result indicates that some of the foam coating variables or the LOI test method variables have been ignored. From Table 7, it is seen that the effect of foam density on the model is significant and the contribution percentage is at 80.94%. The effect of fixing temperature on the model appears to be insignificant.

3.5 Response contour for the foam coating method

Figure 3 demonstrate the 2-D contour plot for LOI responses. Figure 3 exhibits that the increasing density of foam remarkably increase the LOI value. It is obvious that the LOI value does not vary substantially in the fixing temperature range of 110 °C to 190 °C. In this case, it will be economically reasonable to use a fixed temperature of around 110 °C while coating the mattress fabrics. The highest LOI value (32.7%) was reached with 700 g/cm foam density and 110 °C fixed temperature.

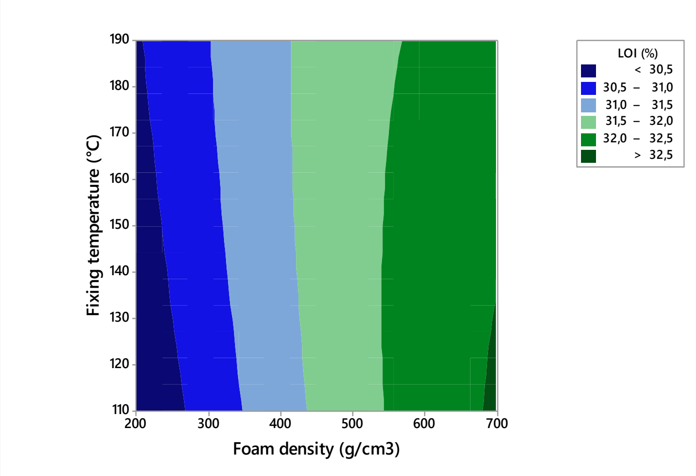


Figure 3. 2-D contour plot for LOI responses

3.6 Optimization of parameters for the foam coating method

According to Table 8, the optimum LOI value (%32.55) for the foam coating method was achieved with 700 g/cm^3 foam density and 110 °C fixing temperature. As can be seen from this result, the lowest temperature of the experiment set is sufficient for optimum results. When the experimental data in Table 6 are examined, it is seen that the highest LOI value was obtained with these parameters. Experimental data and estimated values shows results compatible with each other.

Table 7. ANOVA for the RSM model of LOI test

Source	DF	Adj SS	Adj MS	F	P	Percent(%)
Model	5	22.506	4.501	27.50	0.000	86.75
X_1	1	20.999	20.999	128.32	0.000	80.94
X_2	1	0.0181	0.0181	0.11	0.743	0.07
X_1^2	1	0.298	0.298	1.82	0.191	1.15
X_2^2	1	0.007	0.007	0.05	0.831	0.03
X_1X_2	1	0.400	0.400	2.45	0.133	1.54
Residual error	21	3.737	0.164			14.40
Lack of fit	3	2.770	0.923	24.93	0.000	10.68
Pure error	18	0.666	0.037			2.57
Total	26	25.943				

Table 8. Optimum predicted parameters and responses for foam coating method

	Factors		Response	CI
	X_4	X_5		
Y	700	110	32.55	32.12; 32.99

4. CONCLUSION

In this work, the variable parameters of two different methods (the pad-dry-fixation and the foam coating method) used to coat the mattress fabrics were optimized for flame retardant efficiency, by RSM. The flame retardancy values of the mattress fabrics were evaluated by Limit oxygen index (LOI). Based on RSM, it was observed that the quadratic models proposed for both methods were suitable for prediction of LOI values. For pad-dry-fixation, all parameters were found to have a statistically significant effect on the model, however the chemical quantity was observed to be the most important parameter affecting flame retardant properties of mattress fabrics. Furthermore, analysis of variance showed that there was high correlation between the input parameters and LOI responses of fabrics treated with pad-dry-fixation method (R^2=0.9571). The increase in the values of all pad-dry-fixation method parameters had a positive effect on the LOI value of the mattress fabrics. The optimal conditions of the pad-dry-fixation method were at 150 g/lt chemical quantity, 6 bar squeezing pressure and 189.2 ◦C fixing temperature.

For foam coating method, it was understood that foam density statistically significantly changed LOI value and optimal conditions were at 700 g/cm^3 foam density and 110 °C fixing temperature. Moreover, it was understood that the quadratic model with the R^2 value of 0.8675 was satisfactorily compatible with the LOI values of the fabrics treated with the foam coating method. Consequently, the model with higher compatibility with LOI values was reached with the pad-dry-fixation method compared to the foam method. In addition, it was determined that the variable in the parameters of the pad-dry-fixation had a higher effect on LOI value.

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