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EFFECT OF CAVITATION PROCESS ON THERMAL COMFORT PROPERTIES OF DENIM FABRICS

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Abstract: The process, which is defined as ultrasonic treatment or cavitation, ensures that the dirt is removed from the surfaces without damaging the fabric surface. There are studies on the ultrasonic washing processes of denim fabrics in the literature, but there is no study on the effect of the cavitation process on the thermal comfort of denim fabrics. For this purpose, denim fabrics were treated at three different times, 15, 30, and 45 minutes, and at two different frequencies 8khz and 16khz in the ultrasonic homogenizer test device. It was observed that the applied cavitation process reduces the air permeability, thermal conductivity, and thermal absorptivity values. On the other hand, the cavitation process increased the water vapour permeability value by cleaning the materials such as dirt and oil on the surface. It can be concluded that the applied cavitation process provides comfort by enabling quick throwing of the sweat to the outer surface, provides less heat conduction from the fabric, and the denim fabric felt warmer after the cavitation process.

Keywords: Ultrasonic washing, cavitation, denim fabrics, thermal properties

Kavitasyon İşleminin Denim Kumaşların Termal Konfor Özelliklerine Etkisi

Öz: Ultrasonik işlem yada kavitasyon, kumaş yüzeyine zarar verilmeden kirlerin uzaklaştırılmasını sağlayan bir proses olarak tanımlanmaktadır. Literatürde denim kumaşların ultrasonik yıkama işlemleri ile ilgili çalışmalar bulunmaktadır ancak kavitasyon işleminin denim kumaşların ısıl konforuna etkisi ile ilgili herhangi bir çalışma bulunmamaktadır. Bu amaçla denim kumaşlara ultrasonik homojenizatör test cihazında 15, 30 ve 45 dakika olmak üzere üç farklı zamanda ve 8khz ve 16khz olmak üzere iki farklı frekansta işlem uygulanmıştır. Uygulanan kavitasyon işleminin hava geçirgenliği, ısıl iletkenlik ve ısıl soğurma değerlerini azalttığı gözlemlenmiştir. Diğer yandan kavitasyon işlemi yüzeydeki kir, yağ gibi maddeleri temizleyerek su buharı geçirgenlik değerini artırmıştır. Uygulanan kavitasyon işleminin terin dış yüzeye hızlı bir şekilde atılmasını sağlayarak konfor sağladığı, kumaştan daha az ısı iletimi sağladığı ve kavitasyon işleminden sonra denim kumaşın daha sıcak hissedildiği sonucuna varılabilir.

Anahtar Kelimeler: Ultrasonik yıkama, kavitasyon, denim kumaşlar, termal özellikler

1. INTRODUCTION

Denim fabrics are produced as warp dyed indigo, the weft yarn is generally cotton or polyester, and fabrics are produced with or without elastane. Denim is manufactured with 3/1 and 2/1 twill weave structures that weigh 14.5 ounces per square yard (Muthu, 2017). Denim fabrics are subjected to processes such as dyeing, finishing, and coating to satisfy the consumers' expectations of fashion. Since denim fabrics have a very tight and hard structure after weaving, different washing processes should be done and the surface properties should be changed in terms

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of aesthetics and comfort. Denim fabrics can be affected by washing processes such as rinse washing, enzyme washing, stone washing, and bleach washing. With these processes, it is aimed to attract the attention of the consumer by causing changes in the appearance of the denim fabric. In addition, the color and appearance properties of the denim fabric can be changed by ultrasonic washing or ozone treatment. Different chemicals are applied to the fabric during industrial washings such as hypo, sulphite, and enzyme. In ultrasonic washing, the washing effect was made without using any chemicals, so these washings do not have any harmful effects on the environment.

Ultrasonic homogenizers are mainly used for homogenization, desaglomerization, emulsification, accelerating chemical reactions as well as disruption of cells, bacteria, fungi, or spores. Low-frequency ultrasonic oscillations cause millions of tiny vacuum bubbles to form in all liquids, which immediately burst, creating highly effective pressure fluctuations. This process is called cavitation.

Like any sound wave, ultrasonic energy is transmitted by waves, and the frequency of these sound waves varies between 20kHz and 20MHz. Thanks to ultrasonic sound waves, compression and relaxation occur in the molecular structure of the environment. During successive compression periods, the cavitation bubbles collide with each other, resulting in a large amount of energy being released (Mason, 1988). Low frequencies of about 20 kHz create bubbles with larger diameters and more intense pressure fluctuations compared to frequencies of about 35 kHz. Low frequency ultrasound has been used in various ultrasound baths in the past. The cavitation process is used to effectively and gently remove residual dirt from the surfaces of immersed components. Here, one of the most important factors affecting ultrasonic washing is the power of the applied ultrasonic cavitations.

In previous studies, it has been stated that while ultrasonic washing ensure less fiber migration, it has many advantages such as a reduction in processing time, energy, and chemicals (Sun et al., 2010). Khajavi et al. (2007) investigated the effects of the ultrasonic process on worn out properties of denim fabrics. It was found that using the ultrasonic washing technique increases the efficiency of worn out process and produces a different view. Uzun (2013) studied the impact of ultrasonic washing on the thermal comfort of some knitted fabrics and it was discovered that the thermal comfort features like thermal conductivity, thermal resistance, thermal absorptivity, and water vapour permeability were affected by ultrasonic washing treatments. Arıkan et al. (2018) searched the impact of ultrasonic washing on improving chemical substances and temperature parameters in denim fabrics. It has been stated that the fastness results obtained by using classical washing techniques and cleaners in denim fabric washing can be achieved at lower temperatures and without using chemicals and acids by using ultrasonic sound signals. Eyüpoğlu and Merdan (2020) investigated the impact of enzymatic treatments on the physical and chemical characteristics of cotton fabrics. For this purpose 3/1 Z twill woven fabrics were treated with classical and ultrasonic energy methods. It was declared that the color difference was less than those washed with ultrasonic washing, but when the pilling properties were examined, the pilling value of those which were washed with enzymatic treatment was higher. Fraj and Jaouachi (2021) investigated the effects of the ozone process on denim garment features to develop the effects of washing on the view and physical properties. It was found the breaking force and shrinkage properties of treated fabrics were influenced by the ozone treatment negatively. Ticha and Meksi (2021) developed a new sustainable method for processing denim fabrics, and the effect of this process was investigated. It was found that ultrasonic washing affects the thermal and evaporative resistance of denim fabrics.

Although there are studies on the impacts of ultrasonic washing on the color features of fabrics in the literature, there is no study on the impact of cavitation on the thermal comfort of denim fabrics. Denim fabrics are widely used in daily and sportswear due to their performance properties. Today, different washing techniques are applied to denim fabrics, trying to meet consumer expectations in terms of aesthetic and comfort properties. In this study, cavitation processes were applied on three different denim fabrics (cotton, cotton elastane, and cotton polyester elastane) for three different times, 15, 30 and 45 minutes, and at two different frequencies like 8Khz and 16Khz. Since the amount of chemicals used in industrial washing processes is harmful to the environment and the chemicals are expensive, the cavitation process was applied to improve the surface properties and comfort properties of denim fabrics. The aim here was to compare untreated and ultrasonically treated denim fabrics in terms of thermal comfort in the case of only ultrasonic washing without industrial washing. For this purpose, air permeability, thermal conductivity, thermal absorption, and water vapour permeability properties treated and untreated denim fabrics were tested.

2. MATERIAL AND METHOD

The desized samples were supplied from the manufacturer to examine the impact of the ultrasonic homogenization process applied to three different denim fabrics produced from 100% Cotton, Cotton Elastane, and Cotton Polyester Elastane. Fabric samples structural properties were given in Table 1. The samples were cut into 10x10 cm dimensions and placed in distilled water at room temperature. Within the scope of this study, sample fabrics were treated at three different times (15, 30, and 45 minutes), with 40% and 80% efficiencies of the maximum 20kHz power of the device. Since the device can work with a maximum of 20 kHz, it was operated at 8 and 16 kHz frequencies in order to achieve selected efficiencies. The ultrasonic homogenizer (Bandelin, HD2200) used in this work was given in Figure 1 (Bandelin Manual). The thickness measurements of the untreated fabrics and ultrasonic homogenization treated fabrics were done using a James H. Heal R&B test device (ASTM D 1777 Standard). The air permeability tests of fabrics were done with SDL Atlas Air Permeability device due to TS 391 EN ISO 9237 standard and the test area was chosen 5 cm^2 (EN ISO9237). The thermal properties of tested fabrics were measured with the Alambeta test device due to EN ISO 11092 procedure (EN ISO 11092 Standard). The water vapour permeability results of tested fabrics were taken from the Permetest device and the tests were done according to EN ISO 11092 standard (EN ISO 11092 Standard). Statistical analyze measurements of tested fabrics were made with SPSS 23.0 program. A two-factor (Frequency*Time) repeated measures analysis of variance (ANOVA) were used to analyze the effect of frequency and time for thermal comfort parameters of fabrics. Multiple-comparison LSD tests were performed to investigate where the difference lies.

Table 1. Structural properties of fabrics used in the experimental study

Fabric Code	Warp Yarn Count	Weft Yarn Count	Warp/Weft Density (Thread/cm)	Weight (g/m^2)	Bulk Density (kg/m^3)	Weave
F1	7.4 Ne Cotton	8 Ne Cotton	27-21	421	526	3/1 Z
F2	9 Ne Cotton	12 Ne Cotton78 dtex Elastane	20-20	367	460	3/1 Z
F3	6 Ne Cotton	10 Ne Polyester 78 dtex Elastane	25-19	447	525	3/1 Z

Table 2. Thickness properties of untreated and cavitation treated fabrics

Fabric Code	Time	Frequency	Thickness (mm)
F1	Untreated	-	0.80
F1.1.	15min	8 Khz/ 16khz	0.86/ 0.87
F 1.2.	30 min	8 Khz/ 16khz	0.85/0.87
F.1.3.	45 min	8 Khz/ 16khz	0.85/0.85

F2	Untreated	-	0.79
F2.1.	15min	8 Khz/ 16khz	0.79/0.78
F2.2.	30 min	8 Khz/ 16khz	0.78/0.78
F2.3	45 min	8 Khz/ 16khz	0.77/0.78
F3	Untreated	-	0.85
F3.1.	15min	8 Khz/ 16khz	0.81/0.81
F.3.2	30 min	8 Khz/ 16khz	0.83/0.82
F3.3.	45 min	8 Khz/ 16khz	0.81/0.83

Figure 1:

Ultrasonic homogenizer test device (Bandelin HD2200)

3. RESULTS AND DISCUSSIONS

3.1. Air Permeability

When the air permeability results of the untreated fabrics were investigated, it was observed that the F1 coded 100% cotton fabric has the highest air permeability. Air permeability is a parameter that varies due to the thickness, weight and weaving construction of the fabric. Although the thickness and weight value of the fabric produced from 100% cotton yarn were higher than the F2-coded cotton/elastane fabric, the highest air permeability value was observed in this fabric. Because it was the only fabric woven without elastane. It can be said that the use of elastane in the fabric structure makes the structure tighter and reduces the air permeability value (Ciukas and Abramavičiūtė, 2010). The F3-coded cotton/polyester elastane included fabric was woven with thicker yarns and the air permeability value was found to be lower than the other fabrics because of the higher thickness. In previous studies, it was observed that the air permeability value decreases as the thickness of the weft and warp yarn count increases in the woven fabric structure (Oğulata, 2006). The air permeability values of untreated and 8kHz and 16kHz power ultrasonically treated fabrics were given in Fig.2.

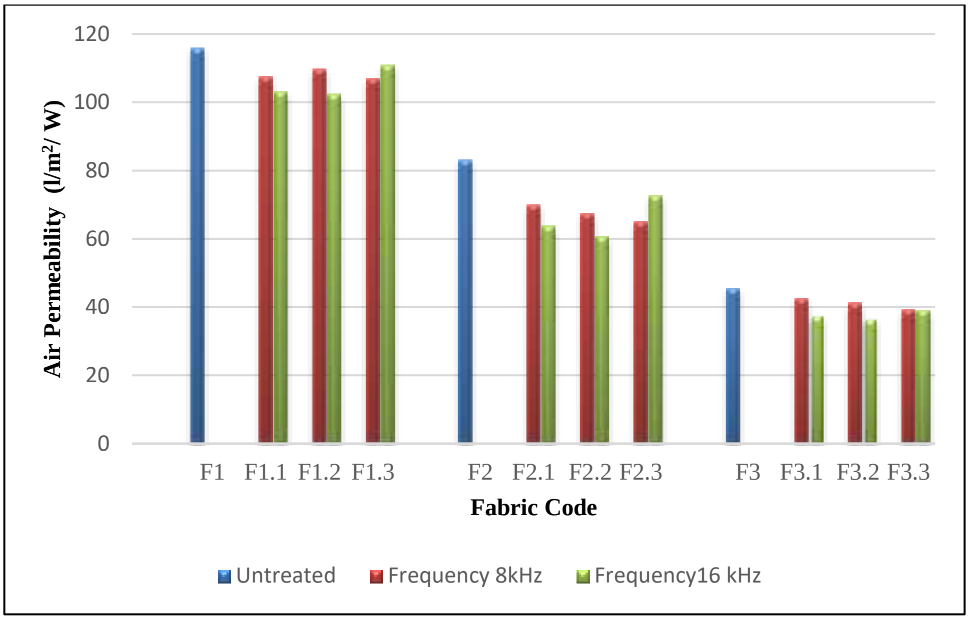

Figure 2:
The air permeability values of raw and ultrasonic treated fabrics in 15, 30 and 45 minutes

Considering the effect of the applied ultrasonic homogenization process on air permeability, the lower air permeability values were seen compared to the untreated fabrics. It was observed that the thickness values of the 100% cotton fabric included fabrics increased after the applied treatment, and therefore the air permeability value decreased. Although the thickness value of the other two fabrics did not increase after treatment, air permeability values decreased. This can be explained by the fact that the yarns gain volume after washing as stated in previous studies (Yıldırım et al., 2014). Considering the effect of the applied time, the air permeability values decreased as the time increased in general. Considering the effect of the applied power on the air permeability, it was observed that the air permeability value of the fabrics treated with 8 kHz was higher than the fabrics with 16 kHz (except 45 min). It can be said that as the power increases, the pressure applied to the fabric structure increases. The pressure fluctuations that occurred during homogenization caused reducing the air permeability values in 15-minute and 30-minute applicated samples. The effect of the frequency and time of the applied cavitation process on the air permeability values of denim fabrics were analyzed by Post- hoc LSD test. It was found no statistically significant difference.

3.2. Thermal Conductivity

The thermal conductivity coefficient of textile surfaces is a parameter that the thickness of the fabric and the heat transfer rate caused by the unit temperature difference affect this parameter. Also, it can be defined as the thermal conductivity of a textile structure is a measure of that material's capability to conduct heat. The thermal conductivity of fabrics can be calculated according to the below formula:

$$\lambda = Q/(F.\tau.\Delta T/\sigma) \ W.m^{-1}K^{-1} \qquad (1)$$

Where; Q conducted heat amount, F area of which the heat conducted, τ time of heat conducted, ΔT drop of temperature, and σ fabric thickness (Frydrych et al., 2002). The thermal conductivity values of ultrasonic process treated and untreated fabrics were given in Fig. 3. It was known, the thermal conductivity values of fibres are higher than the thermal conductivity of entrapped air (Morton, 2008). When the thermal conductivity of untreated fabrics was examined, it was seen that the highest thickness F3-coded cotton/polyester elastane yarn included fabric had the highest thermal conductivity value. This was thought to be due to the high fiber density in the fabric structure. This supports a previous study that heavier fabrics that contain less entrapped air had higher thermal conductivity values (Özkan and Kaplangiray, 2020). The lowest thermal conductivity value was seen in F2-coded cotton elastane yarn included fabric which has the lowest thickness and bulk density value.

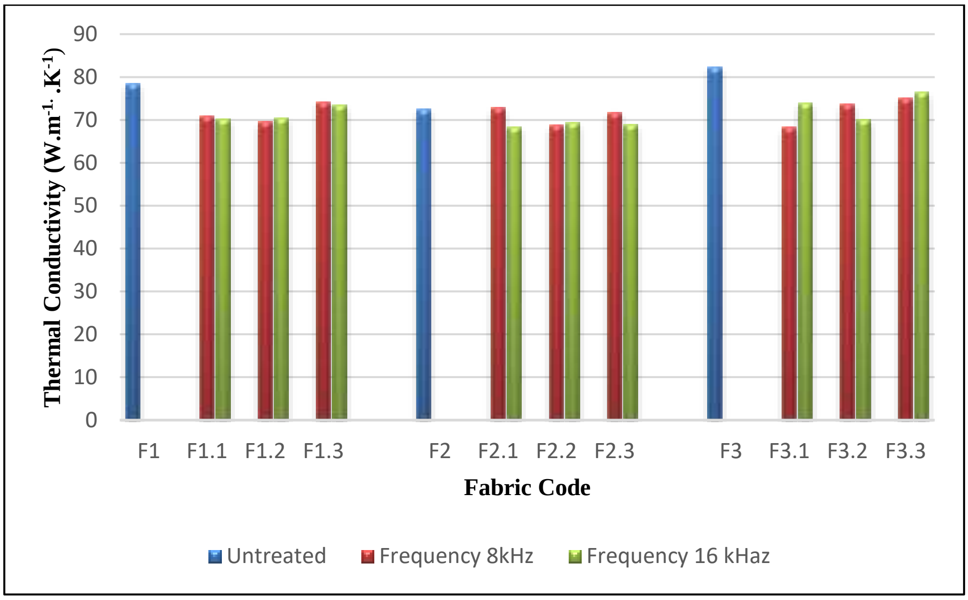

Figure 3.
The thermal conductivity values of ultrasonic process treated and untreated fabrics

Considering the effect of the applied ultrasonic homogenization process on the thermal conductivity values of the fabrics, treated fabrics showed lower thermal conductivity values than untreated fabrics (except F2). Considering the effect of the applied time, it was concluded that the applied time had no significant effect on the thermal conductivity value. This supports a previous study, washing time did not have a great impact on thermal conductivity (Uzun, 2013). Because the thermal conductivity value changes with the fiber properties mostly. Likewise, the thermal conductivity values of the fabrics with 16 kHz frequency ultrasonic washing treated samples were found to be close to the fabrics with 8 kHz frequency treated samples. Statistical analysis of thermal conductivity measurements was made with the SPSS 23.0 program. A two-factor (Frequency* Time) repeated measures analysis of variance (ANOVA) was used to analyze the effect of frequency and time for thermal conductivity measurements of the cavitation treated and untreated fabrics. Post-hoc LSD statistical tests were used to understand the relationship between parameters when a difference was seen between variables. The results showed that there was a significant difference between cavitation treated and untreated fabrics. However, when the effect of application times on thermal conductivity was examined, no statistical difference was observed (Table 4). Considering the effect of applied frequency on thermal conductivity, statistically significant results were observed between untreated and cavitation treated fabrics. However, there was no statistically significant result between frequency differences (Table 5).

Table 3. Two-way ANOVA for thermal conductivity test results

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	133.900[a]	6	22.317	2.520	.072
Intercept	102232.721	1	102232.721	11543.025	.000
Time	30.813	2	15.407	1.740	.211
Frequency	.802	1	.802	.091	.768
Time * Frequency	.871	2	.436	.049	.952
Error	123.993	14	8.857		
Total	110022.307	21			
Corrected Total	257.893	20			

Table 4. Post-Hoc LSD test for effect of cavitation time on thermal conductivity of denim fabrics

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
No Treatment	15	6.9800*	2.10436	.005	2.4666	11.4934
	30	7.4133*	2.10436	.003	2.8999	11.9267
	45	4.4467	2.10436	.053	-.0667	8.9601
15 min.	No Treatment	-6.9800*	2.10436	.005	-11.4934	-2.4666
	30	.4333	1.71820	.805	-3.2518	4.1185
	45	-2.5333	1.71820	.163	-6.2185	1.1518
30 min.	No Treatment	-7.4133*	2.10436	.003	-11.9267	-2.8999
	15	-.4333	1.71820	.805	-4.1185	3.2518
	45	-2.9667	1.71820	.106	-6.6518	.7185
45 min.	No Treatment	-4.4467	2.10436	.053	-8.9601	.0667
	15	2.5333	1.71820	.163	-1.1518	6.2185
	30	2.9667	1.71820	.106	-.7185	6.6518

Table 5. Post-Hoc LSD test for effect of frequency on thermal conductivity of denim fabrics

(I) Frequency	(J) Frequency	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
-No Treatment	8	6.0689*	1.98401	.008	1.8136	10.3242
	16	6.4911*	1.98401	.006	2.2358	10.7464
8	-No Treatment	-6.0689*	1.98401	.008	-10.3242	-1.8136
	16	.4222	1.40291	.768	-2.5867	3.4312
16	-No Treatment	-6.4911*	1.98401	.006	-10.7464	-2.2358
	8	-.4222	1.40291	.768	-3.4312	2.5867

3.3. Thermal Absorptivity

The thermal absorption value determines the "hot and cold feeling" of the material at the time of contact. As the thermal absorption value of the material increases, the heat absorbed from the material increases, and the material felt colder. On the other hand, materials with low thermal absorption values felt warmer by users. Thermal absorptivity varies depending on thermal conductivity, fabric density, and the specific heat value of the fabric. Substances with high thermal conductivity coefficients also have high thermal absorption values. The variation of the thermal absorption values of the samples was given in Fig. 4.

When the thermal absorption values of the untreated fabrics were investigated, it was observed that the F1-coded 100% cotton and F3-coded cotton/polyester elastane included fabrics had close thermal absorption values. Because the bulk density values of these fabrics were almost the same. The highest thermal absorption value was seen F1 coded 100% cotton fabric. It can be concluded that this fabric felt colder than the others. F2-coded cotton elastane included fabric had lower thermal absorption values because the bulk density and thermal conductivity of this fabric were lower than the other two fabrics. Therefore, it can be concluded that this fabric felt warmer than the other two untreated fabric.

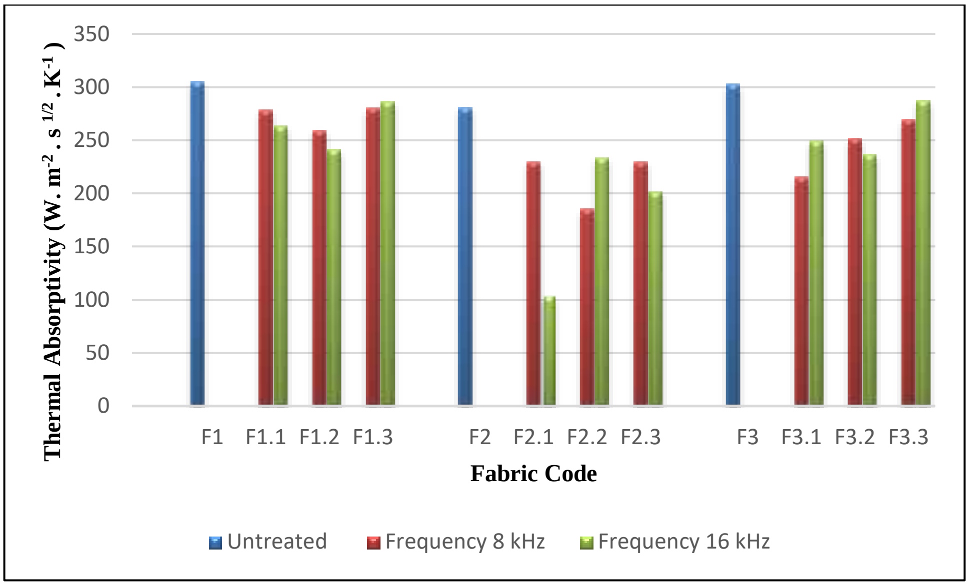

Figure 4.
The thermal absorptivity values of ultrasonic process treated and untreated fabrics

Considering the effect of the applied ultrasonic homogenization process on the thermal absorption of the fabrics; In the treated fabrics, lower thermal absorption values were obtained than in the untreated fabrics contrary to previous work (Uzun, 2013). Considering the effect of the homogenization process on the thermal absorptivity value, the highest absorptivity values were seen in the 45 minutes cavitation treated fabrics. There was no significant difference between 15 and 30 minutes cavitation treated fabrics. It was not observed that the applied frequency has any effect on the thermal absorptivity value. Thermal absorptivity varies depending on fiber conductivity and fabric specific heat especially. So, the highest thermal absorptivity values were seen in 100% cotton yarn woven fabrics both cavitation-treated and untreated fabrics. The effect of the frequency and time of the applied cavitation process on the thermal absorptivity values of denim fabrics were analyzed by Post- hoc LSD test and no statistically significant difference was found.

3.4. Water Vapour Permeability

In order for the person to feel comfortable, the heat accumulation above the normal values (50 W/m^2h) must be removed from the body. This is not possible due to the limitations caused by the clothes on the person or the weather conditions of the environment. As a result, the internal body temperature rises. Removal of heat from the body is possible through sweating and subsequent evaporation of sweat. In order for the person to be thermally comfortable, sweat must be thrown away from the body and transferred from the clothing system to the environment. The water vapour permeability of fabric determines comfort, especially in high metabolic heat and sweating conditions resulting from high activity and hot weather conditions. The highest water vapour permeability value was observed in the F1 coded 100% cotton fabric that does not contain elastane. In previous studies, it was stated that the use of elastane in the structure caused water vapour resistance due to the presence of hard layers in the elastane. It can be said that cotton fabrics can absorb more water vapour than elastane (Ivanovska et al., 2021).

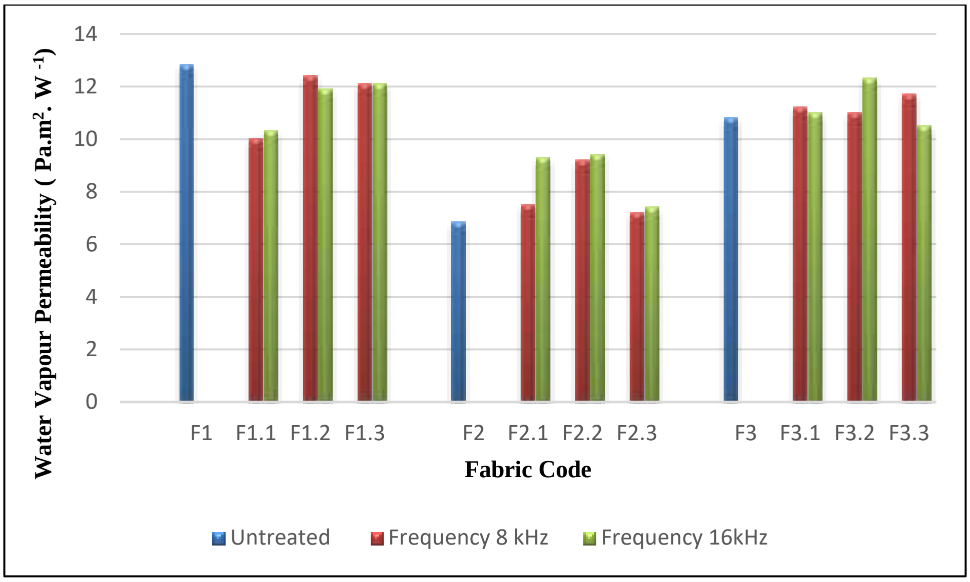

Figure 5.
The water vapour permeability values of ultrasonic process treated and untreated fabrics

Considering the effect of the applied ultrasonic homogenization process on the water vapour permeability of the fabrics; In treated fabrics, higher water vapour permeability values were obtained than in untreated fabrics (except for F1). The results of 30 minutes and 45 minutes showed close results to the untreated fabric, while the water vapour permeability value of the fabrics treated for 15 minutes decreased after cavitation process in F1 coded 100% cotton woven fabric. It was observed that the homogenization process increased the water vapour permeability value in contrast to the air permeability results. Because unlike air permeability, water vapour permeability depends on the fabric composition. In hygroscopic fibers such as cotton, water vapour transfer occurs by diffusion between the fibers (Lee, 2012; Polipowski, 20017; Havlova, 2020). When the effect of the applied homogenization process was examined, the applied process removes the dirt and excess fibers on the surface. As a result, the water vapor permeability of the fabric increased. Considering the effect of homogenization time, there was not much difference between cavitaton treated samples (except for F2.1 and F3.2). Considering the effect of the applied frequency, it was seen that the increase in frequency only increased the water vapour permeability value in the F2-coded fabric cotton elastane yarn woven fabrics. The effect of the frequency and time of the applied cavitation process on the water vapour permeability values of denim fabrics were analyzed by Post- hoc LSD test and no statistically significant difference was found.

4. CONCLUSION

Nowadays, many chemicals are used to provide different washing effects, which harms both human health and the environment. The aim of this paper was to see the changes in the thermal properties of denim fabrics by applying cavitation only, without any chemicals. In this way, it was thought that the expectations of the consumers can be met by changing the surface properties, aesthetic expectations, and comfort properties only with the effect of cavitation in future studies. In this study, the cavitation process was applied to three different denim fabrics with the help of an oxygen homogenizer device at two different frequencies and at three different times, and the effect of this process on the thermal comfort of denim fabrics was investigated. When the effect of the cavitation process on the comfort properties was examined, it was seen that the air permeability, thermal conductivity, and thermal absorption properties of the treated fabrics decreased. Since the air permeability is affected by the structural properties of the fabric, the air permeability value decreased as the cavitation process and the applied time increased. This can be explained by the increase in thickness in the F1-coded %100 cotton fabric and by the increase in the volume of the yarns after washing in the other two fabrics. Although the thermal conductivity and absorptivity values were mostly affected by the fiber properties, the applied cavitation process was not a determining factor for conductivity and absorptivity values. It can be concluded that the cavitation process caused a decrease in the thermal conductivity and thermal absorptivity values of the denim fabrics. It was observed that the cavitation process increased the water vapor permeability properties by removing substances such as dirt, oil and floating fibers from the fabric surface. It can be concluded that the applied cavitation process provides comfort of use by enabling quick throwing of the sweat to the outer surface. Also, these fabrics provide less heat conduction and felt warmer after the cavitation process.

CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

AUTHOR CONTRIBUTION

'Esra Taştan Özkan determining the concept and design process of the research and research management, Binnaz Kaplangiray data collection, analysis and management'.

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