(REFEREED RESEARCH)

DESIGN OF AUTOMATIC TEXTILE AIRING PROGRAM: AN APPROACH TO SUSTAINABLE LAUNDERING

OTOMATİK TEKSTİL HAVALANDIRMA PROGRAMI TASARIMI: SÜRDÜRÜLEBİLİR TEKSTİL BAKIMI

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ABSTRACT

Laundering includes exposing textile materials to a combined effects of water, heat, agitation and detergent. Depending on the laundry temperature the water and the energy consumption may vary. The energy which is required to heat the water and operate the machine, together with the chemicals and water discharged down the drain cause majority of environmental impacts along the life cycle of a textile product. Manufacturers are engaged in optimizing the type and design of laundering programs to minimize the consumption of the resources. This paper focuses on the design of an automatic refreshing program to reduce water&energy consumption and environmental impact of textile products during the use period of the life cycle thus achieving a more sustainable laundering. The mechanical parameters (time, tumbling speed, airflow) were examined to find out the optimum airing program which achieves removing significant amount of the odour from textile surfaces and causes the least linting for different fabric structures.

Keywords: Sustainability, sustainable laundering, textile refreshing/airing program, odour removing

ÖZET

Tekstil mamullerinin yıkama işlemi esnasında tekstil malzemesi su, ısı, mekanik etki ve deterjanın kombine etkilerine maruz bırakılmaktadır. Yıkama işleminde kullanılan su sıcaklığına bağlı olarak su ve enerji tüketimi yüksektir. Bunun yanısıra; suyun ısıtılması, makinenin çalışması için gereken enerji ile birlikte drene atılan kimyasallar ve su, bir tekstil ürününün kullanım ömrü boyunca yol açtığı çevresel etkilerin büyük çoğunluğunu oluşturmaktadır. İmalâtçılar, maliyetlerin ve/veya çevresel etkinin en aza indirgenmesi için otomatik temizleme program ve tasarımlarını optimize etmeye çalışmaktadırlar. Bu çalışmada, tekstil ürününün kullanımı sırasında su ve enerji tüketimini ve çevresel etkileri en aza indirerek daha sürdürülebilir yıkamayı sağlayan otomatik havalandırma programının tasarımı hedeflenilmiştir. Bu kapsamda, farklı tekstil konstrüksüyonları için en fazla kokuyu uzaklaştıran ve en az hav oluşumuna sebep olan optimum programı tasarlamak amacıyla otomatik havalandırma programı mekanik parametreleri (süre, tambur devri, debi) incelenmiştir.

Anahtar Kelimeler: Sürdürülebilirlik, sürdürülebilir tekstil temizle işlemi, tekstil havalandırma programı, koku uzaklaştırma

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1. INTRODUCTION

Environmental issues are playing an increasingly significant role in the textile industry. The way consumers use textiles has an enormous impact on the ecology. The use phase of textiles initiates with the purchase of the textile products and covers washing, drying, dry-cleaning and ironing applications. The earlier researches indicates the consensus that laundering is responsible for the majority of the environmental impacts over the life cycle of clothings (Laitala, et al., 2012)(Fletcher, 2008)(Allwood, et al., 2006). In terms of energy consumption the use-phase of a garment is responsible for the 80% of the total energy consumed throughout its entire life (Laitala, et al., 2012). In the average residental home (based on Europe) washing laundry accounts for 15% to 40% of the overall consumption of a typical household. Recent tehnological advancements such as embedded ozone, water recovery, and recycling systems target water, energy and chemical reduction for commercial washing machines to achieve required ‘cleanliness’ (Bio Intellegence Service, 2009). Alongside its negative environmental impacts a washing process is also considered a highly destructive cleaning method for textiles (Kadolph, 2007). Under the use-phase stages the mechanical action, the heat and the chemical agents cause corrosive effects on fibers’ structure and shorten textiles’ life span (Goynes & Rollins, 1971). Laundering is considered to be a reasonable process in presence of a dirt or stain, but certainly it is not an ecological way to get rid of odour only. However, the modern world's consumers tend to wash their clothes even if there is not a visible dirt or perceptible smell on it. Shove stated that people perform laundering because of 'conviction' rather than any rational reason (Shove, 2003). Understanding how and why people do laundering in certain ways is critical to further improve alternative sustainable practices. In tackling with environmental problems businesses and governments increasingly concern with consumer behaviour (Yates & Evans, 2016). Researcher Jack (2013) investigated the traditional laundering and consumers' alternative ways to keep their jeans fresh. The study revealed that one of the most favourably alternative practices was airing the jeans. The researchers reported that airing was the best method for keeping jeans fresh. The study also showed that in case of no stain users prefer to hang jeans indoor or outdoor, and occasionally expose textiles to direct sunlight. Respondents also noted that, applying substances to the jeans helps freshing up. In addition it was observed that talcum powder, perfume, and vinegar combat odour presence (Jack, 2013).

Odour molecules remove away by desorption mechanism. Air circulation, heat and time are the factors that can accelerate desorption. Even though the chemistry of odour has not yet fully understood, the interaction between odour and fiber helps understanding odour removing mechanism. Wide surface area of textile materials adsorbs odour molecules and retain them within the structure (Schindler & Hauser, 2004). Interaction between fibers and volatile organic acid (carboxylic acid) odour molecules depends on the fiber structure form. Fibers with higher rate of amorphous region tend to adsorb and store more carboxylic acid odour molecules. In the same fashion, fibers with higher crystalline region own a lower capacity to adsorb and retain odour molecules. In this regard, natural fibers have higher potential to attract and store odour molecules than synthetic fibers have.

There are little published research investigating the relationship between textile fibers and odour molecules as well as some other research that develops mechanism for odour removal. Xiao *et al.* (2011) examined the relation between fiber structure and acetic acid odour molecules which belong to the volatile organic acid compounds (carboxylic acid) that is the same group of butyric acid (see Table 2). It was reported that the adsorption rate of acetic acid by wool, linen, and deodorizing acrylic fibers was higher, followed by Modal® and cotton fibers. Polyester fibers gave the lowest adsorption results due to their high degree of crystallinity. Researcher McQueen *et al*. (2007) suggested that odour intensity is strongly associated with the fiber type: while odour intensity is high in polyester fabrics, it is lower in cotton and wool structures. Researchers at NASA (Johnson & Ganske, 2013) developed a waterless clothes-cleaning machine that removes loose particulates and deodorizes dirty laundry with regenerative chemical processes which was investigated to have effect on odour removing and/or bacteria killing. These processes are airflow, filtration, ozone generation, heat, ultraviolet light, and photocatalytic titanium oxide. The system is controllable independently on airflow, ozone, UV light, and the heat so each parameter can be turned on or off depending on the needs of the specific type of clothing or different types of soil on the clothes.

Linting and pilling are another main issues of laundering. Gintis and Mead (Gintis & Mead, 1959) provide us with the information about textile linting mechanism during automatic washing and drying processes. Okubayashi and Bechtold (Okubayashi & Bechtold, 2005) illustrated linting and pilling mechanism caused by washing and drying processes. Throughout laundering treatments fiber-ends tend to protrude from the inside of the yarn structure. These fibers may break off from the main structure as lint or induce fuzz formation and finally resulting in pill. In an automatic tumble dryer lints are collected on the filters. (see the chapter *Experimental Set Up*)

Automatic refreshing programs stand for a sustainable laundering solution. The program simply removes odour that absorbed by fibers and aims to refresh textiles for the subsequent use. Although automatic refreshing programs have already came into the market by several white appliances companies, its odour removing capacity has not been investigated. This paper examines the effect of parameters namely tumbling speed, airflow, and time which are decisive on odour removal and linting. The test mechanism was set on a domestic tumble dryer. 100% cotton single jersey fabric was used as the main test material. The analysis of the test results enabled the identification of the optimum airing program. The control tests of the optimum program were carried out by using also different types of textile materials. The designed automatic airing program has potential to preserve not only natural resources and energy but also cause less linting. We should also note that in this paper the unpleasant ambient odour such as food or smoke was aimed to be removed from the textiles rather than bacteria based human sweat odour. Butyric acid was chosen as artificial odour source.

2. MATERIAL AND METHOD

2.1 Textile Materials

In this study, 100% cotton single jersey fabric was chosen as the main/reference textile material. However, under the control tests, textile materials were diversified in construction and in fiber content. Therefore; odour removal and linting behaviour of different textiles were also examined. Control tests included double-knit, napped double-knit, triple knit and napped trible knit cotton/polyester fabrics. Textile types were carefully chosen in order to imitate the real life laundry load mixures. The mentioned textile materials are widely used for manufacturing of sweatshirts, t-shirts, hooded cardigan, top and bottom fleece tracksuit. Each of the textile materials used in the study, see the Table 1, were manufactured in the same textile mill under the same conditions in order to eliminate any resource related differences.

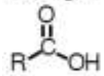
2.2 Chemical/ Odour Resources

Butyric acid (butanoic acid) which is one of the key odour compounds was selected depending on the fact that it is present in the sharp, cheesy, rancid, sour smell. It presents in food smell, cigarette, human sweat and many other odour sources (d'Acampora Zellner, et al., 2008). As shown in Table 2, butyric acid compound takes place under the carboxylic acid class.

Table 1. Textile materials used for the experiment (*for the main tests, **for the control tests)

Fiber content	Yarn No	Spinning Type	Knitting Type	Weight (g/m2)
100% cotton*	Ne 30/1	Ring Spun	Single Jersey*	1,3934
80% cotton/20% PES**	Ne30 /20	Ring Spun	Double-Knit**	2,1666
80% cotton/20% PES**	Ne30 /20	Ring Spun	Napped Double-Knit**	2,052
90% cotton/10% PES**	Ne 30/20/20	Ring Spun	Triple-Knit**	2,8544
90% cotton/10% PES**	Ne30/20/20	Ring Spun	Napped Triple-Knit**	2,7824

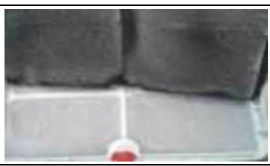
Table 2. Carboxylic acid compound and butyric acid (Haynes, 2011)

Class	Chemical Notation	Example Notation
Carboxylic Acid	RCOOH RCO_2H 	Acetic acid, CH_3COOH Butyric Acid, $CH_3(CH_2)_2COOH$

2.3 Experimental Set Up

A domestic, A++ energy classed, 8 kg tumble dryer machine, including heat pump and variable speed motor was used for the experiments. The simple working mechanism of the machine is shown in Figure 1.

Table 3. Filters within the test mechanism

Filter V	Nonwoven Filter
Polyester 190/38	Polyurethane
Monofilament	Foam filter
Plain weave	
	

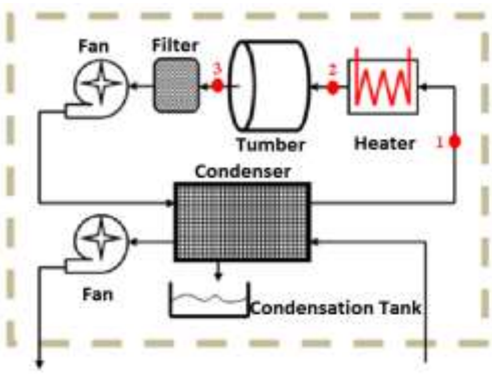


Figure 1. Condenser tumble dryer

The mechanism contains two filters, as shown in the Table 3. The main function of the filters is trapping the lints and other particules coming from the textiles thus preventing particles reaching to the heater and to the other components and avoiding the risk of fire.

2.4 Method

All the tests were carried out in standardized laboratory conditions accordingly to the IEC 61121, at 23°C ± 2 and 55 ± %5 RH. Main odour and linting tests were carried out by using 100% cotton single jersey fabric. Different types of textiles, as specified in Table 1, were tested for control experiments. Odour removing tests and the linting tests were carried seperately. Odour removing tests were carried on fabric swatches (7x10 cm) while linting test consisted of 1 kg of test samples (1x1m).

- **Design of Experiment (DOE)**

Investigated variants were tumble engine speed, airflow and process time. DOE was created as three variants, one center point, two replicate using full factorial thus resulting in 9 different test conditions. Investigated upper and lower levels of the parameters are shown in the Table 4. Prior to setting the parameter levels drum motions at different rates were observed. 1600 rpm provides a very slow motion of drum. 3400 rpm is observed to be the critical speed where clothes move outward centrifugal force and stick to the drum inner wall. Thus, 1600 rpm and 3400 rpm were set as the lower and upper level for Tumble Engine Speed parameters (TES). The central point was given as 2500 rpm. Each test condition was carried out twice for odour removing tests and for linting tests. The results of the experimental design were analyzed using Minitab 16® statistical software to evaluate the odour removing and linting effects.

Table 4. Parameters of the program

Parameters	Investigated Levels
Tumble Engine Speed	1600 - 3400 rpm
Airflow	30 - 60 lt/s
Process time	20 - 60 min

- **Odour Solvent Preparation, application on the batched and airing test**

Odour solvents were prepared at 5 ml/L concentration using distilled water and butyric acid in a sterilized microbiology laboratory environment. Textile samples were cut into the size of 7x10 cm and wetted with 2 ml of odour solvent. Wetted samples were placed in petri dish, sealed and placed in the oven at 36°C for 15 minutes. The samples removed from the oven were attached on a shirt prior the tests to be able to simulate the real life condition. For each airing cycles three samples were tested. Each of the three samples was attached onto seperate shirts. Then the test samples were placed in the tumble dryer, each were folded and positioned in the same manner.

- **Control Tests**

Effectiveness of optimized airing program was evaluated on different textile structures (See Table 1). In addition, automatic airing program and other traditional odour removing methods; airing outdoor, airing indoor and a washing programme (30°C, fast-cycle) were compared with the use of single jersey. Each test duration was set as one hour and each experiment was repeated twice. Outdoor and indoor environment's humidity, temperature and weather conditions, as well as washing conditions were noted as in Table 5.

Table 5. Outdoor drying weather conditions

Airing Method	Weather Conditions (average)
Outdoor	52 % RH, 20,5 ºC, 60 minute
Indoor	55±5 % RH, 23 ºC, 60 minute
Washing	30 ºC, 60 minute

- **Sensory Evaluation**

Odours are volatile substances which enter one's nasal cavity during inspiration that allows it to be perceived (Powers, 2004) which is used in the sensory evaluation method. Sensory evaluation is a scientific discipline used to measure, analyze, and interpret reactions to characteristic odours of foods and materials (Sidel & Stone, 2006). In this study, the butanoic acid odour references, as seen on the Table 6, were prepared as mixtures of 6 different concentrations of n-butanol and water as suggested by ASTM (ASTM, 1997).

Table 6. A six stage classification of odour intensity

Intensity (ml/L)	Status
0	None (water only)
1	Threshold
2	Moderate
3	Strong
4	Very strong
5	Excessively Strong

After the odour removing test, samples were removed from shirts and immediately placed into a capped jar. Subsequently, the samples removed from the jar and evaluated by six panelists. Finally "removed butyric acid percentage" was calculated (5 – evaluated rating) *100/5) for each test condition. Panelists were trained according to ISO 8589:2007 and ASTM standards (ISO, 2007) (ASTM, 1997). Panelist group composed of six people, aged between twenty-four to fourty, three female and three men. Each of the panelists group was employed by the cleaning tehnology company.

- **Linting Test Method and Measurement**

Apart from odour removing tests, linting tests were carried out individually. Linting is small fibers protrude from the structure of the yarn and appears on the fabric surface. Linting is a result of mechanical action such as wearing, washing, and tumble drying of the textiles (Okubayashi & Bechtold, 2005).

In order to determine how much lint or fuzz fiber is generated and released from the fabric during airing cycle and see the effects of the mechanical parameters of designed automatic airing program on linting, textile samples were prepeared at the size of 1m x 1m. The test load was set to 1 kg. The load was treated to a reference airing cycle prior to each test in order to clean any sort of hanging particle. Every test condition was repeated twice, for five cycles in a squence. The lint which was accumulated onto V filter was collected manually and weighed on the sensetive scale (Mettle Toledo PR503, 0.001g sensetivity) after every cycle. On the other hand, the lint accumulated on the sponge filter was weighed after five cycles.

- **Statistical Analyzing of the Odour Removing and Linting Test Results**

Minitab 16® was used for statistical analysis of the test results. The interactions between the independent factors were determined with Analysis of variance (ANOVA). The main effects on odour removing and linting were identified based on the P value with >95% of confidence level. Graphical analysis of the odour removing and the linting test results were obtained through ANOVA which is a collection of statistical models used to analyze the variation among group means and their associated procedures. Finally, the optimized program which removes maximum odour and causes minimum lint was designed.

3. RESULTS AND DISCUSSIONS

3.1. Odour Removing Experiment

Statistical analysis of odour removing produced the R-Sq(adj) value at 57.79%. This is the rate which shows the relevance of the factors on odour removing tests. Depending on the sensory evaluation, it is unlikely to obtain a higher R-Sq (adj) value due to the fact that it is not working as accurate as instrumental analysis. A pie chart also provided by Minitab 16® which shows the importance of each parameter on removing odour; so that, as seen in Figure 2 (a), duration (minute), tumble engine speed (rpm), airflow (lt/s) parameters had effect of 14,2%, 10,6%, 2,4% respectively. As can be seen from the results, while the duration was the most effective parameter (14, 2%) on removing odour, airflow (2,4 %) had minor effect on odour removal. Results also showed that tumble engine speed* airflow (20,5%) was superior among double interactions.

The Figure 2(b) demonstrates the main effects on removing odour. It is clearly seen that the percentage of removed odour increases with tumble engine speed, airflow and duration. Double interactions airflow-time and tumble engine speed-time are shown in the Figure 2(c). It was observed that at 60 lt/s airflow longer time enables higher amount of odour removal while it remains constant at 30 lt/s. This can be explained as low air circulation at 30 lt/s alone is not sufficient to remove odour. Similarly, Figure 2(d) demonstrates that longer period of time helps removing more odour at 3400 rpm while 1600 rpm does not provide significant odour removal with longer period. As noted above since 1600 rpm is a low motion tumble speed textiles within the drum are not able to freely move.

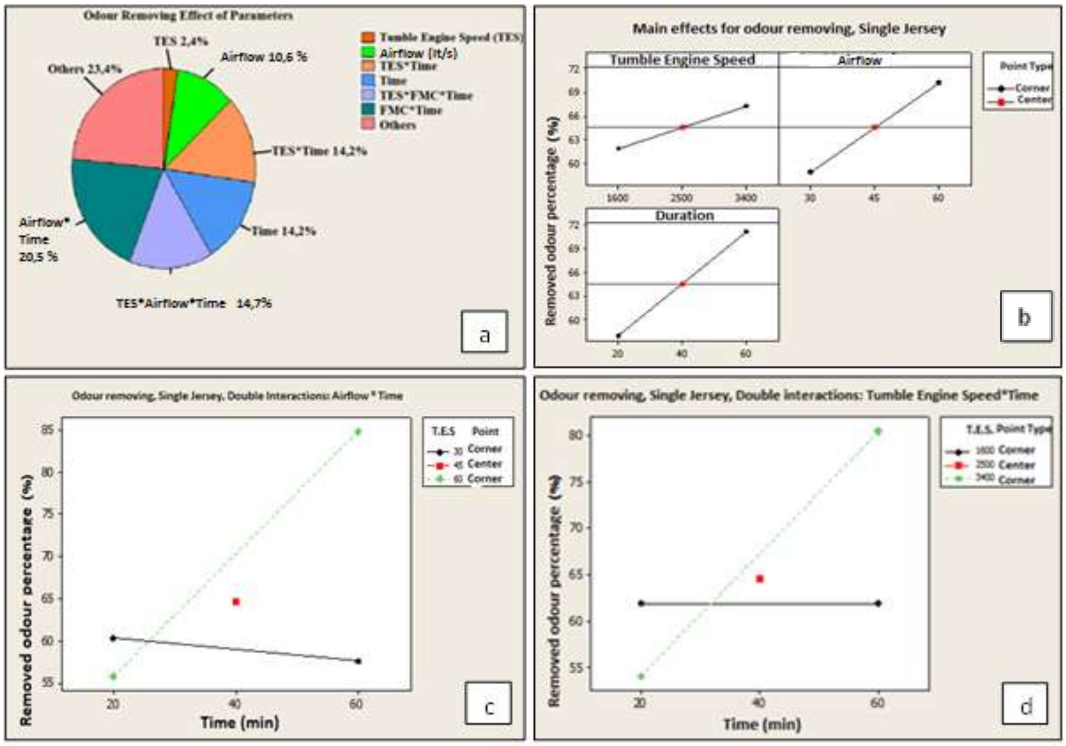


Figure 2. (a) Odour removing effects of program parameters, (b) main effects, (c) double interactions, (d) double interactions

3.2. Linting Experiment

Statistical analyis of linting tests produced the R-Sq(adj) value at 86,62% which shows that linting mechanism can be explained sufficiently. As shown in Figure 3(a), tumble engine speed (TES) (rpm) had the highest effect on linting at 56,9 %. This is followed by duration at 23,7 %. The Figure 3(b) demonstrates the main effects on linting. The amount of lint generation decreased as the tumble engine speed and airflow increased. On the contrary, the amount of lint generation increased with time. The Figure 3(c) center point (=2500 rpm, 45 lt/s) gave the highest amount of lint generation. The reason behind that can be explained as the center point parameters provided the maximum movement of textiles within the tumble thus resulting in high amount of lint. At lower or higher TES rates textiles do not homogenously mix within the tumble.

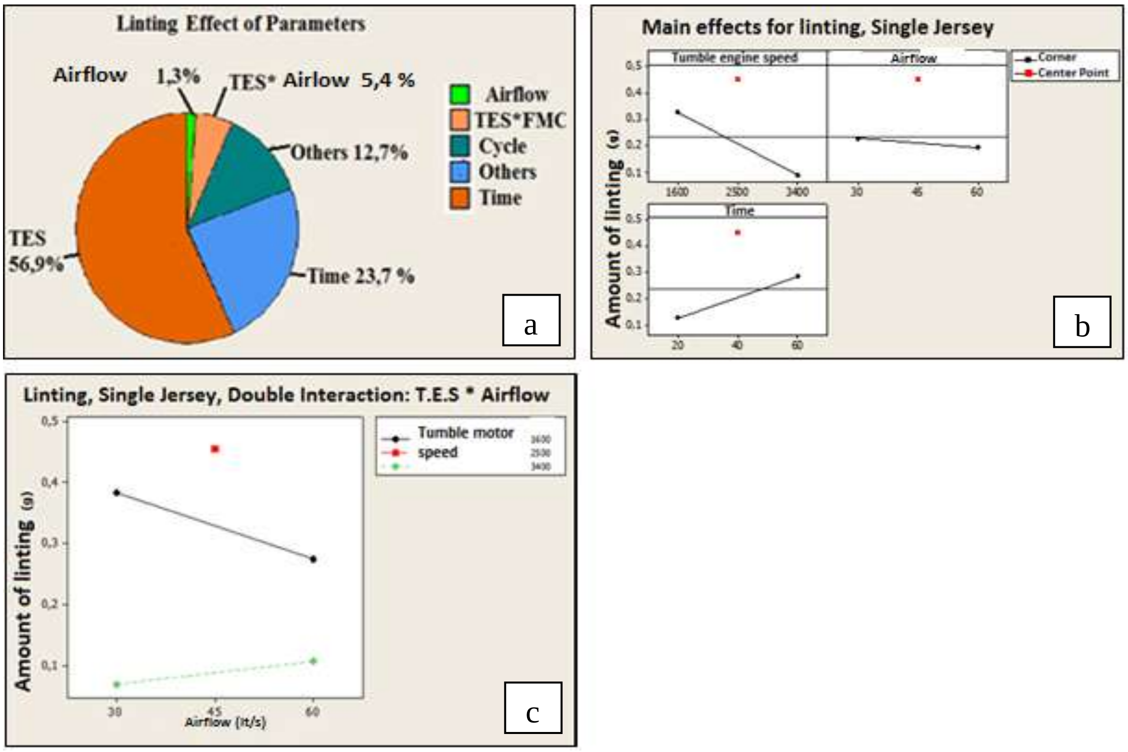


Figure 3. Linting effects of airing program parameters (a), main effects for linting (b), double interactions (c)

3.3. Optimization

Optimization of the airing program which removes the odour at maximum and causes linting at minimum level was designed in Minitab 16® programme. Upper limits, lower limits and goals were determined; odour removing percentage 60%, 70%, 70%, respectively, and 0,15g, 0,15g, and 0,2g lint weigh respectively. Odour removing and linting are given the same importance for optimization and resulting in the parameters as tumble engine speed: 3400 rpm; airflow: 60 lt/s; duration: 60 minute; desirability: 0,56.

4. Control Tests

4.1 Control Test 1

Different odour removing methods were compared as shown in Table 7. It was observed that washing process was the most effective method with removing 91.11% of the odour, while optimized automatic airing program was found to be the second most effective odour removing technique, with the rate of 74,69%. Hanging outdoor and indoor experiments were capable to remove the odour only at 64,17% and 53,89% respectively. There were several drawbacks related to outdoor and indoor airing practices such as uncontrollable outdoor environment odour which was recognized by the sniffer panelists. In similar, malodour was released to the indoor environment which created unpleasant living spaces. This can be attributed to the fact that the low rate of odour removal in indoor could be fixed stationary positioning of the samples.

Table 7. Comparison of different odour removing methods

	Removed Odour (%)
Washing Automatic airing programme	91,11 74,69
Hanging outdoor	64,17
Hanging indoor	53,89

4.2 Control Test 2

In addition to the single jersey, four different types of textile were tested with the optimized automatic airing programme. For the purpose of imitation of real-life scenarious, a diverse control test part is tested. Odour removing and linting behavior of textile types were observed and noted as seen in Table 8, while odour within single jersey, double-knit and napped double-knit fabrics were sufficiently removed, the rate was low for the triple-knit and napped triple-knit. As a general tendency, the percentage of removed odour from single jersey, double-knit, napped double-knit were apparently higher (74,69%, 71,94%, 86,33% respectively) than triple-knit, napped triple-knit samples (64,72%, 55,00% respectively). McQueen *et al.* (McQueen, et al., 2007) reported a significant and clear correlation between knitting structure and odour retention as the heavier and thicker fabric, the higher odour retention. Similarly in this research triple knit ply structure gave the lowest rate of odour removal.

4.3 Control Test 3

In this control step the consumption values of washing programme and airing programme were compared. Water saving is one of the foremost targets for sustainable laundry systems. As seen in Table 9, airing programme provides an aternative green solution since it requires no water, no heater and minimized energy. On the other hand, elimination of detergant use is another positive outcome of the system.

Table 8. Removed odour percentage from different types of textiles

Textile Type	Removed Odour (%)	Produced Lint (g)
Single Jersey	74,69	0,157
Double-knit	71,94	0,125
Napped double-knit	86,33	0,543
Triple-knit	64,72	0,114
Napped triple-knit	55	0,399

Table 9. Comparison of automatic airing programme versus washing programme (washing programme (one hour, 30°C)

	Washing Program	Airing Program
Energy Consumption	400 w/h	180 w/h
Heater	On, 30°C	Off
Duration	60 min	60 min
Water use	14 lt	No

4. CONCLUSION

Airing program has an importance since it can reduce the need of textile wash, thereby decreasing energy and water consumption. In this paper, an automatic textile airing (refreshing) programme parameters were observed via odour removing and linting tests were carried. The results showed that the most effective parameters to remove odour molecules are, in order to importance, duration, airflow, and tumble engine speed; the parameters that stimulate linting are tumble engine speed, duration and airflow respectively. The most effective airing program removing odour at maximum and providing linting at minimum has the parameters of tumble engine speed: 3400 rpm; airflow: 60 lt/s; duration: 60 minute.

Control tests showed that the removed odour percentage was higher on single jersey, double-knit and napped double-knit samples and lower on triple-knit and napped triple-knit samples. Considering linting (Table 8), single jersey, double-knit and triple-knit generated same amount of lint and less than napped samples. Automatic airing program achieved to provide sufficient odour removal as compared with traditional airing methods (indoor and outdoor airing). In comparison to the washing method airing programme distinguish itself since it does not consume water and chemical. Exploring resource consumption through laundering, airing program could shine new and useful insights into unsustainable consumption patterns.

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