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Effect of repeated dry-cleaning process on physical properties of cotton, silk and wool fabrics

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The present study is aimed at analyzing the effect of dry-cleaning solvent on the physical properties of cotton, silk and wool fabrics. The sourced fabrics are dry-cleaned with two different commercial solvents, namely mineral turpentine oil, and dipropylene glycol dimethyl ether. The fabrics are dry-cleaned separately for 5, 10 and 15 times with each solvent and analysed for their performance. The results indicate that the dry-cleaned fabrics become thicker and bulkier, and hence their air permeability, bending ability, crease recovery, tearing strength and abrasion resistance reduce. The water absorbency, stiffness and thickness of the fabrics are found to be increased significantly. The statistical analysis results confirm that the changes in the fabric are significant with 95% confidence limit (p 0.05). Out of the selected dry-cleaning solvents, hydrocarbons are found to be more aggressive than the glycol ethers in terms of fabric deterioration, except tearing strength. The GC-MS analysis results confirm the presence of dry-cleaning solvents deposits on the fabric even after 24 h of airing out process.

Keywords: Apparel fabrics, Cotton, Dry-cleaning process, Dipropylene glycol dimethyl ether, GC-MS Analysis, Mineral turpentine oil

1 Introduction

Cotton fabrics have been widely used in the textile industry, representing more than 50% of the world textile production[1]. Next to cotton, the equally popular clothing is silk. Over cotton, silk fabrics gained a positive reputation of being sensuous and luxurious due to their superior properties, such as being lustrous and having a soft and smooth texture, high moisture absorbency and good elasticity[2]. The normal laundry process called as wet cleaning processes will alter the fabric surface properties, dimensions, physical and mechanical properties[3,4]. The laundry process changes the oxidation state, degree of polymerization, breakdown of molecular structure, loss of tensile strength, discoloration and overall change in appearance, known as secondary laundering effects[5,6]. Among all the properties, the most common problem faced by manufacturers and customers is the changes in dimension of the garment due to wet cleaning[7,8].

Particularly in the case of silk, it crease and dimensionally deform easily. Fibre fractures in the form of fibrillation and degradation usually occur due to fabric rubbing during conventional home laundering process[9,10]. There are large number of publications on the effect of laundering on the physical properties (cloth setting, shrinkage, dimensional stability) and mechanical properties (tensile strength, tear strength and abrasion resistance) of consumer apparel fabrics[11-13]. However, there are very few studies available on the effect of dry-cleaning on the properties of apparels. The dry-cleaning is a process, in which chemical solvent is used to remove the soil and dirt from the fabrics. The dictionary defines dry-cleaning as “the cleansing of fabrics with substantially non-aqueous organic solvents, to which special detergents and soaps are often added”[14,15]. The main advantage of dry-cleaning is its ability to dissolve grease, oils and other hard stains. During the normal wet cleaning process, the natural fibres like wools and silks generally shrink, distort, and lose colour, but in the case of dry-cleaning process, these remain unaltered. Dry-cleaning helps to return garments to a “like new” condition using precautions to prevent shrinkage, loss of colour and change of texture or finish[16]. In the case of wool fibre, the hydrophilic nature of wool makes dry-cleaning a preferred and often the only method for cleaning wool garments. Wool fibres do not swell in the non-polar dry-cleaning solvents and thus problems with wrinkling and shrinkage are avoided[17].

Perchlorethylene also called “tetrachloroethylene (PERC)” is the most common and an excellent

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solvent for organic materials. PERC is highly used in dry-cleaning industries due to its effective cleaning ability. However, in recent times, PERC is becoming less popular due to its environmental problems and potential negative health effects. The petroleum-based compounds have been the most widely used solvents in dry-cleaning as an alternative to PERC. These petroleum-based solvents are less aggressive than PERC and require a longer cleaning cycle. Next to that, glycol ethers (dipropylene glycol tertiary-butyl ether) also proposed to be an environment-friendly promising competitor with PERC with processing advantages.

A study conducted by Lyle showed that the dry-cleaning process with PERC does not wear out the men's and women's wool suites[18]. By an analysis performed on several types of fabric using repeated laundry and dry-cleaning process, it is found that the dry-cleaning process retained better serviceability properties of many fabric types compared to laundry process[19]. The study on effects of repeated dry-cleanings and launderings on physical properties of the fabric shows that the dry-cleaning with PERC has the least effect on fabric thickness[20]. However, Brodmann[21] measured the residual PERC after cleaning in different fabrics and their potential health hazards. He found that the residual value varies widely between fabrics after 24 h. Researchers[22] also reported that this residual amount causes potential health hazard to the wearers for acute toxic effects due to short-term exposure to high level of PERC , which may include headache, dizziness, rapid heartbeat, and irritation or burns on the skin, eyes, or respiratory tract. Chronic exposure to lower PERC concentration level may result in dizziness, impaired judgement and perception, and damage to the liver and kidneys[22]. The literature analysis clearly recognized that the previous studies have been performed on dry cleaned textile material with PERC. The chemicals like glycol ethers and hydrocarbons are commercialized in the recent times and there are no studies found in the literature about the impact of these glycol ethers and hydrocarbons on fabric as well as on human health. Hence, this study has been designed to evaluate the effect of dry-cleaning process, using mineral turpentine oil (MTO) and dipropylene glycol dimethyl ether (DME) on the physical properties of cotton, silk and wool fabric.

2 Materials and Methods

2.1 Materials

The chemicals namely mineral turpentine oil (MTO), a hydrocarbon based solvent, and dipropylene glycol dimethyl ether (DME), a type of glycol ether, sourced from Merck Chemicals, Mumbai were used. The sourced chemicals were of industrial grade and used as such for the experiment. The fabrics used in dry-cleaning process were cotton, silk and wool, sourced from retails outlets of Coimbatore and Tirupur (Table 1).

2.2 Dry-cleaning Process

The sourced fabric samples were dry-cleaned using STEFAB, 15 kg DMX range computer controlled multi solvent machine. In dry-cleaning process, the selected fabrics were loaded into the washing cylinder. The selected solvent was first filtered and then poured into the cylinder to flush soil from the clothes. After a particular number of cycles, the solvent leaves the cylinder and goes back to the holding tank. This process was repeated throughout the entire cleaning cycle, ensuring that the solvent to fabric ratio is maintained to give effective cleaning at all times. After the cleaning cycle, the solvent was drained out and an extraction cycle was performed to remove the excess solvent from the clothes. The clothes were also air dried in the same unit. The drying process used warm air circulated through the cylinder to vaporize the solvent left on the clothes.

2.3 Physical Property Analysis

The dry cleaned fabrics were evaluated for the following physical properties to anlyse the impact of dry-cleaning process, as per the mentioned standards. Tearing strength as per ASTM D1424, abrasion resistance as per ASTM D4970 – 02, air permeability as per ASTM D737, fabric stiffness as per ASTM D1388, fabric crease recovery as per BS 3086 and water absorbency as per BS 4554 were performed.

Table 1 — Construction parameters of selected textile fabrics

Fabric	Cotton	Silk	Wool
EPI	88	120	23
PPI	80	104	14
Warp count	120s	160s	90s
Weft count	105s	150s	75s
Fabric thickness	0.36	0.23	1.20
GSM	180	35	315

2.4 Chemical Analysis

2.4.1 GC-MS Analysis

GC-MS technique was used to identify the residues of dry-cleaning solvents present in the cotton textile material after the number of dry-cleaning cycles. After dry-cleaning process, the dry fabric was allowed to air out for 24 h and the analysis was carried out. Machinery details are: equipment– Thermo GC (Trace ultra ver: 5.0) and Thermo MS DSQ II; column – ZB 5 - MS capillary standard non - polar column; dimension–30 mts; ID–0.25 mm; film–0.25 µm; carrier gas –He; flow –1.0 mL/min; temp. progress– oven temp. 70^0C raised to 260^0C at 6^0C /min; and injection volume –1 microliter.

Identification of the peaks was done based on the computer matching of the mass spectra with that assessed by the National Institute of Standards and Technology (NIST), and by direct comparison with published data.

3 Results and Discussion

3.1 Physical Properties of Dry-cleaned Fabric

3.1.1 Fabric Thickness

The effect of dry-cleaning process on the fabric thickness has been studied against different dry-cleaning process duration and different solvents like hydrocarbons and glycol ethers. The results are shown in Table 2. It is observed that both dry-cleaning solvents increase the thickness of fabric significantly ($p<0.05$), irrespective of the fibre types. It is also noted that the wool fabric has higher thickness increment among the selected fibres. This is because the cotton and silk fabrics are more compact in structure than the woollen fabric, and the yarn used for woollen fabric has low twist. This property of the woollen fabric may be the reason, which allows the yarns for better relaxation than other fabric. The increase in fabric thickness due to the decrease in inner strains of yarns results in relaxation of the fabric structure during mechanics agitation[23]. Therefore, the fabrics swell after dry-cleaning. Several researchers[24, 25] reported the swelling and shrinkage phenomenon of various fabrics after dry-cleaning process. It is also understandable that the increase in fabric thickness is directly related to the compressibility of fabrics, and so this finding confirms that the dry-cleaning process affects the compressibility of fabrics.

3.1.2 Crease Recovery

The crease recovery of the fabric decreases with increase in number of dry-cleaning cycles. When the number of cycles increases, the mechanical agitation is higher and causes the shrinkage. Thus, the crease recovery angle reduces in the subsequent number of dry-cleaning and the 15 times washed samples has less crease recovery angle compared to un-drycleaned sample. Statistical analysis results also reveal that the dry-cleaning cycle affects the crease recovery angle significantly ($p<0.05$). The relaxation and swelling of the fabric structure after dry-cleaning by releasing internal strain in the fibres creates restriction for the movement of yarn in the fabric. The viscoelastic nature of the constituent fibre is responsible for the phenomenon of stress relaxation. As the number of dry cleaning process increases, the fibres get relaxed internally. The process makes the fibre bulkier and so the inter and intra fibre and yarn spaces reduce and the movement gets restricted. The inter-fibre friction provides the fabric frictional stress during deformation and is responsible for the irreversible deformation[26]. The initial energy is stored in the yarn or in fibre

Table 2 — Physical properties of dry-cleaned fabric

Property	Dry-cleaning cycle	Hydrocarbon			Glycol ether		
		Cotton	Silk	Wool	Cotton	Silk	Wool
Thickness mm	0	0.36	0.23	1.13	0.36	0.23	1.13
	5	0.37	0.27	1.17	0.39	0.28	1.15
	10	0.40	0.30	1.35	0.41	0.29	1.17
	15	0.44	0.33	1.37	0.44	0.31	1.21
Crease recovery angle, deg	0	75	90	123	75	90	123
	5	72	84	108	73	86	118
	10	68	80	100	70	80	115
	15	65	71	95	68	78	113
Abrasion resistance weight loss %	0	1.03	0.56	2.29	1.03	0.56	2.29
	5	2.1	0.75	2.46	1.23	0.65	2.3
	10	2.6	0.82	2.72	1.78	0.85	2.42
	15	3	2	3	2	1	3
Bending length*, cm	0	2.5	2.35	2.8	2.5	2.35	2.8
	5	2.7	2.42	2.98	2.62	2.39	2.88
	10	3	2.56	2.65	2.8	2.47	2.65
	15	2.75	2.8	2.79	2.7	2.72	2.71
Tearing strength, g	0	1536	1562	-	1536	1562	-
	5	1339	1490	-	1292	1472	-
	10	1152	1420	-	1126	1344	-
	15	1024	1340	-	960	1280	-
Water absorbency, s	0	18	36	6	18	36	6
	5	10	31	30	17	26	22
	10	8	29	33	10	18	28
	15	5	26	40	6	17	32
Air permeability, $cm^3/cm^2/s$	0	19.4	113	210	19.4	113	210
	5	17	103	159	17	110	190
	10	13	77	130	16.4	105	163
	15	10	50	113	15	98	155

*Average of warp and weft values.

component, which consists of elastic energy and frictional energy. After dry cleaning process, the reduction in elastic energy and increment in the frictional energy restricts free movement of the fibres in fabric from recovering. This increased frictional movement is interrelated with the yarn bulkiness and fabric thickness[27]. Therefore, the fabric flexibility decreases and stiffness increases after the subsequent dry-cleaning processes and so the crease recovery angle decreases. The result also indicates that the reduction in crease recovery angle is higher in the case of wool fabric than in other fabrics due to higher increment in the fabric thickness. The crease recovery angles of all the samples are shown in Table 2.

3.1.3 Abrasion Resistance

The weight loss percentage of the untreated fabric is slightly low as compared to 5, 10 and 15 times dry-cleaned fabrics after 3900 cycles of abrasions. The results indicate that the percentage of weight loss increases with number of cleaning cycles. The mechanical agitation during the dry-cleaning process and the influence of dry-cleaning solvents develop micro level changes in the fabric structure and so the abrasion resistance reduces greatly. The surface of the untreated sample is smooth and shinny as compared to the dry-cleaned fabric by visual analysis; this may be due to the effect of solvent treatment.

In all the fabric samples, the effect of dry-cleaning solvent in terms of weight loss percentage is found statistically significant ($p<0.05$), and the higher weight loss with wool and the lowest with cotton are observed. However, in general the weight loss percentage is found higher in all the fabric for hydrocarbon treatment than the glycol ether. This result confirms that the hydrocarbon treatment damages the fabric more than the glycol ethers. The higher weight loss percentage in wool fabric may be attributed to its structural parameters[28]. The higher swelling due to lose structure in the case of wool fabric is also a factor which should be considered for the highest loss percentage [29].

3.1.4 Stiffness

The dry-cleaning result indicates that the stiffness of the fabric increases as the number of dry-cleaning time increases in terms of bending length (cm) by taking the average of five warp and weft measurements. Bending length is preferred over bending modulus value for the better understanding of the fabric behaviour. The dry-cleaning solvent makes the fabric swell and even stiffer after every cycle. The bending length value of the cotton fabric increases gradually after subsequent cycles, indicating that the stiffness of the fabric increases and after the 10^{th} cycle, a reduction in bending length is noted. For silk, there is a gradual increase, and in case of wool, there is an increase in the bending length value after 5^{th} cycle of dry-cleaning, a sudden reduction at 10^{th} cycle and an increment at 15^{th} cycle are observed. Hence, there is no significant changes observed statistically ($p>0.05$) between the dry-cleaning cycle for both the solvents. The stiffness of the fabric increases with number of dry-cleaning cycle. However, the change in bending length is comparatively less for glycol ethers than hydrocarbons for all the fibre types. As the bending properties have important effects on both the handle and tailoring performance of fabrics, the selection of dry-cleaning solvent becomes crucial.

3.1.5 Tearing Strength

The tearing strength of the fabric is another important aspect of fabric performance. The results show that the tearing strength of the fabric reduces significantly ($p<0.05$) after glycol ether dry-cleaning process as compared to non dry-cleaned sample. However, in the case of hydrocarbon treatment, no significant difference is observed between the dry-cleaning processes. The solvents react with cotton and form weak van der Waals force which causes weak C-H bond in the fibres amorphous chemical structure. The repeated dry-cleaning process increases the number of CH bond and weakens the fabric subsequently. This reaction weakens the yarn structure step by step after repeated dry-cleaning and reduces the tearing strength of the fabric. The same trend is noticed for silk also but the level of strength loss is less as compared to cotton due the inertness of the silk fibre against the organic solvent. The strength loss percentage is relatively higher after glycol ether treatment in the case of all fabric types than the hydrocarbon treatment.

3.1.6 Water Absorbency

The water absorbency of the cotton fabric increases as the number of dry-cleaning cycle increases. This result also confirms that the hydrocarbons are more aggressive than the glycol ether on cotton fabric. For both cotton and silk, the same trend is noted in water absorbency; the solvents affect the surface of the fibre and increase the absorbency. However, in the case of wool, reverse trend is noted. The dry-cleaning treatment reduces the water absorbency capacity in contrast to the cotton and silk fabric.

The water absorbency results are in support with the increase in the fabric thickness. Due to thickness increase and disturbance in the fibre assembly and formation of bulkier structure, the dry-cleaning process form more amount of fuzzy fibre on the surface of the cotton fabric. This might have caused the increase in water absorbency in cotton. In silk, the etching process of these solvents also might have created more amounts of amorphous regions than the untreated sample. For both silk and cotton, absorbency increases drastically after dry-cleaning, in contrast to the wool. The statistical analysis reveals that the absorbency increment in cotton and reduction in wool are statistically significant ($p<0.05$). However, in the case of silk fibre, the changes in the absorbency is not significant ($p>0.05$).

3.1.7 Air Permeability

The air permeability of the dry-cleaned fabric reduces after the subsequent dry-cleaning process. The reduction in air permeability of the dry-cleaned fabric is higher with hydrocarbons than with glycol ether. Due to the fibre swelling, the inter-yarn and the intra-yarn spaces between the fabric reduce and it contributes the reduction in air permeability. The relative porosity of the untreated cotton is noted as 72% and the value reduces after 15 dry-cleaning process by 67% for both hydrocarbons and glycol ethers. In silk, the relative porosity is 92% for untreated and after 15 cycles, it is reduced to 89% and 91% respectively for hydro carbon and glycol ethers. In the case of the wool fibre, the relative porosity is noted 80% for untreated and for hydrocarbons and glycol ether dry cleaned fabric, it is 78% and 79%.

These results of porosity confirm that the dry-cleaning process relaxes the structure and thus it affects the air permeability and water absorbency of the fabrics respectively. With respect to the selected solvents, the hydrocarbon treated fabric show higher reduction in air permeability than the glycol ether. Table 3 lists the significant levels of different properties against dry-cleaning cycle.

Table 3 — Level of significance of changes in physical properties against number of dry-cleaning times (p=0.05)

Property	Glycol ether	Hydrocarbon
Thickness, mm	0.0000<0.05	0.0000003<0.05
Crease recovery angle, deg	0.0058<0.05	0.03<0.05
Abrasion resistance, weight loss %	0.00002<0.05	0.002<0.05
Stiffness, bending length cm	0.62>0.05	0.51>0.05
Tearing strength, g	0.04 <0.05	0.08>0.05
Water absorbency*, s	0.03<0.05	0.004<0.05
Air permeability, $cm^3/cm^2/s$	0.000053<0.05	0.0002<0.05

*Water absorbency values are not significant between dry-cleaning times for both the solvents.

3.2 GC-MS Analysis of Dry-cleaned Fabric

GC-MS analysis performed on the dry-cleaned textile and the residues on the textile are compared with the standard values for the component identification. Table 4 displays different chemical components identified on the surface of the textile material after dry-cleaning process. The results confirm the presence of respective solvents on the textile surface even after the drying process. The identified components are all major derivatives of the selected solvents like glycol ethers and hydrocarbon.

Table 4 — Chemical traces found on dry-cleaned fabric

Compound	Molecular formula	Molecular weight	Probability, %	SI	RSI
		Glycol Ether			
Tripropylene glycol	$C_9H_{20}O_4$	192	4.97	489	744
1-dodecanol	$C_{12}H_{26}O$	186	12.20	816	912
decyltetraglycol	$C_{18}H_3O_5$	334	64.74	754	778
2-propanone	C_3H_6O	58	11.62	871	980
Ethylene glycol bis(3-aminopropyl) ether	$C_8H_{20}N_2O_2$	176	7.94	503	573
Hexadecanoic acid, Methyl ester	$C_{17}H_{34}O_2$	270	41.63	768	901
Hexyltetraglycol	$C_{14}H_{30}O_5$	278	30.92	583	668
N,N-di-(I-butyl)-2-pyridylethylamine	$C_{15}H_{26}N_2$	234	21.68	364	903
		Hydrocarbon			
7-methyl-1,3,5-cycloheptatriene	C_8H_{10}	106	12.34	424	518
1-(2-nydroxy-2-phenylethyl)imidazole	$C_{11}H_{14}N_2O_2$	206	7.3	385	736
9-octadecenamide	$C_{18}H_{35}NO$	281	4.96	707	791
methyl 13c Octadecatrienoate	$C_{19}H_{32}O_2$	292	6.41	417	511
1,2-Benzenedicarboxylic acid	$C_{24}H_{38}O_4$	390	12.814	890	898
Benzene, 2-ethyl-1,4-dimethyl-	$C_{10}H_{14}$	134	13.47	763	842

This can be understood from the 'SI' and 'RSI' values. The reverse match value gives a measure of how well the reference spectrum is represented with its masses in the unknown spectrum. The forward-looking mode of searching, whereby the presence of the unknown spectrum in the reference spectrum is examined, is expressed as the match value (NIST "SI"). The combination of the two values gives information on the purity of the unknown spectrum. In this study, all the identified components of the solvents have high RSI values and lower SI values. This means that the spectrum measured contains considerably more mass signals than the reference spectrum used for comparison. This is expected because the material is not directly treated with the solvent. The probability value for a certain compound hit is derived as a relative probability from the spectral differences between adjacent hits in the list[30].

The results indicate that the dry-cleaned fabric has higher percentage of chemical traces on their surface. This result is confirmed by higher amount of SI and RSI values of chemicals like 1-dodecanol, decyltetraglycol, tripropylene glycol and ethylene glycol. In the case of hydrocarbon, many chemical components with higher SI and RSI values are noted. This indicates that the treated textile material holds the traces of chemicals on it even after the removal of dry-cleaning solvent. These findings are in line with the findings of Tichenor *et al.*[31] who analysed the emissions of perchloroethylene from dry cleaned fabrics. They have mentioned that the fresh dry-cleaned cloth causes elevated levels of perchloroethylene in residences[32]. However, in this research, the residues are found even after 24 h of air-drying process. The findings confirm that even after 99.99% removal of dry-cleaning solvents, the fabric still contains high amount of chemical residual.

4 Conclusion

The study identified the impact of dry-cleaning solvents on the physical properties of apparel fabrics made of cotton, silk and wool material. The results indicate that the dry-cleaning process affects the fabric properties drastically after repeated process. After dry-cleaning, the fabrics become thicker, bulkier and so the air permeability, bending ability, crease recovery, tearing strength and abrasion resistance values of the fabric reduce ($p<0.05$) significantly. The water absorbency, stiffness and thickness of the fabric are found to be increased significantly ($p<0.05$). Out of the selected dry-cleaning solvents, hydrocarbons are found to be more aggressive than the glycol ether except for tearing strength. The chemical trace analysis of the dry-cleaned fabrics is performed with cotton fabric and the residues of hydrocarbons and glycol ethers are found on the dry-cleaned sample surface even after 24 h of airing out process. The results of the current research and the non-availability of the health hazardous data of the selected organic solvents alarm the frequent users of dry-cleaned cloths in terms of potential health impact due to the solvent deposits and the durability of dry cleaned cloths. This research suggests the necessity of understanding the impact of different existing commercial solvents and dry cleaning process parameters on the textiles and personal health.

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