

ISTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

**DESIGN OF A NOVEL WET CLEANING ALGORITHM FOR HOME
LAUNDERING OF DELICATE FABRICS**

M.Sc. THESIS

Hatice AÇIKGÖZ

Department of Textile Engineering

Textile Engineering Programme

JANUARY 2015

**DESIGN OF A NOVEL WET CLEANING ALGORITHM FOR HOME
LAUNDERING OF DELICATE FABRICS**

M.Sc. THESIS

**Hatice AÇIKGÖZ
(503121815)**

Department of Textile Engineering

Textile Engineering Programme

Thesis Advisor: Assist. Prof. Dr. Umut Kıvanç ŞAHİN

JANUARY 2015

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

**HASSAS KUMAŞLARIN EV TİPİ ÇAMAŞIR MAKİNELERİNDE YIKANMASI
İÇİN YENİLİKÇİ BİR ISLAK YIKAMA ALGORİTMASI TASARIMI**

YÜKSEK LİSANS TEZİ

**Hatice AÇIKGÖZ
(503121815)**

Tekstil Mühendisliği Anabilim Dalı

Tekstil Mühendisliği Programı

Tez Danışmanı: Yard. Doç. Dr. Umut Kıvanç ŞAHİN

OCAK 2015

Hatice AÇIKGÖZ, a **M.Sc.** student of ITU **Institute of Science and Technology** student ID 503121815, successfully defended the **thesis** entitled “**DESIGN OF A NOVEL WET CLEANING ALGORITHM FOR HOME LAUNDERING OF DELICATE FABRICS**”, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Assist. Prof. Dr. Umut Kıvanç ŞAHİN**
İstanbul Technical University

Jury Members : **Assist. Prof. Dr. İnkilem GÖCEK**
İstanbul Technical University

Assoc. Prof. Dr. Rıza ATAV
Namık Kemal University

Date of Submission : 15 December 2014

Date of Defense : 26 January 2015

FOREWORD

The author would like to express appreciation for assistance provided by a number of individuals and organizations. Assist. Prof. Dr. Umut Kıvanç ŞAHİN, thesis advisor, has provided advice and guidance throughout the study.

Assist. Prof. Dr. İnkilem GÖCEK has provided advice and guidance throughout the study.

İlkan ERDEM has provided advice and guidance throughout the study in Arçelik Inc. This study has been supported financially by Arçelik Incorporation, Washing Machine Plant. The members of the System Improvement Team of Arçelik Washing Machine Plant and Arçelik Washing Efficiency Laboratory have provided their supports on this study.

The author would like to thank her family for their supports throughout her education life with patience.

January 2015

Hatice AÇIKGÖZ
(Textile Engineer)

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	vii
ABBREVIATIONS	xi
LIST OF TABLES	xiii
LIST OF FIGURES	xv
SYMBOLS	xvii
SUMMARY	xix
ÖZET	xxi
1. INTRODUCTION	1
1.1 Introduction and Aim of The Study	1
2. LITERATURE REVIEW	3
2.1 Cleaning Techniques	3
2.1.1 Conventional washing machines.....	3
2.1.2 Dry cleaning	4
2.1.2.1 The solvents used in dry cleaning	7
2.1.2.2 Dry cleaning performed by using perchloroethylene.....	8
2.1.2.3 Disadvantages of dry cleaning	8
2.1.3 Wet cleaning	9
2.1.3.1 Wet cleaning steps.....	10
2.1.3.2 Properties of wet cleaning machines.....	12
2.1.4 Comparison of wet cleaning and dry cleaning	13
2.1.5 Alternative cleaning systems	14
2.1.5.1 Carbon dioxide	14
2.1.5.2 Green jet	15
2.1.5.3 Green earth	16
2.1.5.4 Icy water.....	16
2.1.5.5 Hydrocarbon.....	16
2.1.5.6 Pure dry	17
2.1.5.7 Glycol ether.....	17
2.1.6 Comparison of several cleaning techniques.....	17
2.2 Professional Wet Cleaning Systems.....	18
2.2.1 Professional wet cleaning systems of Miele	19
2.2.2 Electrolux professional wet cleaning systems	20
2.2.3 Patents related with wet cleaning.....	21
3. EXPERIMENTAL STUDY	23
3.1 Materials.....	23
3.1.1 Fabrics	23
3.1.1.1 Silk samples	23
3.1.1.2 Wool test fabrics for shrinkage measurement.....	23
3.1.1.3 Soiled test fabrics for washing performance.....	24
3.1.1.4 EMPA 304 test fabrics for mechanical action performance	24
3.1.1.5 Polyester ballast fabrics	25
3.1.2 Detergent.....	25

3.1.3 Water	25
3.2 Machines	26
3.2.1 Grundig washing machine.....	26
3.2.2 Wascator.....	26
3.3 Method.....	27
3.4 Design of Experiments and Statistical Analysis.....	28
3.4.1 Design of experiments.....	28
3.4.2 Statistical analysis	29
3.5 Testing	29
3.5.1 Shrinkage.....	29
3.5.2 Color loss.....	30
3.5.3 Rinsing performance	30
3.5.4 EMPA 304: Mechanical action test.....	31
3.5.4 Washing performance	33
4. RESULTS AND DISCUSSION.....	37
4.1 Analysis of Test Results with ANOVA.....	37
4.1.1 Shrinkage test results of the profiles by using silk fabrics	37
4.1.2 Color loss test results of the profiles by using silk fabrics.....	39
4.1.3 Shrinkage test results of the profiles by using wool specimen	40
4.1.4 Rinsing performance test results of the profiles.....	42
4.1.5 EMPA 304 mechanical action test results of the profiles	43
4.1.6 Washing performance test results of the profiles	44
4.1.6.1. Carbon black	45
4.1.6.2 Blood	46
4.1.6.3 Chocolate – milk	47
4.1.6.4 Red wine.....	48
4.2 Analysis of test results with box plot	49
4.2.1 Boxplot analysis for shrinkage of silk.....	49
4.2.2 Boxplot analysis for color loss of silk.....	50
4.2.3 Boxplot analysis for shrinkage of wool.....	50
4.2.4 Boxplot analysis for rinsing performance of the profiles.....	51
4.2.5 Boxplot analysis for mechanical action tests with EMPA 304.....	51
4.2.6 Boxplot analysis for washing performance of the profiles	52
4.2.6.1 Carbon black	52
4.2.6.2 Blood	52
4.2.6.3 Chocolate – milk	53
4.2.6.4 Red wine.....	53
4.3 Analysis of Energy Consumption.....	54
5. CONCLUSIONS.....	57
6. FUTURE WORK	59
REFERENCES.....	61
CURRICULUM VITAE	65

ABBREVIATIONS

ANOVA	: Analysis of Variance
DEN	: Denier
DOE	: Design of Experiments
ED	: Rate of Mechanical Action
EPA	: Environmental Protection Agency
LCD	: Liquid Crystal Display
RPM	: Revolution per minute
WFK	: Cleaning Technology Institute
PFC	: Perfluoroether
HFE	: Hydrofluoroether
D5	: Decamethylcyclopentasiloxane
PCE	: Perchloroethylene

LIST OF TABLES

	<u>Page</u>
Table 2.1 : Classification of solvents used in dry cleaning [10]	7
Table 2.2 : Details on dry cleaning cycle	8
Table 2.3 : Comparison chart of cleaning techniques used commercially.....	18
Table 2.4 : Properties of Miele wet cleaning machines	20
Table 2.5 : Properties of Miele drying machines	20
Table 3.1 : Properties of silk fabric samples used in experiments	23
Table 3.2 : Levels of parameters chosen for testing.....	27
Table 3.3 : Full factorial experimental design of the study.....	29
Table 4.1 : Shrinkage values of silk fabrics for profiles created.....	37
Table 4.2 : Color loss values of silk fabrics for profiles created.....	39
Table 4.3 : Shrinkage values of wool specimens for profiles created.....	40
Table 4.4 : Rinsing performance of profiles according to the amount of HCl.....	42
Table 4.5 : Yarn loss of EMPA 304 for profiles created.....	44
Table 4.6 : Stain removal for profiles created	45

LIST OF FIGURES

	<u>Page</u>
Figure 2.1 : Top loaded washing machine [2]	3
Figure 2.2 : Front loaded washing machine [3]	4
Figure 2.3 : Dry cleaning cycle [4]	5
Figure 2.4 : A dry cleaning machine [5]	6
Figure 2.5 : Recycling of perchloroethylene [7]	7
Figure 2.6 : Perchloroethylene dry cleaning machine [11]	8
Figure 2.7 : Garment dry cleaning process flow diagram [18]	13
Figure 2.8 : Garment wet cleaning process flow diagram [18]	14
Figure 2.9 : Liquid CO ₂ cleaning machines [19]	14
Figure 2.10 : Green Jet cleaning machines [20]	15
Figure 2.11 : Hydrocarbon cleaning machine [19]	17
Figure 2.12 : Professional wet cleaning systems	18
Figure 2.13 : Miele wet cleaning machines [22]	19
Figure 2.14 : Electrolux Lagoon wet cleaning machine [23]	21
Figure 2.15 : Related pictures of US 2006018567 (A1) [24]	21
Figure 2.16 : Representation of cleaning system of DE 102008039669 (A1) [25] ..	22
Figure 3.1 : Wool shrinkage specimen	24
Figure 3.2 : Soiled test strips for washing performance	24
Figure 3.3 : EMPA 304 test fabric for mechanical action performance	25
Figure 3.4 : Polyester base load fabrics	25
Figure 3.5 : Grundig washing machine which is used in this study [30]	26
Figure 3.6 : Marked silk fabric to measure color loss	30
Figure 3.7 : Cutting of EMPA 304 test sample from selvages [36]	31
Figure 3.8 : Marking of the sample and removing blue end threads [36]	32
Figure 3.9 : Flattening of specimen to remove “not remaining” threads [36]	32
Figure 3.10 : Red and blue squares on the specimen easily [36]	33
Figure 3.11 : Spectrophotometer used for carrying out washing performance	34
Figure 3.12 : Positions for measuring soiled test pieces [29]	34
Figure 4.1 : Main effects plot for shrinkage of silk	38
Figure 4.2 : Main effects plot for color loss of silk fabrics	40
Figure 4.3 : Main effects plot for shrinkage of wool specimens	41
Figure 4.4 : Main effects plot for rinsing performance of newly designed profiles .	43
Figure 4.5 : Main effects plot for mechanical action performance	43
Figure 4.6 : Main effects plot for removal of carbon black stain	46
Figure 4.7 : Main effects plot for removal of blood stain	47
Figure 4.8 : Main effects plot for removal of chocolate-milk stain	48
Figure 4.9 : Main effects plot for removal of red wine stain	48
Figure 4.10 : Boxplot for shrinkage results of silk fabrics	49
Figure 4.11 : Boxplot for color loss results of silk fabrics	50
Figure 4.12 : Boxplot for shrinkage results of wool fabrics	50

Figure 4.13 : Boxplot for rinsing performance results of profiles.....	51
Figure 4.14 : Boxplot for mechanical action results of profiles.....	51
Figure 4.15 : Boxplot for removal of carbon black stain of profiles.....	52
Figure 4.16 : Boxplot for removal of blood stain of profiles	52
Figure 4.17 : Boxplot for removal of chocolate-milk stain of profiles	53
Figure 4.18 : Boxplot for removal of red wine stain of profiles	53
Figure 4.19 : Energy consumption of fourteenth profile.....	54
Figure 4.20 : Energy consumption of fifteenth profile	54

SYMBOLS

CO₂ : Carbon Dioxide
HCl : Hydrochloric acid
H₂O : Water

DESIGN OF A NOVEL WET CLEANING ALGORITHM FOR HOME LAUNDERING OF DELICATE FABRICS

SUMMARY

From ancient times, cleaning has been an essential requirement and various developments have been achieved until today. Besides daily used garments, delicate garments produced from silk and wool; as well as leather products are popular. These delicate garments demand special care; i.e. washing in specialized machines with novel techniques to prevent inevitable harms which occur when delicate garments are laundered in a home type washing machine. This risk can be minimized with dry cleaning technique in which a hazardous petroluem-based solvent, namely perchloroethylene, is widely used. This common solvent has many side effects including carcinogenic effects on human health and detrimental wastes which are one of the main causes of environmental contamination. Environmental Protection Agency, a foundation, has limited the usage of perchloroethylene and pronounced that using perchloroethylene in dry cleaning will not be continued as of 2023. This limitation brings out a need for a novel environmental friendly cleaning technique without the use of solvents, and the best alternative offered so far appears to be wet cleaning. In wet cleaning, water and biodegradable detergents are used. Thus, wet cleaning process provides an environmental friendly and harmless cleaning technique for human health. There are some commercial wet cleaning applications which attracted attention, however, a non-commercial application is yet missing.

The objective of the study is to design an algorithm to launder delicate fabrics in home-type washing machines with a newly designed wet cleaning algorithm for minimum shrinkage with acceptable color loss. To achieve this, different levels of washing parameters in wet cleaning technique are taken into consideration. These parameters are water amount, mechanical action during laundering (ED) and number of rinsings whose levels are selected to design different washing algorithms. Shrinkage, color loss, rinsing performance, washing performance and mechanical action performance of algorithms are determined with aforementioned algorithms with silk fabrics and other standard test references. The effects of selected parameters on shrinkage, color loss, rinsing performance, washing performance and mechanical action performance are investigated with Minitab® ANOVA analysis. Finally, the parameters, with no or minimum adverse effect on delicate garments, are chosen and two alternative novel washing algorithms possessing these parameters are proposed.

HASSAS KUMAŞLARIN EV TİPİ ÇAMAŞIR MAKİNELERİNDE YIKANMALARI İÇİN YENİLİKÇİ BİR ISLAK YIKAMA ALGORİTMASI TASARIMI

ÖZET

Geçmişten günümüze giysilerin yıkanması önemli bir unsur teşkil etmiştir ve bugüne kadar bu konuda birçok gelişme kaydedilmiştir. Geçmişte insanlar çamaşırlarını nehirlerde taşlara vurarak temizlerken, son yüzyıllarda yapılan gelişmelerle hayatımızı oldukça kolaylaştıran çamaşır makinelere icat edilmiştir. Özellikle son 50 yıldır yapılan çalışmalar otomatik çamaşır makinelerinin kullanımı oldukça yaygınlaşmıştır. Çamaşır makineleri giysilerin makineye yerleştirilme şekline göre; üstten yüklemeli ve önden yüklemeli olarak ikiye ayrılır. Üstten yüklemeli çamaşır makinelerini daha çok Amerika kıtasında yaygınken, önden yüklemeli çamaşır makineleri Avrupa ve Asya'da tercih edilmektedir. Türkiye'de de yaygın olarak önden yüklemeli çamaşır makineleri kullanılmaktadır.

İnsanlar günlük giysilerinin yanısıra ipekli ve yünlü giysiler gibi hassas, elde yıkama veya kuru temizleme gerektiren ürünler de tercih edebilmektedir. Bu tip hassas ürünler sıradan yıkama algoritmaları ile yıkandığında hasar görmekte bazen ise kullanılamayacak hale gelmektedir. Kuru temizlemeyi zorunlu kılan bu tip ürünlere yıkama süresinde uygulanan çeşitli kimyasallar vardır. Kuru temizleme işlemini şans eseri keşfeden Jolly Belin, 1840'lerde Paris'teki ilk kuru temizleme dükkanını açtığına, bu işlem için ilk olarak kerosen kullanmıştır. Bu kimyasal parlama noktası oldukça düşük ve yanıcıdır. Bu özelliklerde çalışılacak bir makinede ve ortamda çalışanların oldukça dikkatli olması gerekir. Bu problemi aşmak adına günümüze kadar birçok kimyasal kullanılmasına rağmen 1930'lardan beri bunların yerini perkloretilen adı verilen bir çözücü almıştır. Perkloretilen yanıcı olmamasına rağmen oldukça zararlı bir kimyasaldır. Kanserojen etkileri insan sağlığı üzerinde olumsuz etkiler oluştururken aynı zamanda da bu tip temizleme sonucu oluşan atık ürünler, çevreye de oldukça zarar vermektedir.

Amerika Birleşik Devletleri'nde Çevre Koruma Ajansı olarak bilinen bir kurum; hükümetin insan sağlığı ve çevre koruma ile ilgili kabul ettiği yasaların ve yönetmeliklerin çerçevesinde uygulamalar sürdürmektedir. Çevre Koruma Ajansı perkloretilen ile yapılan kuru temizleme işlemine bir limit getirmiştir. Bu kimyasalın 2023 itibari ile Çevre Koruma Ajansı tarafından duyurulduğu üzere kuru temizlemede kullanımı devam etmeyecektir.

Profesyonel olarak yapılan karbon dioksit, hidrokarbon, green jet, green earth temizleme yöntemleri gerek yetersiz temizleme performansı gerekse yüksek makine ve ekipman maliyeti sebebiyle, perkloretilenli kuru temizleme işleminin yerini tutamamış ve yaygınlaşmamıştır. Ayrıca bu işlemler için kullanılan kimyasalların da zararları olmaktadır. Tüm bunlara alternatif olarak kullanılabilir bir diğer yöntem de ıslak temizleme olarak bilinen ve su ile doğada bozunabilir deterjanlarla yapılan temizleme yöntemidir. Birçok ülkede kuru temizleme dükkanlarının yerine almaya

başlayan bu yöntem doğa dostu olmasıyla dikkat çekmektedir. Kuru temizlemeye benzer şekilde yıkama öncesinde leke çıkarma işlemiyle başlayan proses ıslak yıkamada; yıkama ve kurutma adımlarının farklı makinelerde yapılmasıyla tamamlanır. Böylece kuru temizlemeden beklenen sonuçları karşılayan aynı zamanda insan sağlığı ve çevre üzerinde negatif etkileri olmayan bir yöntemle hassas giysiler yıkanabilir hale geldi.

Bu çalışmanın amacı ıslak temizleme benzeri bir algoritma geliştirilerek hassas kumaşların minimum çekme değerleriyle ev tipi çamaşır makinelerindeki bir program sayesinde temizlenmelerini sağlamaktır. Geliştirilecek olan algoritma sayesinde, profesyonel kuru veya ıslak temizleme gerektiren giysiler, profesyonel temizleme yapan dükkanlara gitmek ve giysinin temiz hale gelmesi için günlerce beklemek zorunda kalmayacaktır. Evde kullanılan çamaşır makinesinde yıkama öncesi seçilecek ıslak temizleme programı yeterli olacaktır.

Bu doğrultuda yıkama sırasında etkili parametreler belirlenmiştir. Bunlar; su miktarı, mekanik hareket oranı, durulama miktarı, sıcaklık, makinenin dönüş hızı olarak seçilmiş; makine kısıtlamaları ve standartlar göz önüne alınarak sıcaklık ve dönüş hızı sabitlenmesine ve farklı miktarlardaki su, mekanik hareket oranı ve durulama adımları belirlenerek 18 farklı algoritma üzerinden yıkama testlerinin yürütülmesine karar verilmiştir. Su miktarı için profesyonel ıslak yıkama algoritmalarındaki, Wascator yıkama makinesindeki ve ev tipi çamaşır makinelerindeki hassas yıkama su miktarları göz önüne alınmış, iki farklı su seviyesiyle çalışmaya karar verilmiştir. Mekanik hareket oranları belirlenirken, ev tipi çamaşır makinelerinde uygulanmakta olan en düşük seviyeler ve referans olan hassas Wascator programının seviyesi dikkate alınmıştır. Durulama miktarının ve durulama sırasındaki ısıtmanın etkisini incelemek için ise normal durulama adımı içeren profillerin yanısıra ilave bir durulama adımı eklenmiş profiller ve bu adımlarda ısıtmanın yapıldığı profiller oluşturulmuş ve yıkama testleri yapılmıştır.

Yıkama testleri sırasında makineye test kumaşı olarak; açık renkli ipekten üretilmiş dokuma bir numune, Woolmark standartında yer alan ve yıkama sırasındaki çekmeyi değerlendirmemize yardımcı yünlü örme bez, EMPA 304 mekanik etki değerlendirme kumaşı, yünlü EMPA leke şeritleri ve dolgu yükü olarak standartlar doğrultusunda SM37 olarak bilinen %100 polyester dolgu yükleri kullanılmıştır. Test sonuçları tekrarlı üç yıkama sonrasında değerlendirilmiştir.

Her algoritmada; kullanılan kumaşlardan ipekli olanla AATCC 135 numaralı test metoduna göre çekme ve IEC 60456 standartına göre Tristimulus Y değerleri incelenerek renk kaybı testleri, yünlü Woolmark standart örme kumaşla yine AATCC 135 numaralı test metoduna göre çekme, EMPA yünlü leke şeridiyle IEC 60456 numaralı standartta belirtildiği gibi yıkama öncesi ve sonrasında ölçüm alınan noktalardan elde edilen Tristimulus Y değerleri kullanılarak yüzde olarak leke temizlenmesi ve böylece yıkama performansı, EMPA 304 kumaşıyla IEC 60456 standartına göre iplik kaybı hesaplanarak mekanik etki performansı, yıkama sonrasında polyester dolgu yüklerinin üzerinde kalan sudan ekstraktör yardımıyla elde edilen su ile titrasyon yapılmış ve son suyun alkalitesi ölçülerek algoritmaların durulama performansı değerlendirilmiştir.

Elde edilen test sonuçları MiniTab® istatistiksel analiz programındaki ANOVA testiyle değerlendirilmiştir. Bu analizlerde seçilen parametrelerin; çekme, renk kaybı, yıkama performansı, mekanik etkinin sebep olduğu hasarlanma ve durulama performansına etkisi incelenmiştir. ANOVA grafiklerinin yorumlanması doğrultusunda test

kumařları üzerindeki en az hasar ve daha yksek performans saęlayan parametreler belirlenerek ıslak temizleme benzeri iki algoritma uygun bulunmuřtur.

Son olarak, belirlenen yk miktarı iin profesyonel ıslak yıkamadaki enerji tketim miktarı hesaplanmıřtır. Veri toplama sistemlerinden alınan bilgiler deęerlendirilerek, bir nceki adımda uygun bulunan algoritmaların enerji tketimleri profesyonel ıslak temizleme yntemiyle karřılařtırılmıřtır. evreci bir yaklařım sergilenerken enerji tketimi daha dřk olan algoritma, ev tipi amařır makinelerinde uygulanabilecek ıslak yıkama benzeri bir program iin seilmiřtir.

1. INTRODUCTION

1.1 Introduction and Aim of The Study

Ancient people washed their garments by pounding them on rocks or rubbing them with abrasive sands; and cleaning the dirt away in local streams. History of washing machines dates back late 1600's when a British patent is written in washing and spinning machine category. However, until late 1800's, an electrical washing machine had not been invented; it was designed and announced in 1904 by newspapers. After this invention, especially during 1930's, number of alternative designs of washing machines were developed incrementally which brought widespread use of electrical washing machines.

First automatic washing machine was patented and commercialized by Bendix in 1937. This was the most similar one amongst those designed so far when today's washing machines are considered. Late 1930's and mid 1940's, automatic washing machines equipped with mechanical timer were produced. In 1950's shifting to electronic timer provided additional benefits of convenience. In the early 1990's, micro-controllers have been started to be used as time controlling devices and they are still being used in modern washing machines, both top loaded and front loaded.

Thorough cleaning of delicate garments like silk, wool or genuine leather products cannot be achieved without giving any damage in conventional washing machines, which creates an entailment for developing new cleaning technologies. Dry cleaning is the most known one among these alternative cleaning systems in which garments are cleaned in non-aqueous media. However, petroleum-derived solvents are used in dry cleaning, especially perchloroethylene, some of which are carcinogenic. Besides having direct adverse effects on human health, the evaporation of this chemical contaminates air, creates various leakages and wastes that pollute soil and water generating an environmental threat which brings its limitation by Environmental Protection Agency (EPA). As of 2023, use of dry cleaning machines working with perchloroethylene will be banned. Wet cleaning is developed for human and

environmental health as an alternative cleaning system to dry cleaning for washing delicate garments which comprises a specific algorithm as well as utilization of environmentally friendly detergents [1].

In this study, it is aimed to create an algorithm in conventional washing machines which resembles professional wet cleaning programs. In order to offer a novel wet cleaning algorithm applicable to conventional home laundering machines; shrinkage, color loss, mechanical action performance, washing performance and rinsing performance results of a designed experiment with varying levels of parameters including water amount, mechanical action and rinsing are considered.

2. LITERATURE REVIEW

2.1 Cleaning Techniques

A washing machine is designed for cleaning garments, towels, sheets, etc. Washing machine term is used for machines which clean with water. All washing machines work with mechanical and thermal energy also with the help of cleaning agents; namely detergents.

2.1.1 Conventional washing machines

Conventional washing machines are mainly divided into two; top loaded and front loaded. In the top loaded washing machines mechanical action is provided with propeller which is drum in the front loaded washing machines. Thermal energy is supplied from heat of the washing water. In these machines, garments are loaded through the top of the machine as shown in Figure 2.1. The washing cycles are shorter when compared to front loaded machines. However, energy costs of the machine in long-term can increase according to the usage of hot water. Since, garments after last spinning have more residual water on them, drying part takes much more time and consumes more energy when compared with that of front-loaded machines. Also these machines cause noise during washing.



Figure 2.1 : Top loaded washing machine [2]

Front loaded washing machines, an example to which is shown in Figure 2.2, have been commonly used for laundering garments in recent decades. Front loading machines are more energy efficient when compared to top loading machines, because these machines use less water; as low as half of water used in top loaded washing machines. Also, loading capacities are higher than those of top loaded ones. Noise, created by front loaded machines, is lower than that of top loaded machines'. Front loaded washing machines are ideal for cabins in kitchen or bathroom which enables saving room.



Figure 2.2 : Front loaded washing machine [3]

It is needed to separate garments before laundering in terms of color and fabric type. To prevent staining of light colored garments during washing, garments should be separated into light and dark colors. Also, reading care labels before cleaning the garments and following instructions offered on them, is necessary to avoid damaging in washing machine. Then dirty garments are loaded into the washing machine, and a proper detergent with adequate quantity is decided, which depends on size of load and degree of dirtiness on garments.

2.1.2 Dry cleaning

With the technological developments, alternative cleaning methods are expected to come into our lives instead of conventional laundering and drying. Dry cleaning is the most known one among these alternative cleaning methods which was found by Jolly Belin who spilled kerosene on his clothes accidentally and saw that kerosene cleaned the stain which was astonishing. This experience of Jolly Belin resulted with opening the first dry cleaner of Paris in 1840's. At first, kerosene and turpentine were

used in dry cleaning as solvent; nowadays perchloroethylene is used as solvent almost all around the world. In conventional washing machines, water is the solvent liquid which solves the dirt on textile during laundering process with the help of surfactants. However, wool and silk garments, which are delicate textile products, can be damaged during laundering. Dry cleaning is effective and economical way of laundering of delicate garments without damaging which makes dry cleaning a preferable alternative cleaning method. The main difference of dry cleaning when compared to conventional cleaning is that cleaning does not occur in water media and some petroleum-derived solvents are used instead of water. Contrary to common belief, there is not a dry environment which is applied in dry cleaning machines. These solvents have nearly no water which helps the evaporation of liquids on garments before the end of cleaning with the help of heated drying air, these evaporated solvents are collected in work tanks after filtering in every cycle not to pollute air and to be used again [1].

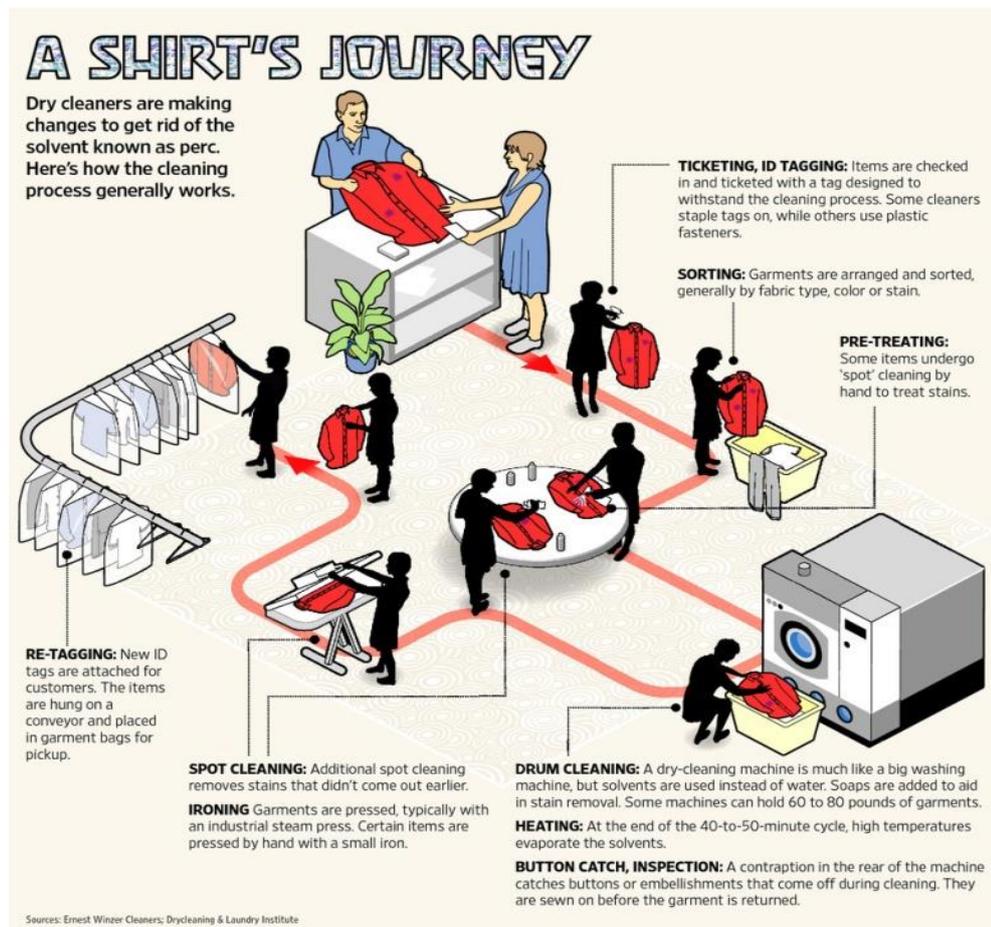


Figure 2.3 : Dry cleaning cycle [4]

The dry cleaning cycle is depicted in Figure 2.3. Dry cleaning process begins with the pretreatment of removing spots and dirt on garments with using special cleaning chemicals. The subsequent step is the laundering process of the garments which are washed in a dry cleaning machine that resembles a large volume washing machine in solvent chemical. In Figure 2.4, a dry cleaning machine is presented.



Figure 2.4 : A dry cleaning machine [5]

During laundering, the solvent chemical particularly cleans the oil-based stains from the clothes. Also, dry cleaning machine applies a mechanical process similar to conventional washing machine to soften the stains on textiles. Meanwhile, garments get washed in the continuously fed solvent and the solvent, is sent back to the tanks after treatment. After the cleaning process, the solvent which is discharged from the machine gets evaporated and condensed for purification, followed by collection in previously mentioned tanks after several times filtration (see Figure 2.5). Later the recycled solvent is used to clean garments again. In the drying step of dry cleaning process, the air temperature is around 70°C in the drum which helps the evaporation of the solvent on the garments in such a way that no moisture is left when the process is ended. The evaporated solvent is removed from the medium and recycled without damaging textile products [6].

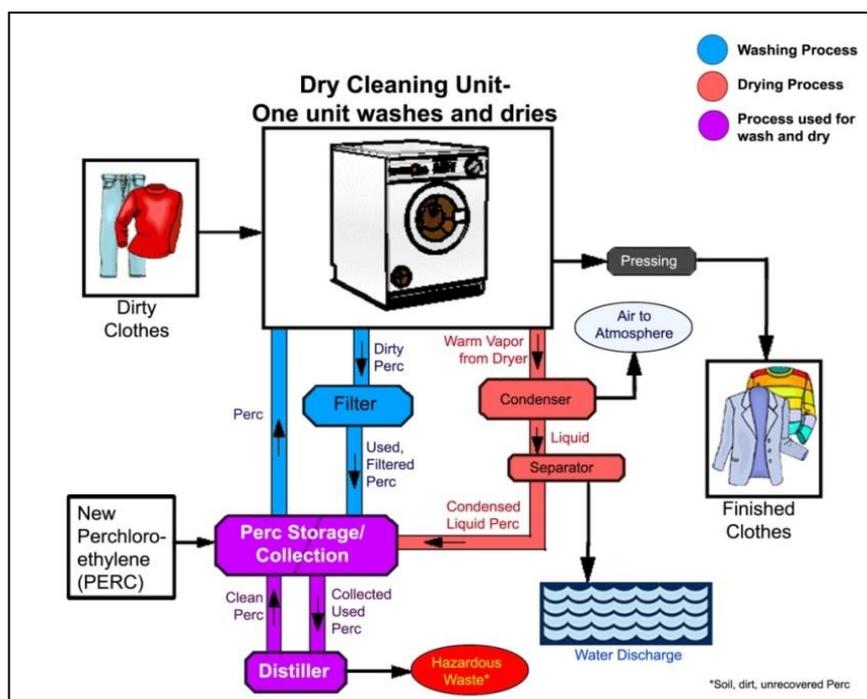


Figure 2.5 : Recycling of perchloroethylene [7]

2.1.2.1 The solvents used in dry cleaning

From the middle of 19th century to early 20th century, the solvents used in dry cleaning are highly flammable which are listed as turpentine, kerosene, benzene, naphtha oil, camphor oil, carbon tetrachloride. Since 1930, perchloroethylene has been used in the dry cleaning sector, especially in the USA, which is non-flammable. It is generally known as PERC, the other names' are PCE, tetrachloroethylene and tetrachloroethane [8].

The working temperature of dry cleaning machines varies depending on flash point of the solvent used in operation. Flash point is the lowest temperature at which dry cleaning solvent produces adequate vapor to create a mixture with air which is flammable. In Table 2.1, the classification of the dry cleaning solvents is shown [9].

Table 2.1 : Classification of solvents used in dry cleaning [10]

Solvent Class	Flash Point (°C)
Class I	$x < 38$
Class II	$38 < x < 60$
Class III A	$60 < x < 93$
Class III B	$93 < x$
Class IV	Non-flammable

2.1.2.2 Dry cleaning performed by using perchloroethylene

In Figure 2.6, a 16 kg capacity, Class IV dry cleaning machine is shown.



Figure 2.6 : Perchloroethylene dry cleaning machine [11]

Details on cleaning process is indicated in Table 2.2, in which durations and amounts are depend on the load in the machine.

Table 2.2 : Details on dry cleaning cycle

Professional Dry Cleaning Machine's Parameters	
Total cycle time	45 minutes
Washing time	15 minutes
Dryin time	25 minutes
Concentration of detergent	1% of the solvent
Amount of loading	13 kg(80% of capacity)

2.1.2.3 Disadvantages of dry cleaning

The most significant drawback of dry cleaning process is the problems caused by solvents used in operation. Especially perchloroethylene, which is a commonly used solvent in dry cleaning, is a carcinogenic chemical. Besides having adverse effects on human health directly, the evaporation of this chemical contaminates ambient air or various leakages and its wastes that pollute soil and water generates an environmental threat. Due to the detrimental effects of perchloroethylene usage in dry cleaning, perchloroethylene is limited by EPA (European Protection Agency), and non-toxic solvents and alternative cleaning systems are encouraged to be developed. As of 2023, dry cleaning machines, which work with perchloroethylene, will not be continued to use [12].

The reasons why new technologies and alternative cleaning techniques are needed in textile cleaning include;

- The decline and the removal of the dry cleaning because of the hazardous solvents
- Environmental consciousness and regulations
- Reduction of the consumption of natural sources
- Usage of renewable sources
- The incremental interest in technology and innovative products;
 - New instruments and equipments
 - Recent chemicals
 - Advanced processes
- Adaptation for accelerating time
- Developments in textile industry;
 - Due to the heavily focus on technical and smart textiles in textile market, washable textile products have been decreased which causes difficulties on washing these new products
 - Widespread use of functional textiles, coated garments
 - Studies on washability and dryability of delicate or special textiles (silk, viscose) which are performed by textile manufacturers and white goods producers.

2.1.3 Wet cleaning

Wet cleaning system was developed for human and environmental health as an alternative cleaning system for dry cleaning with an idea of 'everything can be washed'. Delicate garments are washed in specialized washing machines with a specific algorithm also with environmental friendly detergents in wet cleaning technique. Wet cleaning machines, whose popularity is spreading, have been debuted to Turkey in 2009 with Miele machines. It is planned to open wet cleaning shops instead of dry cleaning shops which occupy large number of professional cleaning system currently, approximately more than 4000 shops.

Wet cleaning is developed for garments which should be laundered delicately (wool, silk, viscose, etc.) because it is possible to encounter several problems like shrinkage, color loss, abrasion, felting during washing and drying processes which are handled

in wet cleaning with the help of special techniques and detergents also with water as solvent or washing liquid. Wet cleaning system is basically a combination of a washing machine and a drying machine [13-15].

The main differences between conventional home laundering and wet cleaning include;

- Very sensitive control of washing and drying parameters, as well as flexible laundering and drying algorithms (gentle mechanical action, strict control of temperature and moisture) with computer-equipped systems
- Usa of gentle detergents and special chemicals
- Use for very delicate garments which have ‘only dry cleaning’ phrase on care label
- Cleaning expert supports

In professional wet cleaning, laundering process is performed in large volume machines with water, and special detergents are used in wet cleaning instead of commercial detergents in the market.

Modern wet cleaning machines, which can be adjusted for mechanical action, washing temperature, drying temperature, moisture, water and detergent amount, are smart machines. For example, it is possible to wash garments with very low rotational speed like 6 rpm which is very low when compared with 52 rpm for a commercial cotton program.

2.1.3.1 Wet cleaning steps

Wet cleaning steps include controlling of garments before treatment, dimensional measurement of garments, classification of garments, a sorting process, color fastness test, stain removal process before wet cleaning, laundering of garments in wet cleaning machines, followed by drying of laundered garments [13-15].

1. Controlling of the pretreatments which were applied to garment previously

These questions are answered for this step; Identification of the stain, what is done for removing stain by user, which chemical is necessary for removing stain, duration of the stain on garment, is garment laundered in a washing machine or drying machine, etc.

2. Measurement of the garment

3. Classification

Garments are classified for the proper program. The programs in wet cleaning machines are prepared for particular fabrics and garments. These programs include:

Outer wear: Cotton-based programs which have high mechanical action, high temperature, and much water

Delicate garments: Delicate programs which have less mechanical action, low temperature

Woolen garments: Wool-based programs which include minimum mechanical action, minimum washing temperature, less water for woolen coats or suits.

4. Color fastness test

A control fabric, which is in white color and gets moisture in 25% (mass/mass) detergent-water solution, is rubbed against garment that is to be cleaned. If the control fabric is colored, the color test is failed which will be important while deciding detergent type.

5. Stain removal

Stain is examined to determine its type.

70% of the all stains are water soluble stains which means it is possible to remove these stains during laundering. If it is desired to remove the stain beforehand, 25% (mass/mass) detergent-water liquid is applied on the garment delicately with an appropriate tool.

Oil-based stains cover 30% of the all stains which should be removed before wet cleaning. If they are not, stains might be permanent after drying. Some tools are available for removing these stains, including steam spray, water spray pistols, brushes, spatula and scrims.

6. Laundering

Wet cleaning machine, which resembles conventional washing machine, is equipped with a frequency controlled motor which has a microprocessor on. Thanks to that, rotational speed of drum and mechanical action are controlled precisely which makes it possible wet cleaning to simulate hand washing. Settings related with special

programs can be done. 50% or 60% of the total capacity of the wet cleaning machine is filled with garment for washing.

7. Drying

These machines are similar to drying machines used at home with a higher volume which is approximately two times bigger than those of wet cleaning machines. It is important to mix garments sufficiently in the machine and to circulate air while drying for uniform performance on clothes. Mechanical action can be harmful on delicate garments; this problem can be solved with high temperature and less duration of drying cycle to lower the mechanical action. By this way; it is possible to limit shrinkage, deformation and wrinkling problems. Air temperature and humidity control in the drum are carried out. Shrinkage during cleaning occurs when the humidity decreases to a value as low as 10%. Because of shrinkage problem it is suggested by manufacturers to keep humidity in the machine between 10% and 14% before the end of the cycle. Depending on garment type, drying outdoor might be necessary.

2.1.3.2 Properties of wet cleaning machines

Properties of wet cleaning machines are summarized and listed as below:

- There are control systems for rotational speed, spinning level, mechanical action, time, temperature, water quantity and automatic chemical dosing.
- Setting machine and programming mechanical action are the most important factors. In new generation wet cleaning machines, very low mechanical actions are applied like 5-10 rpm, in other words 1 s on / 60 s off.
- Humidity control in drying machine helps to prevent garments not to be dried excessively.
- Loading capacity of wet cleaning machines vary from 4.5 kg to 60 kg. But during wet cleaning, only half of this capacity can be used.
- This technique can be used for garments which has 'dry clean only' label.

2.1.4 Comparison of wet cleaning and dry cleaning

The most significant difference between wet cleaning and dry cleaning is usage of water in wet cleaning instead of hazardous solvents in dry cleaning which are detrimental to human health and environment [16,17].

In Figure 2.7, dry cleaning process is shown as flow diagram. Also from Figure 2.8 wet cleaning process can be seen as flow diagram.

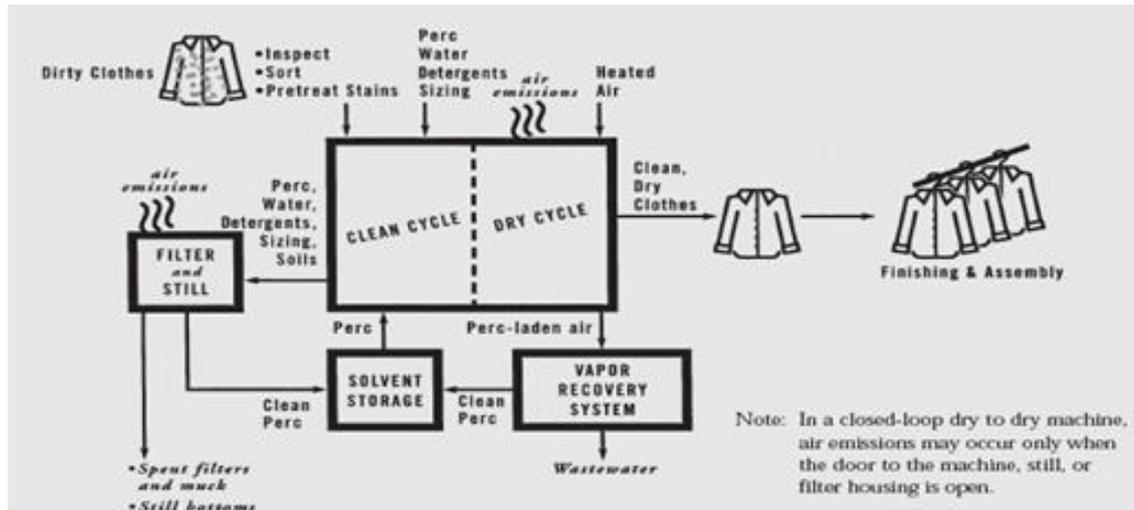


Figure 2.7 : Garment dry cleaning process flow diagram [18]

When systems are compared, similarities and differences can be listed as follows:

- Both systems are effective and economic for cleaning.
- Both methods consist of pretreatment, cleaning, drying and finishing processes.
- Cleaning and drying cycles are performed in separate machines in wet cleaning which are performed in the same machine in dry cleaning
- In wet cleaning, drying can be done outdoor.
- In dry cleaning, several organic solvents are used like perchloroethylene. In wet cleaning, water and specific detergents are applied to garments.
- In dry cleaning, toxic substances occur at the end of the process. To reduce release of these substances, specific filters and control tools are equipped with dry cleaning machines. In wet cleaning, there is no hazardous wastes, however it is sometimes needed to apply pretreatments with specific stain removers which can be harmful.

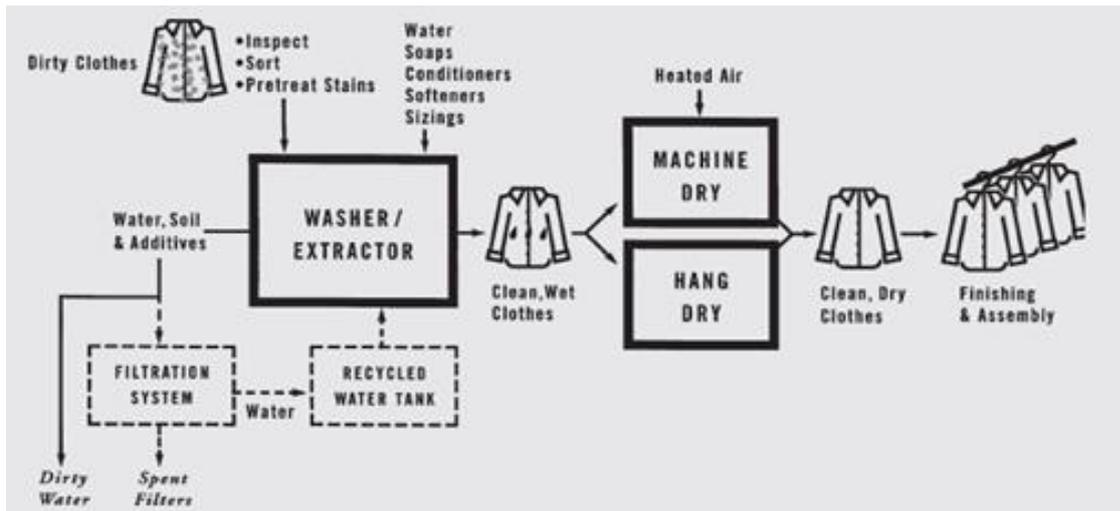


Figure 2.8 : Garment wet cleaning process flow diagram [18]

2.1.5 Alternative cleaning systems

Cleaning systems mentioned in this section have been developed and have been growing up as alternatives for dry cleaning.

2.1.5.1 Carbon dioxide

The most essential key for this technique is using liquid CO₂ under high pressure which is 49 bars (700 pounds per square inch). Cleaning with liquid CO₂ has been modified for laundering garments which is used for cleaning optical and electrical components in aerospace industry.

Required chemicals in carbon dioxide cleaning are liquid CO₂ as solvent and detergent. Liquid CO₂ is an effective stain remover which is also non-toxic, recyclable, and non-destructive for ozone layer. On the other hand, necessary equipments are very expensive used for carbon dioxide cleaning technique which is main disadvantage of this system [19].



Figure 2.9 : Liquid CO₂ cleaning machines [19]

In Figure 2.9, A liquid carbon dioxide cleaning machine by Electrolux is presented. There are 15 kg and 30 kg capacity carbon dioxide cleaning machine models. After carbon dioxide cleaning, CO₂ is distilled for reuse. Cleaning cycle is shorter when it is compared with conventional dry cleaning cycles and cleaning temperature is 10°C which is lower than that for conventional dry cleaning. This is advantageous while cleaning as low temperature prevents color transfer between garments. At the end of the process, garments are taken out of the machine as cold and dried, which means there is no need for drying process.

Considering the cleaning performance of textiles; liquid carbon dioxide cleaning is quite effective process, in which it is possible to clean suede, leather, and fur as well as silk and woolen garments delicately [20].

2.1.5.2 Green jet

Similar to dry cleaning Green Jet system includes cleaning and drying in one machine (Figure 2.10). Cleaning process involves water and detergent mist which is applied to the drum by spraying. This system is applicable for garments which are slightly soiled and it does not require an aggressive washing. Also these machines have a specific drum structure which is patented and have pads under drum for absorbing stains. Cleaning and drying cycle lasts for 30 minutes; it is shorter than the total cycle of dry cleaning system. Besides, spotting is more difficult because of the gentle cleaning process. Being less expensive and easier finishing are other advantages of green jet cleaning [20].



Figure 2.10 : Green Jet cleaning machines [20]

2.1.5.3 Green earth

Cleaning process involves decamethylcyclopentasiloxane (D5) as solvent which is a combustible liquid and has a flash point of 76.7°C in green earth system. Equipments used for green earth system are designed to handle combustible solvents. D5's vapor pressure is lower than it is in conventional dry cleaning with perchloroethylene. Therefore, the cycle duration of technique is longer than that of perchloroethylene dry cleaning which also depends on the load in machine [19].

2.1.5.4 Icy water

Icy water cleaning system resembles wet cleaning system and has been designed for controlling shrinkage and minimizes tension with very low agitation, in which water and detergent is used for laundering. Washing process is performed at a speed of 1 rpm which prevents dimensional change of textiles in the machine. Also the machine is combined with a refrigerated condenser so it is possible to launder garments at around 3°C. In drying step, drying machine is agitated at 60 rpm and garments are partially dried in heated air and then in cold air. To take out garments from the drying machine, a compressor is used to eliminate residual moisture [19].

2.1.5.5 Hydrocarbon

Hydrocarbon cleaning technique is widely used as an alternative to conventional dry cleaning technique. A typical hydrocarbon cleaning machine is shown in Figure 2.11. Isoparaffin is a combustible liquid whose flash point is at around 64°C. Solvent used in hydrocarbon technology is less toxic than in conventional dry cleaning. Cycle time of hydrocarbon technology is longer than it is in dry cleaning, which is around 45 minutes in conventional dry cleaning and 60-75 minutes in hydrocarbon cleaning. Cleaning cycle depends on washed garment quantity. This cleaning system has an advantage of being less aggressive when compared to perchloroethylene dry cleaning system to achieve cleaning of delicate fibers like silk shirts, wedding gowns, drapes, suedes. Also its handle is better than that of perchloroethylene dry cleaning [1,19].



Figure 2.11 : Hydrocarbon cleaning machine [19]

2.1.5.6 Pure dry

Pure dry cleaning system is a kind of hydrocarbon process. It needs additional materials like perfluoroether (PFC) and hydrofluoroether (HFE). PFC is used for suppressing the flash point of the hydrocarbon solvent and HFE is used for speeding up the drying cycle which also shortens the drying time. This technique is not aggressive as perchloroethylene dry cleaning process [19].

2.1.5.7 Glycol ether

Cleaning is performed with glycol ether whose flash point is slightly over 93°C. Glycol ethers are infinitely miscible in water. The combination of glycol ether and water solvent make possible to remove oil-based and water soluble contaminants on textiles without any additional stain removing step. Moreover, there is no need for use of additional detergents. Cleaning cycle is longer than those of other cleaning techniques because of distillation of glycol ether and water solvent. Glycol ether is hazardous for health which is a volatile organic compound [19,21].

2.1.6 Comparison of several cleaning techniques

Advantages and disadvantages of these alternative cleaning systems are summarized in Table 2.3.

Table 2.3 : Comparison chart of cleaning techniques used commercially

	Perchloroethylene Dry Cleaning	Wet Cleaning	CO ₂ Cleaning	Green Earth Cleaning	Hydrocarbon Cleaning
Chemical properties	Halogenated hydrocarbon	Water	Carbon dioxide	Siloxane	Hydrocarbon
Odor	Strong ether-like smell	Odorless	Odorless	Odorless	Slight petroleum smell
Commercial Introduction	1940's	1994	1993	1999	1993
Machine Cost	Moderate	Moderate	Expensive	Very expensive	Moderate to expensive
Health Issues	Poor	Excellent	Excellent	Good	Average
Hand of Garments	Average	Good	Good	Exceptional	Good
Problem Garments	Silks, beads, trims, vinyl, buttons, leather, cashmere	Wool, natural fiber & skins, items with water soluble dyes	Acetates, triacetates, elastic, beads, trims, buttons	None	Beads, trims, vinyl, buttons, certain colors
Cycle Time	35 – 55 minutes	28 minutes (with 20% residual moisture)	35 – 45 minutes	47 – 65 minutes	37 – 65 minutes

2.2 Professional Wet Cleaning Systems

Professional wet cleaning machines have been produced by Miele and Electrolux brands.



Figure 2.12 : Professional wet cleaning systems

As can be seen from Figure 2.11 these professional machines have dosing systems. Adequate amount of detergent with water is supplied to machine after mixing. Wet cleaning detergents have several properties for preventing color loss and shrinkage; also rinsing performance is increased with wet cleaning detergents which are environmental friendly.

2.2.1 Professional wet cleaning systems of Miele

Various types of fibers, fabrics and garments can be cleaned safely with Miele wet cleaning machines which are designed easy to use and to control. Digital screen located on control panel simplifies choosing programe with graphical representation. There are advanced sensors in Miele's machines which control temperature and optimize water quantity, needed detergent amount, energy consumption and time according to the loading amount just before washing. It has been fully controlled with the help of card reader [22].



Figure 2.13 : Miele wet cleaning machines [22]

Miele wet cleaning machines have a honeycomb drum which prevents deformation of garments during cleaning and helps washing performance to become better. Honeycomb drum's structure with reduced number of holes on the drum provides less friction between garments and drum. During drum rotation, and generates a fine water film. It is approved by Cleaning Technology Institute (WFK) that honeycomb drum's structure protects garments more than four times when compared with conventional drums (see Figure 2.13).

In Table 2.4 and 2.5, properties of Miele wet cleaning and drying machines are shown, respectively.

Table 2.4 : Properties of Miele wet cleaning machines

Feature	Benefit
Miele Honeycomb™ drum	More gentle care, extending garment life cycle up to four times longer
Uses water and biodegradable detergents, not harmful solvents	No EPA regulations, no fear of ground contamination
Electronically controlled programming	Ease of use, repeatability and predictability of results
Minimal mechanical action and gentle drum rhythm	Reduced changes of shrinkage/fiber damage
Processes both ‘Dry Clean Only’ garments and traditional laundry	Reduced machine costs, reduced space requirements
Compact footprint	Reduced space required for Miele Professional Wet Cleaning Plant

Table 2.5 : Properties of Miele drying machines

Feature	Benefit
Reverse tumbling action	Reduced drying time, reduced wrinkling
Miele Honeycomb™ drum	Air cushions providing more gentle fabric care
Residual moisture control	Accurate drying times
Axial air flow	Advanced air circulation in drum greatly improves drying
Recycling of air (60%)	Reduce power usage
Compact footprint	Reduced space required for Miele Professional Wet Cleaning plant

2.2.2 Electrolux professional wet cleaning systems

Electrolux Professional wet cleaning systems are commercialized by the name of Lagoon™ are shown in Figure 2.14. Temperature, timing and mechanical action can be controlled, and biodegradable detergents are used in Lagoon wet cleaning machines. Wool cleaning algorithm in Lagoon wet cleaning machines which is approved by Woolmark is applicable for cleaning of woolen garments that have ‘only dry clean’ labels [23].



Figure 2.14 : Electrolux Lagoon wet cleaning machine [23]

2.2.3 Patents related with wet cleaning

US 2006018567 (A1) – Methods for laundering delicate garments in a washing machine:

In this invention, it is aimed to wash delicate and dry-clean only garments in home type washing machine instead of professional wet cleaning machines. The invention includes a pretreatment process and a flexible wrap container within which the garments are contained during washing. In Figure 2.15, it is shown some of these apparatuses which are the wash pretreatment applicator with using hand pressure and the flexible wrap container, which can be a roll-like shaped, for washing [24].

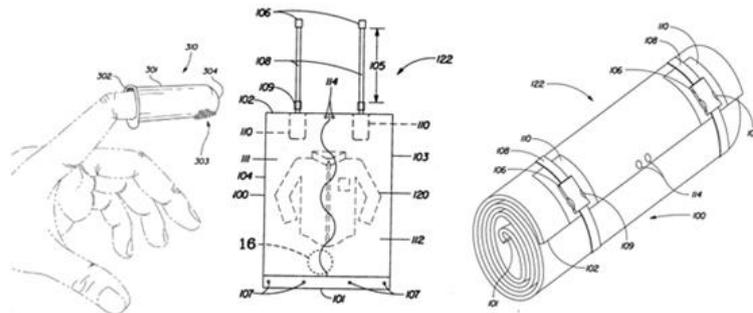


Figure 2.15 : Related pictures of US 2006018567 (A1) [24]

DE 102008039669 (A1) – Device for textile care of clothing articles, particularly shirts, blouses or jackets, has rack, on which clothing article is wound up, where nozzles are provided in work connection with rack

Garments are wound up with a rack and nozzles, connected with this system. In addition to cleaning the garments via wet cleaning principle, drying process is applied with this system. In Figure 2.16, invention is shown with its apparatuses [25].

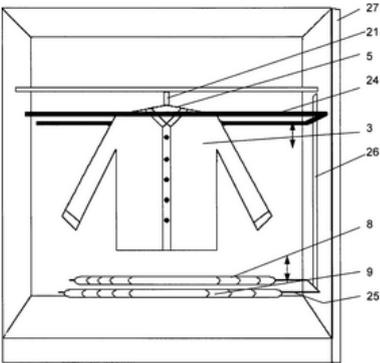


Figure 2.16 : Representation of cleaning system of DE 102008039669 (A1) [25]

3. EXPERIMENTAL STUDY

3.1 Materials

3.1.1 Fabrics

3.1.1.1 Silk samples

Most common use of silk fiber is seen in luxurious and fashion garments which are delicate ones. Although the production percentage of textile industry with silk is 0.2% for all over the world. Silk made garments have pretty good properties like softness, drapeability, good moisture regain which is around 11%, high resilience, high strength and beautiful appearance which makes silk garments special when compared with other fiber based products. These delicate silk garments are needed to be cleaned gently that ‘dry clean only’ label is usually seen in silk products [26-28]. Due to the necessity of gentle cleaning action, silk fabric samples have been examined in wet cleaning study to evaluate gentle washing action of algorithm created in commercial washing machines. Properties of silk samples used in experiments are shown in Table 3.1.

Table 3.1 : Properties of silk fabric samples used in experiments

Properties	
Content	100% Silk
Density (Warp/cm*Weft/cm)	70 Warp/cm * 34 Weft/cm
Yarn Count (Warp and Weft)	45 den / 80 den
Mass/Area (g/m ²)	70 g/m ²
Construction	Plain Weave

3.1.1.2 Wool test fabrics for shrinkage measurement

Woolen fabrics because of scales present on fiber surface have a tendency to shrink during washing treatments especially when performed with heat. So, woolen fabrics are commonly used for measuring shrinkage values of laundering algorithms on washing machines to prevent possible shrinkage problem observed after repeated home laundering. Wool shrinkage specimens used for measuring the effect of

algorithms on dimensional change in this study are knitted woolen fabrics, and an example to wool shrinkage specimen is given in Figure 3.1. It has two layers of knitted wool fabric sewn along two sides of fabric.

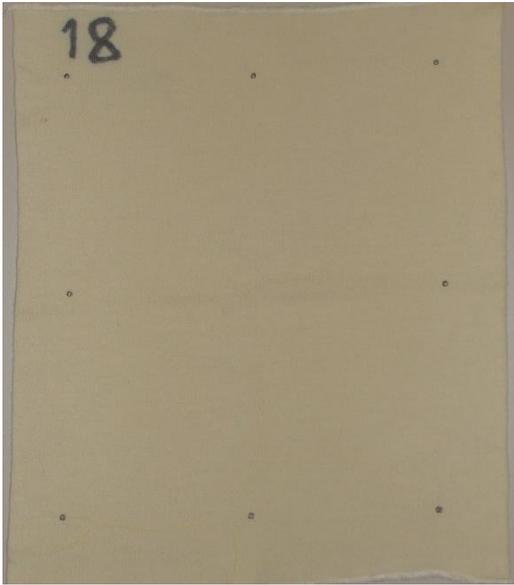


Figure 3.1 : Wool shrinkage specimen

3.1.1.3 Soiled test fabrics for washing performance

Soiled test strips are used to evaluate washing performance of created algorithm according to IEC 60456 Test Method [29].

They are EMPA 105 soiled test strips with a difference of base fabric, wool woven fabrics (Figure 3.2). Using soiled wool test strips helps to observe stain removal from wool products during washing.



Figure 3.2 : Soiled test strips for washing performance

3.1.1.4 EMPA 304 test fabrics for mechanical action performance

EMPA 304 test fabrics, which are polyamide woven textile structures with plain weave, are shown in Figure 3.3. Mass per unit area of EMPA 304 test fabric is 85 g/m² which is used for determining mechanical action of washing machines and tumblers. EMPA 304 mechanical action fabric includes 499 threads on it when

specimen is ready for test. Remaining threads on sample are counted after test for measuring yarn loss [29].

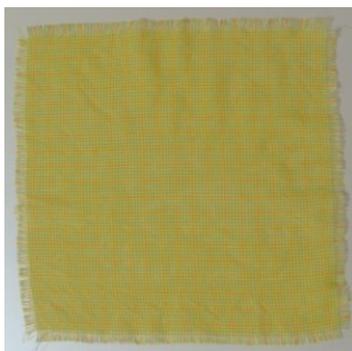


Figure 3.3 : EMPA 304 test fabric for mechanical action performance

3.1.1.5 Polyester ballast fabrics

The base load used in experiments is chosen as knitted polyester fabric which consists of two layers sewn along all four edges. Mass of one piece is approximately 35 g and its dimensions are 30 cm x 30 cm. These fabrics are also known as SM 37 fabrics (see Figure 3.4).



Figure 3.4 : Polyester base load fabrics

3.1.2 Detergent

ECE 2 non-phosphate detergent which is free of optical brightener is used in this study for tests.

3.1.3 Water

Water used for laundering was prepared according to Method B of the IEC60456 standard. It had hardness of 15°dH, conductivity of 800 mS and pH of 7.5. Inlet water temperature was fixed at 15°C in all trials.

3.2 Machines

3.2.1 Grundig washing machine

Washing machine, which is used in this study and shown in Figure 3.5, is a front loaded machine, with a loading capacity of 11 kg, and a maximum spinning speed of 1400 rpm, as well as a liquid crystal display (LCD) screen on its touch button electronic control board. Its energy efficiency class is A+++ (- 40%) energy category. The machine has multi-sensors for loading weight, water amount, rinsing, rotational speed, etc. The machine is equipped with a direct drive motor and newly designed drum pattern with 72 L volume. It is also multi-programmable machine having different programs for different types of textiles and different types of washing durations, providing sufficient washing efficiency according to the cleaning needs of the textiles.



Figure 3.5 : Grundig washing machine which is used in this study [30]

3.2.2 Wascator

Wascator meets with IEC and ISO international standards and is suitable for testing effects of detergents and chemicals.

3.3 Method

Most common parameters used in washing machines are water quantity, mechanical action, rotational speed, temperature, time and rinsing [31]. The variables of these parameters are shown in Table 3.2 with levels.

Table 3.2 : Levels of parameters chosen for testing

Parameters	Levels		
Water Quantity (liters)	15	25	-
Mechanical Action (ED %)	3 %	5 %	12 %
Rinsing	2	3 Rinsing	3 Warm Rinsing

Water amounts chosen for common laundering algorithms vary that 15 L is one of the highest levels which are used in conventional washing algorithms like cotton, and delicate. When 15 L water is used, the liquid amount in the machine increases. At this level, the quantity of water in the machine reaches a point which is not stated under the drum. Also to generate a wet cleaning media, it is needed enough water in the laundering process. The other water quantity, which is preferred to observe the effect of water amount in wet cleaning of delicate garments, is 25 L and is selected according to the limits of washing machine design. Water quantities more than 25 L during laundering cause overflow of the washing liquid. Mechanical action during laundering is the most essential parameter which effects dimensional change on garments. Higher mechanical actions cause more shrinkage when garments are cleaned. Levels of parameters, which are determined for testing their effects on garments, are listed as 3% ED, 5% ED and 12% ED. ED, in other words rate of mechanical action, is calculated by the formulation that gives the percent value of the duration of the working period over the total duration. On and off durations of each ED are as followings; 4 s on and 120 s off for 3% ED which is developed by Arçelik to launder very sensitive textile products approved by Woolmark, 4 s on and 80 s off for 5% ED which is commercial rate of mechanical action used in apparel care, and finally 4 s on and 30 s off for 12% ED which is used in wascator in wet cleaning algorithm, respectively. When effect of rinsing is taken into consideration, it is known that wet cleaning is water-intensive process and more steps applied with much water provide higher efficiency of cleaning garments. Thus, increase in numbers of rinsing step is believed to give better results for cleaning and rinsing performances, and it is found suitable to investigate 2 rinsing, 3 rinsing and 3 warm

rinsing levels. Also warm rinsing, which is performed at washing temperature 30°C, is considered to improve washing and rinsing performance of algorithms without causing any additional damage on garments during laundering [32].

Rotational speed is chosen as 10 rpm which is the slowest available one in Grundig Best washing machines equipped with direct drive motor. The lowest speed is needed to prevent garment from deformation during cleaning process in which garments just slip over each other without friction. The temperature, at which sensitive and delicate garments are laundered, is determined as 30°C according to the standard of wet cleaning procedure, namely BS EN ISO 3175 – 4 [33].

IEC 60456 Test Method - Clothes Washing Machines for Household Use – Methods for Measuring the Performance states the methods for measuring the performance of clothes washing machines for household use, with or without heating devices utilizing cold and/or hot water supply. In addition to this, this international standard deals with appliances for water extraction by centrifugal force (spin extractors) and can be applied to appliances for both washing and drying textiles (washer-dryers) regarding their washing-related functions. In this method, measurement of the color and loading of the fabrics are mentioned. Fabric loading instructions of this method are applied. In order to complete the weight of the fabrics to 2.5 kg that is specified in the standard, polyester ballast fabrics were loaded into the machine chamber [29].

The order of loads' placement in the drum is followed as half of polyester ballast fabrics, silk test fabric, stain strip of EMPA 105 on wool, EMPA 304 mechanical action test fabric, wool shrinkage test specimen and lastly the remaining half of polyester ballast.

3.4 Design of Experiments and Statistical Analysis

3.4.1 Design of experiments

In order to specify and design the full factorial experimental set-up, eighteen laundering profiles, which are shown in Table 3.3, were formed by using the MiniTab® program Design of Experiments (DOE) with the parameters previously mentioned [34].

Table 3.3 : Full factorial experimental design of the study

Profiles	Water Amount (L)	Mechanical Action (%)	Rinsing
1	15	12	2 Rinsing
2	15	12	3 Rinsing
3	15	12	3 Warm Rinsing
4	15	5	2 Rinsing
5	15	5	3 Rinsing
6	15	5	3 Warm Rinsing
7	15	3	2 Rinsing
8	15	3	3 Rinsing
9	15	3	3 Warm Rinsing
10	25	12	2 Rinsing
11	25	12	3 Rinsing
12	25	12	3 Warm Rinsing
13	25	5	2 Rinsing
14	25	5	3 Rinsing
15	25	5	3 Warm Rinsing
16	25	3	2 Rinsing
17	25	3	3 Rinsing
18	25	3	3 Warm Rinsing

3.4.2 Statistical analysis

All test results obtained from newly created profiles, which are shown in Table 3.3, are examined by MiniTab® ANOVA analysis, main effects and interaction effects as well as boxplots are presented graphically.

3.5 Testing

To evaluate the profiles which are created by DOE, there are several tests performed which are shrinkage of silk fabrics, shrinkage of wool specimens, color loss of silk fabrics, rinsing performance of profiles, mechanical action performance of profiles and washing performance of profiles.

3.5.1 Shrinkage

AATCC Test Method 135 - Dimensional Changes of Fabrics after Home Laundering is utilized for the determination of dimensional changes of the fabrics when subjected to home laundering procedures used by consumers. In this standard method, the dimensional changes of the fabric specimens subjected to home laundering care are measured using pairs of bench marks implemented on the fabric before laundering. The shrinkage values are calculated as percentages. According to

the standard method, the fabric specimens are required to have 50x50 cm² dimensions and the area between the bench marks needs to be 35x35 cm². However, the fabric specimens used in this study have dimensions of 35x35 cm² and the area between the bench marks is 24x24 cm² [35]. After third laundering these marked areas are measured again to calculate shrinkage of silk fabrics. The difference between marked area of silk fabric before laundering and marked area of silk fabric after third laundering shows the shrinkage which is also converted to percentage of lost area for evaluation.

3.5.2 Color loss

Color loss of silk fabrics is performed with a spectrophotometer and tristimulus Y values are taken into consideration. Tristimulus Y values of silk fabrics before laundering and after third laundering are measured with Datacolor Model 650 spectrophotometer to evaluate the effect of parameters on color loss. Measurements are taken from marked areas for repeatability which are shown in Figure 3.6. Then, average value of these five points is calculated.

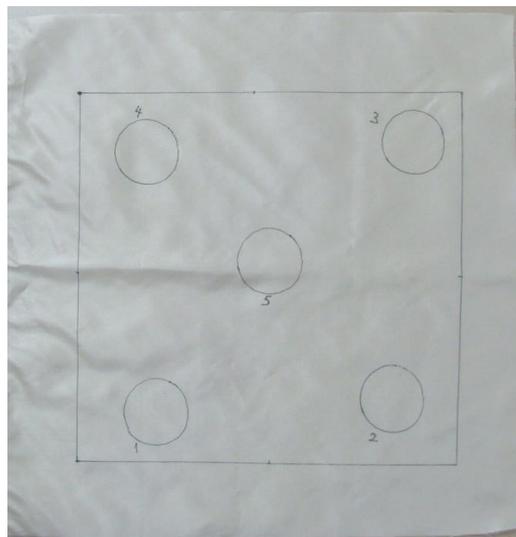


Figure 3.6 : Marked silk fabric to measure color loss

3.5.3 Rinsing performance

Rinsing performance is measured to evaluate the degree of detergent removal at the end of the laundering profiles.

When washing process is completed, testing materials which are silk fabric, wool shrinkage test fabric, EMPA 304 mechanical action fabric, soiled test strip are

separated from ballast. After that polyester ballast fabrics are applied a water-extracting in which residual water on the base fabrics is removed from polyester ballast by centrifugal action. Spinning speed of extractors reach up to 3000 rpm in which residual water on fabrics is removed easily to evaluate rinsing performance of the washing algorithm. There are two extractors to spin base fabrics, so base fabrics are divided into two equal parts. Then spinning process is begun with a speed at higher than 2000 rpm which continues for 5 minutes. Water extracted from these fabrics in two parts is gathered in one beaker to mix them uniformly. It is needed minimum 100 ml extracted water to test rinsing performance for once which should be repeated as low as two times. The extracted water from polyester ballast is titrated to an end point with pH-meter using 0.1 M HCl. The amount of expended HCl solution is directly proportional to the alkalinity of the extracted water and thus, the lower the expended HCl solution the lower the alkalinity the higher the rinsing performance [29].

3.5.4 EMPA 304: Mechanical action test

EMPA 304 test fabrics are used to evaluate mechanical action of washing machines and tumblers [36]. EMPA 304 test fabrics are needed to be prepared; first, one specimen is cut between blue end marking threads from 100 cm long, 160 cm wide test fabric which is shown in Figure 3.9.



Figure 3.7 : Cutting of EMPA 304 test sample from selvages [36]

Then sample is marked in the warp direction and blue end threads are removed which makes the sample ready for testing (Figure 3.10).

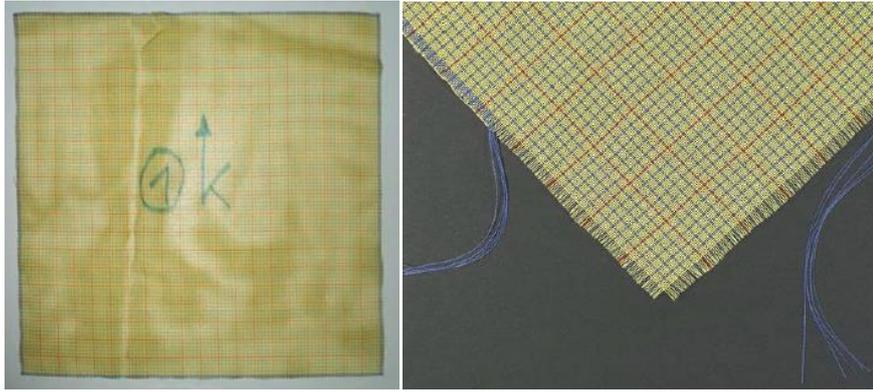


Figure 3.8 : Marking of the sample and removing blue end threads [36]

After preparation of test specimen, it is placed in washing machine according to IEC 60456 and washing occurs. When the process is completed, EMPA 304 mechanical action test specimen is taken out and gently flattened by hand to remove threads on edges which are called “not remaining” (see Figure 3.11).

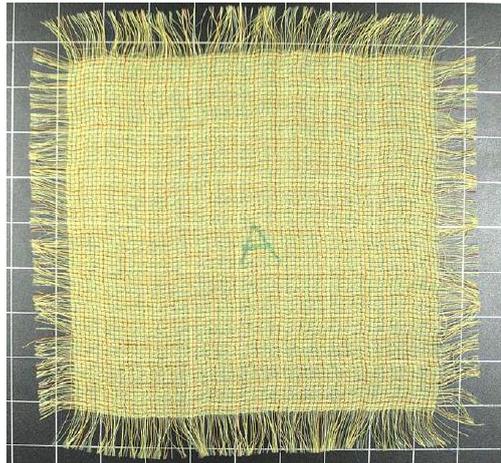


Figure 3.9 : Flattening of specimen to remove “not remaining” threads [36]

Then remaining threads on the specimen is counted with the help of squares which are marked by red and blue threads in warp and weft directions. Each square between red threads has 25 threads which is 5 threads between blue threads (see Figure 3.12). Firstly, considering the warp direction, red squares are counted which is followed by counting of blue squares. Finally, remaining yellow threads on each edge are counted to accomplish. Then the same procedure is performed for weft direction.

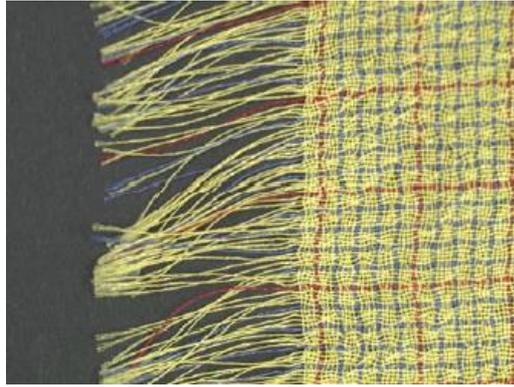


Figure 3.10 : Red and blue squares on the specimen easily [36]

Final result is calculated with both not remaining threads of warp and weft directions. There are 499 threads on each direction at the beginning, which can be said there are 998 threads on the test specimen. It is possible to express lost area with not remaining threads. For example; it is counted 169 threads are not remaining which can be converted lost area with following equation; $(169/998)*100 = 16.93\%$ lost area

Lost area calculation on EMPA 304 mechanical test fabrics are calculated by equation (3.1).

$$Lost\ Area\ (\%) = \frac{\text{Number of not remaining threads after test}}{\text{Total number of threads before test}} * 100 \quad (3.1)$$

In this study, only numbers of not remaining threads are taken into consideration to evaluate mechanical actions of profiles.

3.5.4 Washing performance

Soiled wool test strips are used to perform washing performance of the program with respect to IEC 60456 Test Method [29].

After third laundering, test strips are removed from test load at the end of the programme. For measuring stain removal from test strips, they need to be dried and flattened. So test strips are laid flat to dry. Dried test strips are ironed in such a way not causing shine on the surface of test strips.

Tristimulus Y reflectance measurements are achieved individually with a spectrophotometer for each stain type and unsoiled test piece [37]. Datacolor Model

650 spectrophotometer is used to measure tristimulus Y reflectance values (see Figure 3.11).



Figure 3.11 : Spectrophotometer used for carrying out washing performance

The measured tristimulus value was accepted as the parameter to be assessed by the CIE Nr.15.2 1986 measurement system, since it can express the brightness independently of the color, and this value is considered according to the standard during the washing performance measurement in washing machine plants.

Reflectance measurements are taken four times for individual stain fabric; two of them are from the front side and the other two from backside of the fabric which is represented in Figure 3.12.

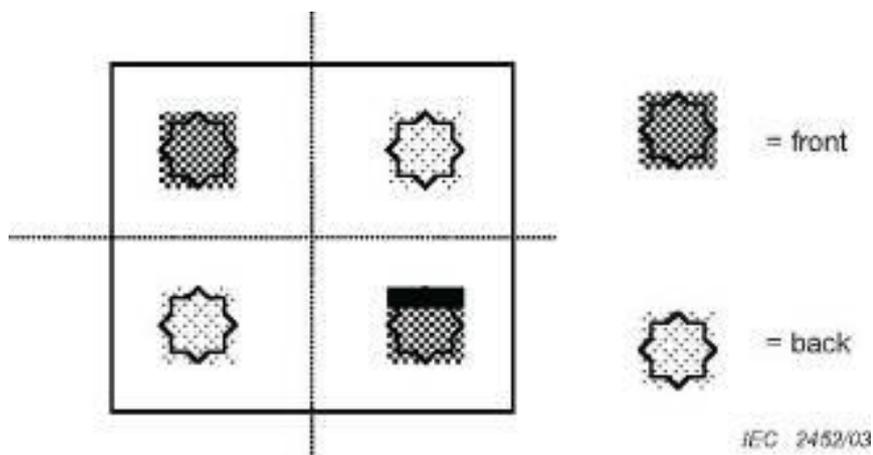


Figure 3.12 : Positions for measuring soiled test pieces [29]

Measurement of stain removal in terms of percentage is done with a formula (3.2).

$$\text{Stain Removal (\%)} = \frac{\left[\begin{pmatrix} \text{Tristimulus} \\ \text{Y value of} \\ \text{soiled fabric} \\ \text{after washing} \end{pmatrix} - \begin{pmatrix} \text{Tristimulus} \\ \text{Y value of} \\ \text{soiled fabric} \\ \text{before washing} \end{pmatrix} \right]}{\left[\begin{pmatrix} \text{Tristimulus} \\ \text{Y value of} \\ \text{unsoiled fabric} \\ \text{before washing} \end{pmatrix} - \begin{pmatrix} \text{Tristimulus} \\ \text{Y value of} \\ \text{soiled fabric} \\ \text{before washing} \end{pmatrix} \right]} * 100 \quad (3.2)$$

In this calculation, it is important to measure Tristimulus Y values for each stain and reference fabric part, which is the unsoiled one, on the test strip. It is needed to get measurement at the same points before and after laundering for comparison in the stain removal. Measuring points are shown in Figure 3.12.

4. RESULTS AND DISCUSSION

4.1 Analysis of Test Results with ANOVA

All of the test results were analyzed with ANOVA by using the MiniTab® package program. All test results in this study are analyzed which are shrinkage of silk, color loss of silk, shrinkage of wool, rinsing performance of profiles, mechanical action performance of profiles and washing performance of profiles performed with soiled test strip.

4.1.1 Shrinkage test results of the profiles by using silk fabrics

The shrinkage values, which are performed for silk fabrics, are shown in Table 4.1 for newly created algorithms with different water amounts, mechanical actions and rinsing profiles.

Table 4.1 : Shrinkage values of silk fabrics for profiles created

Profiles	Shrinkage Values (%)
1	8.48
2	6.55
3	6.92
4	6.53
5	6.72
6	5.54
7	6.35
8	5.16
9	5.76
10	4.97
11	4.19
12	4.38
13	3.79
14	4.00
15	3.60
16	4.19
17	4.18
18	4.38

The individual effects of water amount (15 L and 25 L), mechanical action (3%, 5%, and 12%) and rinsing (2 rinsing, 3 rinsing and 3 warm rinsing) on average shrinkage

after third laundering are shown in Figure 4.1. Considering the individual effects of water amounts which are 15 L and 25 L, the shrinkage values are observed lower at higher water amount. At higher water amount, environment in the washing machine is shifted from water and air media to water media for garments laundered in the machine. Because of the low mechanical action in wet cleaning algorithms, garments in the drum just move extremely slowly, especially with 3% ED and 5% ED. In this environment, slow agitation of machine causes garments to slide over each other without hitting to the drum. This kind of mechanical action in the machine generally leads to dimensional changes on the garments. At higher water amount, effect of mechanical action on shrinkage decreases due to the aforementioned information. When the effect of mechanical action on shrinkage of silk is considered, it is seen that higher mechanical action (12% ED) causes higher shrinkage values on fabrics. Lower mechanical actions (3% ED and 5% ED), because of the prevention of hitting fabrics on the drum, give better shrinkage results when compared to high mechanical action, which belongs to wascator’s wet cleaning programme. So, it is indicated that lower mechanical actions used in wet cleaning algorithms are more delicate for dimensional stability. It is apparent from Figure 4.1, the effect of rinsing on shrinkage of silk fabrics changes adversely. It is a result of increased mechanical action duration, because the increased number of rinsing step means longer laundering time.

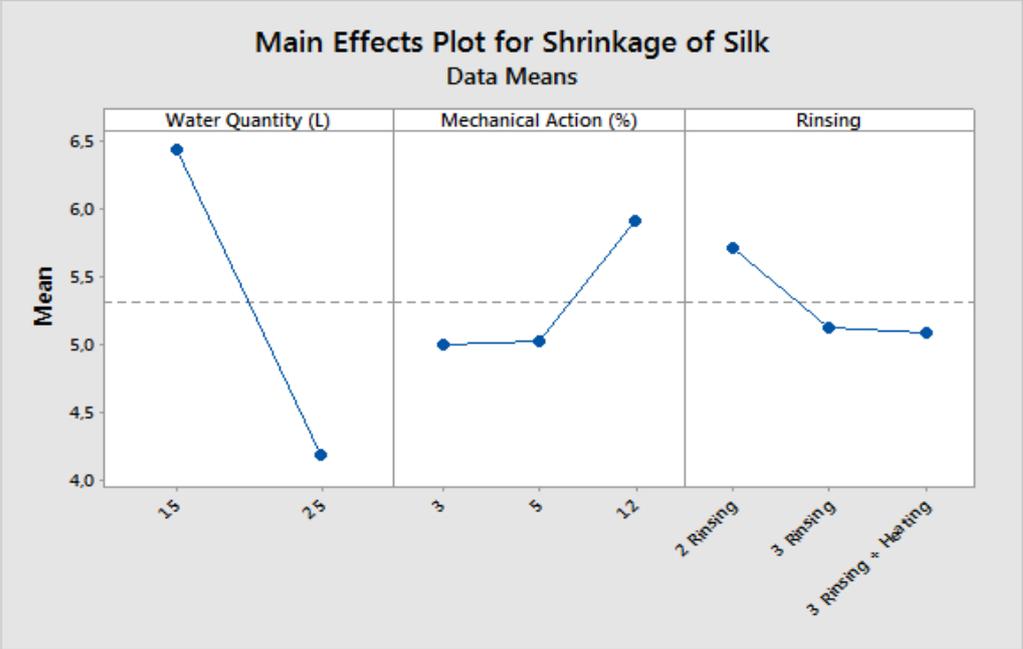


Figure 4.1 : Main effects plot for shrinkage of silk

4.1.2 Color loss test results of the profiles by using silk fabrics

Tristimulus Y values for silk fabrics are shown in Table 4.2 for newly created algorithms with different water amounts, mechanical actions and rinsing profiles.

Table 4.2 : Color loss values of silk fabrics for profiles created

Profiles	Tristimulus Y values	Tristimulus Y values	Difference of
1	82.69	78.70	-3.99
2	81.14	80.01	-1.13
3	82.81	80.47	-2.34
4	82.41	80.86	-1.55
5	82.49	80.56	-1.93
6	82.52	80.22	-2.3
7	82.77	80.95	-1.82
8	83.10	81.33	-1.77
9	82.61	81.50	-1.11
10	82.70	81.11	-1.59
11	81.83	80.25	-1.58
12	82.77	81.63	-1.14
13	82.26	81.68	-0.58
14	82.25	81.73	-0.52
15	81.98	81.69	-0.29
16	82.00	80.97	-1.03
17	82.56	80.89	-1.67
18	82.41	81.63	-0.78

The individual effects of water amount (15 L and 25 L), mechanical action (3%, 5%, and 12%) and rinsing (2 rinsing, 3 rinsing and 3 warm rinsing) on color loss after third laundering are shown in Figure 4.2. When color loss of silk during laundering is examined, the parameter levels, which bring better results for shrinkage of silk, also bring similar results on color loss of silk. When water quantity used for washing increases, the color loss of silk decreases, it depends on less mechanical action provided by higher water amount in the drum. Also lower EDs bring lower agitation in the machine (3% ED and 5% ED) in which dye on the fabric does not transfer much to the laundering water. It is apparent that numbers of rinsing processes or warm rinsing processes have no significant effects on color loss of silk.

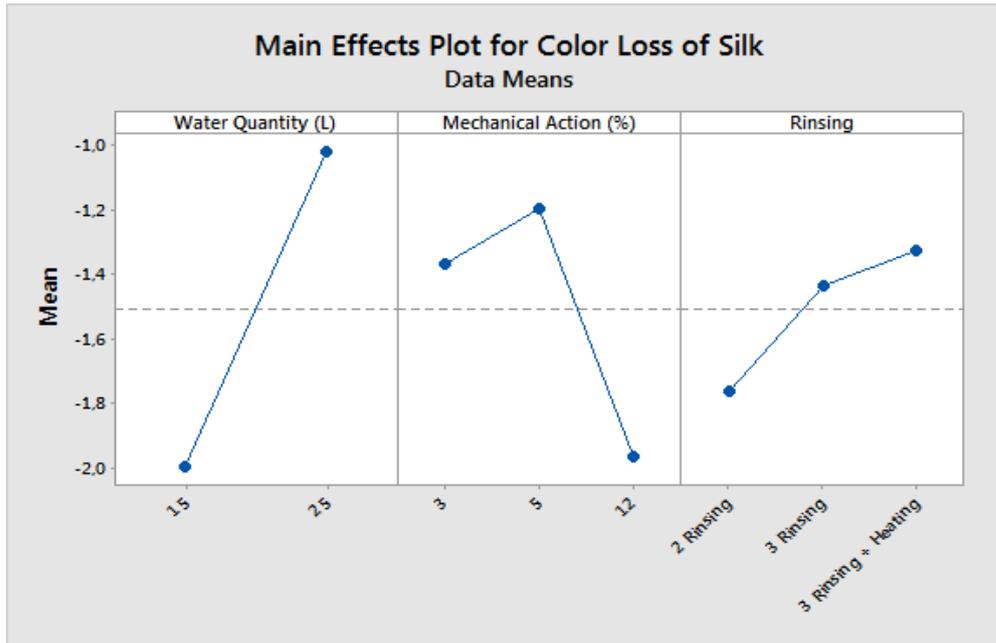


Figure 4.2 : Main effects plot for color loss of silk fabrics

4.1.3 Shrinkage test results of the profiles by using wool specimen

The shrinkage values, which are performed for wool specimens, are shown in Table 4.3 for newly created algorithms with different water amounts, mechanical actions and rinsing profiles.

Table 4.3 : Shrinkage values of wool specimens for profiles created

Profiles	Shrinkage Values (%)
1	5.87
2	2.44
3	2.07
4	4.02
5	3.78
6	4.34
7	2.58
8	3.69
9	4.12
10	4.48
11	3.18
12	2.11
13	1.95
14	0.73
15	1.44
16	2.96
17	1.99
18	1.31

The individual effects of water amount (15 L and 25 L), mechanical action (3%, 5%, and 12%) and rinsing (2 rinsing, 3 rinsing and 3 warm rinsing) on shrinkage after third laundering are shown in Figure 4.3. Considering the effect of water quantities on shrinkage of wool specimens, it is shown in Figure 4.3 that less water amount in washing machine causes more shrinkage on wool specimen. As it is mentioned previously, high water quantity during laundering prevents adverse effects caused by mechanical action. Agitation of fabric will be lower because of lots of water. Also mechanical action during washing is increased, agitation of specimens will be higher and shrinkage values will be raised as it is apparent in Figure 4.3. So shrinkage of wool specimen is lower at 3% ED and 5% ED. Lastly, 2 rinsing, 3 rinsing and 3 warm rinsing are examined for their effects on shrinkage of wool specimens, and it is seen that 3 rinsing and 3 warm rinsing affect shrinkage of wool less than 2 rinsing. It is explained that the additional rinsing step in 3 rinsing helps removal of detergent on the wool by diluting the alkalinity of media. It is known that alkalinity effects wool garments negatively and causes shrinkage. In 3 warm rinsing, shrinkage of wool specimen decreases slightly when compared to 3 rinsing. In hot wet processes, scales on wool fibers open and detergent on the fiber can be removed easily. Thus, alkalinity decreases and shrinkage of wool specimen drops off.

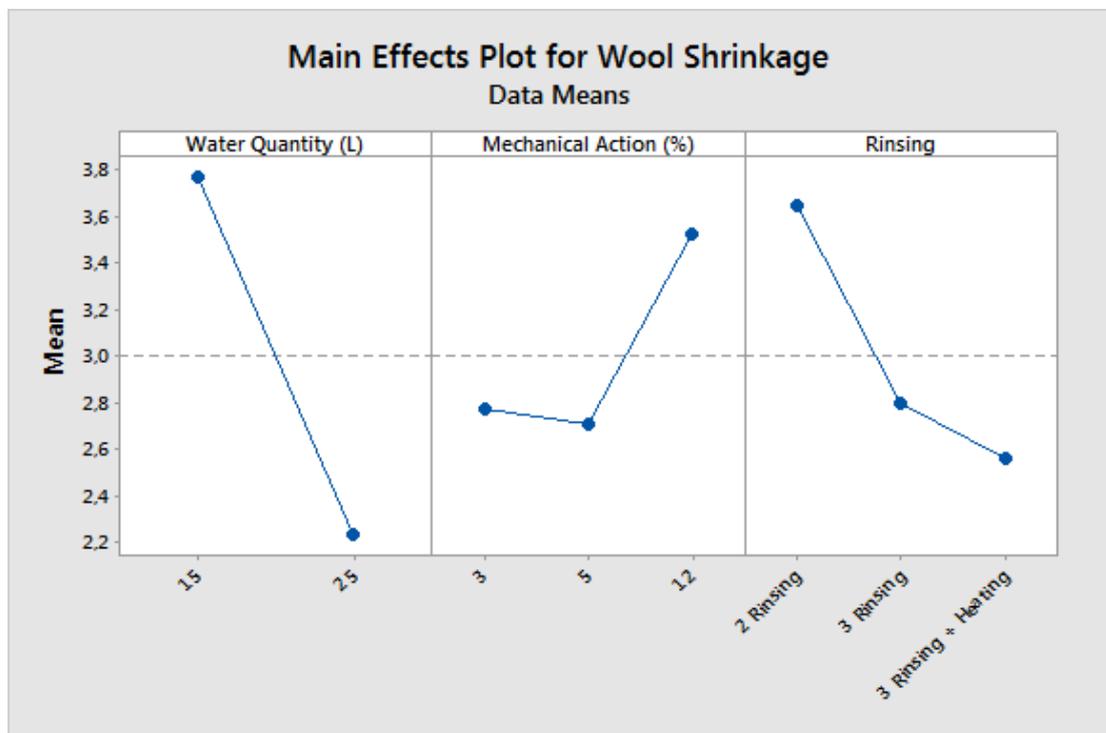


Figure 4.3 : Main effects plot for shrinkage of wool specimens

4.1.4 Rinsing performance test results of the profiles

HCl amounts, which are used in rinsing performance measurements, are shown in Table 4.4 for newly created algorithms with different water amounts, mechanical actions and rinsing profiles.

Table 4.4 : Rinsing performance of profiles according to the amount of HCl

Profiles	HCl amounts (mL)
1	6.900
2	5.662
3	4.328
4	6.552
5	5.366
6	5.958
7	7.408
8	8.378
9	4.566
10	6.220
11	6.527
12	4.376
13	6.088
14	4.866
15	6.140
16	6.770
17	6.169
18	4.709

The individual effects of water amount (15 L and 25 L), mechanical action (3%, 5%, and 12%) and rinsing (2 rinsing, 3 rinsing and 3 warm rinsing) on rinsing performance after third laundering are shown in Figure 4.4. When the effect of water quantities on rinsing performance is considered, it is seen from Figure 4.4 that high water amount increases rinsing performance, which is expected. Because less HCl in milliliters used for test means more effective rinsing during laundering. Mechanical action in washing algorithm makes removal the detergent from textile better when it is applied at high speeds. So rinsing performance of profiles, which have 12% ED, show more removal of detergent and HCl used for test are lower. At 3% ED and 5% ED because of lower agitation, rinsing performance is lower too. But it is seen from Figure 4.4 3% ED, 5% ED and 12% ED do not have much significant difference between each other. Finally the effect of 2 rinsing, 3 rinsing and 3 warm rinsing is performed to observe their effects on rinsing performance. As it is expected, additive rinsing steps during washing provide higher rinsing performance. Because more

processes applied with water increases removal of the detergent from garments during laundering. Also heating during rinsing step provides higher removal of the detergent from garments. So as it is apparent in Figure 4.4, 3 warm rinsing shows much more effective rinsing performance.

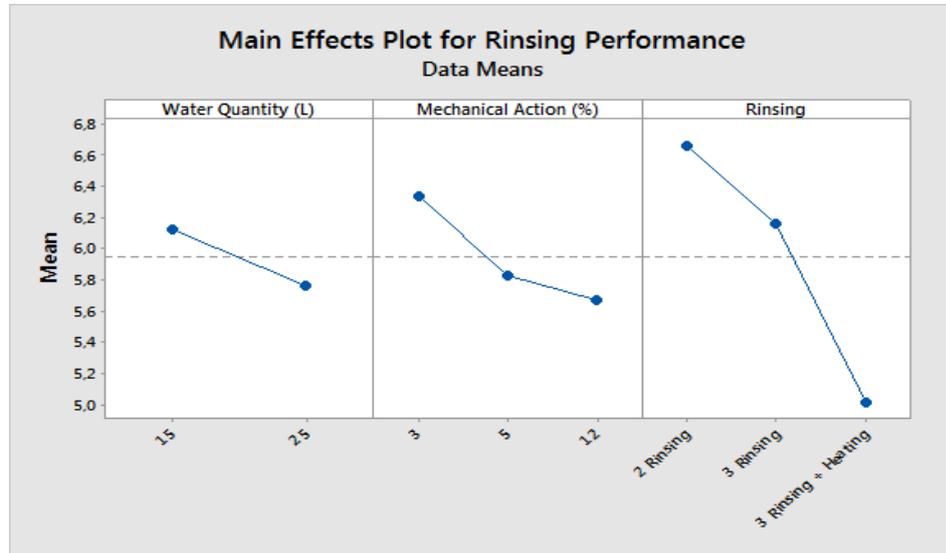


Figure 4.4 : Main effects plot for rinsing performance of newly designed profiles

4.1.5 EMPA 304 mechanical action test results of the profiles

Loss yarn quantities in EMPA 304, which is used for determining mechanical action performance, are shown in Table 4.5 for newly created algorithms with different water amounts, mechanical actions and rinsing profiles.

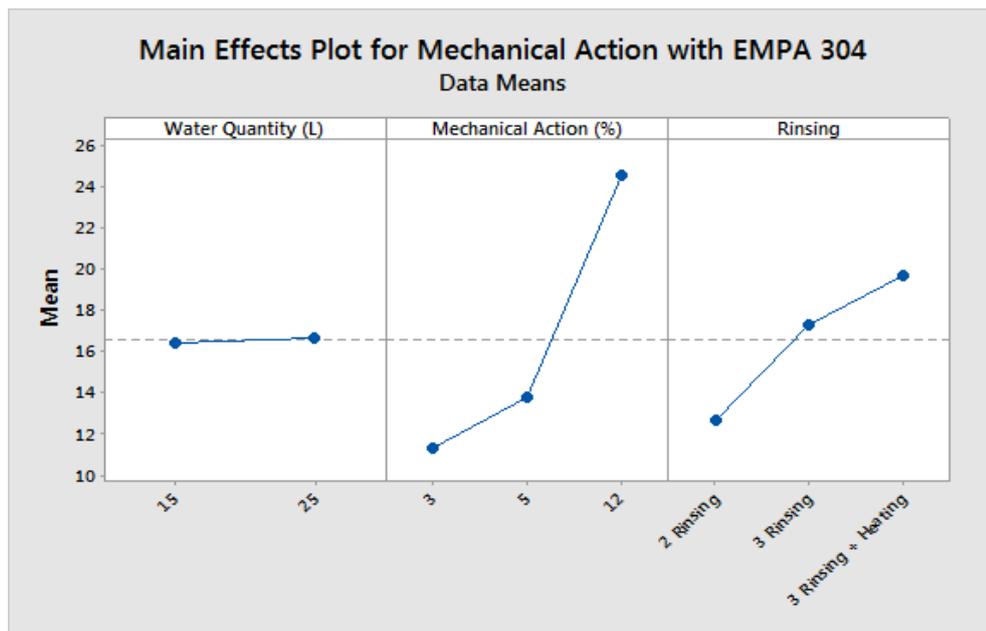


Figure 4.5 : Main effects plot for mechanical action performance

The individual effects of water amount (15 L and 25 L), mechanical action (3%, 5%, and 12%) and rinsing (2 rinsing, 3 rinsing and 3 warm rinsing) on mechanical action test fabric after third laundering are shown in Figure 4.5. The effect of water quantities on yarn loss of EMPA 304, mechanical action test fabric, is presented in Figure 4.5. It is observed that different water amounts do not affect yarn loss on EMPA 304 significantly. But mechanical action's effect on yarn loss of EMPA 304 is more significant as expected. When higher mechanical action is applied which is 12% ED, (see Figure 4.5), yarn loss is increased when compared to lower EDs. As agitation of fabric is getting higher while mechanical action is increasing, garments hit to the drum unkindly. Considering the numbers of rinsing and heating during rinsing, it is observed that yarn loss increases when numbers of rinsing increased. It is apparent that more steps in algorithm cause more mechanical action during laundering, which creates more yarn loss on EMPA 304.

Table 4.5 : Yarn loss of EMPA 304 for profiles created

Profiles	Total Yarn Loss
1	18
2	17
3	31
4	11
5	16
6	20
7	9
8	13
9	13
10	20
11	31
12	30
13	14
14	10
15	12
16	4
17	17
18	12

4.1.6 Washing performance test results of the profiles

Removal of stains from test strips in terms of percentages, which are used for determining washing performance of algorithms, are shown in Table 4.6 for newly created algorithms with different water amounts, mechanical actions and rinsing profiles.

The individual effects of water amount (15 L and 25 L), mechanical action (3%, 5%, and 12%) and rinsing (2 rinsing, 3 rinsing and 3 warm rinsing) on washing performance after third laundering are shown in Figure 4.6 for carbon black stain, in Figure 4.7 for blood stain, in Figure 4.8 for chocolate-milk stain and in Figure 4.9 for red wine stain, respectively.

Table 4.6 : Stain removal for profiles created

Profiles	Carbon Black	Blood	Chocolate-Milk	Red Wine
1	26.29	92.85	29.44	20.37
2	20.90	91.50	14.11	17.05
3	19.38	89.63	19.60	17.52
4	13.43	89.43	13.55	17.67
5	19.02	90.90	8.72	19.68
6	12.95	87.09	10.74	18.27
7	20.12	88.15	7.27	19.57
8	12.99	92.03	6.90	15.53
9	13.16	88.38	6.72	21.96
10	19.33	91.12	0.85	15.80
11	21.14	90.97	11.06	17.91
12	17.60	89.45	8.73	17.47
13	15.63	88.68	1.20	16.77
14	11.99	87.83	5.56	17.34
15	10.68	90.05	0.83	16.82
16	14.60	89.21	3.47	20.28
17	10.68	83.81	3.54	18.01
18	9.98	89.11	4.52	19.68

4.1.6.1. Carbon black

When the effect of parameters on removal of carbon black stain is considered, it is observed that removal of the carbon black stain varies from 10% to 26% which are shown in Table 4.6.

For effective removing of carbon black stain, higher mechanical action, longer laundering time and higher amount of detergent are needed. These mentioned parameters are not suitable for a delicate washing algorithm and percentage removal of carbon black stain is limited for created algorithms.

Although different water amounts during laundering is not very efficient for increasing stain removal of carbon black, in this study less water amount provides higher removal of carbon black stain with a slight difference, which can be explained as detergent concentration of washing media is higher at less water quantity and this helps to increase washing performance. Considering the effect of mechanical action

on removal of carbon black stain, it is seen that higher mechanical action provides higher stain removal, as expected. 12% ED is much more effective on stain removal when compared to lower EDs. Also rinsing has no significant effect on removal of carbon black stain.

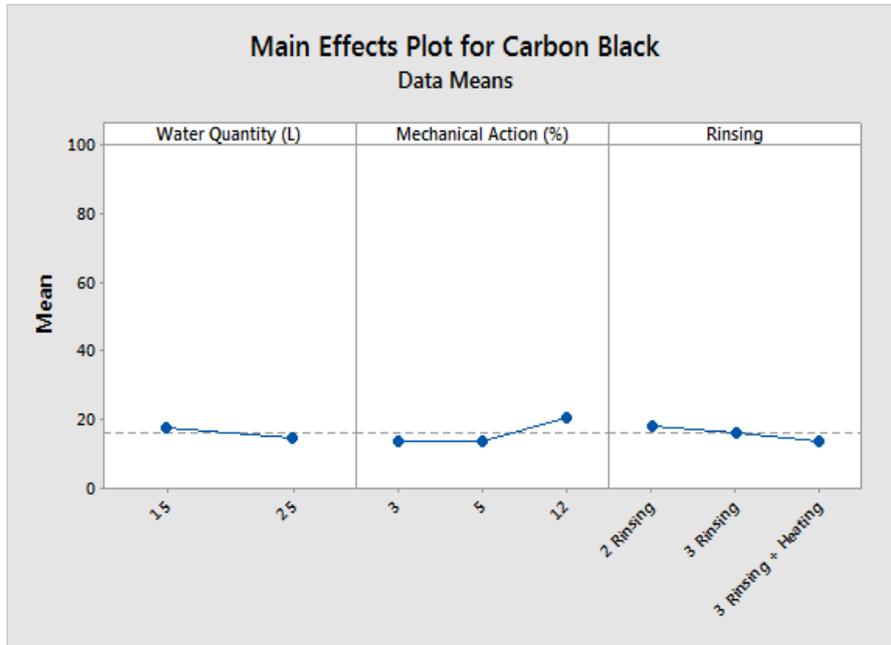


Figure 4.6 : Main effects plot for removal of carbon black stain

4.1.6.2 Blood

It is shown in the Figure 4.7 that almost all created algorithms are very effective on removing of blood stain (as high as 93%).

For removing blood stains effectively; higher mechanical action, washing without heating and protease enzyme should be applied during washing garments. Once again, higher mechanical action is not appropriate for delicate washing algorithms.

Water quantities effect percentage of blood stain removal only slightly. When mechanical action is considered, it is observed that higher mechanical action provides higher removal of blood stain, as expected. Because higher mechanical action during laundering causes removal of stains from garments significantly. Considering the effect of rinsing on removal of blood stain, it is apparent that almost no difference is observed between 2 rinsing, 3 rinsing and 3 warm rinsing.

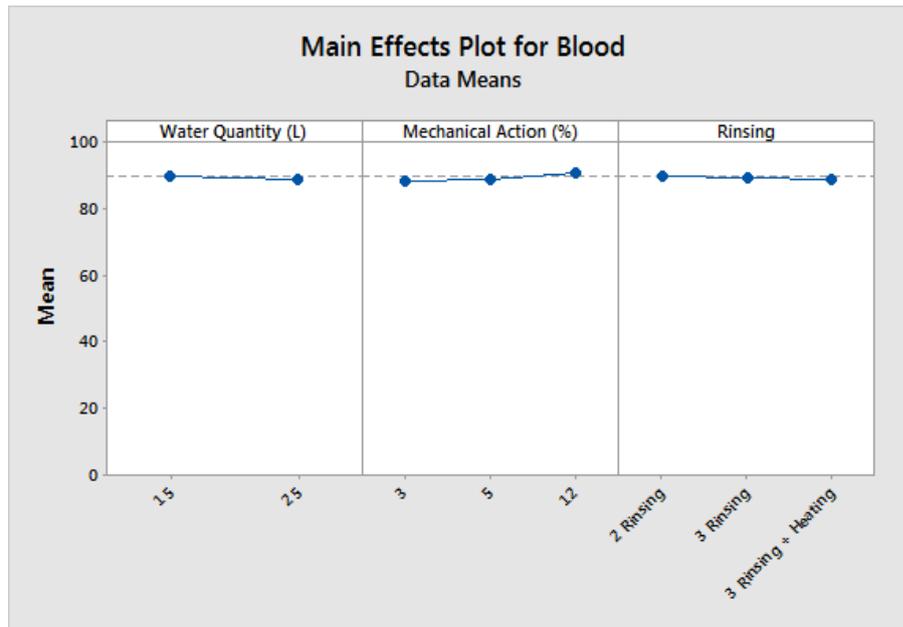


Figure 4.7 : Main effects plot for removal of blood stain

4.1.6.3 Chocolate – milk

Removal of the chocolate milk stain cannot be performed influentially when compared to removal of the blood stain. To improve removal of chocolate – milk stain; more detergent amount is needed to be applied during laundering. According to the standards used for designing experimental study, detergent amount is determined lower than it is needed for removing this stain. Because of laundering delicate garments with created algorithms, limited amount of detergent has to be used, which as well as limits removal of the stain.

Less water appears to be more effective to remove chocolate-milk stain which is possible to explain because of the concentration of the detergent is higher in less water, but there is not much significant difference between less and much water. Mechanical action is efficient on removal of chocolate-milk stain, which is also influential in previously mentioned stains. It is shown in Figure 4.8 that 12% ED which is highest mechanical action in newly created algorithms, has the best stain removing performance for chocolate-milk stain. It is also a limited performance that the best stain removing among these profiles is achieved as 30%. The effect of 2 rinsing, 3 rinsing and 3 warm rinsing on washing performance is not very significant as it is shown in Figure 4.8, which is also similar for aforementioned stains.

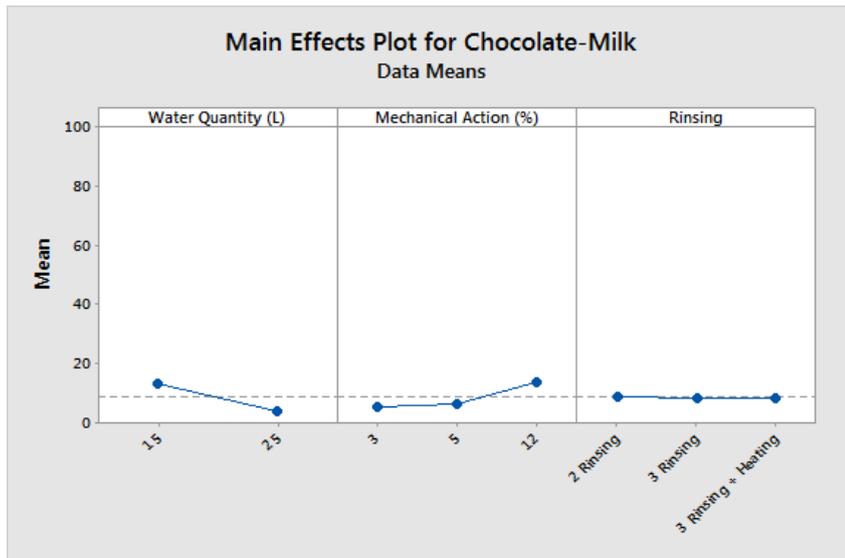


Figure 4.8 : Main effects plot for removal of chocolate-milk stain

4.1.6.4 Red wine

Considering the effects of water amount on stain removal of red wine, it is shown in Figure 4.9 that less water quantity in washing process is helpful for removing red wine stains because of increased detergent concentration in the drum.

Taking the effects of 3%, 5% and 12% EDs into consideration, it is observed that 3% ED mechanical action provides more effective removal of red wine stains, which is also not very significant when compared to 5% and 12% EDs. Not only different water quantities but also numbers of rinsing steps and heating in rinsing steps do not have significant effects on removing red wine stain.

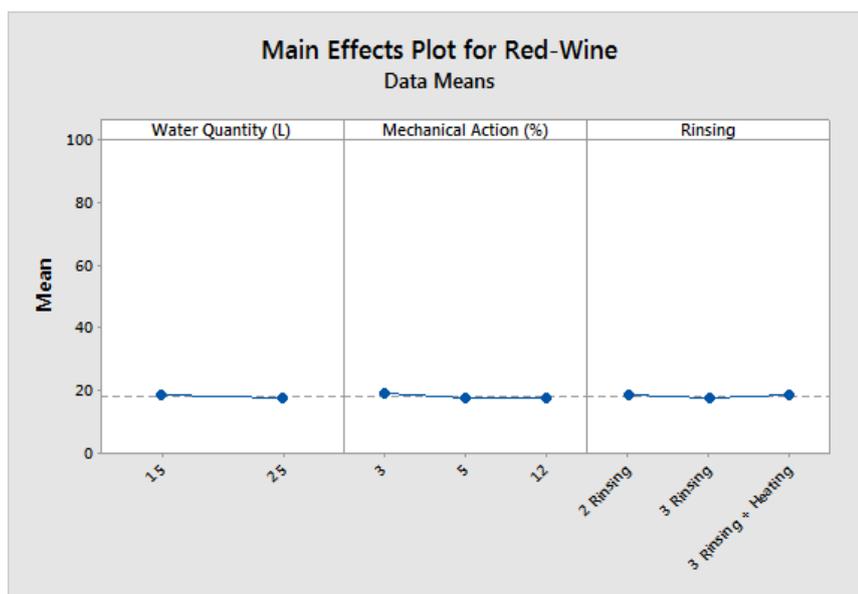


Figure 4.9 : Main effects plot for removal of red wine stain

Due to the need of heat and bleaching agent for removing red wine stain, removal of mentioned stain is limited. As mentioned in method, maximum 30°C heat is applied during laundering, which is not adequate removal of red wine stain. In addition to low washing temperature, selected detergent in this study is ECE without optical brightener. In other words, without pretreatment step and heating during laundering as well as brightener, removal of the red wine stain is very limited when compared to wascator program or other conventional washing algorithms.

4.2 Analysis of test results with box plot

Boxplot graphics are used to depict the variation in samples by MiniTab® package program. All test results done in this study are analyzed which are shrinkage of silk, color loss of silk, shrinkage of wool, rinsing performance of profiles, mechanical action performance of profiles and washing performance of profiles performed with soiled test strip.

4.2.1 Boxplot analysis for shrinkage of silk

As it is shown in the Figure 4.10, fourteenth and fifteenth profiles provide best performance for shrinkage of silk fabrics. These profiles include high water amount (25 L), 5% mechanical action (ED) and 3 rinsing with and without heating, respectively. The reference washing algorithm of wascator has the worst shrinkage results of silk among examined profiles.

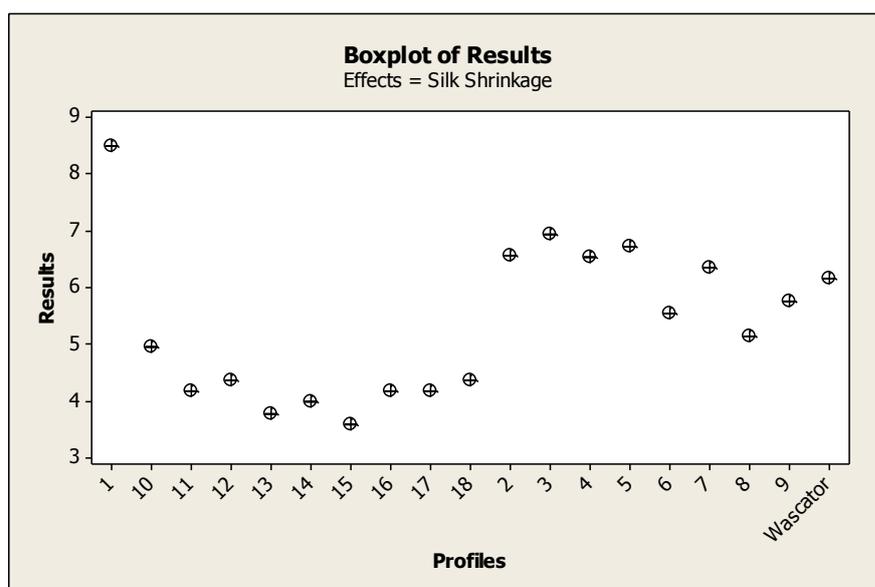


Figure 4.10 : Boxplot for shrinkage results of silk fabrics

4.2.2 Boxplot analysis for color loss of silk

In Figure 4.11, it is apparent that minimum color loss is observed in fourteenth and fifteenth profiles. In which there is nearly no difference before and after washing silk fabrics. On the other hand, high color loss after laundering in wascator is observed.

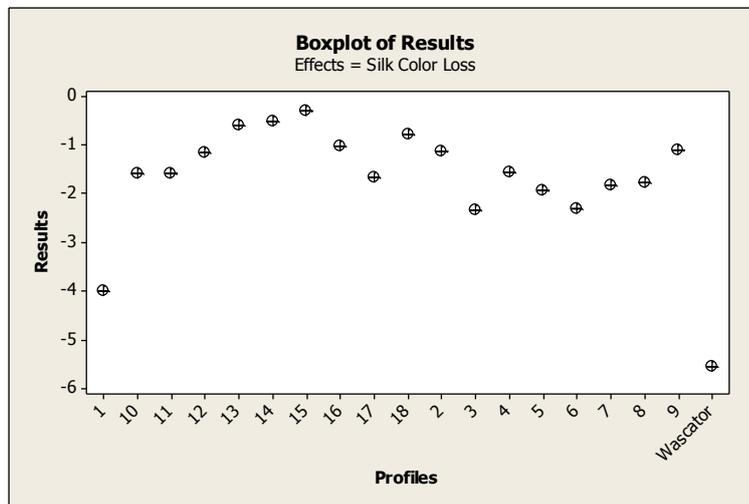


Figure 4.11 : Boxplot for color loss results of silk fabrics

4.2.3 Boxplot analysis for shrinkage of wool

When shrinkage of wool specimens is examined, it is obvious from Figure 4.12 that it is obtained minimum shrinkage is obtained in fourteenth profile, followed by fifteenth one. Once again, wascator program gives higher shrinkage values. In other words, higher mechanical action during laundering causes higher shrinkage values.

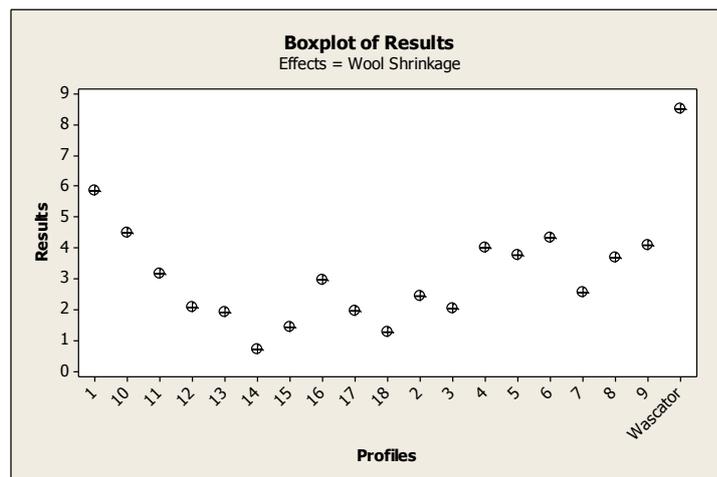


Figure 4.12 : Boxplot for shrinkage results of wool fabrics

4.2.4 Boxplot analysis for rinsing performance of the profiles

When boxplot for rinsing performance results of profiles is investigated, it is observed that the algorithm of wascator is more effective when compared to created eighteen profiles. Also they are distributed randomly in boxplot, and there are several algorithms which have rinsing performance results close to wascator's test results (see Figure 4.13).

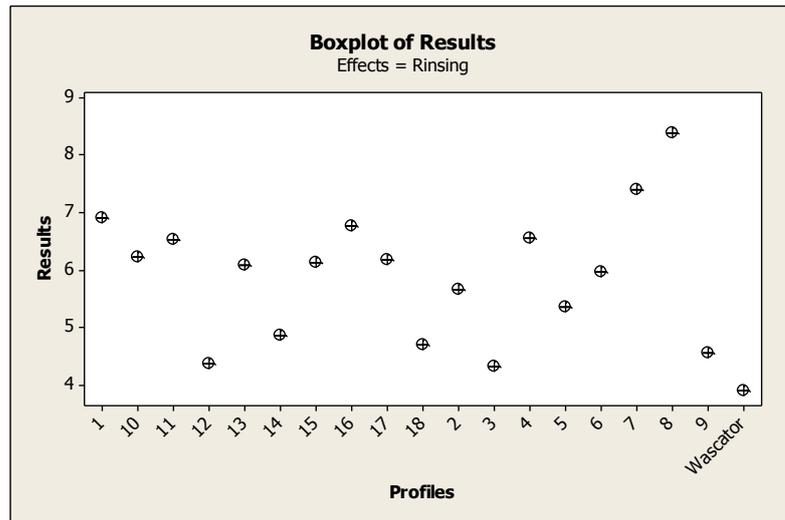


Figure 4.13 : Boxplot for rinsing performance results of profiles

4.2.5 Boxplot analysis for mechanical action tests with EMPA 304

Boxplot for mechanical action results of profiles shows that sixteenth profile is the most delicate one as seen in Figure 4.14. The subsequent profiles to sixteenth one are fourteenth and fifteenth ones, in which there are very few yarn loss when compared the wascator's programmes. Also these profiles have 5% ED.

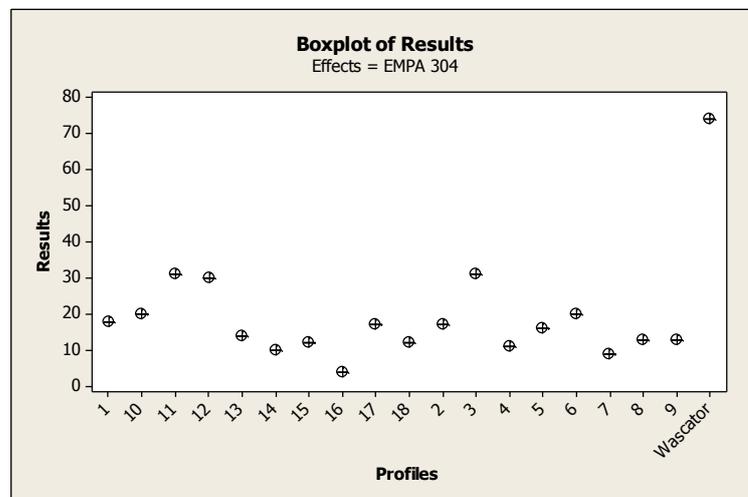


Figure 4.14 : Boxplot for mechanical action results of profiles

4.2.6 Boxplot analysis for washing performance of the profiles

4.2.6.1 Carbon black

When washing performances of the profiles are examined, it is observed that removal of the carbon black stain is not very effective in these programs. It is known that the profiles, which have higher mechanical action, remove stains slightly better than others with a non-significant difference which is shown in Figure 4.15.

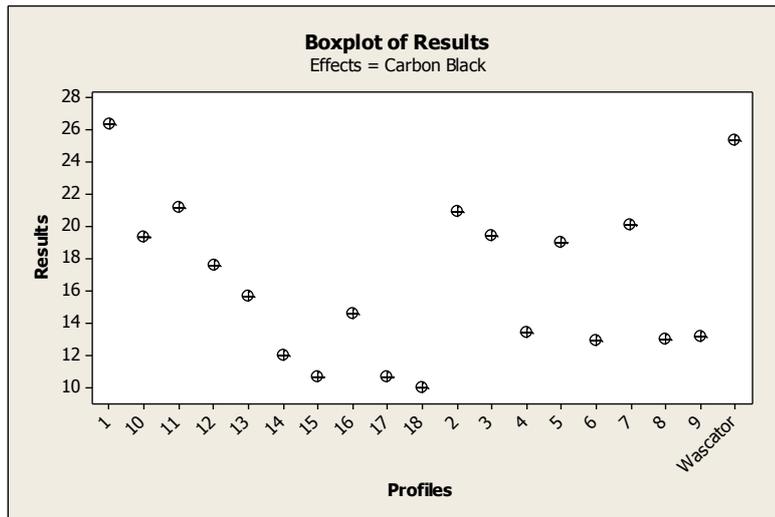


Figure 4.15 : Boxplot for removal of carbon black stain of profiles

4.2.6.2 Blood

When boxplot for removal of blood stain is investigated (see Figure 4.16), with the exception of seventeenth profile and wascator programme, it is apparent that almost all profiles have similar results on removal of blood stain with a narrow distribution.

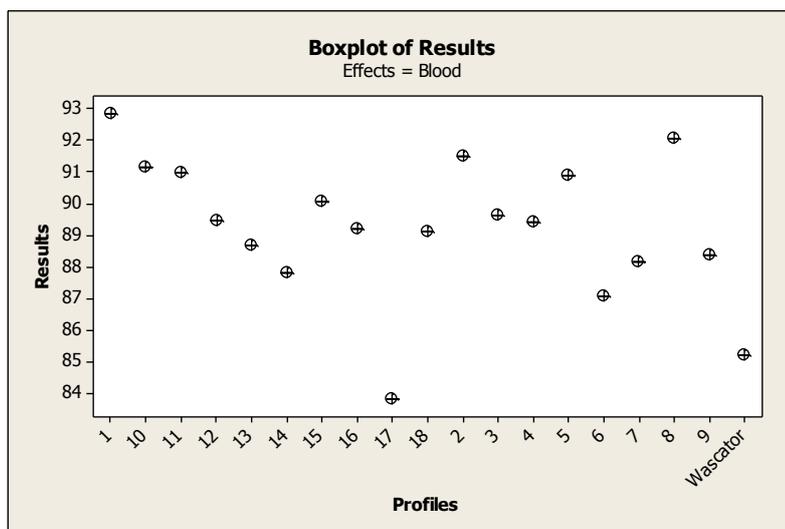


Figure 4.16 : Boxplot for removal of blood stain of profiles

4.2.6.3 Chocolate – milk

It is apparent from Figure 4.17, that created profiles are not very influential about removing chocolate-milk stain. Similarly, wascator has a limited effect on removal of this stain type.

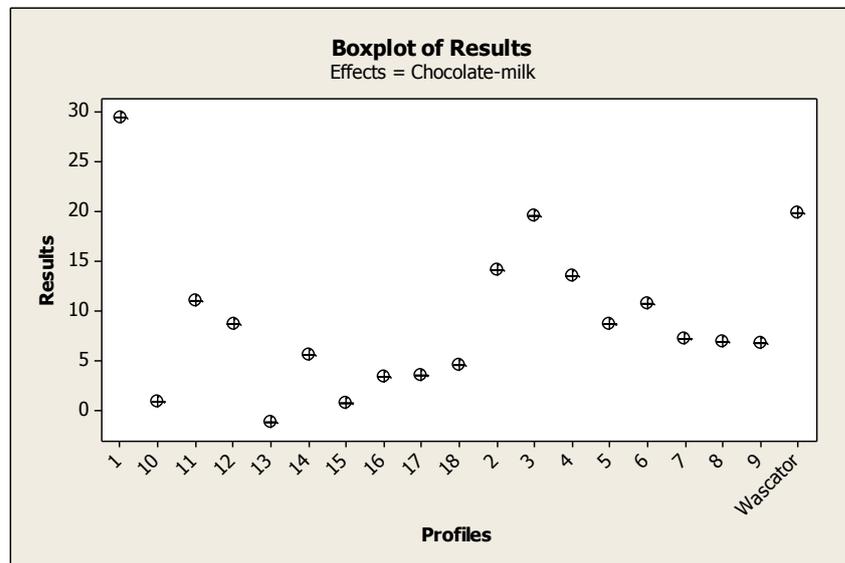


Figure 4.17 : Boxplot for removal of chocolate-milk stain of profiles

4.2.6.4 Red wine

In Figure 4.18, it is apparent that created profiles have similar effects on removing red wine stain. Moreover, wascator has the worst stain removal result among others.

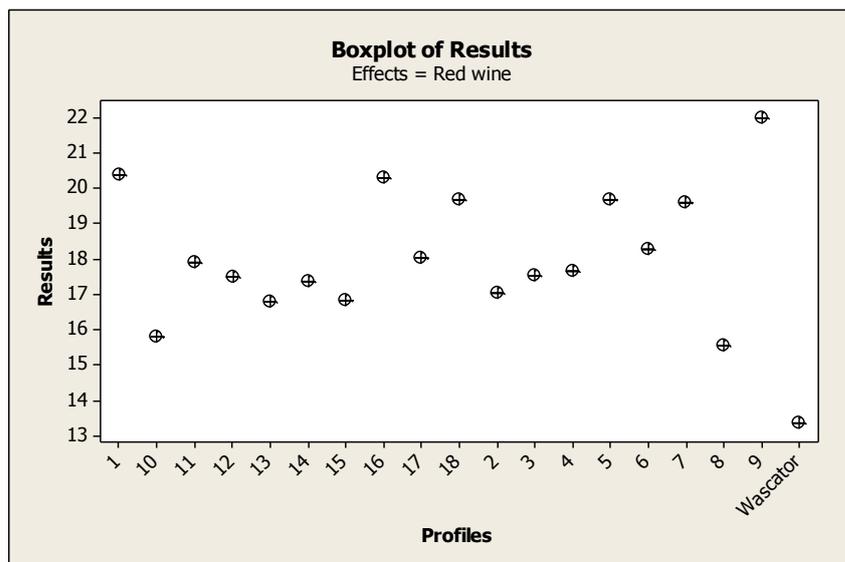


Figure 4.18 : Boxplot for removal of red wine stain of profiles

4.3 Analysis of Energy Consumption

In Figure 4.19 and Figure 4.20, data collecting system's outcomes are shown. With this system, the quantity of water, energy consumption, spinning speeds, washing temperatures can be controlled after test.

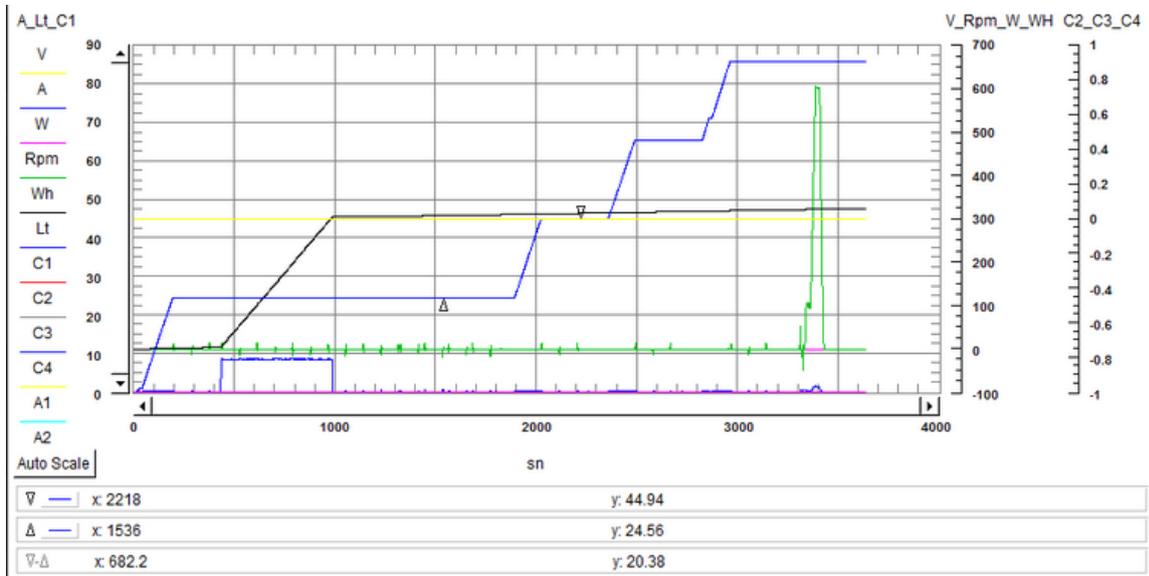


Figure 4.19 : Energy consumption of fourteenth profile

Fourteenth profile's datas are shown in Figure 4.19, in which for 2.5 kg load, 325 W/h energy consumption is observed. Energy consumption in professional wet cleaning machines are two times higher than fourteenth profile's, which is approximately 670 W/h for the same load [38].

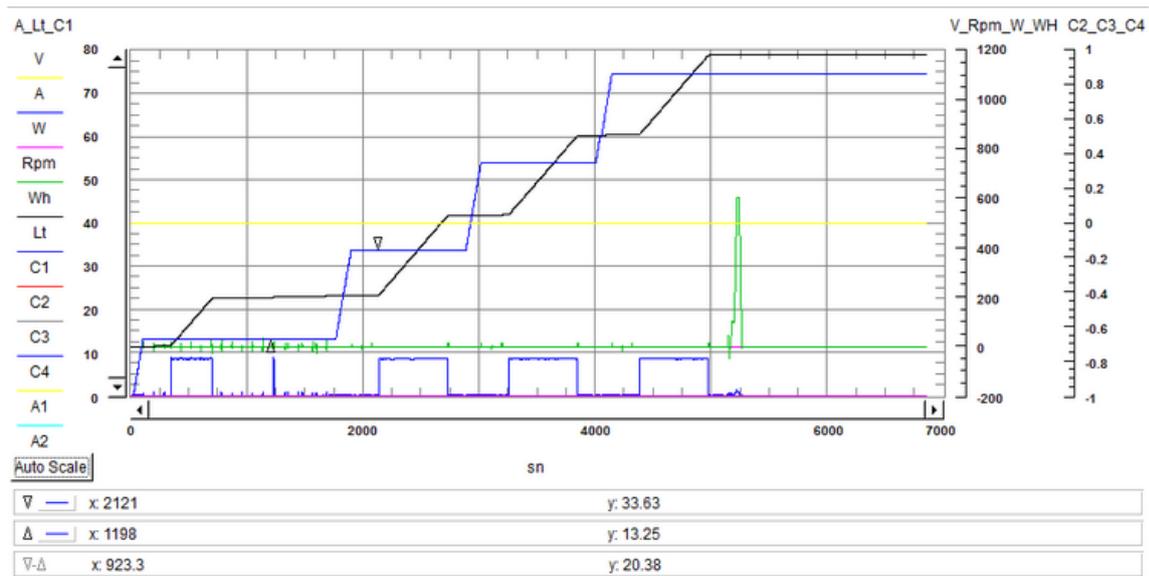


Figure 4.20 : Energy consumption of fifteenth profile

Fifteenth profile, which includes warm rinsing step, consumes more energy when compared to fourteenth profile. As it is shown in Figure 4.20, fifteenth profile's energy consumption is observed 1180 W/h. High energy consumption in this profiles is caused by heating in the rinsing steps.

Taking into consideration ANOVA analysis and energy consumption values, fourteenth profile is much more energy saving and suitable for washing delicate garments when compared to fifteenth one.

5. CONCLUSIONS

Cleaning has been a must from ancient times and various cleaning technologies are developed according to the necessity. Delicate like silk garments, wool, leather products, which are preferred by many people, need cleaning in a way that does not harm them. Dry cleaning is the most known cleaning technique for laundering delicate garments. However, petroleum-derived solvents used in dry cleaning, especially perchloroethylene, are carcinogenic chemicals. Perchloroethylene usage in dry cleaning is limited by EPA and its use is to be banned as of 2023. Wet cleaning technique is developed for human and environmental health as an alternative cleaning system for dry cleaning to wash delicate garments with a specific algorithm in addition to environmental friendly detergents.

In this study, it is aimed to create an algorithm which resembles professional wet cleaning programs. Effects of water amount, mechanical action and rinsing on shrinkage, color loss, rinsing performance, washing performance and mechanical action performance of chosen algorithms are investigated. Results show that higher water amount during laundering which is 25 L provides less deformation on test fabrics and leads to higher washing and rinsing performance. Mechanical actions examined in tests show that higher mechanical action during laundering causes higher shrinkage and color loss on delicate fabrics which is the undesirable result after cleaning. Lower mechanical actions which means lower EDs provide more delicate algorithms in laundering silk and wool fabrics. Considering the effects of rinsing on test fabrics, the results show that 3 rinsing steps and 3 warm rinsing steps in the algorithms provide less deformation on fabrics with higher rinsing performance.

Considering ANOVA analysis and energy consumptions of profiles, fourteenth profile is selected as the best among created algorithms with being more energy saving as well as environmental friendly and it is appropriate

Taking into consideration ANOVA analysis and energy consumption values, fourteenth profile is much more energy saving and suitable for washing delicate garments when compared to fifteenth one.

6. FUTURE WORK

As a further study, detergent type and its amount can be determined according to fabric content. It is known that in conventional wet cleaning applications, pretreatments as well as special detergents are being used. However, in the current study only ECE WOB standard detergent is used. Therefore, in order to catch up with the performance of the professional wet cleaning, a pre-treatment step, i.e. soaking in pre-washing baths with detergent, can be implemented to this algorithm, and special detergents can be chosen and applied leading to optimized wet cleaning recipes considering different stain types and their combinations.

REFERENCES

- [1] **U. S. Environmental Protection Agency** (1998). Cleaner Technologies Substitutes Assessment: Professional Fabricare Processes, *Report Number, EPA 744-B-98-001*, Washington, DC, USA.
- [2] **Url-1** <<http://www.lg.com/us/washers/lg-WT5480CW-top-load-washer>>, date retrieved 17.12.2014.
- [3] **Url-2** <<http://www.arcelik.com.tr/camasir-makineleri-12-kg-12143-cmk-camasir-makinesi-onden-yuklemeli.html>>, date retrieved 19.12.2014.
- [4] **Url-3** <<http://wassuplaundry.com/dry-cleaning.html>>, date retrieved 20.12.2014.
- [5] **Url-4** <<http://sealiongroup.en.made-in-china.com/product/DowxRWfdrIVF/China-Drycleaning-Machine-GXZQ-22F-.html>>, date retrieved 20.12.2014.
- [6] **Linn B.** (2002). Chemicals Used In Drycleaning Operations, *Florida Department of Environmental Protection (FDEP)*, Scott Stupak, North Carolina Superfund Section.
- [7] **Url-5** <<http://eco18.com/is-dry-cleaning-bad-for-your-health/>>, date retrieved 21.12.2014.
- [8] **Sinsheimer P., Saveri G.** (2009). Sacramento Municipal Utility District Professional Wet Cleaning Demonstration Project, Final Report, *Pollution and Prevention Center, Urban and Environmental Policy Institute*, Occidental Collage.
- [9] **Hasenclever K. D.** (2007). Dry Cleaning of Textiles, Handbook for Cleaning/Decontamination of Surfaces, *Kreussler & Co GmbH*, Wiesbaden, Germany.
- [10] **International Fire Code**, 6th Edition, Dry Cleaning, Chapter 12, Solvent Classification, *International Code Council*, New York, USA.
- [11] **Url-6** <<http://www.sermacltd.co.uk/BOWE/Bowe-dry-cleaning-laundry-and-ironing.htm>>, date retrieved 24.12.2014.
- [12] **Stevens J., McAree M.** (2014) Greenwashing Environmental Claims Give Rise to Legal Liability, Fabricare Canada.
- [13] **Hasenclever K. D.** (2007) Wet Cleaning of Textiles, Handbook for Cleaning/Decontamination of Surfaces, *Kreussler & Co GmbH*, Wiesbaden, Germany.
- [14] **Hasenclever K. D.** Report of Professional Wet Cleaning in Europe, *Kreussler Chemical Manufacturing Company*, Weisbaden, Germany.

- [15] **Otter W. A. J. L.** Report on the European Wet Cleaning Committee, *TNO Cleaning Research Techniques Institute*, Delft, The Netherlands.
- [16] **Gregory A. Keoleian, Catherine E. Blacker, Denbow R., Polk R.** (1997). Comparative assessment of wet and dry garment cleaning, Part 1. Environmental and human health assessment, *Journal of Cleaner Production*, Volume 5, USA.
- [17] **Keoleian G. A., Blacker C. E., Nemsick K., Levine W.** (1998) Comparative assessment of wet and dry garment cleaning, Part 2. Performance, economic and regulatory assessment, *Journal of Cleaner Production*, Volume 6, USA.
- [18] **Training Curriculum for Alternative Clothes Cleaning** (1997). *EPA Report Number 744-R-97-004a*, The Massachusetts Toxics Use Reduction Institute, University of Massachusetts, Lowell, Massachusetts, USA.
- [19] **Morris M., Wolf K.** (2005) Evaluation of New and Emerging Technologies for Textile Cleaning, *Institute for Research and Technical Assistance*, Prepared for; California Air Resources Board and the California Environmental Protection Agency, and the US Environmental Protection Agency.
- [20] **California Air Resources Board, California Environmental Protection Agency** (2011). Non-Toxic Dry Cleaning Incentive Program Grant Guidelines, *The California Dry Cleaning Industry*, Sacramento, California, USA.
- [21] **Hesari N., Francis C. M., Halden R. U.** (2014). Evaluation of Glycol Ether as an Alternative to Perchloroethylene in Dry Cleaning, *Arizona State University*, USA.
- [22] **Miele Inc.** (2005). Miele Professional Wet Cleaning, A Revolution in Cleaning Brochure.
- [23] **Electrolux.** Lagoon™ the only wetcleaning fabric care system approved by Woolmark, Brochure.
- [24] **Curry J., Barnabas F., Doty J., Hortel T., Mellea M., Schmidt C., Snyder C., Wernicke T.** (2006). *US 2006018567 (A1) Patent*, Methods for laundering delicate garments in a washing machine.
- [25] **Maßmann F.** (2013). *DE 102008039669 (A1) Patent*, Device for textile care of clothing articles, particularly shirts, blouses or jackets, has rack, on which clothing article is wound up, where nozzles are provided in work connection with rack, Miele & Cie. Kg.
- [26] **Dayioğlu H., Karakaş H.** (2007). Elyaf Bilgisi, *Ajans Plaza*, İstanbul, ISBN: 978-975-01610-1-8.
- [27] **Karahan N., Mangut M.** (2006). Tesktil Lifleri, *Baran Matbaacılık*, Ankara, ISBN: 975-8768-63-0.
- [28] **Mather R. R., Wardman R. H.** (2011). The Chemistry of Textile Fibers, *The Royal Society of Chemistry Publishing*, Cambridge, United Kingdom, ISBN: 978-1-84755-867-1.

- [29] **IEC 60456 International Standard Clothes Washing Machines for Household Use** (2011). Edition 5.
- [30] **Url-7** <<http://www.grundig.com.tr/>>, date retrieved 16.12.2014.
- [31] **Gocek I., Sahin U.K., Erdem I., Namal O., Acikgoz H.** (2013). A Study on Easy-care Laundering of Linen Fabrics, *Textile Research Journal*, Vol. 83, No. 18, 11/2013, pp. 1961-1973, ISSN: 0040-5175, Sage Publications, DOI: 10.1177/0040517513485624.
- [32] **Sahin U.K., Gocek I., Acikgoz H., Erdem I.** (2015) A Novel Algorithm for Easy-Care Laundering of Linen Fabrics: A Cleaner Solution to Wrinkling Problem during Care, *Textile Research Journal*, (accepted for publication).
- [33] **BS EN ISO 3175** (2003). Textiles – Professional care, drycleaning and wetcleaning of fabrics and garments, Part 4: Procedure for testing performance when cleaning and finishing using simulated wetcleaning.
- [34] **Montgomery, D.C.** (1991). Design and Analysis of Experiments, *John Wiley & Sons*, Singapore.
- [35] **AATCC Test Method 135** (2012). Dimensional Changes of Fabrics after Home Laundering.
- [36] **Fah D., Frey F.** (2003). Instruction Manual for EMPA-MA(s) Fabric to Test Mechanical Action in Washing and Tumble Dry Processes.
- [37] **Duran. K.** (2001). Tekstilde Renk Ölçümü ve Reçete Çıkarma, Ege Üniversitesi *Tekstil ve Konfeksiyon – Araştırma Uygulama Merkezi*, Bornova, İzmir, sayfa 52, ISBN NO: 975-483-496-2.
- [38] **Sinsheimer. P., Grout. C.** (2004). Comparison of Energy and Water Use of Five Garment Care Technologies: Evaluation the Potential for an Electricity Rebate Program for Professional Wet Cleaning, Pollution Prevention Education and Researcher Center, Urban and Environmental Policy Institute.



CURRICULUM VITAE

Name Surname: Hatice Açıkgöz
Place and Date of Birth: 17 August 1988, Zonguldak
Address: Istanbul Technical University, Faculty of Textile Technologies and Design
E-Mail: acikgozh@itu.edu.tr
B.Sc.: Istanbul Technical University (2007-2013)
M.Sc.: Istanbul Technical University (2013-2015)

List of Publications:

- Sahin U.K., Gocek I., **Acikgoz H.**, Erdem I., “A Novel Algorithm for Easy-Care Laundering of Linen Fabrics: A Cleaner Solution to Wrinkling Problem during Care”, *Textile Research Journal*, (accepted for publication).
- **Acikgoz H.**, Gocek I., Erdem I., Sahin U. K., “Laundering of Linen Fabrics with a Novel Algorithm”, *2nd International Conference on Natural Fibers*, 27 – 29 April 2015, Azores, Portugal, (accepted for oral presentation).
- Erdem I., Gocek I., Sahin U.K., Acikgoz H., “ Verification of the Washing Algorithm Developed Specifically for Linen Fabrics”, *2nd International Textile Summit*, October 22nd to 24th 2014, Kahramanmaraş, Turkey
- **Acikgoz H.**, Gocek I., Erdem I., Sahin U.K., “Using Different Steaming Step Combinations for Improving Features of Linen Fabrics in Laundry Process”, *2nd International Textile Summit*, October 22nd to 24th 2014, Kahramanmaraş, Turkey
- Gocek I., Sahin U.K., Erdem I., **Acikgoz H.**, “Utilisation of Steaming in Laundry Process as a Factor Improving Laundering Performance”, *14th Autex World Textile Conference*, May 26th to 28th 2014, Bursa, Turkey

- Sahin U.K., Erdem I., Gocek I., **Acikgoz H.**, “Development of a Novel Washing Algorithm for Linen Fabrics”, *14th Autex World Textile Conference*, May 26th to 28th 2014, Bursa, Turkey
- Eren O., Ucar N., Onen A., **Acikgoz H.**, Kızıldag N., Karacan I., Sezer E., Tascan M., Ustamehmetoglu B., “The Effect of Modified CNT and Processing Parameters on Properties of CNT-PAN Composite Nanofiber Web”, *XIII. International Izmir Textile and Apparel Symposium*, April 2-5, 2014, Izmir, Turkey
- Gocek I., Sahin U.K., Erdem I., Namal O., **Acikgoz H.**, “A Study on Easy-care Laundering of Linen Fabrics”, *Textile Research Journal*, Vol. 83, No. 18, 11/2013, pp. 1961-1973, ISSN: 0040-5175, Sage Publications, DOI: 10.1177/0040517513485624