# THE EFFECTS OF HOUSEHOLD FABRIC SOFTENERS ON THE THERMAL COMFORT AND FLAMMABILITY OF COTTON AND POLYESTER FABRICS

by

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Committee Chairman: Jessie Chen-Yu

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#### (ABSTRACT)

This study examined the effects of household fabric softeners on the thermal comfort and flammability of 100% cotton and 100% polyester fabrics after repeated laundering. Two fabric properties related to thermal comfort, water vapor transmission and air permeability, were examined. A 3 X 2 X 3 experimental design (i.e., 18 experimental cells) was developed to conduct the research. Three independent variables were selected: fabric softener treatments (i.e., rinse cycle softener, dryer sheet softener, no softener), fabric types (i.e., 100% cotton, 100% polyester), and number of laundering cycles (i.e., 1, 15, 25 cycles). Three dependent variables were tested: water vapor transmission, air permeability, and flammability. The test fabrics were purchased from Testfabrics, Inc. To examine the influence of the independent variables and their interactions on each dependent variable, two-way or three-way Analysis of Variance (ANOVA) tests were used to analyze the data.

Results in this study showed that both the rinse cycle softener and the dryer sheet softener significantly decreased the water vapor transmission of test specimens to a similar degree. The rinse cycle softener decreased the air permeability of test specimens most and was followed by the dryer sheet softener. The rinse cycle softener increased the flammability of both cotton and polyester fabrics, but the dryer sheet softener had no significant effect on the flammability of

both fabric types. Statistical analysis also indicated that the interactions were significant among the independent variables on water vapor transmission, air permeability, and flammability of the test specimens. For example, the rinse cycle softener significantly decreased the water vapor transmission and air permeability of cotton fabric but had no effect on polyester fabric. The dryer sheet softener also decreased the water vapor transmission of cotton fabric but had no effect on polyester fabric, and it had no effect on the air permeability of both cotton and polyester fabrics. In addition, the air permeability of cotton specimens treated with the rinse cycle softener continuously reduced after repeated laundering, but that of polyester fabrics treated with the rinse cycle softener only reduced after 15 laundering cycles and showed no continuous decrease when laundering cycles increased.

When the influence of fabric softener treatments on flammability was examined, the results showed that the more the specimens were laundered with the rinse cycle softener, the greater the flammability of the test specimens. However, the dryer sheet softener did not have a significant effect on the flammability of the test fabrics even after repeated laundering. For the polyester fabric, all specimens treated with the dryer sheet softener or no softener passed the standard of children's sleepwear even after 25 laundering cycles, but those treated with the rinse cycle softener did not pass the standard.

In conclusion, fabric softener treatment had a significant influence on the thermal comfort (i.e., water vapor transmission and air permeability) and flammability of 100% cotton and 100% polyester fabrics after repeated laundering cycles and the effects were significantly different among the three independent variables (i.e., fabric softener treatments, fabric types, and number of laundering cycles). The applications of these results were also discussed.

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## CHAPTER I INTRODUCTION

Prior to World War II (1940), soaps were used in family laundering. Soaps are made up of fats or fatty acids, and some fat residue left on the laundered fabrics might possibly soften the clothes (McCarthy & Drozdowski, 1989). After World War II, the synthetic detergents were developed and used frequently as laundry products, accompanying the advent of modern washing machines and automatic dryers. The synthetic detergents were more powerful cleaning clothes than soaps and left no residue on the fabrics. However, the harsh mechanical agitation of the washing machine distorted surface fibers and created entanglement, leaving the fabric with a stiff and uncomfortable hand. During the drying process, the automatic dryers tended to "set" the distorted fibers, especially in thermoplastics (Puchta, 1984). When fabrics containing thermoplastic fibers are heated higher than their glass transition temperature but less than their melting temperature, the molecules within the fibers can move freely and change (Hatch, 1993). When the fabric cools down, the structure of the fiber will be permanently set. In addition, the machine laundering left fabrics with an uncomfortable hand as a result of the removal of the fatty finish and lubricating waxes on the fabric when the synthetic detergents removed dirt and oil. As a result, after the introduction of synthetic detergents to the market, the need for a fabric softener was recognized. Fabric softeners were introduced to the United States market in the early 1950s to modify the hand and to restore lost physical properties of laundered clothes (Simpson, 1958).

By coating yarn and fibers with lubricants and humectants, softeners make fabrics feel smooth, soft and flexible by internal lubrication of the fibers (Consumer Reports, 1991).

After the introduction of fabric softeners in the 1950s, their use continued to grow (Ward, 1957; Egan, 1978; Mullin, 1992). In addition to the benefit of improving fabric hand, another reason for the increasing usage of fabric softeners was the decrease of unpleasant static cling, which was prone to be created by synthetic fibers. Friction between fibers causes static electricity, resulting in static cling. Static charges can be dissipated by the natural moisture. Natural fibers like cotton, linen, and wool have high moisture regain (i.e., percent of moisture in a fiber calculated on the basis of its dry weight) (Hatch, 1993). Synthetic fibers, such as polyester, nylon, and acrylic, have very low moisture regain, and static charges may accumulate on fabrics, resulting in clinging and crackling. Fabric softeners act as anti-static agents by enabling synthetic fibers to retain sufficient moisture to dissipate static charges (Ward, 1957). After the application of fabric softeners on synthetic fibers, the lubricating film absorbs moisture from the air, which provides a way for discharging static electricity (Lyle, 1977). Puchta (1984) indicated that anti-static properties related to household fabrics might be the primary reason for American consumers to apply fabric softeners in their home laundering activities.

#### **Statement of the Problem**

Since the 1950s, household fabric softeners have been used in the United States for more than 50 years. Much research had been conducted on the effects of softeners on fabric properties, such as the appearance properties (i.e., wrinkle recovery, pilling, and whiteness) (Baumert & Crews, 1996; Chiweshe & Crews, 2000; Crutcher, Smith, Borland, Sauer, & Perine, 1992; Robinson, Gatewood, & Chambers IV, 1994; Simpson & Silvernale, 1976; Wilson, 1987), and maintenance properties (i.e., dimensional stability and stain release) (Baumert & Crews, 1996; Kaiser & Riggs, 1980; Simpson & Silvernale, 1976). Although some studies examined the effect of fabric softeners on comfort properties such as hand and static electricity (Egan, 1978; Simpson & Silvernale, 1976; Williams, 1982), little research has examined the relationship between fabric softeners and thermal comfort.

Several textile properties would influence the thermal comfort of a garment, such as water absorbency, water vapor transmission, air permeability, and heat transfer. For example, when the wearer is active, it is very important for the textile to have the ability to absorb moisture vapor from the skin (Taylor, 1991). Whenever fibers absorb liquid water or moisture vapor, heat is released, and therefore, water absorbency of fabrics is an important factor that affects the wearer's thermal comfort (Tortora & Collier, 1997). Water vapor transmission is another important factor related to thermal comfort. Water vapor transmission is the speed at which water vapor passes through a textile material (Kadolph, 1998). The transfer of water/moisture vapor is usually from the wetter environment to the dryer environment until equilibrium is reached (Collier & Epps, 1999). The ability of a fabric to carry away water/moisture vapor or to maximize the evaporation of liquid moisture contributes to the thermal comfort of a garment, especially for summer clothes and sportswear. Air permeability is another factor related to the thermal comfort of a garment. Air permeability is the ability of air to flow through the fabric (Tortora & Collier, 1997). In some products, such as sportswear and summer clothes, high air permeability is desirable. However, for some products, such as outerwear, tents, sleeping bags, blankets, and protective textile products, low air permeability is required to keep the wearer comfortable (Kadolph, 1998). Heat transfer is also one factor affecting thermal comfort. Heat transfer refers to the transfer of heat energy from a hotter

environment to a cooler environment (Collier & Epps, 1999; Tortora & Collier, 1997). If the temperature of an environment is lower than the body, heat will be transferred from the body to the environmental surroundings. As a result, people would feel cool. In contrast, under hot conditions, if the ambient temperature is higher than the body, heat will flow from the environment to the body to make people feel warm. In either direction, textiles can provide the resistance to heat flow as insulation between the two environments; thus more heat will be kept near the body and less heat will flow through the fabrics. The amount of trapped air that is contained within a textile structure (i.e., dear air) determines the thermal insulation of a fabric.

Regarding the relationship of household fabric softeners and thermal comfort, some researchers have examined the effect of softeners on water absorbency (Egan, 1978; Robinson, Gatewood, & Chambers IV, 1994; Williams, 1982). They found that rinse cycle softeners would decrease water absorbency, while dryer type softeners had either no effect or slightly decreased water absorbency. However, other factors that influence thermal comfort, such as water vapor transmission and air permeability, have not been examined. Repetitive use of fabric softeners during the laundering process may leave residue of softener on the fabrics, which may create a barrier to airflow and water vapor transmission of the fabric. A study of the influence of fabric softeners on the thermal comfort in terms of water vapor transmission and air permeability is needed.

Flammability has become one of the interests in safety and protective aspects of textile products (Collier & Epps, 1998). Flammability of textile products refers to their burning behavior, especially ease of ignition and sustained burning after ignition. Except glass fibers, almost all the textile fibers are flammable. Therefore, textile products, such as garments, mattresses, bedding or upholstery, by their nature are easy to burn (Merkel, 1991; Thiry, 2001).

Some easy-burning fabrics may cause serious bodily injuries or fatalities and property loss. In 1972, a total of 6,714 people died from fire and flames related accidents (Statistical Abstract of the United States, 1976), in which 542 deaths were from ignition of clothing (Vital Statistics of the United States, 1973; Weaver, 1978). Consumer Reports (2000) reported that in recent years, between 3,000 and 4,000 people were treated for burns because of flammable clothing. Fabric softeners contain lubricants, which are derived from tallow. The residue of softeners on the garment may influence the flammability of fabrics. As an important issue of human safety, how flammability is affected by fabric softeners needs to be investigated. Although the Consumer Report magazine (2000) and the website of NBC10 (2001) reported the effect of fabric softeners on flammability, little scientific research has been found in the investigation of this issue. A study of the influence of fabric softeners on the flammability of textiles is needed.

#### **Purpose of the Study**

The purpose of the study is to explore the effects of household fabric softeners on the thermal comfort and flammability of fabrics after repeated laundering cycles. Household fabric softeners are applied to textile products when people do home laundering with detergents and dryers by coating the laundry with lubricant and humectant chemicals (Consumer Reports, 1991; Robinson, et al., 1994). The study results could complement the gap in fully understanding of the effects of household fabric softeners on fabric properties. The influence of softener treatments on water vapor transmission, air permeability, and flammability of the fabrics may provide knowledge for consumers to make an informed choice of how to care for their textile products. Manufacturers may also use the results from the study to provide better care instruction for their textile products.

### CHAPTER II

#### LITERATURE REVIEW

This chapter of literature review has three sections. The first section, household fabric softeners, includes the discussion of the mechanism of fabric softeners, softener treatments, effects of fabric softeners on the skin, effects of fabric softeners on fabric properties, and the comparison of three fabric softener treatments. The second section, comfort, includes the definition of garment comfort and the discussion of thermal comfort. The third section, flammability, discusses the factors that influence the flammability of textiles, flammability regulations, and measurement of flammability.

#### **Household Fabric Softeners**

Fabric softeners were introduced to the United States (U.S.) market in the early 1950s, and the application of household fabric softeners during laundering has become a routine for American families (Baumert & Crews, 1996). Fabric softeners can help to improve fabric hand and decrease unwanted static cling. The main ingredient in fabric softeners is a cationic surfactant. Cationic softeners were discovered in the early years of the 20th century but were not used by the textile industry until the late 1930's (DuBrow & Linfield, 1957). Since the 1940's, fabric treatment with cationic softeners has gained worldwide acceptance in the textile-finishing and textile-maintenance areas. The first produced household fabric softener in the U.S. in the 1950s was based on di(hydrogenated tallow) dimethyl ammonium chloride, which is one of the sulfated quaternary ammonium compounds (Egan, 1978). American cationic surfactant manufacturers primarily produce sulfated quaternary ammonium compounds because they are excellent lubricants and powerful anti-static agents (Puchta, 1984; Ward, 1957). There are three main types of quaternary ammonium compounds used in the formulation of household fabric softeners: dialkyldimethyl ammonium compounds, diamido alkoxylated ammonium compounds, and imidazolinium compounds (Egan, 1978; Williams, 1982).

#### **Mechanism of Fabric Softeners**

The surfactant of softeners consists of two distinct parts: hydrophobic and hydrophilic (Ward, 1957). The hydrophobic (or fatty) part is water hating, and does not mix with water. The hydrophilic part is water loving, resulting in compounds dispersing in water. When the surfactant is floated on the surface of the liquid, it lowers the surface tension and ionizes to create positive ions containing the hydrophobic groups. The hydrophobic part has a positive electrical charge, while the hydrophilic part is negatively charged. The fabric softeners are called cationic because the positively charged hydrophobic parts are predominant in the rinse water when cationic softeners are added. Most fabrics are negatively charged, so all the cationics will be picked up by the fabrics and be retained on the fabric during the laundering process when fabric softeners are applied. The hydrophobic part of a fatty hydrocarbon is the agent that causes cationic softeners to lubricate the fibers in a fabric (McNally & McCord, 1960).

#### **Softener Treatments**

Puchta (1984) reported that three household softener treatments share high market popularity in the U.S.: (a) water cycle softeners – softeners that are used in the wash cycle, (b) rinse cycle softeners – softeners that are used in the final rinse, and (c) dryer sheet fabric softeners – softeners that are used in the dryer. These products are commonly sold as 75% concentrates of isopropanol or isopropanol and water, in which isopropanol is used to dissolve the cationic agent, and water is used to ensure dispersion of the softener in water (Egan, 1978). The water cycle and rinse cycle softeners are generally liquid aqueous softener dispersions. The rinse cycle softeners were the first to appear in the market, followed by the water cycle softeners. Williams (1982) reported that rinse cycle softeners were the most popular and the most effective way to soften the fabrics. The dryer sheet fabric softeners, which are fabric softeners saturated onto sheets of a non-woven fabric or polyurethane foam, were introduced to the market in the early 1970s.

The effects of these three fabric softener treatments on softness and static electricity vary. Rinse cycle softeners formulated with dihydrogenated dimethyl ammonium compounds have the highest rating of softening and good anti-static performance, but they are less convenient to use because they are added into the final rinse process (Baumert & Crews, 1996). Wash cycle softeners, in the same formulation of dihydrogenated dimethyl ammonium compounds, need two to three times more softener agents to reach the same level of softness compared to the rinse cycle softeners, which makes laundering more expensive, and they also have the tendency to decrease the cleaning properties of the detergent used. However, wash cycle softeners are convenient to use because they are added at the very beginning of the laundering process. As for dryer sheet fabric softeners, they are convenient to use and yield the best anti-static properties because of the formulation of imidazolinium compounds used in the dryer type softeners (Williams, 1982). However, dryer sheet fabric softeners are less effective in softening fabrics than rinse cycle softeners because of erratic deposition of softener and less lubrication on the fabric.

#### Effects of Fabric Softeners on the Skin

Many studies showed that the usage of fabric softeners has no adverse effects on the skin (Bouchier-Hays, 1988; Jenkins & Batham, 1983; Pierard, Arrese, Dowlati, Daskaleros & Rodriguez, 1994; Pierard, Arrese, Rodriguez & Daskaleros, 1994; Rodriguez, Daskaleros, Sauers, Innis, Laurie & Tronnier, 1994). For example, Rodriguez, et al. (1994) conducted a series of studies to evaluate the effects of liquid fabric softeners on human skin. These studies included contact sensitization and contact irritation tests of softener formulations and softenertreated fabrics, and extended family usage tests for a liquid fabric softener. The authors used a variety of liquid fabric softener formulations available on the market in Europe and North America. Their study results showed that liquid softeners were not allergy sensitizers or irritating to the skin. Continuous home usage and wearing of softener-treated fabrics had no adverse effect on the skin. In the two studies conducted by Pierard, Arrese, Dowlati, Daskaleros, and Rodriguez (1994), and Pierard, Arrese, Rodriguez, and Daskaleros (1994), instrumental measurement of biophysical skin parameters showed that, due to the reduced friction on skin, the softened fabrics provided a beneficial effect on previously damaged skin and on infant and sensitive skin.

#### **Effects of Fabric Softeners on Fabric Properties**

The effects of household fabric softeners on textiles have been studied in various areas, such as, fabric weight, fabric strength, dimensional stability, wrinkle recovery, pilling, whiteness, hand, static electricity, odor, absorbency, flammability, and stain release.

#### Effects on fabric weight and fabric strength

Simpson and Silvernale (1976) investigated the effects of three fabric softener treatments on the properties of three types of flame retardant finished woven cotton fabrics after 75 laundering cycles. The three fabric softeners were different in their formulation for adding during wash cycle, rinse cycle or dryer spray process. A control group (i.e., no softeners) was also included in the experimental design. The results regarding fabric weight showed that, after 75 launderings, the fabric treated with the dryer spray softener lost weight, but both rinse cycle softener and wash cycle softener resulted in gaining weight. The authors also examined the effect of fabric softeners on tensile strength. The results showed that the laundering without softener and the use of the dryer spray resulted in better strength retention in the warp direction than the laundering with the rinse cycle or wash cycle softeners. For the filling direction, the laundering without softener resulted in better strength retention than the use of softeners. These results were similar to the study of Chiweshe and Crews (2000), which found that the tensile strength of the cotton flannel and polyester woven fabrics decreased significantly after the fabrics were treated with rinse cycle softeners. The authors suggested that the lubrication of the softener on fibers increased fiber mobility, resulting in weak spots and fiber slippage, which caused yarn to break more easily and reduced the tensile strength of the fabric. Fabrics treated with dryer sheet softeners or with no fabric softeners slightly increased tensile strength. The authors believed that

the reason why the fabric treated with the dryer sheet softeners did not reduce tensile strength was because the fabric did not absorb softeners enough to give high lubricity. These findings were consistent with the report from AATCC's Midwest ITPC Committee (1973), which indicated that softeners decreased bursting strength of cotton fabrics.

#### Effect on dimensional stability

Simpson and Silvernale (1976) also examined the effect of fabric softener on dimensional stability. The washed flame retardant fabrics without a softener and with the dryer spray showed a higher degree of shrinkage. The rinse cycle softener and the wash cycle softener gave better dimensional stability in both the warp and filling directions of the fabric. The authors suggested that the application of wash cycle and rinse cycle fabric softeners helped stabilize the fabric and minimize the shrinkage of the tested flame retardant-finished cotton fabrics. This result was consistent with the study conducted by Kaiser and Riggs (1980), who investigated the effects of wash and rinse cycle fabric softeners on the dimensional stability of fire retardant flannelette fabric and tricot fabric for use in children's sleepwear. The findings showed that the rinse cycle softener provided the most favorable results regarding dimensional stability for flannelette fabric. The authors suggested that the rinse cycle softener might leave some form of film on the warp yarns which prevented progressive shrinkage to some extent. However, they found that the tricot fabric was not stable in dimension after the treatments of wash and rinse cycle softeners. A significant shrinkage was observed in the course direction of the fabric.

#### Effect on wrinkle recovery

Baumert and Crews (1996) investigated how the inclusion of rinse cycle and dryer sheet fabric softeners influenced wrinkle recovery of the 100% cotton and the polyester/cotton woven fabrics with and without the durable press finish after three laundering cycles. The authors used the recovery angle test method and found that rinse cycle fabric softeners markedly improved wrinkle recovery angle in most test fabrics. The dryer sheet fabric softeners only significantly improved the wrinkle recovery angle of the 100% cotton broadcloth without a durable press finish, and showed no effect on other fabric types. The authors suggested that these results were possibly caused by non-uniform application of softener from the dryer sheet. When Robinson, Gatewood, and Chambers IV (1994) examined the effect of dryer sheet fabric softener on the smoothness of 100% cotton fabrics, they also found a similar result. The smoothness of 100% cotton sheeting specimens significantly improved after 25 cycles with dryer sheet fabric softeners.

#### Effect on pilling

Chiweshe and Crews (2000) examined the influence of fabric softeners on pilling in selected woven and knitted fabrics. The researchers used the elastomeric pad pilling test according to the ASTM D 3514-96 Standard Test Method for Pilling Resistance and Other Related Surface Changes of Textile Fabrics. The visual examination of the specimen showed that the softener treatment perceptibly influenced the size and nature of the pill formed on the cotton flannel fabric. Specifically, cotton flannel laundered with rinse cycle softeners tended to form bigger and softer pills than the specimen treated with dryer sheet softeners or without fabric softeners, which formed smaller and harder pills. However, when the researchers analyzed the

experimental data statistically, they did not find a significant difference in the effect of softener treatment on pilling ratings. Similar results were found with cotton jersey, cotton interlock knit, and cotton/polyester jersey fabrics. The authors also indicated that softener dosage had no significant effect on the amount of pilling or on the size and nature of pills formed on cotton flannel and cotton interlock knit.

#### Effect on fabric whiteness

Many researchers examined the effect of fabric softeners on fabric whiteness. Simpson and Silvernale (1976) found that the use of the rinse cycle softener and wash cycle softener caused a decrease in fabric's whiteness. The use of dryer spray softener increased the whiteness of the THPOH-amide treated fabric and decreased slightly the whiteness of THPC-urea treated fabric. Similar results were found in the study of Crutcher, Smith, Borland, Sauer, and Perine (1992). The authors investigated the effect of fabric softeners on the whiteness of 100% cotton toweling fabric. The researchers asked panelists to rank the fabrics' whiteness after being treated with fabric softeners. Towels laundered with a rinse fabric softener were ranked the least white after four laundering cycles, while untreated fabrics were ranked the whitest. Towels laundered with dryer sheet formulations were ranked almost the same as untreated towels. Another consistent result was found in the study of Wilson (1987), who tested the influence of three brands of commercially available softeners (i.e., Downy rinse cycle, Bounce dryer sheet, and Bold 3 detergent-softener combination) on fabric whiteness. The researcher asked 15 female observers to evaluate whiteness after the towels had been laundered 25 times. Towels laundered with a rinse cycle softener received the fewest votes for whiteness while those towels laundered with a dryer sheet and detergent-softener combination yielded more whiteness. Another result

from Baumert and Crews (1996) also showed that the rinse cycle fabric softener significantly decreased whiteness in most test fabrics. The 100% cotton laundered fabric with a dryer sheet softener had higher whiteness indices than 100% cotton control specimens laundered without softener. However, the dryer sheet softener did not significantly improve the whiteness indices of polyester/cotton shirting. Although the differential influence on the whiteness indices of fabrics laundered with a rinse cycle softener versus a dryer sheet softener was significant based on the instrumental measurements, the differences in whiteness indices were not visually perceptible.

#### Effects on fabric hand, static electricity and odor

Some researchers studied the effects of fabric softener on fabric hand, static electricity, and odor. Simpson and Silvernale (1976) found that rinse cycle softener yielded the best performance in hand, followed by the dryer spray. The wash cycle softener gave the poorest performance in hand, which was sticky and gummy. These results were consistent with the study conducted by Williams (1982), which showed that the degree of softening of wash cycle softeners was less than that of dryer cycle softeners, and the softening level for most dryer cycle softeners was less than the softening of most rinse cycle softeners.

Egan (1978) studied the effect of fabric softeners on anti-static performance and found that the wash cycle softeners imparted adequate anti-static properties, but dryer type softeners were the best in imparting anti-static properties to the cloth, up to a 90% or higher reduction of static charge. This excellent anti-static performance would be maintained till three times of usage. Consistent results were also found in the study conducted by Williams (1982), which showed that dryer cycle softeners were the best for controlling static cling, and wash cycle softeners were better than rinse cycle softeners.

As for the odor of fabrics laundered with softeners, Simpson and Silvernale (1976) revealed that the use of the dryer spray was the most effective way to bring a pleasant odor, followed by the rinse cycle softener, no use of a softener, and then the wash cycle softener.

#### Effect on absorbency

Egan (1978) indicated that rewetting properties is an important indication for the absorbency characteristics of fabric after treated with a softener. Too much fabric softener would waterproof the cloth. The author conducted a wicking test to evaluate rewetting characteristics. Wicking refers to the ability of a fiber to transport moisture along its surface or through the capillary spaces in yarns (Kadolph & Langford, 1998; Tortora & Collier, 1997). In this wicking test, a strip of softener-treated fabric was dipped into water containing a dye, and the height to which the water will go up the strip was measured. The general rule is that the higher the water climbed the test strip, the better the rewettability. The author found that the greater the ability in softening fabrics, such as rinse cycle softeners, the poorer in rewetting. This result was consistent with the study conducted by Williams (1982), who also found that the more the amount of rinse cycle softener in the fabric, the poorer the water absorbency. As softness increased, absorbency decreased. Robinson, et al. (1994) investigated the effects of three dryer type fabric softeners (i.e., Bounce® Outdoor Fresh, Cling Free® Spring Fresh Scent, and Top Crest®) on the absorbency of three 100% cotton fabrics (i.e., sheeting, rib knit, and terry cloth). The fabric specimens were laundered once and then 25 times using home laundering and drying procedures according to the AATCC Test Method 79-1986. The authors found that treatments using dryer type fabric softeners did not have an adverse effect on the rate of water absorption for tested specimens. When the ASTM D 4772-88 test method was used to test the absorbency of terry

cloth, the water absorbency of terry cloth treated with Cling Free was greater after 25 laundering cycles than one laundering cycle. However, the other two softeners, Bounce and Top Crest, brought a slight decrease in absorbency of the terry cloth after the same treatment.

#### Effect on flammability

A report from Consumer Reports (2000) investigated whether fabric softeners would affect flammability of a fabric. Flammability tests were performed on 2,400 fabric swatches with and without fabric softeners after 5, 15, 30, and periodically up to 60 laundering cycles. The swatches came from men's, women's and children's clothing such as fleece sweatshirts, sheer blouses and skirts, pajamas, robes, and chenille sweaters. A leading brand of rinse cycle fabric softener and a leading brand of dryer sheet softener were used. The results showed that although rinse cycle softener accelerated the burning speed of most tested fabrics, most fabrics remained within the legal limits except for three fabric types used in a men's reverse-fleece sweatshirt, a women's cotton terry-cloth robe, and a men's cotton velour robe. Fabrics laundered with dryer sheets burned almost at the same speed as those laundered without fabric softener. The report concluded that clothing might become more flammable when laundered with rinse cycle softeners and recommended avoiding rinse cycle fabric softener with cotton clothing made of fleece, terry cloth, or velour. Consistent results were also found in the study conducted by Davidson (2001), reported on the NBC10 website. The result showed that liquid fabric softener increased the flammability of the fabrics, but dryer sheets appeared to have no effect on the flammability of the fabrics. Few studies were found in academic journals. One study, conducted by Kaiser and Riggs (1980) and published in an academic journal, investigated the effects of wash or rinse cycle fabric softeners on the flame retardant properties of cotton flannelette fabric

for use in children's sleepwear. The authors also found that a buildup of wash or rinse cycle fabric softener on the flannelette significantly increased the flammability of the fabric. The effect of dryer sheets on flammability had not been examined in this study.

#### Effect on stain release

Baumert and Crews (1996) examined the effect of fabric softener on stain release and found that both rinse cycle softener and dryer sheet softener improved stain release compared to specimens washed without fabric softener. The dryer sheet fabric softener provided the best improvement. The authors suggested that this improvement in stain release could be explained by the build up of dryer sheet softeners on the fabric surface. This build up created a barrier to oily soils.

#### **Summary of Household Fabric Softeners**

Household fabric softeners have been used for textile products during home laundering for more than 50 years to improve fabric hand and to decrease the static charges. Cationic surfactant is the main ingredient in fabric softeners which are structured part hydrophobic and part hydrophilic (Ward, 1957). The hydrophobic part is the agent that causes cationic softeners to lubricate the fibers in a fabric (McNally & McCord, 1960). There are three household fabric softener treatments: water cycle softeners, rinse cycle softeners, and dryer sheet fabric softeners. The effects of these three fabric softener treatments on softness and static electricity are different. Rinse cycle softeners provide the best improvement of hand, and dryer sheet fabric softeners bring the best improvement of static electricity. The past studies showed that there was no association between the usage of fabric softeners and the adverse effects on the skin

(Bouchier-Hays, 1988; Jenkins & Batham, 1983; Pierard, Arrese, Dowlati, Daskaleros & Rodriguez, 1994; Pierard, Arrese, Rodriguez & Daskaleros, 1994; Rodriguez, Daskaleros, Sauers, Innis, Laurie & Tronnier, 1994). Research has been conducted to examine the effects of fabric softeners on the appearance properties (i.e., wrinkle recovery, pilling, and whiteness), maintenance properties (i.e., dimensional stability and stain release), and thermal comfort (i.e., absorbency) of cotton and polyester fabrics (AATCC Midwest ITPC Section, 1973; Baumert & Crews, 1996; Chiweshe & Crews, 2000; Kaiser & Riggs, 1980; Robinson, Gatewood, & Chambers, 1994; Wilson, 1987). Results indicated that rinse cycle softeners minimize shrinkage, reduce static electricity, bring good odor, and improve hand, smoothness, wrinkle recovery, and stain release. However, the disadvantages of rinse cycle softeners are the increase of flammability, the formation of bigger pills, and the decrease of fabric strength, whiteness, and absorbency. Wash cycle softeners provide fabric stability and control static electricity. The disadvantages of wash cycle softeners are the decrease of fabric strength and whiteness. The most negative effect of wash cycle softeners is the sticky and gummy hand. Dryer type softeners provide the best improvement of static electricity, odor, and stain release. Dryer type softeners also provide better fabric strength retention, form smaller pills, and improve wrinkle recovery, whiteness, and hand. The disadvantages of dryer type softeners lie in uneven softener deposition.

#### Comfort

#### **Definition of Garment Comfort**

Comfort is an important factor for consumers to evaluate their purchases and to determine their satisfaction with products (Kadolph & Langford, 1998). Collier and Epps (1999) defined comfort as a human feeling for a condition of ease or well-being. Slater (1985) defined

comfort as "a pleasant state of physiological, psychological, and physical harmony between a human being and the environment" (p.4). Consistent with Slater's definition of comfort, Branson and Sweeney (1990) defined clothing comfort as "a state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" (p.371). Physiological comfort relates to the human body's ability to continue functioning and can be identified by all parts of the body and in all of its mechanisms (Slater, 1985). Some performance properties of fabric that contribute to physiological comfort include the feel of the fabric against the skin, such as an itchy, rough or warm/cool feeling, and the static cling and shock that result from the electrical resistivity of fabric (Hatch, 1993). Other properties of fabrics, such as water/moisture vapor transmission and air permeability that influence sweating rates and local skin wetness, may contribute to general feeling of warm discomfort (Gonzalez, Endrusick, & Levell, 1998). For example, winter sportswear satisfies the demands of physiological comfort by serving the complete functions of heat retention and moisture permeability while still being waterproof (Furuta, Shimizu, & Kondo, 1996).

The psychological comfort, as a mental comfort, refers to the mind's ability to function satisfactorily without direct physical distraction from the body (Slater, 1985). For example, psychological discomfort may occur when the wearer perceives a garment to be the wrong color, out of fashion, unflattering in fit and style, or unsuitable for an occasion (Merkel, 1991).

The physical effects on human comfort can be divided into two distinct types (Slater, 1985). One type is the actual physical sensations within the body. For example, physical changes occur in the sense functions of sight, hearing, taste and smell to bring about an alteration in the level of comfort. Skeleton and muscles could also affect human comfort. Another type of

physical effect would be the external factors. For example, temperature and moisture are important environmental factors related to physical comfort (Collier & Epps, 1998).

#### **Thermal Comfort**

Thermal comfort refers to sensations of hot, cold, dry or dampness in clothes and is usually associated with environmental factors, such as heat, moisture, and air velocity (Collier & Epps, 1998). Many properties of textile materials, such as water/moisture vapor transmission and air permeability, are important factors that affect the thermal comfort of textiles.

#### Water/moisture vapor transmission

Water/moisture vapor transmission is the rate at which water/moisture vapor diffuses through a fabric (Hatch, 1993). The moisture transport from the skin to the outer environments through clothing materials, often referred to breathability of the fabric, is an important factor in human comfort (Tortora & Collier, 1997; Weiner, 1970; Whelan, MacHattie, Goodings, & Turl, 1955). The transfer of water/moisture vapor is usually from the wetter environment to the dryer environment until equilibrium is reached (Collier & Epps, 1999). The body produces moisture in the form of perspiration, which includes sensible perspiration and insensible perspiration. Sensible perspiration is produced as liquid perspiration under hot or strenuous conditions. Insensible perspiration evaporates within the skin layers in the form of emitting water/moisture vapor. A significant amount of perspiration should leave by vapor diffusion through the fabric components of the garment to maintain heat balance (Weiner, 1970). As moisture is evaporated from the skin surface, a moisture-vapor-permeable fabric allows moisture vapor to go through, keeping the fabric and skin dry and permitting evaporative cooling (Hatch, 1993). Hygroscopic

fabrics have the capability to absorb water vapor when they are surrounded by humid air and release water vapor in dry air (Barnes & Holcombe, 1996).

A garment for daily use should have a degree of water/moisture vapor transmission, in which the hotter the environment or the greater the activity level, the higher the water/moisture vapor transmission is required (Weiner, 1970; Whelan, et al., 1955). For example, when people do exercise in a hot environment, the function of perspiration as a factor in body-temperature regulation will be most effectively achieved if insensible evaporation can take place immediately. If people wear clothing with a low water/moisture vapor transmission property under hot situations, the heat transfer from people's skin outward will be suppressed or reduced, and thus, people may feel uncomfortable. However, for some products, fabrics with low water/moisture vapor transmission capability are required (e.g., chemical protective clothing, raincoats, diapers, tents, tarpaulins, and apparel) (Wehner, Miller, & Rebenfeld, 1988). In these products, a vapor barrier is needed to achieve the performance of their end-use.

Factors that influence water/moisture vapor transmission. Fiber content and fabric geometry are two main factors that may affect the water/moisture vapor transmission of textiles. Fiber content is one of the determinants of water/moisture vapor transmission because water/moisture vapor is absorbed by fibers, transported through fibers, and then desorbed to the environment (Tortora & Collier, 1997). In this process, the inherent absorbency of the fibers or their affinity for water will determine the process of water/moisture vapor transmission. For example, rayon and wool absorb moisture readily from the body, but polyester and olefin do not. Whelan, et al. (1955) studied the influence of fiber composition on the resistance to water/moisture vapor transmission. The researchers used a wide range of textile materials including wool, cotton, silk, acetate, nylon, and viscose rayon with different fabric structures,

such as thickness, weight, and density. The results showed that different types of fibers had different influences on water/moisture vapor transmission because they had different moistureabsorption characteristics. Lower resistance to water/moisture vapor transmission was exhibited in more hygroscopic fabrics. As the moisture-absorption capacity decreased, the resistance to water transfer increased. Fabrics with different wicking characteristics may also have different influences on water/moisture vapor transmission. Olefin fabrics are excellent in wicking, and therefore, often used in sportswear. Although olefin fabrics do not absorb water, they permit liquid perspiration to wick through the yarns very efficiently and provide high water/moisture vapor transmission as well.

Whelan, et al. (1955) found that the spatial/geometric distribution of fibers in a fabric might also play a significant role in water/moisture vapor transmission properties. The changes of thickness and percentage fiber volume would affect the resistance to water/moisture vapor transmission of any particular cloth. As the fabric's thickness and percentage fiber volume increased, the resistance of the fabric to water/moisture vapor transmission increased. Yoon and Buckley (1984) tested the water/moisture vapor transmission rate (WVTR) for plain jersey knit fabrics of 100% polyester, 80/20, 65/35, and 50/50 polyester/cotton blends, and 100% cotton. The results showed that 100% polyester fabric exhibited a substantially higher WVTR value than the 100% cotton fabric, and the WVTR value for polyester/cotton blends fell between the WVTR values of the two pure fabrics, responding to their blend level. The researchers explained that the reason for variation of WVTR values with different fiber contents lay in the effect of fiber type on fabric geometry. Instead of the physical properties of the fiber, such as absorbency and wicking, the difference in fiber geometry brought about difference in fabric geometry. For example, the water/moisture vapor transmission property of a fabric is basically a property of

inter-yarn pore air, which is affected by inter-yarn pore size and thickness of the fabric. The fabric geometric parameters of porosity and thickness are affected by yarn diameter, which is determined by the fiber composition.

<u>Measurement of water/moisture vapor transmission</u>. Gibson (1993) discussed two common methods that were applied to measure water/moisture vapor transmission of clothing materials: cup/dish tests (i.e., the ASTM test method of E96-80) and sweating guarded hot plate devices (i.e., the ASTM test method of D1518-77). The cup/dish methods are easy to carry out and inexpensive equipment is used. People usually prefer the sweating hot plate method, which simulates the heat and mass transfer conditions of the human body very accurately, although the hot plate method needs much more elaborate equipment and much larger sample sizes.

In the ASTM E96–80 water method, the WVTR is determined by measuring the grams of water/moisture transmitted per square meter of specimen in a 24 or 48-hour period. The reported quantity in g/m<sup>2</sup>/hour was acquired by periodically weighing the sample dish. The water method of ASTM E96-80 has its inherent problems. The still air layer in the cup between the fabric sample and the water surface may have a higher resistance to water/moisture vapor transmission than the fabric sample itself (Gibson, 1993). Because of this limitation, the ASTM E96-80 method is only appropriate for evaluating water/moisture vapor transmission of fabrics with high water vapor resistances. However, the ASTM E96-80 method of the cup/dish test is used continuously because of its wide acceptability, convenience, and large existing database of previous research results.

The sweating guarded hot plate method comes from the ASTM D 1518-77, Standard Test Method for Thermal Transmittance of Textile Materials between Guarded Hot Plate and Cool Atmosphere. The plate measures the required power to keep a flat isothermal area at a constant

temperature. There are two effects in the test. First, when the plate is covered with a test fabric, the amount of required power to keep a flat isothermal area at a given temperature is related to the dry thermal resistance of the test sample. Second, if the plate is saturated with water, the amount of required power to keep it at a given temperature is related to the WVTR at which water evaporates from the surface of the plate and diffuses through the test material. Because the sweating guarded hot plate methods account for both heat and vapor transfer effects, the dry thermal resistance of the test material needs to be tested first and then water/moisture vapor transmission properties of the test fabric is determined by saturating the plate surface with water and repeating the test.

Gibson (1993) used a variety of materials to study whether there was an experimental correlation between the two kinds of water/moisture vapor transmission tests (i.e., cup/dish test and sweating guarded hot plate test). The researcher used a full range of testing materials grouped by four classes: (a) permeable materials (i.e., woven and non-woven fabrics), (b) hydrophilic membrane laminates, which were made with a monolithic hydrophilic polymer coating or layer, (c) hydrophobic membrane laminates, which were made from a hydrophobic polymer that contained tiny interconnected pores to allow water/moisture vapor to diffuse through the membrane, and (d) impermeable materials. The researcher found that for the permeable materials and hydrophobic membrane laminates, a linear correlation existed between the two test methods. However, the hydrophilic materials showed much better water/moisture vapor transmission properties in the sweating guarded hot plate test than they did in the cup/dish test. The lower resistance to water/moisture vapor transmission in the sweating guarded hot plate tests was due to much greater water concentration in the hydrophilic polymer layer. The

researcher concluded that the ASTM E96-80 method was adequate for measuring most materials that experienced water/moisture vapor diffusion through the air spaces in their inner structures.

Another test method, which is called Desiccant Method in ASTM E 96-00, is also used for measuring water/moisture vapor transmission. In a controlled atmosphere (a recommended temperature of 32°C and relative humidity of 50%), a test material is sealed to the open mouth of a dish containing a desiccant with known weight, which is able to absorb water/moisture vapor from the air. The periodic weightings of the assembled test dishes determine the rate of water/moisture vapor transmission through the specimen into the desiccant.

#### Air permeability

Air permeability is the capability of airflow through the fabric (Tortora & Collier, 1997). It is denoted in U.S. standard units as cubic feet of air per minute per square foot of fabric (ft<sup>3</sup>/min/ft<sup>2</sup>) at a stated pressure differential between the two surfaces of the cloth (Lyle, 1977). Air permeability is an important factor in the performance of many textiles materials such as filters, clothing fabrics, mosquito netting, sails, hot air balloons, and parachutes. For example, high air permeability is required for fabrics used to make clothing for hot conditions to provide ventilation (Taylor, 1991). Air permeability is also very important as a comfort element for outerwear, tents, sleeping bags, blankets, and other protective textile products (Kadolph, 1998). For example, for rainwear to act as a barrier to the penetration of rain, or a windbreaker to prevent wind from going through the fabric and maintain body temperature under cold conditions, low air permeability is required.

<u>Factors that influence air permeability.</u> The ability of a fabric to inhibit air or allow air to go through it freely is mainly dependent on the thickness, porosity, construction and geometry of

the fabric (Vigo, 1994). For example, fabric cover factor is an important aspect of air permeability. Cover factor refers to the ratio of fabric surface area that is covered by the component yarns to total fabric surface (Tortora & Collier, 1997). Partridge, Mukhopadhyay, and Barnes (1998) investigated the air permeability aspects of airbag fabrics. Specimens that they selected were nylon 66 yarn type fabrics, which were model representative materials of airbag fabrics currently used in the automotive industry. Their results indicated that fabrics with increasing cover factors showed declining permeability values. The combined effect of coarser yarn elements and small ports would stifle the airflow within the fabrics. Yarn twist also has an effect on air permeability. When yarn twist is increased, the circularity and density of the yarn increases; the varn diameter and cover factor are reduced and the air permeability increases (Lyle, 1977). However, fabrics with compact, tightly twisted yarns or high fabric counts will have lower air permeability due to reduced air space between yarns, resulting in little air flow through the fabric (Tortora & Collier, 1997). Meanwhile, yarn crimp and fabric weave would influence the shape and area of the interstices between yarns. If yarns are permitted to extend more easily, the yarn extension will open up the fabric, increase the free area, and increase the air permeability of fabric (Lyle, 1977). The amount of finish and coating applied on the fabric may also have an effect upon air permeability by bringing a change in the length of airflow paths through a fabric. For example, hot calendaring flattens yarns, thus reducing air permeability. Ciréing of thermoplastic fabrics may also decrease air permeability by causing fibers and yarns to fuse slightly (Tortora & Collier, 1997).

Some researchers examined the effect of fiber wetting on the air permeability of a fabric. Wehner, Miller and Rebenfeld (1987) found that at a low differential pressure, hydrophilic fibers such as cotton and wool would easily swell after absorption of water and the change in fabric
porosity and thickness resulted in decreasing air permeability. Belkacemi and Broadbent (1999) used several woven (plain and twill weave) and non-woven fabrics containing a range of fiber types to examine the influence of fiber wetting on the air permeability of fabrics at both low and high differential pressures. The authors found that fabric air permeability was in general lower when the fabric was wet, even for those fabrics made of fibers that do not swell. At a low pressure drop of 12.5Pa, the low air speed through the fabric channels was not enough to remove water droplets from fiber surfaces and intersections, and thus, the pore volume and air permeability was decreased. At a high pressure drop of 55 kPa, the air speed approached the acoustic velocity and the shear forces created tore water droplets from the fibers, thus leaving little water on the fabric. The change of pore volume was limited. The effect of fiber wetting on the air permeability is less significant at higher pressure differentials than for lower.

<u>Measurement of air permeability</u>. A common test method for measuring air permeability is the ASTM Test Method D737 for Air Permeability of Textile Fabrics, in which the rate of air flow passing perpendicularly through a known area of fabric is adjusted to secure a prescribed air pressure differential between the two sides of the fabric surface in the test area (ASTM 2000). On the basis of this airflow rate, the air permeability of the fabric is determined. This standard test method can be applied to woven, knitted, or non-woven fabrics; therefore, it has been used by many researchers to measure fabric air permeability (Belkacemi & Broadbent, 1999; Lee & Obendorf, 2001; Partridge, et al., 1998).

Air permeability measurement is more complex for fabrics with very open structures than those with less permeable structures (Vigo, 1994). Epps (1996) defined "open-structured" fabrics as those having air permeability measurements exceeding the maximum range of standard instruments operated in accordance with standard test procedures such as ASTM Test Method

D737 for Air Permeability of Textile Fabrics. The author reported two ways of determining air permeability for fabrics with open structures. One method applies a pressure differential other than the standard one, and the other method uses statistical prediction based on extrapolation from measurements of multiple fabric layers.

# **Summary of Comfort**

Comfort is an important criterion by which customers judge their clothes via the interaction between the body and the textile. Clothing comfort is defined as "a state of satisfaction indicating physiological, psychological, and physical balance among the person, his/her clothing, and his/her environment" (p.371) (Branson & Sweeney, 1990). Thermal comfort refers to sensations of hot, cold, dryness or dampness in clothes and is usually associated with environmental factors such as heat, moisture, and air velocity (Collier & Epps, 1998). Two properties of textile materials, water/moisture vapor transmission and air permeability, are important factors that affect the thermal comfort of textiles. Water/moisture vapor transmission is the rate at which water/moisture vapor diffuses through a fabric (Hatch, 1993). Fiber content and fabric geometry are two primary factors that may affect the water/moisture vapor transmission. Two common methods that measure water/moisture vapor transmission of clothing materials are cup/dish tests (i.e., the ASTM test method of E96-80) and sweating guarded hot plate devices (i.e., the ASTM test method of D1518-77) (Gibson, 1993). Air permeability is the capability of airflow through the fabric (Tortora & Collier, 1997). Many factors may affect air permeability, such as fabric cover factor, yarn twist, yarn crimp, fabric weave, fiber wetting, and the amount of finish and coating applied on the fabric. A common test method that measures air permeability is the ASTM Test Method D737 Air Permeability of Textile Fabrics, in which the

rate of air flow passing perpendicularly through a known area of fabric is adjusted to secure a prescribed air pressure differential between the two sides of the fabric surface in the test area (ASTM 2000). The air permeability of the fabric is determined by the airflow rate.

#### Flammability

Flammability is related to the safety of clothing and textile products, which are closely related to our daily life because flammability of textiles can directly lead to serious bodily injury or fatality and loss of property (Tortora & Collier, 1997). Collier and Epps (1998) defined the flammability of textile products by characterizing their burning behavior, especially ease of ignition and sustained burning after ignition.

#### **Factors that Influence Flammability**

Many factors, such as fiber content, fabric weight and structure, finishes, and garment design, affect flammability of clothing and textile products.

#### Fiber content

Fiber content is probably the most important fabric property that affects flammability (Collier & Epps, 1998). Cellulosic fabrics, such as cotton and rayon, without a flame-resistant finish, can burn easily. A survey conducted by Gandhi and Spivak (1994) showed that an increased usage of cotton fibers in upholstered furniture fabrics led to increased ease of ignition. The researchers suggested that modification should be made in the textile finishing process to create safer upholstery fabrics. In contrast, wool fabrics, especially heavy weight, usually self-extinguish because of their high ignition temperatures (570°C~600°C) and high moisture content

(Taylor, 1991). Blends of wool with inherently flame retardant fibers, such as Kevlar, Nomex, Ryton, and Inidex, could be utilized to provide flame retardant and thermally insulative protective clothing systems for firefighters (Marsden, 1991). Thermoplastic fibers, such as nylon, polyester, and olefin, do not ignite easily because they shrink away when exposed to flame (Collier & Epps, 1998). However, if they are forced to ignite or are engulfed in flames, thermoplastic fabrics will melt and burn.

Blends of fibers, or yarns of different fibers, are more likely to be flammable than fabrics made from a single fiber type (Taylor, 1991). For example, although polyester is less flammable than cotton, because of a "scaffolding" effect, cotton/polyester blends burn rapidly; they generate more heat than all-cotton fabrics (Collier & Epps, 1998). In the burning process, charred cotton in the blend acts as a support or scaffold to support the burning polyester fiber, which prevents the melting polyester from dripping away as pure polyester products do, and allows the melting polyester to contribute to the burning system. Similar concerns may apply to products made of fabrics and fillings, such as upholstered seating, mattresses, bed covers, duvets and pillows (Taylor, 1991). If the fabrics and fillings are highly flammable, their combinations can be even more dangerous.

#### Fabric weight and structure

Heavier fabrics ignite less easily and burn more slowly than lighter weight fabrics (Collier & Epps, 1998). Tightly woven and knitted fabrics also ignite more difficultly and burn slower than sheer fabrics. The reason why lighter weight and sheer fabrics ignite and burn more easily is because there is more air space and more oxygen among fibers in the sheer fabrics to fuel the flames as the fabrics burn. Kotresh (1996) tested 25 commonly used fabrics as to the

potential hazard they present in flame temperature during burning and burning rate. The researcher found that the rate of burning decreased as the fabric weight increased. The light weight fabrics burned faster than the heavier ones no matter what the fabric type was. As the fabric weight increased, flame temperature increased, indicating that heavy fabrics provided more amount of fuel sustaining burning. The researcher concluded that although the heavier fabrics burned at a slower rate than light fabrics, the high flame temperature during burning made heavier fabrics as dangerous as the light ones. Fabrics with projecting surface fibers are ignited easily by an unexpected flame or flash on the surface of the fabric (Taylor, 1991). For example, pile fabrics can ignite easily and cause flames to spread rapidly over the fabric surface (Collier & Epps, 1998). Rayon sweaters in the 1940s were banned from the U.S. market due to the effect of raised fiber surfaces for ignition and burning, resulting in high flammability.

# **Finishes**

Flame-retardant (FR) finishes were developed for flammable fabrics to provide flameresistant properties and to change the burning behavior of the fabric (Collier & Epps, 1998). FR finishes can be used on cotton, rayon, nylon and polyester fabrics (Kadolph & Langford, 1998). By chemically modifying the surface of the fibers, FR finishes make the fabric less flammable by reducing the volume of flammable gases that generate heat further decomposing the fiber (Taylor, 1991). Phosphorus containing substances, which react chemically with the fibers, are the most common FR finishes for cellulosic materials (Collier & Epps, 1998). However, FR cottons are unsatisfactory to consumers because the FR finishes for cotton increase the stiffness of the fabric, reduce the tearing strength, yellow easily, and add to the cost of production (Collier & Epps, 1998; Shekar, Yadav, Kasturiya, & Raj, 1999; Taylor, 1991). FR finishes were also

developed for fabrics made of thermoplastic fibers, such as polyester and nylon, to quench the flame by inhibiting the creation of flammable gases. Sometimes fabrics lose their FR properties after washing or dry cleaning and it becomes more dangerous than a fabric without FR finishes because the users are not aware of the change.

Shekar, et al. (1999) studied the combined effect of flame-retardant and water-repellent treatments on a bleached cotton drill fabric and found that for a flame-retardant fabric, satisfactory performance in terms of appearance, functional properties such as water repellency and oil repellency, and physical properties such as breaking strength, stiffness and tear strength, could also be achieved by an effective combination of the finishing agents.

# Garment design

Garment design also affects flammability, especially ignition (Collier & Epps, 1998). For example, loose-fitting and flowing garments, such as nightdresses, dressing gowns, and fullskirted dresses, are more liable to catch fire than tight-fitting garments or apparel with closefitting cuffs and necks because loose clothing provides greater air supply (Taylor, 1991).

#### **Flammability Regulations**

It was not until the 1940s that the public's attention in the U.S. started to focus on the flammability of fabrics (LeBlanc, 2001). In the late 1940s, a number of people were seriously injured due to burning apparel; the most dangerously flammable fabrics were brushed rayon (Collier & Epps, 1998). In reaction to highly flammable garments resulting in many cases of injury or death, the Flammable Fabrics Act (FFA), a federal law, was passed by Congress in 1953 (Tortora & Collier, 1997). Under this regulation, the use and sale of highly flammable

textile materials including brushed rayon was prohibited. Local and state laws and other regulations imposed more restrictions on the use of flammable textile materials in public buildings. In 1967, the FFA was amended to include additional items such as carpets, draperies, bedding, and upholstery. Flammability standards for various products were also established. After 1967, the regulations have been amended in the intervening years. In 1972, the federal Consumer Product Safety Commission (CPSC), a division of the Federal Trade Commission, which is responsible for most of the mandatory testing procedures for the safety of consumer products, started to administer and enforce the law of FFA (Kadolph, 1998; Kadolph & Langford, 1998; Tortora & Collier, 1997). At present, various government agencies such as CPSC and the Department of Transportation are responsible for the enforcement of these safety standards, and CPSC has the authorization to administer the flammability test methods. Mandatory standards have been issued for children's sleepwear, sizes 0-14, large and small carpets and rugs, and mattresses and mattress pads. Since 1978, most children's sleepwear is made of 100% polyester fabrics without any flame retardant finish (LeBlanc, 2001). Recently, in order to allow more untreated cotton to be used in children's sleepwear, the CPSC has loosened the standard and allows sleepwear in sizes 0 to 9 months be exempt from this regulation.

An AATCC Research Committee, which was called the Special Committee on Flammability of Consumer Textiles, began to develop a test method in 1945 to distinguish between dangerous and nondangerous fabrics (LeBlanc, 2001). In 1953, the AATCC Test Method 33 was proposed by the National Bureau of Standards (NBS) Technical Committee as a commercial standard and it became the Department of Commerce Commercial Standard CS 191-53. At the present time, CS 191-53 is referred to as the standard 16 CFR 1610, which is a test standard for measuring the ease of ignition and rate of burn of textile products. Currently many

different testing methods for fabric flammability are mandated by federal or state safety regulations; others are developed as ASTM standards or used as procedures by some organizations (Collier & Epps, 1998). The procedure of flammability testing and a pass/fail scale for identifying acceptable performance are listed in the laws and regulations (Kadolph & Langford, 1998). The standards and/or test methods may be altered in the future by research and evaluation.

#### **Measurement of Flammability**

There are two common tests for the flammability of clothing textiles. They are the 45-Degree Test and the Vertical Flammability Test. The 45-Degree Test is used in 16 CFR 1610, Standard for the Flammability of Clothing Textiles, which is a mandatory testing procedure for all apparel materials except for children's sleepwear, and some accessories such as hats, gloves, shoes, and interlinings (Collier & Epps, 1998; Kadolph, 1998; Kadolph & Langford, 1998). In this test, a specimen of 6" (warp/wale) x 2" (filling/course) is used. Before testing, the specimens should be dried in an oven and be kept in a desiccator until just prior to testing because the moisture level in the fabrics would significantly influence the flammability test result. The specimen is mounted in a holder at a 45° angle and exposed to flame for one second. After the ignition, the flame is removed. The time for the specimen to burn up to its entire length (i.e., 6 inches) is recorded. The test is repeated 10 times. The standard for the flame to spread up the specimen length should be less than 3.5 seconds for smooth fabrics or 4.0 seconds for napped fabrics.

The Vertical Flammability Test is applied to children's sleepwear, which is required to meet minimal flammability performance standards of 16 CFR 1615 (size 0-6X) and 16 CFR

1616 (size 7-14) after 50 washings and dryings (Kadolph & Langford, 1998). Similar to the 45-Degree Test, before testing, the specimens should be dried in an oven and be kept in a desiccator until testing. In the vertical flammability test, a specimen of 10" (warp/wale) x 3.5" (filling/course) is suspended vertically in a holder and subjected to an igniting gas flame along the bottom edge for three seconds. The char length, which is the amount of fabric burned or damaged by the flame, is recorded. The test is repeated 10 times. The minimum performance standard of 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14) requires that specimens cannot have an average char length of more than seven inches and no individual specimen has a char length of 10 inches.

# **Summary of Flammability**

Flammability is an important issue in the clothing and textiles area as it can lead to bodily injuries and property loss. Flammability of textile products is defined by characterizing their burning behavior, especially ease of ignition and sustained burning after ignition (Collier & Epps, 1998). Many factors, such as fiber content, fabric weight and structure, finishes, and garment design, may affect the flammability of clothing and textile products. The Flammable Fabrics Act (FFA) and later the Consumer Product Safety Commission (CPSC) developed flammability standards and tests to separate dangerously flammable fabrics from normally combustible fabrics (Kadolph & Langford, 1998). Two common tests for the flammability of clothing textiles are the 45-Degree Test and the Vertical Flammability Test. The 45-Degree Test is used in 16 CFR 1610, Standard for the Flammability of Clothing Textiles, which is a mandatory testing procedure for all apparel materials except for children's sleepwear and some accessories such as hats, gloves, shoes, and interlinings (Collier & Epps, 1998; Kadolph, 1998;

Kadolph & Langford, 1998). The Vertical Flammability Test is applied to children's sleepwear, which is required to meet minimal flammability performance standards of 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14) after 50 washings and dryings.

# CHAPTER III METHODS

This chapter on the methods of this thesis is presented in six sections: research design, assumptions and limitations of the study, hypotheses of the study, materials, test procedure, and data analysis. In the first section, research design, the experimental design and the selection of independent and dependent variables are described. Based on the research design and test methods, the assumptions and limitations of the study are addressed in the second section. According to the objectives of the study, the hypotheses of the study are stated in the third section of the chapter. The fourth section, materials, describes the fabrics, detergents, and fabric softeners that are used for the study. The fifth section, test procedures, discusses the laundering process, specimen preparation, and test methods. The last section, data analysis, addresses the statistical tools used to examine the hypotheses.

#### **Research Design**

The purpose of the study was to examine the effects of household fabric softeners on the thermal comfort and flammability of 100% cotton and 100% polyester fabrics after repeated laundering cycles. There were two major objectives in this study. The first objective was to investigate the effects of household fabric softeners on the thermal comfort of cotton and polyester fabrics after repeated laundering cycles. Two fabric properties related to thermal comfort, water vapor transmission and air permeability, were examined. The second

objective was to examine the flammability of cotton and polyester fabrics after repeated usage of household fabric softeners.

Based on the objectives of the study, a 3 X 2 X 3 experimental design was developed. The three independent variables were fabric softener treatments (i.e., rinse cycle softener, dryer sheet softener, and no softener), fabric types (i.e., 100% cotton and 100% polyester), and number of laundering cycles (i.e., 1, 15, and 25). Rinse cycle and dryer sheet fabric softeners were selected because they were widely used household fabric softeners on the market (Puchta, 1984). A control group in which no softener was used was also included in the study design as a standard for comparison among the experimental groups. Two fabric types, 100% cotton and 100% polyester fabrics, were selected because they were frequently used for summer clothes and children's sleepwear, and these items required good thermal comfort and needed to meet flammability standards. The test fabrics were examined after 1, 15, and 25 laundering cycles. The selection of the number of laundering cycles was based on the past studies which examined the effects of fabric softeners on the appearance properties (i.e., wrinkle recovery, pilling, and whiteness), maintenance properties (i.e., dimensional stability and stain release), and thermal comfort (i.e., absorbency) of cotton and polyester fabrics (AATCC Midwest ITPC Section, 1973; Baumert & Crews, 1996; Chiweshe & Crews, 2000; Kaiser & Riggs, 1980; Robinson, Gatewood, & Chambers, 1994; Wilson, 1987). In these studies, the researchers used a wide range (i.e., 1, 3, 5, 10, 15, 20, 25, 40, 50, and 75) of laundering cycles in which 1, 15, and 25 launderings were most common. With these independent variables, the research design led to a total of 18 experimental cells (see Table 3.1). For each experimental cell, the tests of water vapor transmission, air permeability, and flammability were repeated five times.

Table 3.1 Research Design

	100% COTTON FABRIC			100% POLYESTER FABRIC		
LAUNDERING CYCLES	CONTROL	RINSE CYCLE SOFTENER	DRYER SHEET SOFTENER	CONTROL	RINSE CYCLE SOFTENER	DRYER SHEET SOFTENER
	No. of Repeat	No. of Repeat	No. of Repeat	No. of Repeat	No. of Repeat	No. of Repeat
1	WVT = 5	WVT = 5	WVT = 5	WVT = 5	WVT = 5	WVT = 5
	AP = 5 $F = 5$	AP = 5 $F = 5$	AP = 5 $F = 5$	AP = 5 $F = 5$	AP = 5 $F = 5$	AP = 5 $F = 5$
15	WVT = 5	WVT = 5	WVT = 5	WVT = 5	WVT = 5	WVT = 5
	AP = 5	AP = 5	AP = 5	AP = 5	AP = 5	AP = 5
	F = 5	F = 5	F = 5	F = 5	F = 5	F = 5
25	WVT = 5	WVT = 5	WVT = 5	WVT = 5	WVT = 5	WVT = 5
	AP = 5	AP = 5	AP = 5	AP = 5	AP = 5	AP = 5
	F = 5	F = 5	F = 5	F = 5	F = 5	F = 5

WVT = Water Vapor Transmission AP = Air Permeability F = Flammability

# Assumptions and Limitations of the Study

Two main assumptions were made about the testing method used in this study. First, the testing apparatuses and operator error were assumed to be random in nature and had no significant influence on the findings of the tests. Second, for the water vapor transmission test, the air velocity over the specimens might influence the test results. To maintain consistent conditions across 18 experimental cells (See Table 3.1), 18 specimens, one specimen from each experimental cell, were tested at the same time. It was assumed that the air velocity over the 18 testing specimens was consistent.

Because financial resources were limited, the study had four main limitations. First, although the usage of fabric softeners in home laundering might have influence on different fabric types, only 100% cotton and 100% polyester fabrics were selected for the study. Second, although there were many different brands of fabric softeners on the market, only "Downy®

April Fresh Scent" and "Bounce® Outdoor Fresh Scent" were selected to represent rinse cycle and dryer sheet fabric softeners. Third, although the influence of fabric softeners on thermal comfort and flammability might differ after different laundering cycles, all the tests were conducted only after 1, 15, and 25 laundering cycles. Fourth, although many properties of textiles might affect thermal comfort, only the factors of water vapor transmission and air permeability were examined in the study. These limitations would affect the general applicability of the test results, especially for other fabric types, other brands of fabric softeners, other laundering cycles, and when other factors related to thermal comfort are examined.

# Hypotheses of the Study

Based on the objectives of the study, the research hypotheses for each dependent variable (i.e., water vapor transmission, air permeability, and flammability) were listed below.

#### Water Vapor Transmission

- H1: There is a significant difference among specimens with different fabric softener treatments (i.e., rinse cycle softener, dryer sheet softener, and no softener) in the water vapor transmission of the specimen.
- H2: There is a significant interaction between fabric softener treatments and fabric types (i.e., 100% cotton and 100% polyester) in the influence on the water vapor transmission of the specimen. In other words, the influence of softener treatments on the water vapor transmission of the specimen is different in 100% cotton and in 100% polyester fabrics.
- H3: There is a significant interaction between fabric softener treatments and number of laundering cycles (i.e., 1, 15, and 25) in the influence on the water vapor transmission of the

specimen. In other words, the influence of softener treatments on the water vapor transmission of the specimen is different after 1, 15, and 25 laundering cycles.

H4: There is a significant interaction among fabric softener treatments, fabric types, and number of laundering cycles in the influence on the water vapor transmission of the specimen. In other words, the influence of softener treatments on the water vapor transmission of the specimen is different in 100% cotton and in 100% polyester fabrics after 1, 15, and 25 laundering cycles.

# **Air Permeability**

- H5: There is a significant difference among specimens with different of fabric softener in the air permeability of the specimen.
- H6: There is a significant interaction between fabric softener treatments and fabric types in the influence on the air permeability of the specimen.
- H7: There is a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the air permeability of the specimen.

H8: There is a significant interaction among fabric softener treatments, fabric types, and number of laundering cycles in the influence on the air permeability of the specimen.

#### Flammability

- H9: There is a significant difference among specimens with different fabric softener treatments in the flammability of the specimen.
  - H9a: There is a significant difference among specimens with different fabric softener treatments in the flammability of 100% cotton fabric.

- H9b: There is a significant difference among specimens with different fabric softener treatments in the flammability of 100% polyester fabric.
- H10: There is a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the flammability of the specimen.
  - H10a: There is a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the flammability of 100% cotton fabric.
  - H10b: There is a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the flammability of 100% polyester fabric.

# Materials

## Fabrics

The fabrics used in the study, 17.5 yards of 100% cotton and 17.5 yards of 100% polyester fabrics, were purchased from the Testfabrics, Inc. For the 100% cotton fabric, a bleached, desized, plain weave print cloth in 45" width was selected. For the 100% polyester fabric, a broadcloth in 58" width was selected. The fabric structure of both cotton and polyester fabrics are plain weaves. These fabrics are light-weight fabrics which are suitable for the use of summer clothes and children's sleepwear. Before conducting the tests, fabric weight, fabric thickness, and fabric count were measured for both fabric types. Fabric weight was 108 g/m<sup>2</sup> for the cotton fabric and 76 g/m<sup>2</sup> for the polyester fabric. Fabric thickness was 0.0122" for the cotton fabric and 0.0070" for the polyester fabric. Cotton fabric is made with staple fibers, and the fabric count was 89 X 78 (warp yarns x filling yarns/inch). Polyester fabric was made with multifilament yarns, and the fabric count was 65 X 38 (warp yarns x filling yarns/inch).

# **Detergent and Fabric Softeners**

Based on the ratings of the leading laundry detergent brands from the Consumer Reports (2002), "Tide® Quick Dissolving" was used for doing the laundering. Based on the last ratings of the leading national fabric softener brands found in Consumer Reports (1991), "Downy® April Fresh Scent" and "Bounce® Outdoor Fresh Scent" were selected to represent the rinse cycle softener and the dryer sheet softener respectively.

#### **Test Procedure**

# Laundering

For each fabric type (i.e., 100% cotton and 100% polyester), 17.5 yards were purchased for testing. Each 17.5-yard (630-inch) fabric was cut into 45 lengthwise sections (3 softener treatments x 3 selected laundering cycles x 5 repeats = 45), and each section was 14-inches long (630 inches/45 sections = 14 inches). To prevent the yarn slippery from the cut edges during laundering, the two cut edges of each swatch were serged with three-thread overlock stitches. Because the washing procedures simulated the household laundering routine, the two fabric types were washed together. Three cotton swatches and three polyester swatches were randomly selected by applying the random and sort functions of Excel software and laundered together. After one laundering cycle, one cotton swatch and one polyester swatch were randomly removed and put in a coded plastic bag. The rest of four 14-inch long swatches were laundered continuously for an additional 14 cycles to equal 15 laundering cycles. After 15 laundering cycles, one cotton swatches of cotton and polyester were laundered continuously for an additional 10 cycles to equal 25 laundering cycles. After 25 laundering cycles, the final two swatches were put in a coded plastic bag. For each softener treatment, the same procedure of laundering and removing swatches was repeated five times.

The test fabrics were laundered according to AATCC Test Method 124-1996:

Appearance of Fabrics after Repeated Home Laundering (AATCC, 2001). The laundering procedure was as follows:

- 1) A MAYTAG Automatic Washer of Model A806 was used for laundering the fabrics. The washing machine was set on regular wash, regular spin, warm wash, warm rinse, and normal water level conditions, in which the warm water temperature was  $41\pm3$  °C  $(120\pm5$  °F).
- 62 ± 0.1 grams (g) of "Tide® Quick Dissolving" Detergent were added to the washing machine.
- Fabric specimens were added with ballast to make a 4.00 ± 0.13 pound (lb) (1.8 ± 0.06 kg) wash load.
- 4) The fabric specimens were washed for 12 minutes.
- 5) In the case of applying rinse cycle fabric softeners, when agitation started during the rinse cycle, 30 milliliter (mL) of rinse cycle softener mixed with one cup of water as recommended by the softener manufacturer was added to the washing machine.
- 6) After the rinse cycle, there was a final spin cycle for five to six minutes.
- 7) Immediately after the final spin cycle, the washed load (fabric specimens and ballast) was placed in a MAYTAG Automatic Tumble Dryer of Model DE806 with dialing on permanent press setting, and the exhaust temperature was  $66 \pm 5^{\circ}$ C ( $150 \pm 10^{\circ}$ F).
- In the case of applying dryer sheet fabric softeners, one dryer sheet softener was placed on top of the wet washed load before the drying process began.

- 9) The dryer was operated for 30 minutes or until the total washed load was dry. The load was removed as soon as the dryer machine stopped to avoid over-dry.
- 10) "No softener" (control group) fabric specimens were subject to the same test procedure except the adding of softeners.
- 11) The washing and drying cycles were repeated up to 15 and 25 times.

# **Specimen Preparation**

After laundering, five 14-inch long swatches were prepared to cut specimens that were needed for each experimental cell. Four specimens were cut from each swatch, in which one specimen was for the test of water vapor transmission, one specimen was for the test of air permeability, and two specimens were for the test of flammability (See Figure 3.1a, 3.1b, 3.1c, 3.1d and 3.1e). After cutting, five specimens were prepared for the test of water vapor transmission, five specimens were prepared for the test of air permeability, and 10 specimens were prepared for the test of flammability. Ten specimens were prepared for the test of flammability because the standards 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14) require a minimum of 10 specimens for the flammability test of children's sleepwear to represent a commercial lot of fabric (Merkel, 1991). However, in each experimental cell, the averaged measurement of flammability test of two specimens from each swatch represented one repeat of flammability test. Because different warp yarns used in a fabric were produced from a different piece of sliver on a different spindle (Merkel, 1991), specimens with different warp and filling yarns were taken into consideration when cutting the swatch to best represent the variability of the fabric. To ensure the specimens were cut from different warp and filling yarns, five specimen cutting plans were prepared for the five 14-inch long swatches to cut specimens for each

experimental cell. Figure 3.1a, 3.1b, 3.1c, 3.1d, and 3.1e show the five specimen cutting plans for cutting the cotton fabric swatches and Figure 3.2a, 3.2b, 3.2c, 3.2d, and 3.2e show the five specimen cutting plans for cutting the polyester fabric swatches. Because the selvages of the fabric were usually constructed in a different way from its body and were often heavier to protect the fabric from damage subjected to handling (Merkel, 1991), no specimen was taken nearer than one tenth of the width on the fabric selvage edge (Collier & Epps, 1999). Following this rule, the 45" width cotton fabric was cut 4.5" from both selvage edges and the 58" width polyester fabric was cut 6" from both selvage edges. Furthermore, one inch was cut at the top and bottom of each 14-inch cotton and polyester fabric swatch because structure distortion or shrinkage might occur during the laundering procedures. In accordance with the different requirements of specimen sizes, specimens in four-inch squares were cut for the water vapor transmission test, specimens in six-inch squares were cut for the air permeability test, and specimens in sizes of 10" (warp) x 3.5" (filling) were cut for the flammability test.



Figure 3.1a The first specimen cutting plan for 100% cotton fabric



Figure 3.1b The second specimen cutting plan for 100% cotton fabric



Figure 3.1c The third specimen cutting plan for 100% cotton fabric



Figure 3.1d The fourth specimen cutting plan for 100% cotton fabric



Figure 3.1e The fifth specimen cutting plan for 100% cotton fabric



Figure 3.2a The first specimen cutting plan for 100% polyester fabric



Figure 3.2b The second specimen cutting plan for 100% polyester fabric



Figure 3.2c The third specimen cutting plan for 100% polyester fabric



Figure 3.2d The fourth specimen cutting plan for 100% polyester fabric



Figure 3.2e The fifth specimen cutting plan for 100% polyester fabric

# **Test Methods**

#### Water vapor transmission

The water vapor transmission test was conducted according to the ASTM E 96 - 00 Standard Test Methods for Water Vapor Transmission of Materials (ASTM, 2001). The test procedure was as follows:

- The test fabric specimens were preconditioned for 24 hours according to ASTM D 1776-96 Standard Practice for Conditioning Textiles for Testing. The preconditioning situation for the test specimens was specified at a temperature of 21 ± 1 °C (70 ± 2 °F) and a relative humidity of 65 ± 2%.
- 2) The test cups were filled with distilled water to a level 0.75 ± 0.25 inches from the specimen. The preconditioned specimen was attached to the cup on the top by clamping and sealing in order that the dish mouth defined the specimen area that was exposed to the vapor pressure in the cup.
- 3) The cup assembly was placed on a horizontal surface. The tests ran 24 hours in a conditioning room at a temperature of 90 ± 2 °F and a relative humidity of 50 ± 2 %. To ensure the test conditions were consistent across 18 experimental cells (see Table 3.1), 18 specimens, one specimen from each experimental cell, were tested at the same time.
- 4) The cup assembly was weighted every four hours to obtain six data points. The results of the water vapor transmission rate were determined numerically. The weight was plotted against elapsed time, which tended to become a straight line. The slope of the straight line was the rate of water vapor transmission in the test area.

5) The water vapor transmission (WVT) was calculated by the following formula:

$$WVT = (G/t)/A$$

where:

WVT = rate of Water Vapor Transmission

G = weight change

t = time during which G occurred

G/t = slope of the straight line

A = test area (cup mouth area)

# Air permeability

The air permeability test was conducted according to the ASTM D 737 – 96 Standard Test Method for Air Permeability of Textile Fabrics (ASTM, 2000). The Air Flow Tester of Model No. 9025 was used. The rate of air flow passing perpendicularly through a known area of a test specimen was adjusted to get a pressure drop of 0.5" water between the two fabric surfaces. The value of air flow rate determined the air permeability of the test specimens. The test procedure was as follows:

- 1) The test fabric specimens were preconditioned in a standard atmosphere of  $21 \pm 1$  °C ( $70 \pm 2$  °F) temperature and  $65 \pm 2\%$  relative humidity for 24 hours according to the ASTM D 1776-96 Standard Practice for Conditioning Textiles for Testing. The air permeability test was also conducted in this standard atmosphere.
- After the two spring loaded hinged fasteners that hold the fabric clamp assembly were unlatched, the clamp assembly was opened.

- 3) The test specimen was placed on the circular clamping assembly so that it lay flat and overhung at least one inch all around. A fabric clamping ring was placed over the specimen and circular plate and was seated against the wooden part of the clamp assembly, resulting in holding the specimen to the plate smoothly without stretching.
- 4) The fabric clamp assembly was raised into position where the two circular plates were parallel to each other with the gasket and the fabric specimen held between them. The hinged fasteners were repositioned to hold the entire assembly together by the springs in the fasteners.
- 5) The water pressure differential across the fabric specimen was 0.5" water.
- 6) From the vertical manometer, the pressure drop in inches of water was read. The flow metering orifice and the corresponding conversion chart for converting pressure drop inches to air flow value determined the air permeability (ft<sup>3</sup>/min/ft<sup>2</sup>) value of the fabric specimen.

#### **Flammability**

The flammability test was conducted in accordance with the two standards of children's sleepwear 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14). A vertical tester was used. The test procedure was as follows:

The test fabric specimens were preconditioned for 24 hours according to the ASTM D 1776-96 Standard Practice for Conditioning Textiles for Testing. The preconditioning situation for the test specimens was specified at a temperature of 21 ± 1 °C (70 ± 2 °F) and a relative humidity of 65 ± 2%.

- 2) According to Merkel (1991), flammability is greatly influenced by the degree of moisture in the fabric, and therefore, the flammability tests were performed on oven-dry specimens. According to Adanur's suggestion (1995), the specimens were dried in an oven at 105°C for 30 minutes and were cooled to room temperature in a desiccator to keep dry at least 30 minutes but no more than 60 minutes.
- 3) A test specimen was tightly clamped on three sides and held vertically in a metal frame in the test chamber, thus avoiding shrinking from the ignition.
- The specimen was ignited by a methane gas flame along its bottom edge for two seconds. Then the flame was removed.
- 5) When the flame was moved, the burning time was read with a stopwatch immediately until the specimen stopped glowing. Two seconds were deducted from the reading of the stopwatch as the recorded burning time.
- 6) The burned specimen was removed from the test chamber and then removed from the metal frame. The char length, which is the length from the bottom edge of the specimen to the end of the charred area, was measured and recorded unless it had been burned its entire length.
- 7) The standards of children's sleepwear 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14) require that specimens cannot have an average char length of more than seven inches, and no more than one specimen has a char length of 10" or burns its entire length. If exactly one specimen burns its entire length, five more specimens will be needed to conduct the test again. If any of the additional five specimens burns its entire length, the fabric specimen fails the test.

 After the specimen had been washed and dried 25 laundering times, it should still pass the standard that was regulated in point 7.

# Fabric weight

Fabric weight was measured using the ASTM D 3776 - 96 Standard Test Method for Mass Per Unit Area (Weight) of Fabric, Option C – Small Swatch of Fabric (ASTM, 2000). A cutting die in six-inch squares was used to cut the specimens to ensure that all specimens were consistent in the length and width. The test procedure was as follows:

- 1) The test fabric specimens were preconditioned for 24 hours according to the ASTM D 1776-96 Standard Practice for Conditioning Textiles for Testing. The preconditioning situation for the test specimens was specified at a temperature of 21  $\pm 1 \text{ °C} (70 \pm 2 \text{ °F})$  and a relative humidity of 65  $\pm 2\%$ .
- A Denver Mettler balance was used to measure the fabric weight to the nearest
  0.001g for each test specimen.
- 3) The calculation formula for fabric weight is:

$$W(g/m^2) = G(g) / A(m^2)$$

where

W = Fabric Weight

G = Mass of Specimen

A = Area of Specimen

4) The fabric weight was reported in grams per meter square  $(g/m^2)$ .

# Fabric thickness

Fabric thickness was measured using the ASTM D 1777 - 96 Standard Method for Thickness of Textile Materials (ASTM, 2000). The hand-held caliper was used to measure fabric thickness with a 14mm semi diameter circular pressure foot. The pressure foot and spindle had a combined weight of 0.5 ounce. The test procedure was as follows:

- The test fabric specimens were preconditioned for 24 hours according to the ASTM D 1776-96 Standard Practice for Conditioning Textiles for Testing. The preconditioning situation for the test specimens was specified at a temperature of 21 ± 1 °C (70 ± 2 °F) and a relative humidity of 65 ± 2%.
- The test specimens were handled carefully to avoid altering the natural state of the fabric and were placed on the anvil of the caliper.
- The pressure foot was brought into contact with the fabric by applying the load on the specimen for five seconds.
- 4) The fabric thickness of the specimen was reported in inches to the nearest 0.001 inch.

# Fabric count

Fabric count was measured using the ASTM D 3775 - 96 Standard Test Method for Fabric Count of Woven Fabric (ASTM, 2000). The fabric count in warp yarns and filling yarns were measured separately. The test specimens of one-inch square were used. The test was repeated five times. The test procedure was as follows:

The test fabric specimens were preconditioned for 24 hours according to the ASTM D
 1776-96 Standard Practice for Conditioning Textiles for Testing. The preconditioning
situation for the test specimens was specified at a temperature of  $21 \pm 1$  °C (70  $\pm$  2 °F) and a relative humidity of 65  $\pm$  2%.

- 2) The warp and filling yarns in one-inch of fabric were raveled out and counted one by one and reported in integral units per inch.
- 3) Fabric count was stated as: Fabric Count = warp yarns x filling yarns/inch.

# **Data Analysis**

The Statistical Package for the Social Sciences Personal Computer (SPSS/PC) program was used to analyze the data. Hypotheses 1 to 8 were examined by three-way Analysis of Variance (ANOVA) tests. Hypotheses 9 and 10 were examined by two-way ANOVA. The Tukey's Honestly Significant Difference Test (THSDT) was used to perform multiple comparisons between group means.

## **CHAPTER IV**

### RESULTS

The purpose of the study was to explore the effects of household fabric softeners on the thermal comfort (i.e., water vapor transmission and air permeability) and flammability of 100% cotton and 100% polyester fabrics after repeated laundering. In this chapter, the results of the study are presented in three sections, which are organized around the order of the hypotheses of the study listed in chapter III. The influences of the three independent variables (i.e., fabric softener treatments, fabric types, and number of laundering cycles) on the three dependent variables (i.e., water vapor transmission, air permeability, and flammability) are also discussed.

#### Water Vapor Transmission

Water vapor transmission is the rate at which water vapor diffuses through a fabric (Hatch, 1993). The water vapor transmission was measured using ASTM E 96 - 00 Standard Test Methods for Water Vapor Transmission of Materials. It was denoted in metric units as grams of weight change per hour per square meter of fabric  $(g/h \cdot m^2)$  under an environment of maintained temperature at 90 ± 2° F and relative humidity at 50 ± 2 %. A three-way Analysis of Variance (ANOVA) was conducted to examine if there was a significant difference in water vapor transmission among different fabric softener treatments (i.e., no softener, rinse cycle softener, and dryer sheet softener), fabric types (i.e., 100% cotton and 100% polyester), or number of laundering cycles (i.e., 1, 15, and 25 cycles) and if there was a significant interaction among the

three independent variables. The results showed that a significant difference existed in water vapor transmission among different fabric softener treatments, fabric types, or number of laundering cycles (F = 27.00, p < 0.001) (see Table 4.1). Significant differences were found in each independent variable, the interaction between fabric softener treatments and fabric types, and the interaction among the three independent variables at the 0.001 significance level. The examinations of four research hypotheses regarding the effects of household fabric softener treatments on water vapor transmission of 100% cotton and 100% polyester fabrics after repeated laundering are discussed as follows.

### Influence of Fabric Softener Treatments on Water Vapor Transmission (Hypothesis 1)

When the influence of fabric softener treatments on water vapor transmission was examined, the *F* value showed that the mean scores of water vapor transmission were significantly different among different fabric softener treatments (F = 74.31, p < 0.001) (see Table 4.1). They were 73.46, 69.69, and 69.61 (g/h·m<sup>2</sup>) for no softener, rinse cycle softener, and dryer sheet softener treatment respectively. The higher the score indicated the greater water vapor transmission. Significant differences were found between no softener treatment and rinse cycle softener, and between no softener treatment and dryer sheet softener (p < 0.001), but no significant difference was found between rinse cycle softener and dryer sheet softener by Tukey's Honestly Significant Difference Tests (THSDT). Water vapor transmission was the highest when no fabric softener was used. Both rinse cycle softener and dryer sheet softener treatments significantly decreased the water vapor transmission of the test specimens. These results supported the research hypothesis H1: there was a significant difference between specimens with different fabric softener treatments (i.e., no treatment, rinse cycle softener

Source	S.S.	D.F.	M.S.	F
Main Effects	894.21	17	52.60	27.00*
Fabric Softener Treatments	289.57	2	144.78	74.31*
Fabric Types	94.52	1	94.52	48.51*
Number of Laundering Cycles	282.27	2	141.14	72.44*
(Fabric Softener Treatments ) x (Fabric Types)	156.41	2	78.21	40.14*
(Fabric Softener Treatments) x (Number of Laundering Cycles)	13.75	4	3.44	1.76
(Fabric Types) x (Number of Laundering Cycles)	6.05	2	3.02	1.55
(Fabric Softener Treatments) x (Fabric Types) x (Number of Laundering Cycles)	51.65	4	12.91	6.63*
Residual	140.29	72	1.95	
Total	453698.42	90		

# Table 4.1. Three-way Analysis of Variance for Water Vapor Transmission

\* *p* < 0.001

treatment, and dryer sheet softener treatment) in the water vapor transmission of the specimen,

and therefore, Hypothesis 1 was accepted.

## Influence of the Interaction between Fabric Softener Treatments and Fabric Types on

## Water Vapor Transmission (Hypothesis 2)

When the interaction between fabric softener treatments and fabric types in the influence on the water vapor transmission of the test specimen was examined, the *F* value showed that there was a significant interaction between fabric softener treatments and fabric types (F = 40.14, p < 0.001) (see Table 4.1). The means and standard deviations for water vapor transmission as a function of the fabric softener treatments and fabric types are presented in Table 4.2 and Figure 4.1. Because the interaction between fabric softener treatments and fabric types was significant, follow-up tests of one-way ANOVA and THSDT were conducted to examine the differences among three fabric softener treatments for each fabric type. The results showed that there was a significant difference in the water vapor transmission with different fabric softener treatments for the cotton fabric (F = 34.80, p < 0.001), but there was no significant difference for the polyester fabric. For the cotton fabric, the results of THSDT indicated that significant differences were found between no softener treatment and rinse cycle softener and between no softener treatment and dryer sheet fabric softener (p < 0.001), but there was no significant difference between rinse cycle softener and dryer sheet fabric softener treatments. Water vapor transmission was the greatest when no fabric softener was used. Both rinse cycle softener and dryer sheet softener decreased the water vapor transmission of 100% cotton fabric. However, for the polyester fabric, water vapor transmission of specimens treated by rinse cycle softener and dryer sheet softener was similar to that of fabrics laundered with no fabric softener. These results showed that the influence of fabric softener treatments on water vapor transmission was significantly different between the two fabric types. These results supported the research hypothesis H2: there was a significant interaction between fabric softener treatments and fabric types in the influence on the water vapor transmission of the specimen, and therefore, Hypothesis 2 was accepted.

	Fabric Softener Treatments (g/h·m <sup>2</sup> )								
Fabric	No So	ftener	Rinse Cycl	e Softener	Dryer Shee				
Types	Mean	SD	Mean	SD	Mean	SD	F		
Cotton	74.15 <sup>a</sup>	2.47	67.19 <sup>b</sup>	2.76	68.35 <sup>b</sup>	2.07	34.80 *		
Polyester	72.76 <sup>a</sup>	3.21	72.19 <sup>a</sup>	2.06	70.88 <sup>a</sup>	1.66	2.41		

Table 4.2. Means and Standard Deviations for Water Vapor Transmission by Fabric Softener Treatments and Fabric Types

<sup>a, b</sup> In the same row, means with different superscript letters are significantly different at 0.001 level by THSDT

\* p < 0.001



Figure 4.1. Mean Scores of water vapor transmission (g/h·m<sup>2</sup>) by fabric softener treatments for 100% cotton and 100% polyester fabrics

### Influence of the Interaction between Fabric Softener Treatments and Number of

## Laundering Cycles on Water Vapor Transmission (Hypothesis 3)

When the interaction between fabric softener treatments and number of laundering cycles in the influence on the water vapor transmission of the test specimen was examined, the F value showed that there was no significant interaction between fabric softener treatments and number of laundering cycles (see Table 4.1). The means and standard deviations for water vapor transmission as a function of the fabric softener treatments and number of laundering cycles are presented in Table 4.3. These results showed that the influence of fabric softener treatments on water vapor transmission was similar in each selected laundering cycle. These results did not support the research hypothesis H3: there was a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the water vapor transmission of the specimen, and therefore, Hypothesis 3 was not accepted.

 Table 4.3.
 Means and Standard Deviations for Water Vapor Transmission by Fabric Softener

 Treatments and Number of Laundering Cycles

		Fabric Softener Treatments (g/h·m <sup>2</sup> )								
Number of	No So	ftener	Rinse Cycl	le Softener	Dryer Sheet Softener					
Laundering Cycles	Mean	SD	Mean	SD	Mean	SD				
1	71.78	1.70	68.33	2.52	68.24	2.21				
15	71.89	1.69	68.93	4.63	68.88	1.33				
25	76.70	1.95	71.81	1.98	71.72	1.42				

# Influence of Interactions among Fabric Softener Treatments, Fabric Types, and Number of Laundering Cycles on Water Vapor Transmission (Hypothesis 4)

When the interactions among fabric softener treatments, fabric types, and number of laundering cycles in the influence on the water vapor transmission of the specimen was examined, the *F* value indicated that there was a significant interaction (F = 6.63, p < 0.001) (see Table 4.1). The means and standard deviations for water vapor transmission as a function of the fabric softener treatments, fabric types, and number of laundering cycles are presented in Table 4.4. Follow-up tests of one-way ANOVA and THSDT were conducted to examine the

differences among different laundering cycles with each fabric softener treatment for each fabric type. For the cotton fabric, no matter which fabric softener treatments, no significant difference was found in the specimens washed after one cycle and 15 cycles, but after 25 laundering cycles, the water vapor transmission of test specimens significantly increased. For the polyester fabric, when no softener or dryer sheet softener was used, the results were similar to that of cotton fabric. No significant difference was found after one and 15 laundering cycles, but after 25 laundering cycles, the water vapor transmission of polyester specimens significantly increased. However, a different result was found in the polyester fabric treated with the rinse cycle softener. The water vapor transmission was significantly different after 15 laundering cycles instead of after 25 laundering cycles. After 15 laundering cycles, the water vapor transmission of polyester specimens treated with rinse cycle softener significantly increased but no continuous increase when laundering cycles increased. These results showed that the influences of fabric softener treatments on water vapor transmission were significantly different after different cycles of

		Number of Laundering Cycles (g/h·m <sup>2</sup> )						
Fabric Types	Fabric Softener Treatments	1		15	5		25	
	-	Mean	SD	Mean	SD	Mean	SD	F
Cotton	No Softener	72.76 <sup>a</sup>	1.87	73.04 <sup>a</sup>	1.07	76.67 <sup>b</sup>	2.20	7.51 *
	Rinse Cycle Softener	66.78 <sup>a</sup>	2.16	64.66 <sup>a</sup>	1.37	70.11 <sup>b</sup>	1.15	14.43 **
	Dryer Sheet Softener	66.55 <sup>a</sup>	1.76	67.88 <sup>a</sup>	0.87	70.61 <sup>b</sup>	0.66	14.91**
Polyester	No Softener	70.79 <sup>a</sup>	0.76	70.74 <sup>a</sup>	1.40	76.74 <sup>b</sup>	1.92	28.67 **
	Rinse Cycle Softener	69.89 <sup>a</sup>	1.90	73.19 <sup>b</sup>	0.89	73.50 <sup>b</sup>	0.60	12.62 **
	Dryer Sheet Softener	69.92 <sup>a</sup>	0.86	69.89 <sup>a</sup>	0.84	72.84 <sup>b</sup>	0.99	17.74 **

Table 4.4.Means and Standard Deviations for Water Vapor Transmission by Fabric SoftenerTreatments, Fabric Types, and Number of Laundering Cycles

<sup>a, b,c</sup> In the same row, means with different superscript letters are significantly different at 0.01 level by THSDT.

\* p < 0.01 \*\* p < 0.001

laundering and between different fabric types. These results supported the research hypothesis H4: there was a significant interaction among fabric softener treatments, fabric types, and number of laundering cycles in the influence on the water vapor transmission of the specimen, and therefore, Hypothesis 4 was accepted.

### **Air Permeability**

Air permeability is the capability of air to flow through the fabric (Tortora & Collier, 1997), which is an important fabric property related to thermal comfort. Air permeability was measured according to the ASTM D 737 – 96 Standard Test Method for Air Permeability of Textile Fabrics. It was denoted in U.S. standard units as cubic feet of air per minute per square foot of fabric (ft<sup>3</sup>/min/ft<sup>2</sup>) at a 0.5" water pressure differential between the two surfaces of the fabric specimens. In order to acquire more accurate results, the pressure drop of each test specimen was measured twice (i.e., face up and face down), and then the measurements were averaged. Corresponding to the air flow tester conversion chart, the air permeability of the test fabrics was determined.

A three-way ANOVA was conducted to examine if there was a significant difference in air permeability among different fabric softener treatments, fabric types, or number of laundering cycles and if there was a significant interaction among the three independent variables. The results showed that a significant difference existed in air permeability among different fabric softener treatments, fabric types, or number of laundering cycles (F = 1462.68, p < 0.001) (see Table 4.5). Significant differences were found in each independent variable and the interactions among the three independent variables at the 0.05 significance level. The examinations of four research hypotheses regarding the effects of household fabric softener treatments on air

Source	S.S.	D.F.	M.S.	F
Main Effects	117178.66	17	6892.86	1462.68**
Fabric Softener Treatments	1043.27	2	521.64	110.69**
Fabric Types	112148.10	1	112148.10	23798.01**
Number of Laundering Cycles	3020.97	2	1510.49	320.53**
(Fabric Softener Treatments) x (Fabric Types)	373.52	2	186.76	39.63**
(Fabric Softener Treatments) x (Number of Laundering Cycles)	392.71	4	98.18	20.83**
(Fabric Types) x (Number of Laundering Cycles)	145.95	2	72.98	15.49**
(Fabric Softener Treatments) x (Fabric Types) x (Number of Laundering Cycles)	54.13	4	13.53	2.87*
Residual	339.30	72	4.71	
Total	990326.50	90		

Table 4.5. Three-way Analysis of Variance for Air Permeability

\* *p* < 0.05 \*\* *p* < 0.001

permeability of 100% cotton and 100% polyester fabrics after repeated laundering cycles are discussed as follows.

# Influence of Fabric Softener Treatments on Air Permeability (Hypothesis 5)

When the influence of fabric softener treatments on air permeability was examined, the *F* value showed that the mean scores of air permeability were significantly different among different fabric softener treatments (F = 110.69, p < 0.001) (see Table 4.5). They were 102.55, 94.22, and 98.67 (ft<sup>3</sup>/min/ft<sup>2</sup>) for no softener, rinse cycle softener, and dryer sheet softener

treatment respectively. The higher the score indicated the greater air permeability. Significant differences were found among all three fabric softener treatments by THSDT (p < 0.001). Air permeability was the highest when no fabric softener was used, and it decreased most when the rinse cycle softener was used and was followed by the dryer sheet softener. These results showed that the influence of fabric softener treatments on air permeability was significantly different. These results supported the research hypothesis H5: there was a significant difference between specimens with different fabric softener treatments in the air permeability of the specimen, and therefore, Hypothesis 5 was accepted.

# Influence of the Interaction between Fabric Softener Treatments and Fabric Types on Air Permeability (Hypothesis 6)

When the interaction between fabric softener treatments and fabric types in the influence on the air permeability of the test specimen was examined, the *F* value showed that there was a significant interaction between fabric softener treatments and fabric types (F = 39.63, p < 0.001) (see Table 4.5). The means and standard deviations for air permeability as a function of the fabric softener treatments and fabric types are presented in Table 4.6 and Figure 4.2. Follow-up tests of one-way ANOVA and THSDT were conducted to examine the differences among three fabric softener treatments for each fabric type. The results showed that there was a significant difference in the air permeability with different fabric softener treatments for the cotton fabric (F= 19.63, p < 0.001), but there was no significant difference for the polyester fabric. For the cotton fabric, the results of THSDT indicated that significant differences were found between no softener treatment and rinse cycle softener, and between rinse cycle softener and dryer sheet fabric softener (p < 0.001), but there was no significant difference between no softener treatment

	Fabric Softener Treatments (ft <sup>3</sup> /min/ft <sup>2</sup> )									
Fabric	No Softener		Rinse Cycl	e Softener	Dryer Shee					
Types	Mean	SD	Mean	SD	Mean	SD	F			
Cotton	67.10 <sup>a</sup>	5.41	56.50 <sup>b</sup>	6.30	65.93 <sup>a</sup>	2.91	19.63 *			
Polyester	138.00 <sup>a</sup>	7.64	131.93 <sup>a</sup>	10.91	131.40 <sup>a</sup>	5.25	2.95			

Table 4.6. Means and Standard Deviations for Air Permeability by Fabric Softener Treatments and Fabric Types

<sup>a, b</sup> In the same row, means with different superscript letters are significantly different at 0.001 level \* p < 0.001



Figure 4.2. Mean Scores of air permeability (ft<sup>3</sup>/min/ft<sup>2</sup>) by fabric softener treatments for 100% cotton and 100% polyester fabrics

and dryer sheet fabric softener treatment. Only the rinse cycle softener treatment significantly decreased the air permeability of 100% cotton fabric. The air permeability of cotton specimens treated with dryer sheet softener was similar to those laundered with no fabric softener. However, for the polyester fabric, fabric softener treatments had no significant influence on air permeability. The air permeability of polyester specimens treated by either rinse cycle softener or dryer sheet softener was similar to that of fabrics laundered with no fabric softener. These results showed that the influence of fabric softener treatments on air permeability of the specimen was significantly different between the two fabric types. These results supported the research hypothesis H6: There was a significant interaction between fabric softener treatments and fabric types in the influence on the air permeability of the specimen, and therefore, Hypothesis 6 was accepted.

# Influence of the Interaction between Fabric Softener Treatments and Number of Laundering Cycles on Air Permeability (Hypothesis 7)

When the interaction between fabric softener treatments and number of laundering cycles in the influence on the air permeability of the test specimen was examined, the *F* value showed that there was a significant interaction between fabric softener treatments and number of laundering cycles (F = 20.83, p < 0.001) (see Table 4.5). The means and standard deviations for air permeability as a function of the fabric softener treatments and number of laundering cycles are presented in Table 4.7. A line chart was used to demonstrate the significant interaction between fabric softener treatments and number of laundering cycles (see Figure 4.3). To statistically examine if two out of three lines were significantly parallel to each other, follow-up tests of three-way ANOVA were conducted. When the line of no softener and the line of rinse cycle softener were examined, the results showed that these two lines were significantly nonparallel to each other, which indicated that there was a significant interaction between these two fabric softener treatments (i.e., no softener and rinse cycle softener) and number of laundering cycles (F = 12.68, p < 0.001). When the line of no softener and the line of dryer sheet softener were examined, the results showed that these two lines were significantly nonparallel to each other, which indicated that there was a significant interaction between these two fabric softener treatments (i.e., no softener and rinse cycle softener) and number of laundering cycles (F = 12.68, p < 0.001). When the line of no softener and the line of dryer sheet softener were examined, the results showed that these two lines were significantly nonparallel to each other, which indicated that these two lines were significant performed to the softener and the line of dryer sheet softener

	Number of Laundering Cycles (ft <sup>3</sup> /min/ft <sup>2</sup> )							
	1		1	5	2	25		
Fabric Softener Treatments	Mean	SD	Mean	SD	Mean	SD		
No Softener	110.25	38.59	101.80	37.35	95.60	36.35		
Rinse Cycle Softener	105.55	42.92	90.45	38.58	86.65	37.90		
Dryer Sheet Softener	103.30	35.98	97.10	32.81	95.60	34.92		

Table 4.7. Means and Standard Deviations for Air Permeability by Fabric Softener Treatments and Number of Laundering Cycles



Figure 4.3. Mean Scores of air permeability (ft<sup>3</sup>/min/ft<sup>2</sup>) by fabric softener treatments after 1, 15, and 25 laundering cycles

other, which indicated that there was a significant interaction between these two fabric softener treatments (i.e., no softener and dryer sheet softener) and number of laundering cycles (F = 12.19, p < 0.001). When the line of rinse cycle softener and the line of dryer sheet softener were examined, the results showed that these two lines were significantly non-parallel to each other, which indicated that there was a significant interaction between these two fabric softener

treatments (i.e., rinse cycle softener and dryer sheet softener) and number of laundering cycles (F = 38.81, p < 0.001). All these results supported and certified that three lines were significantly non-parallel to each other, which showed that the interaction between fabric softener treatments and number of laundering cycles had a significant influence on the air permeability of the specimen. The rate of decrease in air permeability with fabric softener treatments was different from the rate of decrease in air permeability with no softener treatment. After 15 laundering cycles, the air permeability of the fabric treated with the rinse cycle softener decreased most rapidly, followed by the dryer sheet softener and then the no softener. When laundering cycles increased to 25 cycles, the air permeability of test specimens treated with the rinse cycle softener continuously decreased. For the dryer sheet softener, the rate of decrease in air permeability slowed down after 15 laundering cycles, and after 25 laundering cycles, the air permeability of test fabrics with the treatment of dryer sheet softener was the same as that of fabrics treated with no softener. These results supported the research hypothesis H7: there was a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the air permeability of the specimen, and therefore, Hypothesis 7 was accepted.

# Influence of Interactions among Fabric Softener Treatments, Fabric Types, and Number of Laundering Cycles on Air Permeability (Hypothesis 8)

When the interactions among fabric softener treatments, fabric types, and number of laundering cycles in the influence on the air permeability of the specimen was examined, the *F* value indicated that there was a significant interaction among fabric softener treatments, fabric types, and number of laundering cycles (F = 2.87, p < 0.05) (see Table 4.5). The means and standard deviations for air permeability as a function of the fabric softener treatments, fabric

types, and number of laundering cycles are presented in Table 4.8. Follow-up tests of one-way ANOVA and THSDT were conducted to examine the differences among different laundering cycles with each fabric softener treatment for each fabric. For both cotton and polyester fabrics, even when no fabric softener was used, the more the specimens were laundered, the lower the air permeability of specimens. For the cotton fabric, when the rinse cycle softener and dryer sheet softener were used, similar to no softener treatment, the air permeability continuously reduced when laundering cycles increased. For the polyester fabric, the air permeability of polyester specimens treated with fabric softener, either rinse cycle softener or dryer sheet softener, significantly decreased after 15 laundering cycles. However, unlike the cotton fabric, the air permeability of polyester fabric treated with fabric softener had no further significant decrease after 15 laundering cycles. These results showed that the influence of the fabric softener treatments on air permeability were significantly different after different cycles of laundering and between different fabric types. These results supported the research hypothesis H8: there was

		Number of Laundering Cycles (ft <sup>3</sup> /min/ft <sup>2</sup> )						
Fabric	- Fabric Softener	1		15			25	
Types		Mean	SD	Mean	SD	Mean	SD	F
Cotton	No Softener	73.70 <sup>a</sup>	0.84	66.40 <sup>b</sup>	1.71	61.20 <sup>c</sup>	0.45	154.63 *
	Rinse Cycle Softener	64.90 <sup>a</sup>	0.55	53.90 <sup>b</sup>	0.22	50.70 °	0.27	1958.12 *
	Dryer Sheet Softener	69.20 <sup>a</sup>	0.91	66.00 <sup>b</sup>	0.61	62.60 <sup>c</sup>	1.08	68.80 *
Polyester	No Softener	146.80 <sup>a</sup>	3.11	137.20 <sup>b</sup>	1.64	130.00 <sup>c</sup>	3.81	39.61 *
	Rinse Cycle Softener	146.20 <sup>a</sup>	3.56	127.00 <sup>b</sup>	2.92	122.60 <sup>b</sup>	1.14	105.00 *
	Dryer Sheet Softener	137.40 <sup>a</sup>	2.30	128.20 <sup>b</sup>	1.92	128.60 <sup>b</sup>	4.45	14.08 *

Table 4.8. Means and Standard Deviations for Air Permeability by Fabric Softener Treatments,Fabric Types, and Number of Laundering Cycles

<sup>a, b, c</sup> In the same row, means with different superscript letters are significantly different at 0.001 level. \* p < 0.001 a significant interaction among fabric softener treatments, fabric types, and number of laundering cycles in the influence on the air permeability of the specimen, and therefore, Hypothesis 8 was accepted.

### Flammability

The flammability test was conducted in accordance with the two standards of children's sleepwear: 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14). The char length and the burning time were recorded to demonstrate the flammability of test fabrics. All 100% cotton specimens burned over their entire length of 10", but most 100% polyester fabrics did not burn out. Because the entire length of all cotton specimens was burned over, burning time was used to analyze the flammability of cotton fabric. The shorter the burning time indicated the greater the flammability because burning speed was faster. Because most polyester specimens did not burn over their entire length of 10", char length was used to determine the flammability of polyester fabric. The longer the char length indicated the greater the flammability because burning area was bigger. The reason why the burning time was not used for polyester fabric was because when the char length was short, a short burning time indicated that the fire extinguished quickly. However, when the char length was long, a short burning time indicated that the burning speed was fast. Therefore, the burning time could not clearly indicate if the polyester fabric had a greater flammability. Two two-way ANOVA were conducted for each fabric to examine if flammability was significantly related to either the fabric softener treatments or the number of laundering cycles.

### **Influence of Fabric Softener Treatments on Flammability (Hypothesis 9)**

When the influence of fabric softener treatments on burning time of 100% cotton fabric was examined, the *F* value indicated that there was a significant effect of fabric softener treatments on burning time (F = 783.04, p < 0.001) (see Table 4.9). The mean scores of burning time were 35.42 seconds for no softener treatment, 25.64 seconds for rinse cycle softener treatment, and 35.00 seconds for dryer sheet softener treatment respectively. The results of THSDT indicated significant differences between no softener treatment and rinse cycle softener, and between rinse cycle softener and dryer sheet softener (p < 0.001), but no significant difference between no softener treatment and dryer sheet softener treatment was found. Rinse cycle softener treatment significantly increased the flammability of 100% cotton fabric by shortening the time of burning the entire specimen. In other words, rinse cycle softener treatment caused the specimens burning significantly faster than the specimens with no softener treatment or treated with dryer sheet fabric softener. These results showed that the influence of fabric

Source	S.S.	D.F.	M.S.	F
Main Effects	1073.38	8	134.17	229.37*
Fabric Softener Treatments	916.11	2	458.06	783.04*
Number of Laundering Cycles	22.28	2	11.14	19.04*
(Fabric Softener Treatments) x	124.00	1	22 75	57 60*
(Number of Laundering Cycles)	134.99	4	55.75	57.09
Residual	21.06	36	0.59	
Total	47233.34	45		

Table 4.9. Two-way Analysis of Variance for Burning Time of 100% Cotton Fabrics

\* p < 0.001

softener treatments on burning time was significantly different for 100% cotton fabric specimens. These results supported the sub-hypothesis H9a: there was a significant difference between specimens with different fabric softener treatments in the flammability of 100% cotton fabric, and therefore, sub-hypothesis 9a was accepted.

When the influence of fabric softener treatments on char length of 100% polyester fabric was examined, the F indicated that there was a significant effect of fabric softener treatments on char length (F = 29.20, p < 0.001) (see Table 4.10). The mean scores of char length were 6.74 inches for no softener treatment, 8.42 inches for rinse cycle softener treatment, and 6.98 inches for dryer sheet softener treatment respectively. The results of THSDT indicated significant differences between no softener treatment and rinse cycle softener, and between rinse cycle softener and dryer sheet softener (p < 0.001), but no significant difference was found between no softener treatment and dryer sheet softener treatment. Rinse cycle softener treatment significantly increased the flammability of 100% polyester fabric by lengthening the char length of specimens. In other words, rinse cycle softener treatment made the specimens burning significantly longer than the specimens with no treatment or treated with dryer sheet fabric softener. However, the char length of the specimens treated by the dryer sheet softener was similar to those laundered with no fabric softener. These results showed that the influence of fabric softener treatments on the flammability of 100% polyester fabric was significantly different. These results supported the sub-hypothesis H9b: there was a significant difference between specimens with different fabric softener treatments in the flammability of 100% polyester fabric, and therefore, sub-hypothesis 9b was accepted.

Source	S.S.	D.F.	M.S.	F
Main Effects	78.89	8	9.86	23.09**
Fabric Softener Treatments	24.94	2	12.47	29.20**
Number of Laundering Cycles	47.61	2	23.80	55.74**
(Fabric Softener Treatments) x	( ) (	4	1.50	2 71*
(Number of Laundering Cycles)	6.34	4	1.59	3./1*
Residual	15.37	36	0.43	
Total	2543.98	45		

Table 4.10. Two-way Analysis of Variance for Char Length of 100% Polyester Fabrics

\* *p* < 0.05 \*\* *p* < 0.001

Both sub-hypothesis 9a and 9b were supported by the results, and therefore, the main Hypothesis 9 was accepted. There was a significant difference among specimens with different fabric softener treatments in the flammability of the specimen. Rinse cycle softener treatment significantly increased the flammability of 100% cotton and 100% polyester fabric. However, the flammability of test fabric treated by dryer sheet softener was similar to that of fabric laundered with no fabric softener.

# Influence of the Interaction between Fabric Softener Treatments and Number of Laundering Cycles on Flammability (Hypothesis 10)

When the interaction between fabric softener treatments and number of laundering cycles in the influence on the burning time of 100% cotton fabric was examined, the *F* value indicated that a significant interaction existed between fabric softener treatments and number of laundering cycles (F = 57.69, p < 0.001) (see Table 4.9). The means and standard deviations for burning time as a function of fabric softener treatments and number of laundering cycles are presented in Table 4.11 and Figure 4.4. Follow-up tests of one-way ANOVA and THSDT were conducted to examine the differences among different laundering cycles for each fabric softener treatment. Significant differences were found between different fabric softener treatments in the burning time for cotton fabric after 1, 15, and 25 laundering cycles. The results of THSDT showed that the burning time of cotton fabric with no treatment was significantly increased after 25 laundering cycles. For the rinse cycle softener, significant differences were found among all three selected laundering cycles. The more the specimens were laundered with the rinse cycle softener, the greater the flammability of cotton fabric. However, for the dryer sheet softener, no significant difference was found among the selected laundering cycles. The flammability of cotton fabric treated with dryer sheet softener did not significantly increase after repeated laundering. These results showed that the influence of fabric softener treatments on burning time of cotton fabric was significantly different among different numbers of laundering cycles. These results supported the sub-hypothesis H10a: there was a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the flammability of 100% cotton fabric, and therefore, Hypothesis 10a was accepted.

		Number of Laundering Cycles							
Fabric Softener	1		15		25				
Treatments	Mean	SD	Mean	SD	Mean	SD	F		
No Softener	34.82 <sup>a</sup>	0.40	35.09 <sup>a</sup>	0.47	36.33 <sup>b</sup>	0.92	7.89 *		
Rinse Cycle Softener	29.01 <sup>a</sup>	0.65	26.46 <sup>b</sup>	0.61	21.46 <sup>c</sup>	1.01	122.78 **		
Dryer Sheet Softener	34.76 <sup>a</sup>	0.59	34.60 <sup>a</sup>	0.57	35.64 <sup>a</sup>	1.06	2.58		

Table 4.11. Means and Standard Deviations for Burning Time of 100% Cotton Fabrics by<br/>Fabric Softener Treatments and Number of Laundering Cycles

<sup>a, b, c</sup> In the same row, means with different superscript letters are significantly different at 0.01 level by THSDT.

\* *p* < 0.01 \*\* *p* < 0.001



Figure 4.4. Mean Scores of burning time in seconds by fabric softener treatments after 1, 15, and 25 laundering cycles for 100% cotton fabric

When the interaction between fabric softener treatments and number of laundering cycles in the influence on the char length of 100% polyester fabric was examined, the *F* value indicated that there was a significant interaction between fabric softener treatments and number of laundering cycles (F = 3.71, p < 0.05) (see Table 4.10). The means and standard deviations for char length as a function of fabric softener treatments and number of laundering cycles are presented in Table 4.12 and Figure 4.5. Follow-up tests of the one-way ANOVA and THSDT were conducted to examine the differences among fabric softener treatments for each laundering cycle. The results of THSDT showed that after one laundering cycle, there was a significant difference in the char length for polyester fabric between the specimens treated with no softener and rinse cycle softener, and between rinse cycle softener and dryer sheet softener. These results indicated that after one laundering cycle, softener. These results indicated that after one laundering cycle softener significantly increased the flammability of polyester fabric by lengthening the char length of specimens, while the

			Fabric Softer	ner Treatmer	nts		
Number of	No Sc	oftener	Rinse Cyc	le Softener	Dryer Shee	et Softener	
Laundering Cycles	Mean (inches)	SD (inches)	Mean (inches)	SD (inches)	Mean (inches)	SD (inches)	F Value
1	4.86 <sup>a</sup>	0.67	7.33 <sup>b</sup>	0.62	5.88 <sup>a</sup>	0.77	16.35 *
15	7.59 <sup>a</sup>	0.71	8.08 <sup>a</sup>	0.88	7.13 <sup>a</sup>	0.74	1.84
25	7.76 <sup>a</sup>	0.66	9.86 <sup>b</sup>	0.22	7.92 <sup>a</sup>	0.32	34.57 *

Table 4.12	. Means	and Stan	ndard E	Deviations	for Char	Length	of 100%	Polyester	Fabrics by
	Fabric	Softener	Treatn	nents and	Number	of Laun	dering C	ycles	

<sup>**a**, **b**</sup> In the same row, means with different superscript letters are significantly different at 0.001 level. \* p < 0.001



Figure 4.5. Mean Scores of char length in inches by fabric softener treatments after 1, 15, and 25 laundering cycles for 100% polyester fabric

flammability of fabrics treated with dryer sheet softener was similar to that of fabrics treated with no softener. After 15 laundering cycles, the results of THSDT showed that no significant difference was found in the char length for polyester specimens among different fabric softener treatments. The polyester specimens treated with rinse cycle softener or dryer sheet softener burned at about the same speed as those laundered with no softener after 15 laundering cycles. After 25 laundering cycles, three polyester specimens treated with rinse cycle softener burned over their entire length of 10 inches, and the char length of these three specimens was coded as 10 inches. The results of THSDT showed that the flammability of polyester specimens treated with rinse cycle softener significantly increased again after 25 laundering cycles. No significant difference was found in the char length between no softener and dryer sheet fabric softener treatments after 25 laundering cycles. These results showed that the influence of fabric softener treatments on the flammability of 100% polyester fabric was significantly different among different numbers of laundering cycles. These results supported the sub-hypothesis H10b: there was a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the flammability of 100% polyester fabric, and therefore, sub-hypothesis 10b was accepted.

Both sub-hypothesis 10a and 10b were supported by the results, and therefore, the main Hypothesis 10 was accepted. There was a significant interaction between fabric softener treatments and number of laundering cycles in the influence on the flammability of the specimen.

### **CHAPTER V**

### DISCUSSION, CONCLUSION, AND RECOMMENDATION

This chapter is organized in three sections: discussion, conclusion, and recommendations for future research. The first section includes the discussion of the effects of fabric softener on thermal comfort and the effects of fabric softener on flammability of test fabrics. Possible reasons for the results are discussed. In addition, the rinse cycle softener and the dryer sheet softener are compared on the basis of their influence on the property of the fabric. The second section is the conclusion of the study, in which the applications are given based on the results. The third section addresses the recommendations for future research.

### Discussion

### **Effects of Fabric Softener on Thermal Comfort**

In prior studies, researchers examined the effect of fabric softeners on water absorbency regarding the relationship of household fabric softeners and thermal comfort (Egan, 1978; Robinson, Gatewood, & Chambers IV, 1994; Williams, 1982). Researchers found that rinse cycle softeners decreased water absorbency, while dryer sheet softeners had either no effect or slightly decreased water absorbency. However, except for water absorbency, no research was found in the investigation of effects of fabric softener on other factors that influence thermal comfort, such as water vapor transmission and air permeability. The effects of fabric softener on

the water vapor transmission and the air permeability of test fabrics were studied in this research and the testing results were discussed as follows.

### Effects of fabric softener on water vapor transmission

When the effect of fabric softener treatment on water vapor transmission of test specimens was studied in this research, the results indicated that a significant decrease in water vapor transmission of specimens was associated with the fabric softener treatments. Both the rinse cycle softener and the dryer sheet softener treatments significantly decreased the water vapor transmission of the test specimens. The possible reason why fabric softener treatment would decrease the water vapor transmission of the test specimens might be related to the increase of fabric thickness after the use of fabric softeners. This proposition is supported by the study of Whelan, MacHattie, Goodings, and Turl (1955), which found that the changes of thickness of fabric would affect the resistance to water vapor transmission of any particular cloth. As the fabric thickness increased, the resistance of the fabric to water vapor transmission increased.

When the influences of fabric softener treatment on water vapor transmission were compared between cotton and polyester fabrics, the results indicated that the rinse cycle softener and the dryer sheet softener had significantly different effects on the two fabric types. For cotton fabrics, fabric softener treatments, both the rinse cycle softener and the dryer sheet softener, significantly decreased the water vapor transmission of cotton fabric, while the water vapor transmission of polyester specimens treated by either a rinse cycle softener or a dryer sheet softener was similar to that of fabrics laundered with no fabric softener. Possible reasons why the influence of fabric softener treatments on water vapor transmission was significantly different

between the two fabrics might be related to the different moisture-absorption characteristics and the yarn structure of the two fabrics. Fiber content plays an important role in the influence of the water vapor transmission because water vapor is absorbed by fibers, transported through fibers, and then desorbed to the environment (Tortora & Collier, 1997). In this process, the inherent absorbency of the fibers or their affinity for water determines the process of water vapor transmission. Cotton fiber is hydrophilic (i.e., water-loving), which can absorb significant amounts of moisture (Hatch, 1993). Rinse cycle softeners are in a liquid form and the water in the softener helps the softener to get into the cotton fiber. As more rinse cycle softeners were absorbed into the cotton fiber, the wicking capacity of cotton fabric would decrease due to the reduced capillary spaces in the fabric, which led to the decrease of water vapor transmission of the fabric. However, polyester fiber is hydrophobic (i.e., water-avoiding), which can absorb very little amounts of water. Because less amount of the rinse cycle softener would be absorbed into the polyester fabric, rinse cycle softeners had no significant influence on the water vapor transmission of polyester fabric. Although dryer sheet softeners were usually kept on the fabric surface (Williams, 1982), the current study results found that the water vapor transmission of cotton fabric treated with a dryer sheet softener was significantly reduced. A possible reason might be related to the protruding fiber ends of cotton yarns on the surface. Cotton fibers are staple length fibers (i.e., the length of fiber ranges from 0.75~18 inches) and the fiber ends of staple fibers usually come out from the yarn strand, especially after repeated wear and laundering (Hatch, 1993). The short fiber ends of cotton fibers create a fuzzy surface and make the dryer sheet softener more easily to adhere on the fabric. As more dryer sheet softeners were retained on the surface of the cotton fabric, they would reduce the wicking capacity of cotton fabric leading to the decrease of water vapor transmission. Polyester fabric was made with filament

fibers (i.e., the length of fiber could be infinite). The round and smooth structure of filament fibers could prevent a large amount of dryer sheet softener from remaining on the fabric, and therefore, the water vapor transmission of polyester fabric treated with the dryer sheet softener or no softener was similar.

When the influence of softener treatments on the water vapor transmission of the specimen was examined between cotton and polyester fabrics after selected laundering cycles (i.e., 1, 15, and 25 cycles), the results indicated that the water vapor transmission of cotton specimens significantly increased after 25 laundering cycles no matter whether fabric softeners were used. A possible reason why the water vapor transmission of cotton specimens increased after 25 laundering cycles might be related to the reduction of yarn twist due to the repeated laundering. When the cotton yarns were less twisted, they allowed more water to be absorbed into the fabric (Hatch, 1993) and increased the wicking capacity of cotton yarns resulting in the increase of water vapor transmission. Similar to cotton fabrics, the water vapor transmission of polyester fabrics treated with no softener or the dryer sheet softener also significantly increased after 25 laundering cycles. However, the water vapor transmission of polyester fabric treated with the rinse cycle softener increased faster than that treated with no softener or the dryer sheet softener. After 15 laundering cycles, the water vapor transmission of polyester fabric treated with the rinse cycle softener had already significantly increased. A possible reason for the different increase rates might be related to the different degree of increase in yarn slippage. Chiweshe and Crews (2000) suggested that the lubrication of fabric softener in yarns could cause yarn slippage, which increased the porosity of polyester fabric. The transport of vaporous and liquid water through polyester fabric is mainly determined by the porosity of the fabric due to the low moisture regain of polyester fabric (Hatch, 1993). Rinse cycle softeners are in a liquid form,

which easily go into the fabric, and therefore, only after 15 laundering cycles, fabrics treated with the rinse cycle softener had significantly more lubrication than those treated with the dryer sheet fabric softener. The lubrication of rinse cycle softeners in polyester yarns could increase the yarn slippage between yarns and thus increase the porosity of the fabric, which caused the water vapor transmission of polyester specimens treated by rinse cycle softeners to increase significantly.

#### Effects of fabric softener on air permeability

When the effect of fabric softener treatment on air permeability of test specimens was studied in this research, the results indicated that different fabric softener treatments had a significantly different effect on the air permeability of the test fabrics. Both the rinse cycle softener and the dryer sheet softener decreased the air permeability but the rinse cycle softener treatment decreased the air permeability more than the dryer sheet softener treatment did. However, when the influence of softener treatments on the air permeability was compared between cotton and polyester fabrics, the results indicated that the rinse cycle softener treatment significantly decreased the air permeability of cotton fabric but not polyester fabric. The dryer sheet softener did not have a significant effect on the air permeability of both cotton and polyester test specimens. Vigo (1994) found that the ability of a fabric to allow air to go through it freely was mainly dependent on the porosity of the fabric. When the degree of porosity was decreased, the fabric would become less permeable because little air was allowed to flow through the fabric. One possible reason why the influence of fabric softener treatments on air permeability was significantly different between the two fabrics might be related to the difference in the moisture-absorption property between the two fabrics. Cotton fibers are

hydrophilic, which allowed the cotton fabric to absorb a greater amount of rinse cycle softener into its fibers. The absorbed rinse cycle softener within fibers could block the air space between fibers or yarns resulting in decreasing air permeability. Another possible reason might be related to the fiber wetting effect of cotton fabric. Wehner, Miller and Rebenfeld (1987) found that at a low differential pressure, hydrophilic fibers such as cotton would easily swell after absorption of water, and the change in fabric porosity and thickness resulted in decreasing air permeability. Polyester fibers are hydrophobic. The low moisture regain could not allow a great amount of rinse cycle softener and water to be absorbed into the fabric, and therefore, no significant softener buildup and swelling happened to reduce the air permeability of polyester fabric. The dryer sheet softener was usually kept on the fabric surface. Fewer residues would be built up on the fabric and no swelling would happen. This might be the reason why the dryer sheet softener had no significant effect on the air permeability of both cotton and polyester specimens.

When the influence of softener treatments on the air permeability of the specimens was examined after selected laundering cycles (i.e., 1, 15, and 25 cycles), the results showed that significantly different effects of fabric softener treatment on air permeability existed after 1, 15, and 25 laundering cycles. The rinse cycle softener reduced the air permeability of test specimens more than the dryer sheet softener did after 15 laundering cycles. After 25 laundering cycles, the rinse cycle softener continuously decreased the air permeability of test specimens but not the dryer sheet softener. A possible reason why the influence of the rinse cycle and the dryer sheet softener on air permeability was significantly different after selected laundering cycles might be related to the buildup rate of softener residues on the fabric. The buildup rate of the rinse cycle softener was faster than that of the dryer sheet softener, which led to a greater decrease of air

permeability with the treatment of the rinse cycle softener than with the dryer sheet softener after 15 laundering cycles and 25 laundering cycles.

When the influence of softener treatments on the air permeability of the specimen was examined between cotton and polyester fabrics after selected laundering cycles (i.e., 1, 15, and 25 cycles), the results indicated that for the cotton fabric, no matter whether fabric softener was used, the air permeability continuously reduced when laundering cycles increased. However, the air permeability of cotton specimens treated with the rinse cycle softener decreased more than that with the treatment of dryer sheet softener and no softener. A possible explanation of why the air permeability of test specimens still reduced even though no softener was used might be related to the buildup of detergent residues on the fabric, which also could decrease the air permeability of test specimens. The air permeability of polyester specimens treated with either rinse cycle softener or dryer sheet softener significantly decreased after 15 laundering cycles but there was no further significant decrease when laundering cycles increased. A possible reason might be related to the saturation of buildup. The polyester fabric is negatively charged, and the fabric softeners are positively charged (Ward, 1957). All the cationic softeners would be picked up by the polyester fabric and be kept on the fabric during the laundering process. After the 15th laundering cycle, it is possible that the bond of the polyester fabric and fabric softeners had reached a relatively saturated stage, and thus, when laundering cycles continuously increased, the buildup of softener residues on the fabric would not significantly increase.

### **Effects of Fabric Softener on Flammability**

When the effect of fabric softener on flammability of test specimens was studied in this research, the results indicated that different fabric softener treatments were significantly different

on the flammability of cotton and polyester fabrics. The rinse cycle softener increased the flammability of both cotton and polyester fabrics, while the dryer sheet softener had no significant effect on the flammability of both fabric types. A possible reason why the rinse cycle softener could increase the flammability of test fabric might be related to the buildup of rinse cycle softener in the fabric. Fabric softeners contain lubricants, which are derived from tallow. The buildup of softener in the fabric might increase the flammability of fabrics because of its fatty composition. The rinse cycle softeners are in a liquid form, which easily go into the fibers and increase the amount of softener buildup in the fabric. However, dryer sheet softeners remained on the surface of the fabrics instead of going into the fibers. The amount of buildup of dryer sheet softener on the fabric surface was not significant, and therefore, the flammability of fabric treated with the dryer sheet softener was not significantly increased. These results were consistent with the studies reported by Consumer Reports (2000) and Davidson (2001), which found that clothing might become more flammable when laundered with rinse cycle softeners because the buildup of rinse cycle softener in the fabric might increase the flammability of test fabrics, but fabrics laundered with dryer sheet softeners burned almost at the same speed as those laundered without fabric softener.

Kaiser and Riggs (1980) found that the buildup of rinse cycle fabric softeners on the cotton flannelette fabric for use in children's sleepwear significantly increased the flammability of the fabric. According to the standards of children's sleepwear, 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14), 10 specimens should be used for the test of flammability. These specimens cannot have an average char length of more than seven inches, and no more than one specimen has a char length of 10 inches or burns its entire length. After the specimen had been washed and dried 50 laundering times, it should still pass this standard. The current study results

showed that all cotton specimens burned over their entire length of 10 inches no matter whether fabric softeners were used. Cotton fabrics could not pass the flammability standard of children's sleepwear even with no softener treatment. For polyester fabrics, the results showed that the average char length of the polyester specimens treated with no softener was less than seven inches even after 25 laundering cycles, which indicated that the polyester fabric with no softener treatment passed the flammability standard of children's sleepwear at least up to 25 laundering cycles. The reason for this result was because the polyester fiber did not ignite easily due to its shrinking away tendency when exposed to flame (Collier & Epps, 1998). This characteristic of polyester fiber might be the reason why polyester fabric is often used in making children's sleepwear to fulfill the requirement of the flammability standard. When fabric softeners were used, the dryer sheet softener treatment did not significantly influence the flammability of test specimens. The average char length of the polyester specimens treated with the dryer sheet softener was still shorter than seven inches, which suggested that if the polyester fabric in this study was used to make children's sleepwear, the dryer sheet softener is safe for laundering the children's sleepwear at least up to 25 laundering cycles. When the polyester specimens treated with the rinse cycle softener were laundered after 25 laundering cycles, three polyester specimens burned over their entire length of 10 inches, which indicated that polyester fabric treated with the rinse cycle softener did not pass the standard for the flammability of children's sleepwear. Rinse cycle softeners were not safe for laundering children's sleepwear because of the increase of flammability.

When the influences of fabric softener treatment on the flammability were examined at selected laundering cycles (i.e., 1, 15, and 25 cycles) for each cotton and polyester fabric separately, the results indicated that the influence of fabric softener treatments on flammability

of cotton fabric was significantly different after the three selected laundering cycles. The dryer sheet softener did not influence the flammability of either cotton or polyester fabric even after repeated laundering. However, flammability of cotton fabric increased with the rinse cycle softener treatment after repeated laundering cycles. The more the specimens were laundered with the rinse cycle softener, the greater the flammability of cotton fabric. For the polyester fabric, the rinse cycle softener significantly increased the flammability of polyester fabric by lengthening the char length of specimens after one laundering cycle. These results suggested that after one laundering cycle, the buildup rate of the rinse cycle softener in the fabric was faster than that for the dryer sheet softener. However, after 15 laundering cycles, the specimens treated with the rinse cycle softener or the dryer sheet softener burned at a similar speed as those treated with no softener. These results suggested that the rate of buildup of the rinse cycle softener on the polyester fabric slowed down between one and 15 laundering cycles. When laundering cycles increased to 25, the burning speed of polyester fabric treated with the rinse cycle softener was significantly faster than that of fabric treated with the dryer sheet softener and no softener again. A possible reason why the rinse cycle softener increased the flammability of polyester fabric again after 25 laundering cycles was because the lubrication of fabric softener in yarns might cause yarn slippage, which increased the porosity of polyester fabric and allowed more spaces between fibers to keep the rinse cycle softener residues in the fabric after repeated laundering.

### **Comparison of Rinse Cycle Softener and Dryer Sheet Softener**

Prior studies indicated both advantages and disadvantages of rinse cycle softeners and dryer sheet softeners on the properties of fabrics. Rinse cycle softeners could reduce static electricity, minimize shrinkage, bring good odor, and improve hand, smoothness, wrinkle

recovery, and stain release. However, the disadvantages of rinse cycle softener lie in the formation of bigger pills and the decrease of fabric strength, whiteness, and absorbency. Dryer sheet softeners could provide the best improvement of static electricity, odor, and stain release. Dryer sheet softeners also provide better fabric strength retention, form smaller pills, and improve wrinkle recovery, whiteness, and hand. The disadvantages of dryer type softeners lie in uneven softener deposition. This study revealed more knowledge in the effects of rinse cycle softeners and dryer sheet softeners on fabric properties. Rinse cycle softeners decreased the water vapor transmission of cotton fabric but not that of polyester fabric. When the air permeability was examined, the rinse cycle softener continuously decreased the air permeability of cotton fabric when laundering cycles increased. For the polyester fabric, the rinse cycle softener decreased the air permeability of polyester fabric after 15 laundering cycles but no further significant decrease after 15 laundering cycles. In addition, the rinse cycle softener significantly increased the flammability of both cotton and polyester fabrics. The more the cotton specimens were laundered with the rinse cycle softener, the greater the flammability of cotton specimens. Rinse cycle softeners also significantly increased the flammability of polyester fabric after 1 and 25 laundering cycles but no significant increase after 15 laundering cycles.

Similar to the rinse cycle softener, the dryer sheet softener decreased the water vapor transmission of cotton fabric but not that of polyester fabric. The dryer sheet softener and the rinse cycle softener decreased the water vapor transmission of cotton fabric in a similar degree. When the air permeability was examined, the results showed that the dryer sheet softener also decreased the air permeability of test fabrics. However, the dryer sheet softener decreased the air permeability to a lesser degree than the rinse cycle softener did. One significant advantage of the

dryer sheet softener was that the dryer sheet softener did not increase the flammability of cotton and polyester fabric as rinse cycle softener did.

The current study results provide more knowledge in the influence of fabric softener treatment on the thermal comfort (i.e., water vapor transmission and air permeability) and flammability of cotton and polyester fabrics. These results complement some gaps in the understanding of the effects of fabric softeners on the properties of clothing.

#### Conclusion

The purpose of this study was to examine the effects of household fabric softeners on the thermal comfort (i.e., water vapor transmission and air permeability), and flammability of 100% cotton and 100% polyester fabrics after repeated laundering cycles. Two objectives of this research were (a) to investigate the effects of household fabric softeners on the thermal comfort of cotton and polyester fabrics after repeated laundering cycles and (b) to examine the flammability of cotton and polyester fabrics after repeated usage of household fabric softeners. A 3 X 2 X 3 experimental design was developed to conduct the research. The three independent variables were fabric softener treatments (i.e., rinse cycle softener, dryer sheet softener, and no softener), fabric types (i.e., 100% cotton and 100% polyester), and number of laundering cycles (i.e., 1, 15, and 25 cycles). The three dependent variables were water vapor transmission, air permeability, and flammability. Each dependent variable was tested five times.

In the analysis of the first objective, the water vapor transmission was measured by using ASTM E 96 - 00 Standard Test Methods for Water Vapor Transmission of Materials and the air permeability was measured by using ASTM D 737 – 96 Standard Test Method for Air Permeability of Textile Fabrics separately. The three-way ANOVA tests were conducted to
analyze the data and the results showed that both the rinse cycle softener and the dryer sheet softener significantly decreased the water vapor transmission of test specimens. When the influences of fabric softener treatment on water vapor transmission of cotton and polyester fabrics were compared, both the rinse cycle softener and the dryer sheet softener treatments significantly decreased the water vapor transmission of cotton fabric, while fabric softener treatment had no effect on the water vapor transmission of polyester specimens. These results suggest that both the rinse cycle softener and the dryer sheet softener treatments are appropriately used in laundering polyester garments for a hot environment because they keep the water vapor transmission property unchanged. However, both the rinse cycle softener and the dryer sheet softener treatments will make cotton clothes less comfortable during the summer time because of the decrease of water vapor transmission after laundering. These results are beneficial to consumers who are concerned about the water vapor transmission of their clothes, such as T-shirts and underwear, in hot weather. If they are informed that the rinse cycle softener and the dryer sheet softener may decrease the water vapor transmission of their cotton clothes, they can make a better decision whether they want to use a fabric softener during their home laundering.

For the effect of fabric softener on air permeability of test specimens, the results showed that the rinse cycle softener decreased the air permeability most and was followed by the dryer sheet softener. The residues of both fabric softener treatments on the fabric did create a barrier to air flow of the test fabric. This finding can help consumers to make a better decision when choosing softener treatment if they are concerned about the air permeability of their clothing. For example, if consumers prefer very high air permeability of their sportswear or summer clothes, avoiding using fabric softener is a better choice because both the rinse cycle softener and the

dryer sheet softener will decrease the air permeability of their garments. In addition, prior studies indicated that dryer sheet softeners are the best in the improvement of static electricity. If consumers would like to have a softer hand or reduce the static problem in their sportswear, dryer sheet softeners may be a better choice instead of rinse cycle softeners. This is because dryer sheet softeners can improve the softness and reduce the static electricity of clothes, but they decrease the air permeability less than rinse cycle softeners do. When the influence of softener treatment on the air permeability between cotton and polyester fabrics was compared, the results showed that the rinse cycle softener treatment significantly decreased the air permeability of cotton fabric, but the dryer sheet softener had no effect on the air permeability of cotton specimens. Both the rinse cycle softener and the dryer sheet softener treatments had no effect on the air permeability of polyester specimens. These results suggest that if consumers want a high air permeability of cotton clothing, such as summer skirts and pants, using dryer sheet softeners instead of rinse cycle softeners is a better choice for laundering these cotton clothes because dryer sheet softeners will not decrease the air permeability of cotton garments. On the other hand, the customers can freely select the softener treatment for their polyester garments because neither rinse cycle softeners nor dryer sheet softeners will decrease the air permeability of polyester clothing.

In the analysis of the second objective, the flammability was measured in accordance with the two standards of children's sleepwear 16 CFR 1615 (size 0-6X) and 16 CFR 1616 (size 7-14). A vertical tester was used to conduct the flammability test. The burning time was used to demonstrate the flammability of cotton fabric, and the char length was used to demonstrate the flammability of polyester fabric. The data of cotton and polyester fabrics were analyzed separately. The two-way ANOVA tests were conducted to examine the data. The results of the

effect of fabric softener treatments on flammability of cotton and polyester fabrics indicated that the rinse cycle softener increased the flammability of 100% cotton and 100% polyester fabrics, while the dryer sheet softener had no effect on the flammability of both fabrics. These results suggest that when flammability is concerned, a better choice for consumers may be the dryer sheet softener instead of the rinse cycle softener to avoid a potential increase of flammability. In addition, the study results found that the polyester fabric treated with the rinse cycle softener did not pass the flammability standard of children's sleepwear after 25 laundering cycles, but those polyester specimens treated with the dryer sheet softener or no softener passed the standard of children's sleepwear at least up to 25 laundering cycles. Manufacturers of rinse cycle softeners should provide safety warnings for the usage of rinse cycle softeners on products that require a good flame resistance property such as children's sleepwear and infants' clothes due to the potential increase of flammability. On the package of the rinse cycle softeners on the market, some manufacturers state that their products are safe to wash all types of clothes, and some manufacturers avoid a direct statement warning consumers of the possible danger caused by the increase of flammability. Instead, they provide an ambiguous statement indicating that the product would decrease the flame resistance and should be avoided when washing children's sleepwear. This statement may mislead consumers to believe that rinse cycle softeners only are not safe for laundering children's sleepwear or the garments with flame resistance finishes. Better consumer education is needed to help consumers fully understand the potential danger of the increase of flammability when using rinse cycle softeners.

## **Recommendations for Future Research**

In this study, two variables related to the thermal comfort were examined: water vapor transmission and air permeability. Other factors, such as heat transfer, may also play an important role in the thermal comfort. More variables related to the thermal comfort needed to be investigated to have a full understanding of the influence of household fabric softener on the thermal comfort. "Downy® April Fresh Scent" and "Bounce® Outdoor Fresh Scent" were selected in this study to represent the rinse cycle and the dryer sheet fabric softener on the market. Other popular fabric softener brands that are available on the market, such as Snuggle, have not been studied. In further research, other brands of fabric softener may need to be included to examine whether the influence of other fabric softeners is consistent with the selected brands in the current study. Furthermore, both cotton and polyester fabrics selected in this study were of plain weave woven fabrics. Other types of fabric structure (e.g., knitted fabric) should be investigated in future fabric softener research. Only three laundering cycles (i.e., 1, 15, and 25 cycles) were chosen in this study because these numbers of cycles were frequently used by previous researchers in this area. The current study results found that the influences of fabric softener on the thermal comfort (i.e., water vapor transmission and air permeability) and flammability of test specimens were often different after various laundering cycles. However, because the interval between the two selected laundering cycles was quite large, the results could not pinpoint when significant change occurred. For example, the results found that after 15 laundering cycles, the air permeability of polyester fabric treated with the rinse cycle softener or the dryer sheet softener significantly decreased, but it was difficult to determine whether the change occurred right after two laundering cycles or after 15 laundering cycles. More frequent incremental evaluations of laundering cycles need to be included in the future research so that

more comprehensive knowledge about the influence of the interaction between laundering cycles and fabric softeners on fabric properties may be collected.

The standards of children's sleepwear require the flammability test to be repeated 10 times and the specimens should pass the standard after 50 cycles of washing and drying. In this study, the specimens treated with dryer sheet softeners passed the flammability standards of children's sleepwear. However, the flammability test was repeated only five times and the test specimens were washed and dried only up to 25 cycles. In future study, 10 repeats for the flammability test and 50 laundering cycles are needed to examine if the test specimens with the dryer sheet softener treatment pass the flammability standards. In addition, the significant findings in this research were based on the statistical results. Responses from consumers may not be the same as the statistical results. For example, an influence proved to be statistically significant may not be identified by consumers. On the other hand, consumers may distinguish differences that are not statistically significant. Wear studies are needed in the future to understand consumers' responses regarding the effects of fabric softeners on textiles.

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