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Chapter

Innovation in the Comfort of Intimate Apparel

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Abstract

Intimate apparel is the most important clothing layer since it acts as human's second skin due to contact with the skin directly. The comfort issues for intimate apparels are sensorial, thermal, motion, and aesthetical, all of which are interrelated. Since intimate apparel is an inner layer in between the skin and the outerwear, its thermal comfort is very important. Transferring moisture from the clothing to the environment through diffusion, wicking, sorption, and evaporation is regulated by the thickness and tightness of the fabric. On the other part, the behavior of fabric is affected by chemical and physical properties of its constituent fibers, fiber content, physical and mechanical characteristics of its constituent yarns, and the finishing treatments. Thus, major fiber manufacturers such as Nylstar, Invista, and Lenzing have launched different types of fibers such as Meryl Skinlife, Tactel, Tencel, etc., which are suitable for intimate apparel. The aim of this chapter is to introduce the latest developments in fibers used in the manufacturing of intimate apparel products and their contribution to clothing comfort, which the apparels give when the body does not limit its movement and regulation mechanism of its own temperature.

Keywords: intimate apparel, new fibers, thermal comfort, sensorial comfort, body movement comfort

1. Intimate apparel

Intimate apparel is a kind of garment which is worn next to the skin, and thus it behaves as human's second skin. Conventional bra, underwear, sports bra, pantyhose, swimwear, mastectomy bra as well as maternity underwear, body shaper, and corset are described as intimate apparel, and this kind of apparel is an interdisciplinary subject involving body beauty, human anatomy and anthropometrics, pattern design, textile engineering, as well as health science [1]. As intimate apparel contacts with the skin directly, its comfort characteristics are more important than that of outerwear, and from this point of view in this chapter, comfort performances of intimate apparels were discussed.

2. What is comfort?

Comfort is a complex state of mind that depends on many physical, physiological, and psychological factors [2]. Slater defined comfort as "a pleasant state of physiological, psychological and physical harmony between a human being and the environment" [3]. The impact of clothing on comfort and performance of individuals at work or sport is of particular importance because physiological loads may decline the physical and mental capacity of the person [4]. Also, various consumers consider comfort as one of the most important attributes in their purchase of apparel products; therefore companies tend to focus on the comfort of apparel products [2]. Intimate wear, which is described as human's second skin, requires the comfort issue to be maintained perpetually than that of outerwear due to the contact to the skin directly. Also, the daily performance and good feeling of a person are synonymous with intimate apparel comfort characteristics.

Wear comfort can be divided into four main aspects such as thermal comfort, sensorial comfort, body movement comfort, and aesthetic comfort. Thermal comfort is the satisfaction of a person with the thermal environment, and to do so there is a thermal balance between the human body and the environment and the proper balance between body heat production and heat loss. Thus, the person feels neither too cold nor too warm. In addition to heat transfer, moisture transport through the body-clothing-environment system is the main topic of the thermal comfort [2, 5]. Sensorial comfort refers to neural sensations when a fabric or garment comes into contact with human skin. It includes the warmth/coolness, prickliness, surface roughness, and electrical properties (e.g., static) of fabric against skin. Body movement comfort refers to the ability of a textile to allow freedom of movement [2]. Aesthetic comfort is the subjective perception by visual sensation which is influenced by color, style, garment fitting, fashion compatibility, fabric construction, and finish [1, 6].

2.1 Aesthetic comfort

Female consumers, regardless of age and social status, are concerned with keeping up with the fashion trends though fashion items such as laced bras and thongs may be less comfortable to wear than daily bras and basic underwear. Despite an inherent incapacity to display the product, consumers feel they want it to be relevant and fashionable [7]. Thus, intimate apparel is invisible to the public, but it is considered as "inconspicuous fashion" [8].

Bras allow the wearer to express their personality as they contribute to the final breast shape and contour visible through outer clothing that constructs a social identity [8]. Women may lose their youthful appearance after pregnancy, aging, or menopause. So, they would need a bra that makes the breasts look firm, round, and natural. The bra should uplift the drooping breasts to a desirable position with necessary fullness, coverage, and cleavage. On the other hand, the woman who has a plus size breast may suffer from social anxiety, low comfort level, and difficulty in their self-esteem, thinking that her outstanding breast causes shame [9]. Thus, many brands including Berlei, Victoria's Secret, Triumph, and Bonds carry a wide range of bras that provide suitable comfort, support, and fit according to the needs of growing teens, working women, nursing mothers, and older women. Brands have also distinguished between different bra-wearing behaviors by differentiating the product into usage patterns, such as occasions and benefits sought (e.g., T-shirt bra designed for seamless everyday wear, push-up bras for enhanced cleavage, convertible bras for strapless or halter neck outfits, and sports bra for physical activities) [10].

2.2 Thermal comfort

The main property of clothing is to build a stable microclimate next to the skin in order to maintain the body's thermoregulatory system at different environmental

and physical activity conditions, and provision of thermal balance is a function of the clothing in all wear situations. It acts as a barrier to heat and vapor transfer between skin and environment. Thermal comfort depends on several factors, heat and vapor transport, sweat absorption, and drying ability [4, 11], and it is an important criterion for intimate apparel in terms of feeling comfortable. Intimate apparel, being an inner layer in between the skin and outerwear, should be capable of maintaining heat balance between the excess heat produced by the wearer and the capacity of the clothing to dissipate body heat and perspiration. However, it exists within a narrow temperature range [12].

Human body is homoeothermic and has to maintain its core temperature around 37°C, with a skin temperature between 30.7 and 35.6°C [13]. The body cells, especially in the organs and the muscles, produce heat that is partly released to the environment. This metabolic heat production can largely vary depending on the activity, from about 80 W at rest to over 1000 W during most strenuous efforts [2]. At an extreme activity, the heat produced in the muscles creates the greatest thermal stress. A large amount of this heat is often stored in the body resulting in an increase in body temperature [13, 14]. Then, the central nervous system gives indication to the hypothalamus of brain which controls the thermoregulation process. It sends signals to human organs, muscles, glands, and the nervous system. The excess heat is liberated to the outer environment by means of heat loss mechanism process [15]. Heat transfer continues until the two media are the same temperature and have reached equilibrium. The rate of the energy transferred depends on temperature difference and the degree of resistance between the two media [12]. Heat transfer from the body to the environment occurs in several ways [2, 13, 16]:

- Dry heat transfer conduction (heat transfer between two surfaces in contact with each other), convection (heat exchange between a surface and a surrounding fluid, e.g., air or water), and radiation (emission or absorption of electromagnetic waves)
- Evaporation of sweat
- Heat transfer by respiration

In order to maintain the thermoregulation of a human body, heat generation and heat loss should ideally be equal. This principle can be expressed in a heat balance equation (Eq. (1)) (in W or W/m²) for the human body [2]:

$$M - W = E + R + C + K + S$$

(1)

where M is metabolic rate of the body, W is mechanical work, E is heat transfer by evaporation, R is heat transfer by radiation, C is heat transfer by convection, K is heat transfer by conduction, and S is heat storage.

The enclosed still air and external air movement are the major factors that affect the heat transfer through fabric, and it is influenced by fabric construction, thickness, and material [4]. Fibers in a fabric structure serve two main functions in providing thermal insulation. Firstly, they develop air spaces and prevent air movement. Secondly, they provide a shield to heat loss from radiation. The efficiency of the thermal insulation of a fabric depends on fiber physical properties, such as fineness and shape, as well as the structure of fabric [5]. The higher the volume of dead air within a textile structure, the lower will be the thermal transmittance which results in higher thermal resistance [15]; man-made fibers can be produced with a degree of crimp or surface irregularity that increases thermal resistance [5]. Fabrics or garments made from hollow fibers can also provide better thermal insulation values due to the larger trapped air volume provided. Previous research shows that the amount of contact an item of clothing (such as a sports bra) has with the skin may affect thermoregulation. When the clothing fits tightly, there is less exchange of air beneath the clothing with the environment ("flushing"), and this can negatively affect thermoregulation [13]. Therefore, a sports bra, for example, can represent a physical advantage but a thermal disadvantage [13].

Evaporation is the body's main method of heat dissipation during exercise and in hot environments [13]. Heavy sweat is formed in the body that leads to the accumulation of a lot of moisture or a thin film on the skin due to heat dissipation [4]. Sweating majorly acts as a heat loss mechanism of the body and cools where the sweat is being evaporated. Clothing actively affects the amount of sweat produced and the level of evaporation [13]. When fabric is subjected to heavy sweating conditions, not all the sweat absorbed by fabric can be given off to the atmosphere instantaneously. Thus to prevent the wearer from feeling wet and clammy [17], the sweat should be transported away from the skin surface body. The transportation of sweat may be in the form of liquid or vapor so that the fabric touching the skin feels dry [11, 15].

In that respect, water vapor permeability is an important property that determines the capability of transporting perspiration through a textile material [15]. Water vapor permeability plays a very important role when there is only little sweating or insensible perspiration. The garment should have the ability to release the moisture vapor held in the microclimate to the atmosphere to reduce the dampness at the skin [4]. Impermeable structures, i.e., not permitting passage of water vapor to the surrounding atmosphere, increase the relative humidity of the microclimate inside the clothing and thermal conductivity of the insulating air, causing coolness and dampness. Water vapor transfer through textile materials may occur due to diffusion (driven by a water vapor concentration gradient) and convection (driven by an air pressure gradient) mechanisms [12]. Moisture transfer also involves adsorption, absorption, or desorption between the fibers and the surrounding air as well as the movement of condensed liquid water as a result of external forces, such as capillary pressure and gravity. Adsorption occurs when water molecules are attracted to the surface of a solid. A larger fiber surface area within a fabric can increase the amount of water adsorbed. In absorption, molecular moisture diffuses through the material. Desorption is the process of moisture release from adsorbed or absorbed water. The process of moisture absorption or desorption within textile materials absorbs or releases heat, which further complicates the heat transfer process [5]. The sweat absorption, spreading, and drying which determine how quickly the skin can be dried after sweating of a fabric decide the thermophysiological comfort property of the garment [18]. Therefore, fabrics with good moisture transport and drying properties are essential for intimate apparel which contact with skin directly.

During heavy activity when liquid perspiration production becomes high, to feel comfortable the clothing should possess good liquid transmission property. Wicking is an important property to uphold a feel of comfort during sweating conditions and is affected by fabric properties [4]. Discomfort is linked to the presence of liquid on the skin, and the removal of this, either by optimized evaporation or by wicking the moisture away from the skin, is thus a relevant factor [19]. Wicking is the spontaneous flow of liquid in a porous substrate, driven by capillary forces produced in the fabric. This is due to the wetting of fibers, and it causes the liquid to reach the spaces in between the fibers which gives a capillary action. Wicking fabrics can benefit comfort and cooling in two ways. When a person starts to sweat in garment, this sweat can be absorbed by fabric, spreading over a bigger area and thus facilitating evaporation. Also, by removing the liquid from the skin

and transporting it away from the skin-fabric interface, clinging of clothing with its associated discomfort is reduced [4, 19]. The transport of liquid moisture is a complex mechanism dependent on the hydrophilic properties of the material (fibers), the inter- and intra-yarn capillaries, as well as the water absorption capacity (hygroscopicity) of fibers. These phenomena depend on the liquid surface tension, the size of the interstices, and wettability of fiber surface. The capillaries (interstices) in a fabric must form a continuous channel with the proper size. Parameters, such as fabric count, yarn linear density, and yarn twist, affect the size and number of fabric interstices. Fabrics with larger interstices normally allow rapid diffusion of water [20]. Sweat forming on the skin can be transported from the skin surface to the outer surface of the fabric by fabric wicking, where it evaporates to the environment and keeps the skin dry [5]. The spreading of liquid moisture can basically occur in two directions: spreading into the surface of the fabric (lateral wicking effect) or transfer of liquid from one side to the other (vertical wicking effect [2]). Also, moisture regain of a fiber affects wicking performance such that fiber with a larger moisture regain tends to decrease the wicking effect. In addition to these, the radius of capillaries is the key factor in deciding capillary effects [5].

Dryarn, Coolmax, FIELDSENSOR[™], fibers from Meryl product line, AKWATEK, Moiscare[™] fibers, and the others, which will be discussed in detail in following section, provide high thermal comfort performance.

2.3 Ease of movement comfort

People must be able to move in the clothing that they wear. If clothing restrains movement, discomfort may result due to the pressure exerted on the body by the garment, and the clothing may fail [21]. A simple and ordinary body movement expands the skin by about 10–50%. Therefore, the strenuous movements require the least resistance from garment and instant recovery [22]. The dramatic difference between the skin's elasticity and the lack of elasticity in conventional fabrics results in restriction of movement to the wearer and loss of shape, and consequent performance, of garments [9]. Minimizing a garment's resistance to the body's demands in movement can be achieved through increased fabric fullness in the pattern or through fabric stretch. Increasing the fabric's stretch means garments can be cut to achieve a more streamlined appearance and can conform better to the body while still maintaining comfort for the wearer in motion [21]. Thus, intimate apparel should have stretch and elastic recovery to provide sufficient fit and freedom of movement to the wearer.

Fitting is a crucial factor of wearing comfort particularly for the next-to-skin stretch garment. Despite attempts to standardize size, every female's body shape is unique, which complicates the design process [8]. A good bra should fit the 3D complex body contours, to support the breast weight and to provide appropriate tension by well-fitted bottom band, straps, and cups [23]. However, perfect fit for bras is very difficult to achieve because it involves tedious trials and errors on manipulating the shape and support provided to the soft breasts of a live model [9]. Moreover, many pattern adaptations may be required to try different grain lines in the pattern and tension of fabric or changing the fabric and trims for better tension recovery [24]. However, women go through great difficulties to find a perfect-fitting bra to mold the body in a desirable silhouette [9]. A research conducted across western countries reports that at least around 70% of women wears the wrong size of bras [23]. This is not surprising because even within the same brand the bra size and thus bra fit change with the different styles [24]. The big problem of wearing the wrong bra contributes to poor posture due to the lack of support for the chest, and muscles have to do all the breast work. The breast is pulled by weight bra and causes pain on

the back, neck, and back pain [9]. According to a study, the ability of a sports bra is reduced due to the poor bra fit which causes an increased breast discomfort [24].

Creating irritation in skin areas, bruises, and deep creases on the skin by elastic pressing the wrong place make the user feel uncomfortable [9]. It was found that the highest pressure was at the top of the shoulders and under the front elastic band. Costantakos and Watkins [23] suggested that a well-designed bra should prevent concentration of pressure on the sensitive areas such as veins and arteries near the skin surface. To limit the force generation and increase breast comfort level, the positive correlation between the mass of the breast and the vertical displacement suffering in their day by day has to be found. Also, the plus size bra can be the cause of numerous health problems related to the arms, neck, back, and head pain. For a plus size bra, it is advisable to use powernet or more than 20% elastane or lining for the wing or band part. The percentage of elastane will increase support in plus size breast that can be improved with the placement of a bone on the lateral side fitting [9]. Moreover, in the particular stage of a woman's life, with the breast sagging, to create the right bra and the user choosing a more appropriate model, it is important to retain the biomechanical considerations. For pregnant women suffering from low back pain, maternity under garments could provide certain abdominal support and distribute the growing weight of fetus to the shoulder and the upper torso, which may help to relieve back pain and improve the wearer's mobility [23].

Garments including fibers such as LYCRA® W from the Lycra Company, the Meryl Elite® from Nylstar, and ISCRA-S from Sorona offer comfort in terms of fit, shape retention, and freedom of movement.

2.4 Sensorial comfort

Sensorial comfort is the sensation of how the fabric feels when it is worn near to the skin. The tribology of skin in contact with textiles is important in connection with the comfort of clothing, because the tactile properties of fabrics are closely related to their surface and frictional properties. Sensorial comfort is very difficult to predict as it involves a large number of different factors, and this feeling addresses properties of the fabric like prickling, itching, stiffness, or smoothness [2]. In addition, a good performance of movements is always combined with the use of suitable materials and intimate apparel; the proportion of the body has to be assessed so that the product used is the most appropriate for those wearing it [9]. In addition, wet skin is much more easily irritated than dry skin.

Experimental studies showed that raw materials and structural properties of fabrics are important in the determination of tactile properties of fabrics. Suda and Tamura [23] tried to estimate comfort with the help of the tactile sensations like smoothness, softness, and stickiness of underwear fabrics despite the change in air temperature. According to Nielsen et al. [25], knit structures of the underwear influenced sensations of humidity significantly, but not sensations of temperature. The various sensations of temperature correlated best with core temperature, whereas the sensations of humidity correlated with skin wetness. The study which assesses the tactile comfort according to 10 descriptors (soft, thin, smooth, warm, dry, light, loose, sheer, stiff, and pleasant tactile sensation) conducted by Kweon et al. [23] implied that men usually preferred all cotton, while women selected man-made fabrics. In addition, at intimate apparel lace and embroidery are used so often which prick the skin. Also, poor seam coverings or loose threads also bring skin irritation. To minimize the seams and stitches, various sew-free technologies have been widely applied. The bra cup seams have been eliminated by molded cups; the elastic band has been replaced by Bemis thermoplastic polyurethane (TPU) film or Lycra 2.0 polyurethaneurea (PUU) heat-activated elastic adhesive tape. Thread and stitches disappear when the hemming

operation uses ultrasonic bonding with hooks and eyes integrally attached onto the inner surface of the back wing panel. Brand and size labels are seamlessly printed [23]. A study of 1285 female marathon runners found 28% frequently experienced problems with sports bras rubbing or chaffing which is a typical example of the importance of sensorial comfort which if ignored may lead to minor injuries [24]. Moreover, women have sensitive skin especially during puberty and pregnancy.

TACTEL® fiber from Invista, Sensil® Body Fresh, and chitin are some examples for the novel fibers that maintain good sensorial comfort.

3. Innovative fibers and comfort of intimate apparel

"A fiber is a unit of matter, either natural or manufactured, characterized by flexibility, fineness and a high ratio of length to thickness" [26]. The use of natural fibers dates back to 4000 years ago, and they were the fibers used first. Cotton, wool, silk, and all other animal and plant fibers fall in the category of natural fibers. The first attempt to make an artificial fiber was done in the year 1664. However, it was almost 200 years later when the first success was achieved. Man-made fibers became a significant alternative to natural fibers after the 1950s. The development of these fibers opened up fiber applications to various fields like medicine, agriculture, home furnishing, modern apparels, etc. [27, 28]. The timetable of fibers covers four generations [29]:

- Before the 1950s, natural fibers were used, and they are termed as first-generation fibers.
- After the 1950s, second-generation fibers, man-made regenerated and synthetic ones, were introduced.
- Third-generation fibers came in the 1980s. This generation covered specialty fibers, high-performance/high functional fibers, and high technology fibers.
- Super fibers, smart fibers, and nanofibers, which are called new fibers, are the fourth-generation fibers that came after 1985. These fibers give a new dimension to the use of textiles.

As of today, latest trends and innovations in man-made fiber and textile industry can be roughly identified and classified as follows [30]:

- Sustainability
- Development of functional textile
- Development of smart textile
- Manufacturing innovations
- Materials engineering
- Unconventional applications

High-technology fiber is a general term used for fibers made by different methods from ordinary methods, and they are the ones which have improved performance such as high melting point and high decomposition temperature. These high-function fibers are developed according to needs of the user and provide

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higher comfort, easy-care properties. Functional textiles have additional functionalities like flame resistance, breathability, thermoregulation, stain resistance, being antimicrobial, electro conductivity, etc. [31].

Common types of fibers currently used in intimate apparel are cotton, silk, rayon, nylon, polyester, and spandex. Performance and versatility of intimate apparel such as easy-care properties, light weight, durability, ease of movement, having antibacterial or anti-odor properties, and good moisture management are further improved by the use of new fibers. In this section the latest developments in fibers used in the manufacturing of intimate apparel products and their contribution to clothing comfort are discussed [32].

Fibers which attribute ease of movement to intimate garments have superior stretch and recovery properties:

LYCRA® is a synthetic elastane fiber that can stretch up to about six times its initial length and return to its original state repeatedly. Garments including LYCRA® fiber offer comfort, fit, shape retention, and freedom of movement. The fiber can be used in close-to-the-body garments such intimate apparel as well as pantyhose, hosiery, active wear, and swimwear [33].

LYCRA® W technology offered by the Lycra Company elevates the performance of intimate apparel made from warp or circular knit fabrics. "W" elastane fibers with luster permit the garments to deliver outstanding whiteness, whiteness retention, uniformity, and dye pickup for deeper, richer colors. Fabrics made with these fibers also have better resistance to elastane yellowing from heat-setting, exposure to fumes, and UV light [34].

For intimates, body wear, sportswear, etc., different types of polyamide microfibers are offered by Nylstar through the Meryl® product line.

Meryl Elite provides a convenient partnership to elastane in single and double covered yarns (**Figure 1**) offering a good performance for tights, socks, and leggings. Microfilaments of Meryl Elite give lightness, smoothness, high elasticity, durability, and comfort to the garments [35].

ISCRA-S is a highly elastic material-like spandex. It is a bicomponent fiber from Sorona, a material extracted from corn, and PET. After the finishing processes are applied, it gains a spring-like structure (**Figure 2**) [36].

The fiber is suitable to be used in underwear, sportswear, outdoor wear, etc. due to its comfort stretch and good stretch recovery as well as quick moisture absorbing and drying properties.

ECOWAY-Sorona from corn is a soft touch fiber from shape memory material recommended for intimate apparel. Textiles from ECOWAY-Sorona are naturally crumpled and smoothly unfolded due to the shape memory property [37].



Figure 1. *Covered yarn structure* [35].



Figure 2.

ISCRA-S fiber before and after finishing process [36].

To improve moisture management properties of intimate apparel, breathable fibers with modified cross section have been developed to enhance the wearer's comfort. Fibers and yarns that possess improved moisture management properties are discussed in the following section:

TENCEL[™] Intimate cellulosic fibers, lyocell, and modal are produced by sustainable processes from natural, renewable raw material, wood. TENCEL[™] lyocell fibers absorb moisture more effectively than synthetic fibers, and there is less moisture formed on the fiber. The fibrils of cellulosic fibers regulate the absorption and release of moisture. This leads to less favorable media for bacterial growth, and consequently better hygienic qualities are offered. This also enhances breathability of the garment and keeps the skin cool and dry. One of the key factors in choosing materials for intimate apparel is softness. The smooth surface of TENCEL[™] Intimate cellulosic fibers also offers a gentle touch to the skin. High flexibility and low rigidity of fine TENCEL Modal fibers result in a soft feeling twice as soft as cotton [38].

FIELDSENSOR[™], developed by Toray, applies the principles of capillary transport to the structure of knitwear enabling absorption, movement, dispersion, and evaporation of perspiration from the skin. By this way, the perspiration-induced stickiness and clinginess of traditional materials are eliminated. It offers good moisture management functions for running, fitness, and training suits [39, 40].

Flat multi-microfibers as fine as 0.45 dpf (dtex per filament) of Meryl® Sublime, from Nylstar's Meryl® product line, quickly draw perspiration away from the skin to the exterior of the fabric. The fiber is highly demanded for intimates and swimwear due to its special handle, silky touch, light weight, and breathability [41].

Meryl® Nateo is an air-textured polyamide yarn with a round cross section. The main properties of Meryl Nateo, namely, UV productivity, water absorption, breathability, and stretch ability, make the fiber suitable to be used in body wear, sport, swimwear, or intimates [42].

Trilobal cross section of Meryl Satiné reflects the light perfectly and provides garments with a remarkable shine comparable to silk (**Figure 3**). Meryl Satiné is preferred for many applications due to its excellent moisture-wicking properties, breathability, and natural elasticity [43].

Dryarn is a breathable "isostatic polypropylene microfiber" which offers intense performance in terms of lightness, drying, and wicking, with no penalty in the thermal insulation properties specific to polypropylene. It also has a higher capacity for removing moisture compared to polyester [44, 45].

NILIT[®], a manufacturer of nylon 6.6 fibers, offers fashion body wear, active wear, legwear, and intimate apparel. Sensil is a new Nylon 6.6 brand created by NILIT[®]. Sensil[®] Aquarius has built-in moisture management properties thanks to its special triple T-cross section which forms special micro-channels in the fiber and increases the surface area for improved moisture management (**Figure 4**) [46, 47].

Supplex[®], a registered trademark of Invista and licensed by NILIT[®] for nylon fiber products, provides functional benefits for intimate apparel, active wear/fitness, etc. with an exceptionally smooth, natural hand due to the presence of finer,



Figure 3. Trilobal cross section of Meryl Satiné [43].



Figure 4. *T-cross section of Sensil*® Aquarius [48].

multiple nylon filaments and dries up to four times faster than cotton. Supplex® also has permanent protection due to the intrinsic UPF protection qualities [49].

Coolmax is an advanced polyester yarn mainly used for thermoactive underwear, intimate apparel, sport underwear, and sportswear. A capillary transport system main-tained by special four- or six-channeled fiber morphology pulls moisture away from the skin, transfers to the outer layer of the fabric, and dries quickly. It's much convenient for sport applications due to high thermal control under physical stress [50, 51].

Coolmax freshFX, on the other hand, is a suitable fiber for intimate apparel which combines the Coolmax® moisture management and odor shield antimicrobial fiber technologies. Coolmax® freshFX[™] is designed by incorporating a silver-based additive to Coolmax. Coolmax® freshFX[™] fabrics actively suppress the growth of bacteria which are responsible for body odor and related smells. Coolmax® freshFX[™] garments keep the wearer cool and dry while keeping clothes smelling clean and fresh longer [52].

TACTEL® fiber from Invista is a form of nylon fiber which is widely used in women's intimate apparel because of its soft and lightweight nature, quick drying, easy care, breathability, and abrasion-resistant properties [53, 54].

Nike Dri-FIT technology uses microfibers to support the body's natural cooling system by wicking away sweat. The moistures is, then, dispersed evenly throughout the surface of the garment and evaporates quickly. Dri-FIT fabrics can be made of

nylon, polyester, spandex, or a blend of all three but mostly in the form of microfibers. It is proposed that it should be worn next to the skin to keep the body dry [55].

Consumers' awareness of hygiene and active lifestyle has created an increasing demand for antimicrobial/anti-odor textiles. Bacteriostatic fabrics prevent the proliferation of microorganisms and production of unpleasant odor. The formation of fungal growth is also slowed down by the use novel fibers offered.

Normally, some amount of bacteria is present on human skin. Not only the presence of a high level of bacteria but also its complete absence creates various problems such as allergy, odor, illness, etc. While exercising, bacteria are transferred to the textile and with conventional nylon fibers; these bacteria can proliferate and grow very quickly. With the inherent silver microparticles, Meryl Skinlife prevents bacteria growth, maintains the natural balance of the skin, and reduces unpleasant odor [56].

Meryl Nexten from Nylstar is a hollow polyamide fiber with inherent silver microparticles (**Figure 5**). Its hollow structure provides the production of 20% lighter fabrics with the same thickness and insulation of the body against temperature variations. The presence of silver microparticle Meryl Nexten offers an antimicrobial effect [57].

Chitin is a biocompatible compound obtained from the shell of crab and shellfish. Chitosan is a product derived from Chitin. A new fiber Crabyon® is a blend of chitosan and viscose which has permanent antibacterial functions. The fiber is suitable for weak and sensitive skin since it prevents the skin from drying out. Due to Crabyon's velvety touch and other properties, it is recommended to be used in intimate apparel [58].

Sensil® Body Fresh makes sure the garments do not have unpleasant odor thanks to the antibacterial additive embedded in the fiber [59].

With its excellent disinfection power due to the silver ions held in the acrylic fibers, PURECELL[™] and a deodorizing fiber preventing unpleasant smell by absorbing the ammonia CELFINEN[™] are fibers recommended for underwear by TOYOBO [60, 61].

X-STATIC® silver fiber from Noble Fiber Technologies also utilizes the power of silver to inhibit the growth of bacteria on fabrics and to eliminate human-based odor. 99.9% metallic silver is bonded to the surface of a fiber X-STATIC® permanently. One hundred percent coverage area of silver on the fiber gives products with X-STATIC® a maximized performance with soft, flexible, and comfortable features [62].

TruFresh from Unifi is recommended for yoga pants, socks, hosiery, etc., for its odor-killing performance by inhibiting the growth of odor-causing bacteria, mold,



Figure 5. *Hollow polyamide fiber Meryl Nexten from Nylstar* [57]. mildew, and algae on fabrics. For optimal performance, it is recommended that the fabric contains at least 30% TruFresh by weight [63].

Thermal comfort is related to the efficiency of heat dissipation from a clothed human body. One of the primary functions of underwear is to act as a buffer against environmental changes to maintain a thermal balance between the body heat and the heat lost to the environment while allowing the skin to remain free of liquid water. Thermal comfort is provided by the use of recently developed fibers [1].

AKWATEK is a modified polyester fiber with active surface layer with anionic end groups. The active surface transports water molecules and releases them to the atmosphere before they can form liquid water. Thanks to AKWATEK's enhanced properties, thermoregulatory actions of the body are duplicated, and moisture is pulled away from the body much faster than capillary action fabrics. AKWATEK has the ability of keeping the wearer cool in warm temperatures and warm in cold temperatures. It is used in fabrics with Lycra—for apparel tops and tank tops, sport bras, turtlenecks, tights, and leggings [23, 64].

Quick transfer of heat from the body is maintained by the wide surface area of the fiber with flat cross section, and comfort is enhanced by the cooling effect and efficient ventilation of Sensil® Breeze (**Figure 6**). The presence of inorganic micron particles in the polymer further increases the surface area and contributes to the cooling effect [65].

The use of Sensil® Heat in knitted garments provides a delay in heat transfer from the body to the outside. Coffee charcoal, from coffee bean shell residue, is integrated in the yarn together with an oxide additive which captures and keeps body heat. It is claimed that the insulation activity is most effective when the fabric is used nearest to the body [65].

Another fiber recommended for underwear, sports apparel, bed clothes, etc. is an acrylate fiber, Moiscare[™], which is a registered trademark of the Japanese firm TOYOBO. The fiber has heat-generating ability when absorbing moisture. It is claimed that the exothermic energy is about three times higher than that of wool. Depending on the atmospheric conditions, it can absorb and release moisture repeatedly. It also has the ability of deodorizing ammonium gas and others [67].

Thermolite FIR technology from Invista is a spun-dyed black fiber in which special ceramic pigments are embedded. The fiber, recommended for legwear, absorbs the wearer's infrared radiation and reflects it back as heat energy and raises skin temperature by around 1°C [68].



Figure 6. Sensil® Breeze [66].



Figure 7. Outlast® viscose fiber [70].

Outlast® technology manages moisture by reacting to sweat and pulling it away from the skin and proactively manages heat while controlling the production of moisture before it begins. It utilizes phase change materials (PCM) that absorb, store, and release heat for optimal thermal comfort. Outlast® phase change materials can be located inside the fiber. In-fiber applications are for products being worn next to or very close to the skin. Outlast® viscose is a versatile fiber commonly used for underwear, shirts, dresses, sleepwear, work wear, and sportswear (**Figure 7**). The fiber provides softness and comfort similar to cotton or silk [69, 70].

4. Conclusion

Intimate apparel ensures primarily the comfort of people as it contacts with the skin directly and forms an inner layer between the skin and outerwear. To provide intimate apparel comfort, thermal, aesthetical, sensorial, hygienic, and motional performances are required which are mostly related to fiber properties. Thus, the investigations to develop new fibers which provide better comfort performances are carried on by major fiber manufacturers. This chapter presents a detailed review of comfort from intimate apparel side, and also developed novel fibers which are recommended to be used for performing intimate apparel comfort were introduced.

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