CHAPTER ONE

INTRODUCTION

1.1 Motivation

Production and consumption of synthetic fibers such as polyester, nylon, acrylic, and polyolefin highly increase worldwide. In 2017, the consumption of synthetic fibers possessed the highest share of 64.2% compared to regenerated and other types of natural fibers as presented in Figure 1.1. These fibers can be used for clothing, construction, medical, home furnishing, automotive, filtration and other applications depending on the interest of end-users [1]. Among these synthetic fibers, polyester (PET) is the most popular which accounts almost 80% of the total synthetic fiber output and is widely used for clothing fabric due to its strength, lightweight, resistant to many chemicals, and resistance to shrinking and stretching [2, 3]. However, because of its molecular structure and chemical composition, PET fiber lacks many comfort related properties compared with natural fibers [4]. On the contrary, natural fibers have inherent characteristics that fulfil the comfort properties. In this regard, cotton is a typical natural fiber and it has good comfort properties. In fact, there is no perfect fiber having all desirable textile properties. Therefore, blending of PET and cotton fibers can bring an alternative technique to enhance the required qualities and reduce the undesirable features of the fibers [5].

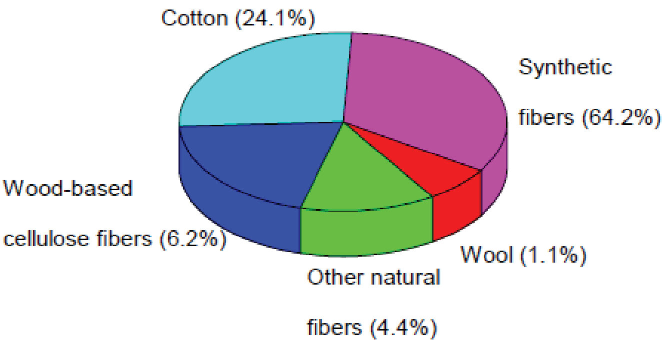

Figure 1.1. Consumption of fibers by the global market in 2017, adapted from [6].

In the textile industries, the polyester/cotton (P/C) blend fabric covers 58.45% of the world's market share [7]. This blending technology brought more attention in home furnishing and apparel applications. Nowadays, the demand of P/C blend fabric in the apparel industry has increased significantly due to the desired properties of user friendly, functional performance, aesthetic value, printability and affordability, which are more difficult to obtain altogether in both PET or cotton fabric products, separately. Despite the outstanding P/C fabric properties, PET surface hydrophobic character hinders the blend fabric comfort properties when functioned as an apparel fabric [8]. In addition, the comfortability of the P/C blend fabric mainly depends on the blend ratio and the environmental conditions [9]. Especially, when the proportion of the PET fiber is higher than cotton fiber the produced garment is uncomfortable for the wearers. Moreover, this problem would be more pronounced during outdoor wear.

As is already known, the hydrophobic nature of PET fiber has the potential to develop electrical resistivity in the fabric due to the tendency of the synthetic PET fiber to static electrification build up [10]. The built-up static charge, under low humidity conditions, does not dissipate for a long time because of the low conductivity of textile fibers. Consequently, accumulated static charges adversely affect the comfort properties of the garments when it rubs against the wearer's body, and at the same time, dust particles have the possibility to be attracted towards the fabric surfaces. The relationship between the fabric resistivity and its potential to build-up electrostatic charge is not always a clear-cut point; nevertheless, it is widely agreed that the most static-electrical problems emerging from the use of textile substrate can be reduced to manageable levels if the surface resistivity (ρ_s) and the volume resistivity (ρ_v) are dropped to 10^{11}–10^{12} Ω/square and 10^7–10^8 Ω.m, respectively [11]. However, the PET fibers have insulating properties and have a volume resistivity of 10^{14} Ω.m [12].

Consequently, the hydrophobic characteristic of PET fiber affects the thermo-physiological comfort by disturbing the transmission of heat, movement of moisture vapor and perspiration from the skin to the surrounding environment through the blend fabric [13, 14]. This indicates that the types of blend component and thermal insulation property of the fabric as well as the abilities of its moisture management influence the clothing comfort. Indeed, in warm environments, the volume of sweat is considerably higher in hydrophobic fabrics when compared with hydrophilic fabrics [15]. Particularly, when the PET fiber content increases in the blend, the water vapor permeability of the fabric decreases linearly. This is due to the decreasing absorption of the water molecules in PET fiber. Under this situation, the body is unable to maintain a steady-state of body temperature within its own heat transfer mechanism, and then, it starts to sweat. Hence, evaporation became low from the fabric. Subsequently, the water vapor is condensed in-between the fabric and skin ahead of flow down on the skin in liquid form. This liquid would wet the fabric and clung with the body. Finally, the wearer feels discomfort [4]. To prevent this and above-mentioned limitations, the P/C blend fabric surface must be treated to give better clothing comfort.

Therefore, the surface treatment of P/C blend fabric is necessary to improve the comfort properties, while retaining its excellent blend fabric properties. In this regard, several techniques have been applied to fabric surface modification, focusing on the enhancement of its surface to be more hydrophilic. These include wet chemical processing, plasma treatment, corona discharge and flame treatment [16]. However, the above mentioned traditional chemical-based treatments have technological and ecological drawbacks such as changing the bulk properties, bringing toxicity to the environment and are not cost effective [17]. In addition, corona and flame treatment can bring contamination and surface non-specific problems, respectively. On the other hand, to improve the fabric static charge dissipation or to eliminate the generations of static electricity, different treatment methods have been performed. These methods have been used to introduce the conductive metal/organic fibers into woven structures [18], radioactive static eliminators [11], and antistatic agents [19]. Nevertheless, introducing the conductive metal fibers into the woven structure also affects the mechanical properties of the fabric. To resolve these problems, plasma treatment is an ideal option.

Plasma technology provides an attractive approach in surface treatment of textile materials as it is considered as a versatile, dry, eco-friendly and resource-saving process as it uses null or minimum amount of water and chemicals [20]. So far, it merely modifies the outermost surface of the textile substrate without changing its bulk properties [21]. In particular, low-pressure plasma system is usually between 0.01 and 10 mbar, which is more preferred due to the high concentration of reactive species, the uniformity of a large surface area, high controllability, and the superior chemical selectivity and reproducibility of the results [22, 23]. This technology has been found to be effective to impart functional properties of several textile fibers, but comfort properties of the P/C blend fabric are not studied yet. Therefore, in this research, the low pressure plasma was implemented to provide a more hydrophilic surface of P/C blend fabric for shirt clothing application. In this study, the researcher selected the blend of 35% cotton and 65% polyester because it is the most popular blend fabric and has been used for many applications [24], such as sportswear [25] and medical protective clothing after finishing treatment [26].

1.2 Objectives of the research

The general objective of this research is to study the influence of plasma surface modification on comfort properties of P/C blend fabric by considering the climatic conditions. Particularly, the intention of this study is to improve the hydrophilicity of shirt cloth, made from 65% of PET and 35% cotton, by modifying the hydrophobic characteristic of its surface with low-pressure plasma. Even though the hydrophobic nature mainly belongs to PET fibers, the plasma treatment can change both the surface of PET and cotton fibers. The reasons for using shirt cloth are due to its wide application for uniform clothing and used next to underwear. In addition, it has a great chance directly to contact the nude body around the neck, shoulder and arms. The specific objectives of the research are:

- To utilize gases and monomer suitable for plasma surface modification medium;
- To evaluate thermal and tactile comfort properties of P/C blend fabric including air permeability, wickability, water absorbency, electro-physical, hand-feel and other properties;
- To investigate the aging behavior of plasma-treated P/C blend fabric;
- To characterize surface morphology and surface chemistry of P/C blend fabric;
- To identify undesirably affected comfort properties of plasma-treated fabric, experimentally.

1.3 Structure of dissertation

The structure of the dissertation approach is organized as follows:

This dissertation focuses on the surface modification of P/C blend fabric by applying low-pressure plasma treatment and consequently studying the comfort characteristics of the treated sample.

Chapter 2 illustrates the basics about clothing comfort and plasma surface modification of textile substrates. First, a brief introduction to clothing comfort is given and key concepts regarding thermo-physiological, physical, and aesthetic comfort as well as assessment of comfort properties are elaborated. Secondly, introduction to fundamentals of plasma technology, mechanism of plasma-textile surface interaction and application of plasma in textiles using gases and liquid monomers are explained.

Chapter 3 describes the set-up of the vacuum reactor for plasma surface modification of the P/C blend fabric which was used in this research work. In addition, the fabric specification of the blend fabric (shirt cloth) and chemicals, consumed for plasma treatment, are mentioned. Moreover, the experimental procedures of the comfort assessment methods and surface characterization techniques were explained.

Chapter 4 discusses the experimental results of plasma surface modification of the P/C blend fabric. The effect of oxygen plasma on thermal comfort properties of the fabric was studied using Taguchi methods. The influence of oxygen, argon and air plasmas on hand-feel and electro-physical properties of the fabric were also evaluated. On the other hand, the effect of the mixture of reactive gases/molecules and Hexamethyldisiloxane (HMDSO) plasmas on tensile strength and pilling resistance properties of P/C blend fabrics were discussed. In addition, the effect of aging on oxygen, argon and air plasmas treated blend fabric was investigated. The surface morphology and surface chemistry of plasma treated and untreated P/C blend fabric was characterized by using scanning electron microscopy (SEM), attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR), and energy dispersive x-ray spectroscopy (EDX).

Chapter 5 presents the conclusions and future works of the research. The conclusion summarizes the findings and contribution of this study. It is drawn from the results of the experimental investigations. Additionally, the future work indicates the outlook that will be continued using the results of this dissertation as a background information.

The overall structure of the dissertation can be outlined in Figure 1.2.

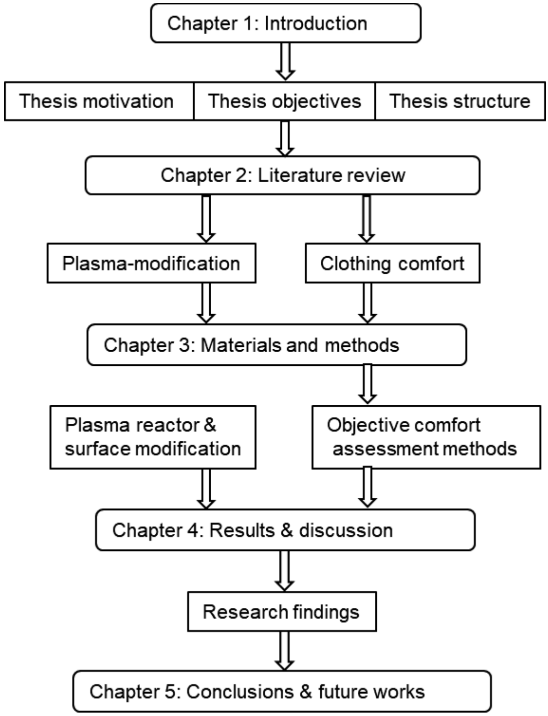

Figure 1.2. Dissertation structure.

CHAPTER TWO

LITERATURE REVIEW

In this chapter, the fundamentals of plasma process and clothing comfort are illustrated and discussed. Here, in addition to the scientific and practical information, other related fundamental evidence is given to realize the concept clearly. However, more attention is given to plasma modification and clothing comfort.

2.1 Fundamentals of plasma process and its surface modification

2.1.1 Introduction to plasma

Plasma is a partially ionized form of gas and often also referred to as the fourth state of matter, next to solid, liquid and gaseous state. In phase transitions, when a solid is heated enough, it can melt into liquid or sublime into gases. After obtaining sufficient energy, the particles in a liquid escape from it and vaporize to gas. Subsequently, when a significant amount of energy is applied to the gas, atoms and/or molecules collide with each other and knock their electrons off in the ionization process. Eventually, the higher number of electrons and ions can change the electrical property of the gas, which consequently becomes ionized gas or plasma [27]. This phase change of states of matter is illustrated in Figure 2.1. Atoms and molecules can be ionized or charged either thermally, magnetically or electrically [22, 28]. The plasma state comprises approximately an equal number of positively and negatively charged particles, i.e. quasi-neutrality, radicals, excited states, metastables, atoms, molecules, electrons, and photons. This state of matter was first noted by Sir William Crockes in 1879, and Irving Langmuir named ‘plasma’ in the 1920s [29]. Plasma differs in various respects including density of charged particle, pressure, temperature, and the presence of external electric and/or magnetic fields.

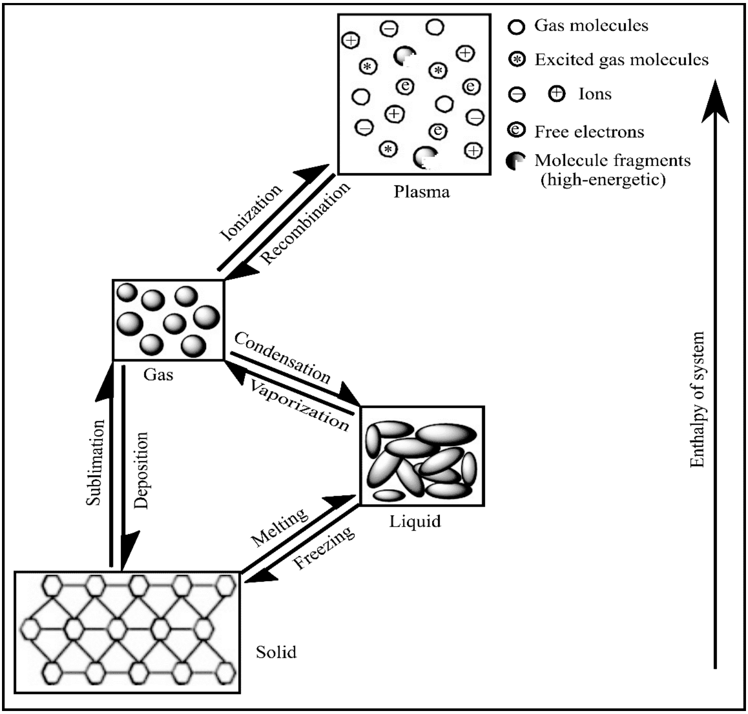

Figure 2.1. Phase changes of state of matter, adapted from [27].

Based on the temperature of electrons, ions and neutrals, plasma can be classified into thermal (hot) and non-thermal (low-temperature or cold) plasma, as shown in Figure 2.2. Thermal plasmas are associated with electric arcs, thermonuclear reactions, and laser-induced reactions [30]. In thermal plasma, all the species (i.e. electrons, ions and neutrals are at a similar temperature) that composing the plasma are in the thermodynamic equilibrium. The temperature of the plasma species produces a high volume of heat (>1,500 ℃) and is used as a source thereof. It is only used for changing the bulk material properties, being not suitable for textile and nearly all other materials. Cold plasma, on the other hand, is maintained at around ambient temperature, or somewhat greater than it (20-250 ℃). This is due to the electron temperature being much higher than ion and neutral temperature. It can be successfully applied to textile processing because textile materials are generally more heat sensitive polymers than metals and ceramics [16, 30, 31].

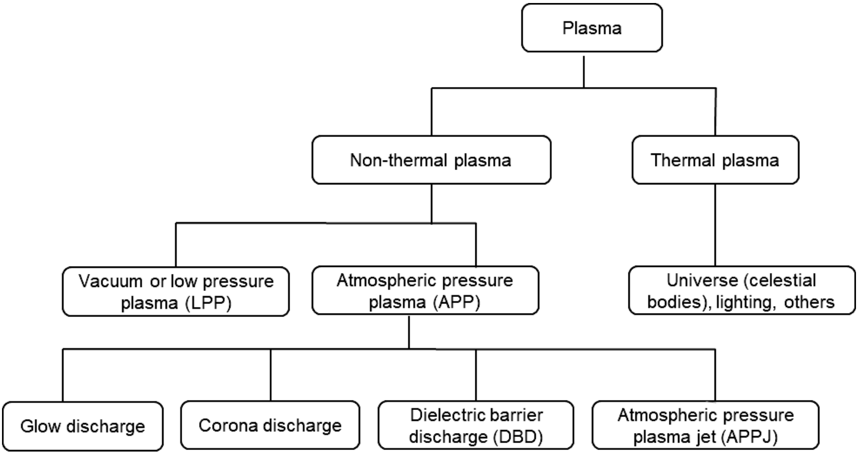

Figure 2.2. Classification of plasma, adapted from [31].

Cold plasma can be done in a vacuum under low pressure or at atmospheric pressure, both of which are used for textile surface modification. As mentioned above, cold plasma contains many reactive species (i.e. electrons, ions and neutrals), and these can initiate physical and chemical reactions on the surface of textile substrates [21]. Such modifications are limited to a few nanometers in depth, which only changes the outermost chemical, structural and surface properties of a substrate. Thus, plasma treatment can impart a desired property to textile fibers. The effectiveness of surface modification depends on plasma conditions and types of treated materials. Plasma treatment is very suitable, versatile, and multifunctional in textile processes [28, 32].

2.1.2 Generation and properties of plasma

Generation of plasma

The plasma state is generated by supplying energy to a neutral gas and creating the formation of charge carriers [33]. When energetic electrons and/or photons collide with the neutral molecules and atoms in the feed gas (electron-impact