NON-AQUEOUS COLOR FADING EFFECT ON COTTON WITH INDUSTRIAL APPLICATION

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Certificate of Originality

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Cheung Hing Fu, Channal (Name of student)

Abstract

This project was conducted under the “Teaching Company Scheme”, and the aim of this study was to investigate an eco-methodology, “atmospheric pressure plasma” (ozone) treatment for non-aqueous color fading effect on cotton with industrial application. “Atmospheric pressure plasma” (ozone) technology harnesses the natural bleaching capabilities of ozone gas to give a range of overall and specialty bleach effects with substantially reduced environmental impact. Among many sustainability technologies in the garment industry production process, ozone can be used to clean back-staining from normal washing processes, or to bleach down to a lighter shade, the shade depends on the parameter, it includes gas concentration, moisture content and treatment time, etc. Different parameters combinations generate different degree of color fading. Other than bleaching chemical, the water use reduction is an additional benefit achieved on this study. While the production process contains chemical bleaching or stonewashing, six to seven wash and rinse cycles are gone through. But finishing treatment by ozone will only require two to three cycles. Meanwhile, the conventional finishing applications require an amount of water, sometimes with the desirable temperature for wet finishing which can be replaced by ozone. Therefore, the “atmospheric pressure plasma” (ozone) technology for fading color application could replace some traditional finishing steps with reduces effluent, including the sludge that pumice stones create.

The ozone technology can benefit the industrial laundry production in the new era, especially on fading color application. To obtain atmospheric pressure plasma (ozone), oxygen is one of the key elements. The purity of oxygen (O2) will directly affects the ozone concentration produced by the ozone generator, as well as the time on ozone generating. In the G2 waterless washing machine, the built-in oxygen generator can generate power which is enough to supply 96% of pure oxygen. The G2 machine is designed for sampling and bulk production. Therefore, it sets up a preliminary control table for samples versus the bulk production application.

Experimental work was carried out to study the relationship between the combinations of the processing parameters, i.e. dye concentration, treatment time, gas concentration and fabric moisture content on the color fading effect induced by atmosphere pressure plasma. Research specimens were gone through a series of analytical studies on color measurement, which were evaluated by use of CIE LAB colorimetric system, K/S sum values, reflectance curve (R%), color levelness (RUI), CIE L*, a*, b* values and ΔE.

The results showed that the degree of color fading effect had positive correlation by adjusting the processing parameters. These data would be used for industrial reference on the application to reduce the variance for the desired color fading effects.

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Chapter 1.   Introduction

1.1.   Background of study

The global population has around 7.5 billion and China occupies over 1.38 billion [1], that is almost 20% population of the world. In China, supply and demand in society are always in mass volume, same for the industrial manufacturer. Under the development of society, human demands for water has been consistently increasing. However, the water resource available for humans is sharply decreasing. In the world, 97.5% of the ground water is seawater, 2.5% is fresh water. Among the 2.5% of fresh water, 70% water is frozen in the ice cap, less than 30% water is in the ground. However, only about 0.025% of the water can be used, which indicates that the water is rare and precious [2].

In the garment washing factory industry, most of the manufacturing processes need to consume water. When the garment washing industry uses more water, the more polluted water is generated. When an industry is over consuming water, the result is the depletion of resources, which is precisely problem that many countries are facing. Therefore, in order to avoid industry over-consumption, many countries are becoming aware that the water crisis will seriously threaten human survival and worsens ecosystems. It is necessary to make effectively use of water resources, e.g. waste water treatment, thus the promotion of sustainable development and protection of water resources has become a critical issue world widse.

The word “sustainability”, has had an impact on textiles industries, such as dyeing mills, weaving mills, industrial laundry, garment manufacturing and even for electroplating industry etc. Sustainability is not as easy as magic. Industries re-arrange their set up to fulfill the local government’s requirements or regulations on the pollution level from waste. Therefore, the textile industry has been seriously affected because the government has highly set the pollution standards.

In recent decades, China government starts launching an unyielding attitude on pollution control and the textile industry is one of the main areas. The textile industry is a very severely affected area, the dyeing industry is one of the most seriously affected. Since the use of water is unavoidable in the dyeing process to turn the material to have color, industries are encouraged to have less water consumption. Furthermore, water is the most used medium for fading color in the dyed textiles.

The industrial washing is another area which is affected seriously. Textile washing factories or dyeing mills have been closed or forced to move to other locations in order to decrease the impact on the environment and meet the legislative requirements. The new policy launched initial focus in Guangdong province [3] [4] and those provinces rely on textile business as their major GDP output. “Xin Tang”, a sub-town under Guangzhou city and many sub-towns under Dong-Guan city, have over 50% of small-scale industrial laundry factories that have been forced to shut down or are restructuring their businesses [5] where their water treatment levels do not comply with the ones required by the government required.

When the factories are restructuring their facilities, higher operation cost would lead them to decrease the competitive edge for getting less orders. Especially competing with the factories in other regions, such as Vietnam, Cambodia and other Asia Pacific countries. To reduce the harmful polluted level, simply by adding more filters (tanks), or using strength purified chemical dosage can lead the water becomes less polluted. However, a simple modification of polluted water treatment system will cost an enormous amount of investment. Therefore, many Industrial washing factory owners are not willing to invest and do release polluted water in furtively and illegally. Many factories that have been found with illegal discharge pollution water and have been banned in their production operation.

Other than closing the business, merging and acquisition would be another ways to maintain their business. However, some of them are forced to move their production to places which refuse water desired level and have lower anchor and those chemical oxygen demand (COD) and biological oxygen demand (BOD) requirements levels are not as strict as developed in the cities, such as Henan province where the requirements for wastewater treatment in the cities of Dancheng or Xiangcheng are lower than in the first tier city of Chengzhou. The government provides the pre-set industry park for the industry as an option it has another issue about bounds or limitation to relocate. The industrial park has a central pipe to collects the discharged polluted water from the end users and then the polluted water is centralized in the treatment plant. This is the most effective and efficient ways, as well as government encouraging model.

Therefore the user does not need to invest enormous amount in developing or improving their own polluted water treatment facilities but this involves high-cost for monthly service charges.

Nevertheless, the industrial washing factories need to survive therefore they should find their own way to fulfil government desired standards or less consumption of water.

1.2. Objectives

In textiles finishing processing, fading out of color by using traditional washing techniques involve much human manipulations. There is a variance between people, especially on quality control of the finished products. When it is applied in bulk production, it becomes a crisis and this needs to be overcome.

The ozone generated by the atmosphere pressure plasma color fading process is one of the method that can reduce error and can be more controllable. By controlling the processing parameters, such as treatment time, gas concentration, moisture content and quantity of textile materials. Technicians can work through the system to achieve the desired color fading effect. The collected parameters and information become a formula for reproducing different batches of production. This project is focusing on the flexibility and possibility of applying plasma treatment (ozone) for bringing up about the color fading effect on textile material.

This project has the following objectives:

(1) To study the results of color fading effects induced by ozone plasma treatment. Since this is a Teaching Company Scheme Project, the supporting company, Jeanologia SL would provide the plasma machine, G2 standard, for the project through existing customer in China. G2 is a waterless washing machine working with the principle of plasma which can generate plasma species as the color fading process. All specimens in cotton knitted fabric and color fading effect will be studied.

(2) The relationship and optimum parameter for ozone plasma color fading treatment versus cotton will be investigated.

In this project, all specimen fabrics are made of cotton, since cotton is the most commonly used fibre in textile and clothing and it accounts the largest market share in the textile industry. Meanwhile, the process parameters of plasma treatment application will be studied because their variations may affect the ultimate color fading effect significantly. As plasma treatment is a complicated process, all process parameters would affect the plasma treatment in interrelation. Therefore, scientific approach methods will be adopted for the study of the relationship among these process parameters, to decide the ultimate color fading effect to establish optimum conditions for achieving desired color fading effect.

(3) To develop a guideline for using ozone plasma treatment on color fading process, which apply on garment manufacturing and industrial washing industries.

Since the color fading behavior of reactive dyes on cotton will be studied. Therefore the result will give reference guidance for garment manufacturers and industrial washing factories. This study will provide a better understanding on the color fading induced by the plasma treatment and let the plasma treatment to become practical for industrial application. At the end, the plasma treatment specimens will be as a standard reference guide.

1.3. Scope of study

In this research, pure cotton knitted fabric will be used for the trial specimen because cotton accounts the largest portion of natural material used in the garment industry in the world. The color "yellow" will be selected as the pilot color because yellow is an essential basic color for color mixing [6]. Specimens will be dyed in concentrations of 0.5%, 1.5% and 3.0% respectively. Other than dye concentration, three parameters in the treatment process will be considered. Specimens will be gone through plasma processing with different time periods, 10 minutes, 20 minutes and 30 minutes respectively. Thereafter each section will be separated in four segments for different gas concentration, which are 10%, 30%, 50% and 70%. In addition, the moisture content may affect the results significantly. Therefore, two moisture contents, 35% and 45% will be used in this study.

1.4. Research methodology

In order to achieve the objectives, the research project will be executed with a scientific approach and a scientific experiment will be developed by studying the plasma color fading treatment. The outcomes of this project will enhance the interdisciplinary knowledge of plasma color fading treatment with cotton material science. The derived knowledge can be applied on developing novel finishing in environmentally friendly textile treatment processes. In order to achieve the outstanding performances and characteristics, the following methodologies will be adopted, aiming to achieve superior aesthetic performances and wearable characteristics.

1. A literature review will be executed so as to obtain sufficient background knowledge on the latest development of ozone treatment.
2. Reactive dyed cotton knitted fabric specimens will be treated by different parameters in atmospheric pressure plasma.
3. Color measurement results will be obtained from spectrophotometer. After the specimens have been measured, the data from K/S sum values, reflectance curves, levelness (RUI), L*, a*, b* values and ΔE will be collected for evaluating the color properties and performances.

1.5. Significance of study

Nowadays environmentally friendly technology is the mainstream in the textile industry and the non-aqueous technology is proposed as a substitution. With the technology of the novel plasma treatment on color fading in textile material, the drawbacks involved in conventional technologies could be tackled such as:

- The inability to create a standardize and replication of color fading effect,
- The successful application of color fading is not applicable on all types of textile surfaces,

- The inability to have required nuances in shading,
- The inability to repeat identical color fading effect on different lot of products,
- The insufficient visual effects,
- The loss of quality.

As the conventional technologies have all these disadvantages, the plasma technology is recommended for fading the color on textile fabric. Plasma technology is a novel technology application which does not require aqueous media to complete the process. Plasma technology has existed for almost a century, it was brought up in the last decade but its uses on textile color fading process has seldom been reported. Therefore, by investigating it systematically this novel application process, the technical and the theoretical aspects of the process can be well explored in order to have both industrial and academic benefits. This project can lead a breakthrough of the development in dry color fading process in Hong Kong. Thus, this technology can also help to increase the competitiveness of the local manufacturers in the rapid expanding global apparel industry.

1.6. Thesis structure

Chapter 1 contains the background of the study, the objectives, the scope of study, the research methodology, and the significance of our study.

Chapter 2 illustrates the literature review, the properties of cotton, the fundamental dyeing concepts of the cotton fabric, the dyeing mechanism, the dyes properties, the conventional methods of color fading on the cotton fabric, the international standard color measurement methods, the properties of the plasma and an application of the plasma treatment on the color fading process.

Chapter 3 explains the preparation details of the reactive dyed cotton knitted fabric specimens. The ozone plasma treatment for color fading of the dyed specimens will be also described.

Chapter 4 focuses on explaining the evaluations and predictions of the color fading performance on the dyed specimens with under different plasma treatment conditions.

Chapter 5 describes the conclusion and the recommendations. Further topics for study will be proposed and recommended.

Chapter 2. Literature review

2.1. Introduction

This project is focused on the cotton knitted fabric color fading by the ozone plasma treatment. It is to investigate the effects and performances under different treatment parameters, i.e. moisture content, gas concentration and length of treatment time for color fading, of the specimens in different depth of the color. 100% cotton knitted fabric is used as specimen substrate in this research. The fabric is dyed with Levafix Brilliant Yellow CA. Color fading effect on reactive dyed fabric is based on ozone generated by an atmospheric pressure plasma technique. In order to have a more thorough understanding, a comprehensive literature review in related fields is conducted, which will cover some fundamental concepts in dyeing the cotton knitted fabric, the structure and properties of cotton fibre, the dyeing mechanism, the properties of the plasma and mechanism of the plasma, the conventional chemical and the physical methods on color fading. Finally, the application of the ozone plasma on the cotton fabric.

2.2. Cotton

In the garment industry, cotton has dominated the production shares. Cotton is the major natural fibre in the textile industry. Cotton consists of about 96% of cellulose in the purest form of cellulose found in nature, other components are protein, pectin, pigment, wax, ash and organic acids [7]. In the current textile product aspect, cotton occupies over one third of the total production.

In general, the length of cotton was classified in two types, short-staple and long-staple. The short-staple cotton is known as Upland Cotton. The linear length of the fibre is generally from 25 - 35mm and its density is between 2.12 - 1.56 dtex. It is most commonly planted in China now. For the long-staple cotton, the most well-known is the “Sea-Island Cotton”. The fibre is thin and long so as it is classified as the best cotton fibre. The length commonly has 33mm or even more. The linear density is within 1.54 - 1.18 dtex. The longer the fibre length is the better performance is obtained for spinning and weaving processes. Therefore it can produce the finest fabric. Based on data in 2011, it was accounted for the largest share in textile business [8].

2.2.1. Molecular structure of the cotton fibre

The natural cellulosic fibres can be obtained from different parts of the plant, such as the cotton fibre, which is from the epidermis or outer skin of the seeds of the cotton plant. The others fibre commonly generated from different parts of plants, such as flax, hemp, jute and ramie come from the stems of the plant, sisal comes from the leaves and the husk of coconut, etc.

This section will discuss about properties of the cotton fibre. Among all types of cellulosic fibres, the cotton fibre could be considered as the universal fibre and a suitable dyeing substrate for reactive dye. It is a cellulose fibre and it is composed of thousands of cellobiose units which is carbohydrate and the molecule is a long chain of glucose (sugar) molecules as shown in Figure 2.1.

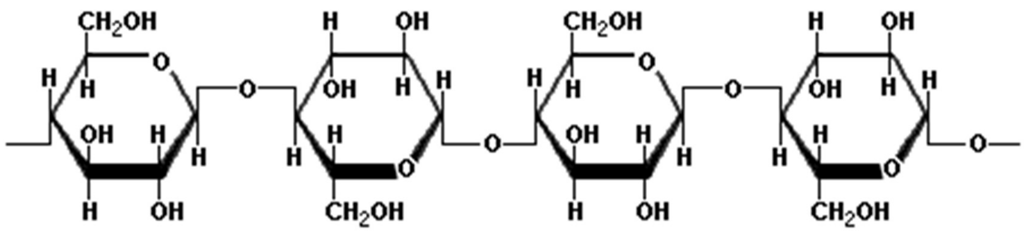


Figure 2.1. Molecular structure of the cellulose molecule (Four-residue segment of cellulose chain) [9]

Cellulose is a natural polymer and it is composed of polymeric sugar (polysaccharide) cellulose. Normally, the mature cotton fibre contents about 94% of cellulose and the rest is a small amount that includes pentosan, wax protein, fat, water-soluble substances, ash concomitant etc [10]. These components perform great impact on cotton fibre at the treatment process. But not all the components are good for cotton. Cotton wax provides good surface properties in the spinning process. However, in order to achieve the homogeneity for dyes, cotton is needs a scouring process to remove the cotton wax before the dyeing process. The Cotton fibre is largely cellulose that is formed from sugars synthesized by the plant that is larger than another cellulosic fibres [11] [12].

2.2.2. Morphological feature of cotton

In prompt mentioned the cotton fibre is dominant in the textile industry in our daily life. Below it is briefed about the features of cotton, cotton is the seed hair of the plant of genus gossypium and is a layered structures fibre. As shown in Figure 2.2 is the structure of the cotton fibre under the microscope. The cotton is a layered structure which shows a unique part of the cuticle of the cotton fibre, layer by layer of the main wall and the lumen, the outermost layer of the thin waxy cuticle and pectin. The thickness and cavity of maturity the cotton fibre cell wall are small. The vertical section of the cotton fibre has a longitudinal surface convulsion. The cross-section of the cotton fibre under the microscope is shows in Figure 2.3. Obviously, the shape of cotton fibres are seen to be quite irregular. Therefore, it leads to the spiraling of the cellulose fibrils and consequently the characteristic of twists appears, therefore it can easier spinning into yarns.

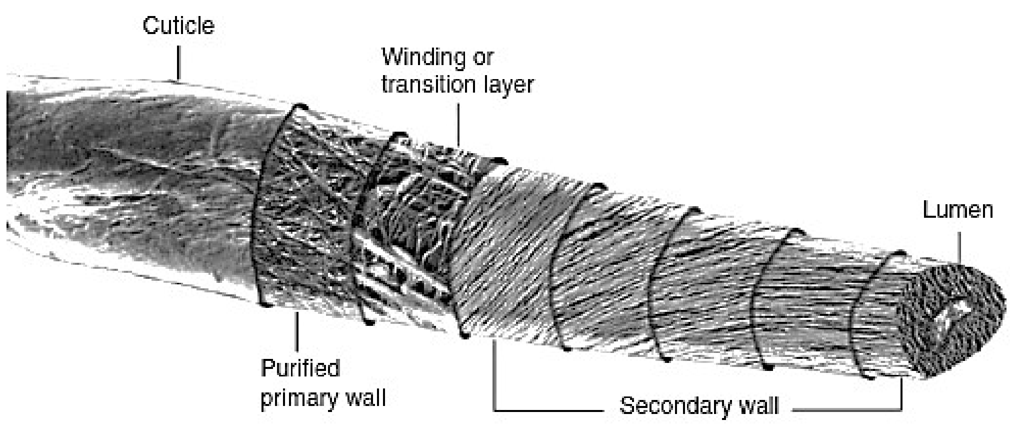


Figure 2.2. The structure of cotton fibre [9]

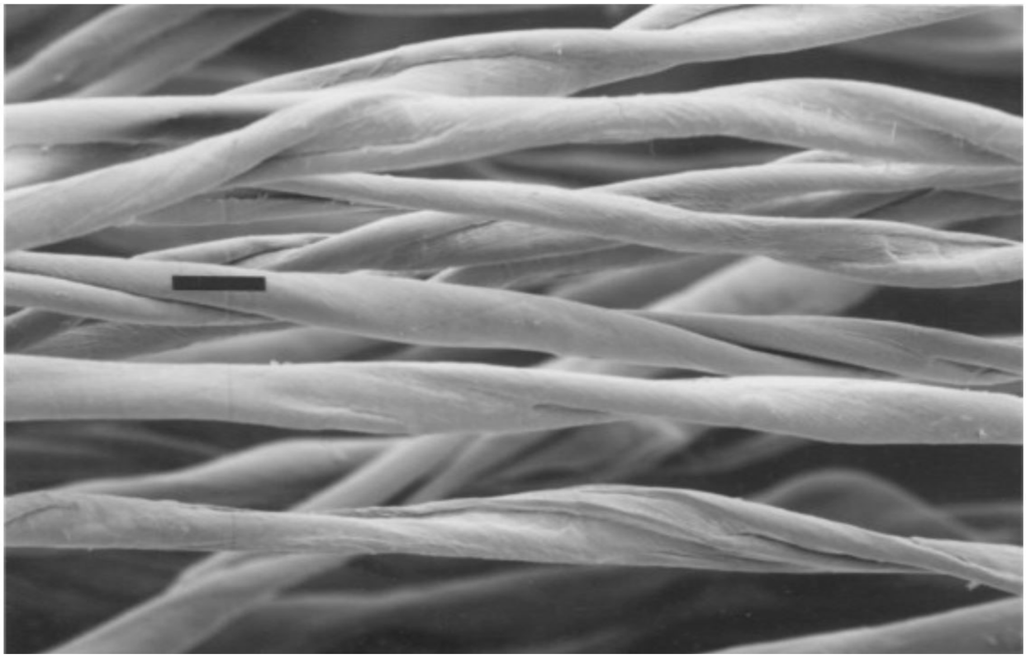


Figure 2.3. Cotton fibres under microscope view (Longitudinal view) [13]

2.2.3. Physical properties of the cotton fibre

The color of cotton fibres are mostly in creamy white (semi-bleach). However, in recent years, there has been a renewed interest in natural pigmented and colored cotton fibre, [14] which has existed for over 5000 years. The purebred cotton plant can grow a quality cotton fibres and it can reach to 98% cellulose. Therefore, it makes high crystalline force between chains in cotton. It results in a moderately strong fibre which has 18 - 45g/tex [15].

Cotton cellulose is insoluble in water, alcohol and ether and other organic solvents but swelling may occur if water, acid, base and aqueous salt solution penetrates into the crystalline zone. When cellulose is heated to about 150°C, significant change is occurred which may lead to dehydration. Cotton is hydrogen bonding in water and is hydrophilic. When cotton absorbes water and is wet, the tensile strength enhances more than 20%. Cotton is a stiff fibre at the absolute dry condition therefore it is easy to create wrinkles and creases. However, as mentioned that water can limit the swelling of cellulose, it can make the fibre swell smoothly and become flat. Nowadays there are many finishing methods being developed to improve the wrinkle recovery and the resin is one of the commonest finishing methods in the textile industry.

2.3. Dyeing of cotton fabric

In this project, cotton knitted fabric is decided to be used and dyed with Levafix Brilliant Yellow CA reactive dye, which prepares it for color fading treatment experiments. This section focuses on the principles of the reactive dyeing process.

2.3.1. Dyeing process mechanism

There are many types of dyes available for cotton dyeing, such as the reactive dye, the sulphur dye, the direct dye, the indigo dye and the vat dye. Each dye has its own characteristics, different dyeing methods and applications. However, most of the dyes go through the below process mechanism.

Solubilization of dye: Dyes are commonly in solid form, such as powder and granule form. Then dyes should necessary be changed into the solubilized state to becomes active. Therefore the solubilization step can be applied and water is one of good media to transform the dyes from the solid form into the liquid form.

Adsorption: To let dyes adsorb into the fibre, only using the natural affinity of dye molecules is not enough. Therefore, auxiliary products are used to enhance the adsorption of the dyes to adhere onto the fibre surface, such as adding sodium chloride. The dyes go to the fibre surface by the heating and stirring process.

Absorption: This is a process for the dyes to go into the fibre. In order to make the dyes go into the surface and inside of the fiber, the concepts of "diffusion" and "migration" should be known. The purposes is to put the dyes into the fibre and to give it a good levelling on the dyeing material. In the absorption process, properties of dyes, time control, temperature, electrolytes, auxiliaries, alkalis, liquor rations, etc. will affects the rate of absorption. When the dye molecules penetrate into the fibre core from the surface, it is known as "diffusion". "Migration" is the dyeability and levelling of dyes on the surface of the fibre.

Fixation: After the adsorption or the absorption steps, the bonding process is required to maintain dyes steadfast into the fibre. Therefore the bonding method is used and it can be classified into two types, the physical bonding and the chemical bonding. Van der waal's force is one of the well-known physical bonding methods, which is used as attractive force between the dye molecules or the atomic groups in the fibre. For the chemical bonding, the covalent bonding is commonly known as chemical bonding on dyeing with reactive dye. Covalent bond involves the sharing of electrons between atoms in a molecule, especially sharing the pairs of electrons by two adjacent atoms [16]. There has another type of chemical bonding named ionic bond. Compared with the covalent bond, ionic bonding is a type of chemical bond that involves the electrostatic attraction between opposite charged and negatively charged ions, which is a primary interaction occurring in ionic compounds [17] .

2.4. Properties of the Reactive dyes

When a dye is attracted to a fibre, the affinity is very important between the mutual attraction within dye and fibre. It is the unlike pigment which is requires binder as a media to attract the dye molecules to the fibre. The dye itself has a chemical functional group to enhance its attraction to fibre. In case of the reactive dye to be used, it can form a chemical covalent bonding to the fibre to enhance its attraction.

The reactive dye is a synthetic dye. The reactive dye molecular structure has one or more active groups which can react with the fibre to form a covalent bond. The scope of the reactive dye can be applied on the cellulose fibre, the protein fibre, the polyamide fibre with the wet dyeing process, and is commonly used in printing nowadays. For dyeing cellulose fibres, the reactive dye is commonly used compared with other dyeing products. It has wide range of colorways and has good color fastness, e.g. the color fastness to dry rubbing can achieve the grade in 4, while the fastness of wet rubbing has grade 3. Nowadays, fast fashion is leading the clothing market, and a wide range of color options is vital for the fashion industry. Therefore, a simple fashion style with a range of color can fulfill the mass fast fashion market. The reactive dye performed more stable from different dye characteristics aspect and have good fastness properties [18]. However, the property of reactive dye was determined by the effect of the reactive dye structure. It depends on the structure of the dye molecules. Therefore, the dye components (molecular structure) should be selected according to the application requirements.

Dystar has launched a series of reactive dyes, Levafix has selected for dyeing all specimens in this project. Levafix series have a structure of di-chloro quinoxaline (Figure 2.4). This type of dyes has a good light fastness in pale shade and a good perspiration and light fastness in the range of the color. It is very good in reproducibility and level dyeing properties.

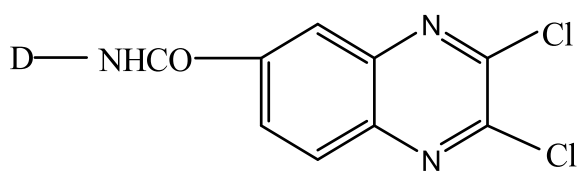


Figure 2.4. Di-chloro-quinoxaline dye structure [19]

2.5. Recent development on reactive dye

In recent years, the reactive dye has developed rapidly since the sustainability becomes a major issue on all types of the manufacturing industries. The developments of the environmental friendly processes are being discussed. Therefore, the research studies on the dyes have increased, especially on improving the application procedures on the reactive dye with ecological aspects. In order to accompany the newly developed reactive dye, fibre modification and development of newly dyeing auxiliaries are involved. The new dye varieties developed, bifunctional and trifunctional reactive dyes are recently developed, such as "Drimaren®CL - exhaust dyeing from Archroma [20].

2.6. The comparison of arts-and-craft on fading color process

Throught history human has recognized fashion and has always looked for fresh and bright appearance. Color was an essential concept but washing effects were developed in detail. Two decades ago, the vintage culture was raised up, fashion with vintage look started to become a trend and gradually became the pioneer in the trend fashion market. The word "vintage" means that the item has been used for a certain period and the appearance becomes old. People would use different methods to replicate the desired vintage look on their items. In recent years, technology can imitate the vintage effect. Vintage garments are commonly applied a bulk of arts-and-craft. One of essential the steps involved is "washing effect finishing" which is a step to make the dyed color strip off from textile material in different depth and the marks effect by the abrasion method. The abraded effect or vintage worn out appearance can be achieved through manual and hand craft processes. Those manual hand arts and crafts process on the fabric could bring an added value to the product. In the old days, the garment wash finishing was made mostly by domestic in-house washing factory and these washing factories a lacked the polluted water treatment facilities. In the present days, there is a great demand in the fashion world of the "washing effect finishing" and the sizable with well facilities setup industries are established. This trendy application has extended until today and has been widely spread throughout different types of garments. It is not just denim jeans but also for non-denim, such as knitted t-shirt, etc. The effects were shown in Figures 2.5 and 2.6. On account of the needs and demands for sustainable production, it encourages textile industry to be more aggressive in developing new techniques for less water consumption for the color fading process. From the existing in garment wash finishing techniques, there are several methods to replicate the "vintage" effects. For fading color, two methods can commonly be adopted, the chemical method or the physical method, sometimes both methods are combined to achieve a more sophisticated effect.

Figure 2.5. Denim jeans fading color by arts-and-craft [21]

Figure 2.6. Knitted T-shirt fading color by chemical [22]

4.1.1. Color fading through the chemical method

The chemical wash is mainly used to achieve the purpose of fading by a chemical reaction. If pumice stone is added, it can enhance the fade and wear out the effects. This section will review a few chemical methods which are commonly used in this industry.

2.6.1.1. Sodium hypochlorite

In the chemical method, the common way is to use the sodium hypochlorite (NaOCl). The sodium hypochlorite is a bleaching agent since 1785 and it was developed by the Sir. Frenchman Berthollet. It is used to oxidize the colorant on the cotton fibre material. Sodium hypochlorite can remove stains from clothes at room temperature. Although the sodium hypochlorite provides a strong oxidation which can achieve quick results, like everything, there are some disadvantages, the result of bleaching depends on the dosage used and the strength of the chemical. For textile which contain elastane, the bleaching procedure will split into 3 or 4 times in order to avoid the elastic fibre be over oxidize and the strength to become weak or break. In the bleaching process, the antichlor or neutralize steps are required, the sodium metabisulfite ($Na_2S_2O_5$) is commonly use in the market. Since the sodium hypochlorite contains dangerous components, industrial washing factory need to pay attention to avoid a possible accident.

Listed below there are the characteristics of the sodium hypochlorite

- It can be reacted with flammable compounds.
- It is difficult to achieve reproducibility on the same bleaching effect in every batch.
- Proper control and time keeping are needed in order to avoid over bleaching on cotton which will affect the fabric strength.
- Since the chemical is a strong oxidizer and oxidation reaction is corrosive. During the production, the inner surface of bleaching machinery will be eroded by the bleaching chemical therefore it will shorten the machine life time.
- Sodium hypochlorite has an unpleasant and irritating smell and the odor will jeopardizes workers' health.
- An antichlor pre-treatment process for garments is needed in order to diminish the potential problems on fabric yellowish or tendering caused by the bleaching process.

- Improper treatment in the bleaching process might cause strength lost on fibre tension, therefore lower tensile strength.
- The bleaching method might bleach all areas but might not in a specific area.

2.6.1.2. Enzyme

Other than the sodium hypochlorite, the enzyme is one of the most popular chemicals for the de-colorization process. Enzyme is a bio-catalyst and it is mostly a molecule of protein. It is made from amino acid chains, which is the structure established in the functions of the enzyme. The enzyme is a generic word, there are many types of enzymes. Different types of enzymes have different usage purposes, the common application for textiles is explained below.

- Amylase is commonly used for desizing, such as removing starch, etc.
- Cellulase helps breaks down and removes cellulose fibre.
- Laccase can be found in many plants and microorganisms. It is a copper-containing oxidase which is very good for bio-bleaching.
- Catalase is a very influential enzyme in protecting the cell from oxidative damage by reactive oxygen species.

Industrial washing factories commonly uses enzyme for the garment ageing process, especially on the denim washing. In order to achieve the desired vintage looks, all kinds of enzymes can give proper application results. Industries commonly used the cellulase enzyme (with acid or neutral properties) for the wash finishing process.

2.6.1.3. Potassium permanganate

Potassium permanganate is one of the popular chemical uses for de-colorization and it is a stronger oxidizing agent [23]. If potassium permanganate is applied in an acidic environment, it breaks down the dye to obtain de-colorization effects. Since potassium permanganate is toxic, to avoid danger, neutralizing step is required, and sodium metabisulfite ($Na_2S_2O_5$) is used as the neutralization agent.

2.6.2. Color fading through the physical method.

Besides the chemical method, the physical method is a unique method to achieve the color fading result. Textiles surfaces can be abraded with one of the physical methods which the craftsman use with sand paper for scraping. Hand scraping can fade out the textile surface color on the desired specific positions.

2.6.2.1. Hand scraping

Hand scraping is used as an abrasion method to fade out the surface color to achieve a natural look. Since the characteristics of the fabric construction, hand scraping is commonly applied on the woven fabric. For the knitted fabric, chemical method is preferred. The hand scraping process is handled by men, therefore variation would be found in mass production which is unavoidable. The standardization becomes an issue. To diminish the quality variation of hand scraping and to standardize in bulk production, it relies on techniques of workers to obtain consistent effects or whisker gradation. Hand scraping is good for de-coloration on specific positions. However, for the desired effect for de-coloration in the entire garment, hand scraping is not suitable to be adopted, because it takes too long and is a heavy workload and it is not cost effective.

2.6.2.2. Stone wash

The stone washing method is widely adopted in washing finishing process. It uses a certain size of pumice stone (Figure 2.7) or artificial ceramic stone (Figure 2.8) in the washing process to wear the finished garments. Through the rotation movement of the rotary drum washing machine, the water level in the grinding cylinder is carried at the low level to complete it with garments. Therefore the pumice stones have sufficient contact with garments. The stones bring the textile material surface to obtain abrasion marks by impact. In order to achieve the desired effects, bleaching or rinsing can also be applied before the stone wash process. There are two types of pumice stone, yellow stone and white stone. The origin of the yellow stone is from Indonesia and the white stone is from Turkey.

Figure 2.7. Pumice stone [24].

Figure 2.8. Ceramic stone [25]

2.6.2.3. Sand blasting

Besides human hand scraping or stone washing, sand blasting is another type of physical method. It provides superfast resultant effects in fading out the color in the physical abrasion method. In the 80's, the sand blasting method (Figure 2.9) for denim started in Italy in 1988 [26]. Due to the fact that the sand blasting process is very efficient and effective, it has been widely adopted in the industry, especially by the denim jeans manufacturer because the sand blasting is managed by a simple spraying equipment machine, the silica sand has a low cost and through the compressed air has high speed spraying out and impacts the surface of textile material. The textile fibre on the surface is scratched out by the impact of the silica sand, it dyes along with fibre which is torn off from the textile material. In spite of the fact that the sand blasting brings economical results to the factory, this method has been recognized as a harmful production method by the Occupational Safety and Health Administration (OSHA), which is a part of the United States Department of Labour. Due to the fact that the sand blasting process can cause silicosis and lung cancer, etc. [27], many textile fashion brands concerned about their company's reputation completely prohibit their factories the use of the sand blasting process and are applying different methods in their production and are developing substitutions.

Figure 2.9. Sand Blasting Process [28].

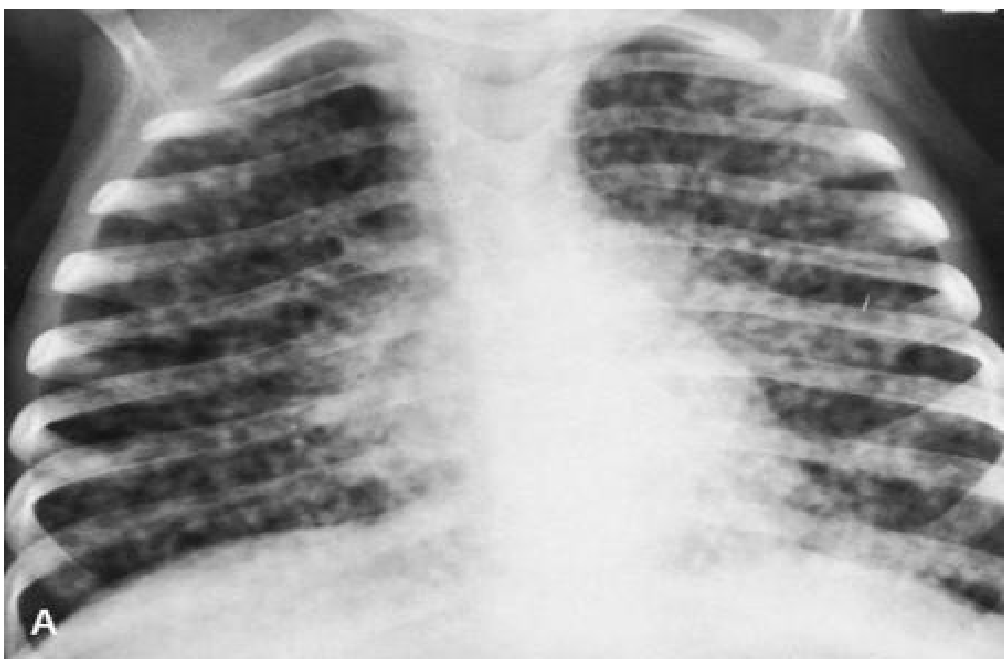


Figure 2.10. shows the X-ray film from the sand blasting worker's lung.

Figure 2.10 X-ray film in lung cancer cause from silicosis by sand blasting [29]. Levi's was the first brand that brought up such statement to their worldwide suppliers. In order to reflect their belief and social responsibility, many fashion brands have followed and announced the prohibition of applying the sand blasting method in their productions. Besides prompt issue, garment cannot go through needle detector examination after sand blasting process. Since the broken needle examination is a required test for many fashion brands. The silica has metal component. During the sand blasting process, the silica gets through the fabric surface into the yarn which may not be removed completely. Therefore the, silica will be detected by the needle detector machine with a scanner based on the metal component.

2.6.2.4. Laser engraving

In recent decades, the technology has been renewed and applied on textile industry this technology is "laser". The word "laser" stands for Light Amplification by Stimulated Emission of Radiation. Laser has been frequently used in garment industry recently. The laser can be applied in two main areas for (i) Laser marking and (ii) laser engraving. The laser engraving process can help to replace the conventional manual engraving process such as the whisker and monkey wash (Figure 2.11).

Figure 2.11. Laser engraving effects [30]

2.7. Introduction to plasma

When a matter is continuously added with energy, its temperature increases and goes from solid through the liquid to gaseous state. The atomic shell breaks down and charged particles are created, negatively charged electrons and positively charged ions. This mixture is called plasma. The plasma is actually comprised of a large number of positive and negative charged particles and neutral particles [31].

Figure 2.12 shows the entire progress for three states, which are solid, liquid and air transform to fourth state, which is plasma.

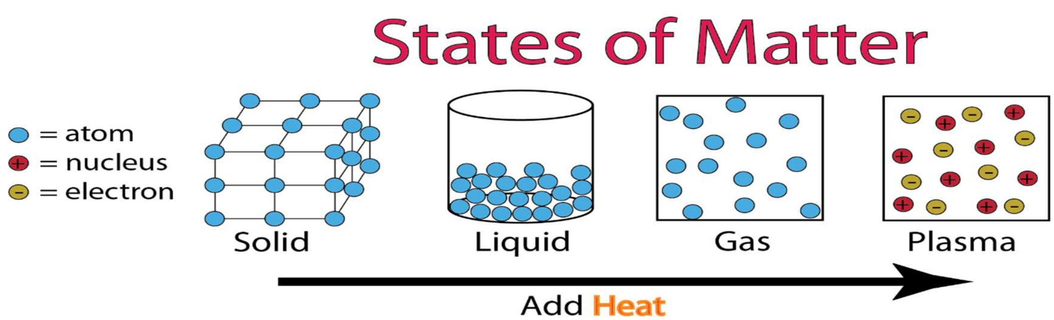


Figure 2.12. Atom states in four matters [32]

2.7.1. Properties of plasma

The temperature range of plasma is very extensive, it can be near total zero as approximate to the most minimal and the most noteworthy of the highest temperature of plasma can be reached to 10^8 - 10^9 degrees of Kelvin. For example, the Sun's core, nuclear combination. Based on this extreme dissimilarity, plasma can be further distinguished in two categories, "high temperature plasma" and designate in equilibrium plasma compared with "low temperature plasma", its named quasi-equilibrium plasma or nor equilibrium plasma. In basic theoretical physics, matter from solid form move to liquid and further to gas. An external force is added, it is commonly used a heat energy in the melting process and then the evaporation results in liquid turning in to gas. The process from gas extending to plasma status is named "ionization". Figure 2.13 shows the range of plasma in term of density and electron temperature

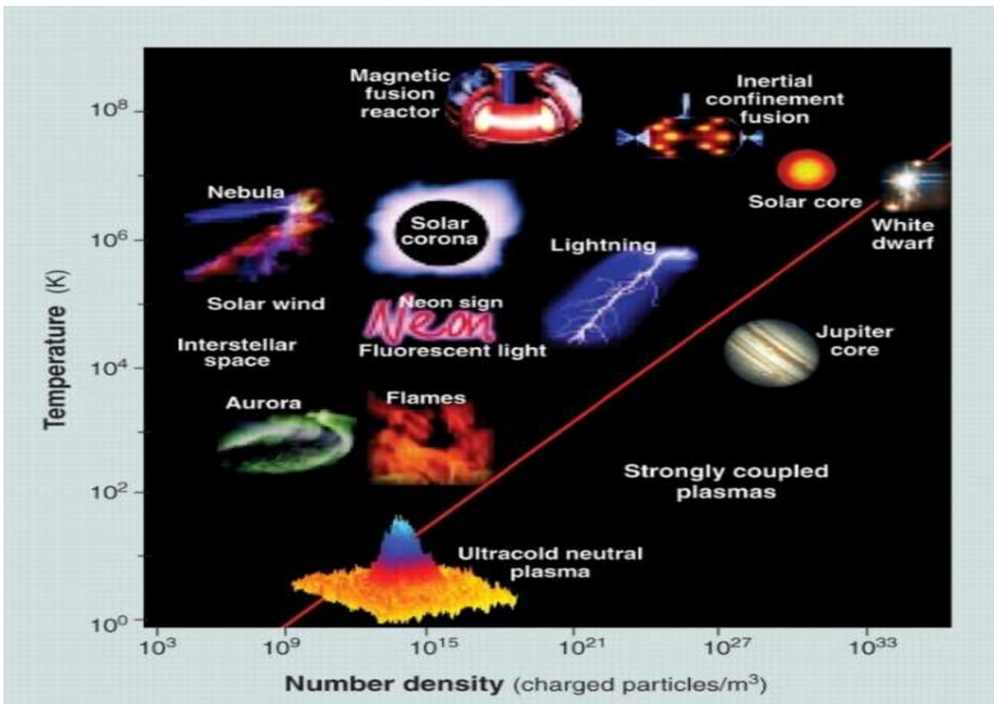


Figure 2.13. Four states of matters [33].

Plasma parameters can change between several directions of magnitude and the parameters can range from several orders of magnitude. However, it obviously on the parameters of different plasma, are quite similar to the nature of the plasma ratio. Tables 2.1 and 2.2 list the typical range of plasma parameters.

Table 2.1. Typical range of plasma

Features	The plasma on the earth	The plasma outside of the earth
Size Dimension	10^{-6} m（Plasma in laboratory ）	10^{-6} m（Spacecraft sheath）
	10^{2} m（Lightning）	10^{25} m（Intergalactic nebula）
Life	10^{-12} s（Plasma generated by laser）	10^{1} s（Solar flare）
	10^{7} s（Fluorescent lamp）	10^{17} s（Intergalactic plasma）
Density	10^{7} m^{-3} to 10^{32} m^{-3} （Inertial confinement plasma）	1 m^{-3}(Intergalactic medium）
		10^{30} m^{-3}（Core of the star）
Temperature	~0 K（Non-neutral crystalline plasma）	10^{2} K（Aurora）
	10^{8} K（Nuclear fusion magnetic plasma）	10^{7} K（Sun core）
Magnetic field	10^{-4} T（Plasma in laboratory ）	10^{-12} T（Intergalactic medium）
	10^{3} T（Pulse power plasma）	10^{11} T（Near neutron star）

Table 2.2. Plasma parameters

Artificial	Natural
A plasma display, such as a TV screen.	Thunder and Lightning
Fluorescent lamp (low energy source), neon.	atmosphere discharge
Corona discharge ozone generator	The aurora
Fusion energy research	Flame
Arc lamp, arc welding machine and plasma torch	The ionosphere
An arc produced by a tesla coil	The solar wind
The laser produces plasma that appears during high energy lasers and material reactions.	Comet ion tail
Formed in argon gas, inductively coupled plasma, used for visible spectrometry and mass spectrometry,	Nebula or interplanetary material
Electrostatic	Electrostatic
Magnetic induction plasma, generated by microwave, is used for resonance coupling.	

2.7.2. Classification for plasma

There are many types of plasma which can be classified into high-temperature plasma and low temperature plasma.

2.7.2.1. High-temperature plasma

At the equivalent of 10^8 - 10^9 degrees of Kelvin then the plasma becomes fully ionized, such as the Sun, controlled thermonuclear fusion plasma. It has nuclear fusion releases or absorbs energy and allows matter to enter a plasma state and the hydroxytryptamine (HTP) is from nuclear fusion, it is not appropriate for the modification in textile surface in vice versa [34].

2.7.2.2. Low-temperature plasma

Low temperature plasma is produced by electrical discharges in low-pressure gases which is safer to operate and more commonly used in textile processing [35].

2.7.2.3. Comparison of plasma and atmosphere air

Plasma comes from the atmosphere air, Table 2.3 shows the difference between the nature of plasma and the atmosphere air [36].

Table 2.3. Comparison of plasma and atmosphere air [37]

The nature of	Atmosphere air	Plasma
Electrical conductivity	Atmosphere air is very low conductivity Isulation is good. but it still can be broken down into plasma when the electric field was more than 30 kV/cm.	In many applications, plasma is usually in very high conductivity. And it assumed the conductivity is infinite.
Heterogeneous particle	All gas particles behave are similarly, it based on the impact of gravity and other particle collisions.	Through the positive and negative values of the charge, it can distinguish electrons, ions, protons and neutrons, by having different speeds and temperatures, so particles behave will be very vary. It produces some special waves and instability.
Velocity distribution	Collisions between particles make all gas particles fit to the maxwell distribution, with very few particles of higher speed.	In normal situation, the behava of thermal plasma collision is not strong, But, external forces can cause the plasma to deviate far from the local equilibrium and produce a group of particles with particularly high velocities
Particles interaction	Interaction is limited to collisions between two particles, and collisions between three particles are extremely rare.	Particles and particles can interact with each other at large distances through electromagnetic force, resulting in waves and other organized motions.

2.7.3. Types of plasma generating methods.

The ways of generating a low-temperature plasma includes ultraviolet radiation, X-rays, electromagnetic field and heating methods etc. Industrial products were commonly powered by electromagnetic excitation plasma, such as by direct current glow discharge, radio frequency discharge and microwave discharge. As it is mentioned above, plasma can be classified into two main categories, thermal plasma and non-thermal plasma. In this project, the study to fade out color is using ozone, and the ozone comes primarily from non-thermal plasma. Based on the methods of the ozone generation, it can divide into three categories, which are listed below:

2.7.3.1. The photochemical method

In the atmospheric, ultraviolet light (UV) there is one know as photochemical. Among many ways to produce ozone, ultraviolet light technology (UV) is also one of the substances that can promote the ozone to be generated. By using ultraviolet light, the decomposition of the oxygen molecules could be possible and the polymerization into ozone. This method produces a wavelength of 185nm (10^{-9}m) UV spectrum, as this light is most easily absorbed by O_2 to achieve the effect of generating ozone. Using the photochemical method to produce plasma has advantages, during the process conditions it is not sensitive, especially on temperature and humidity aspects. Also it is easier to control the reproducibility of ozone and the concentration level. However, it has also disadvantages, the UV spectrum consumes a substantial amount of electricity but lower in ozone generation. Thus the cost is relatively high. If we compare with the ozone out-put volume, there is not cost effectiveness. Therefore this will be on selective application.

2.7.3.2. The corona discharge method

The corona discharge method is one of the methods more recognized for generating plasma. It imitates the ozone produced by nature lighting using artificially high voltage alternating field generating corona in gas. During the corona discharge process, the pressure of gas is almost the same as the atmospheric pressure, which is formed by the passage of electric current at over 15 KV voltages and the range of frequency is above 20 - 40 kHz. That ionization of a fluid generates electrical discharge and free electricity ions dissociate O_2 molecules after the collision cohesion and transform into O_3 molecules. This ozone generating technology is mature, stable, long life and large in ozone production, etc., so it is been widely adopted in the market. Furthermore, ozone can be produced under another condition, which is the common use in swimming pools, as that bound with water (H_2O) and high voltage power [38] as shown in Figure. 2.14.

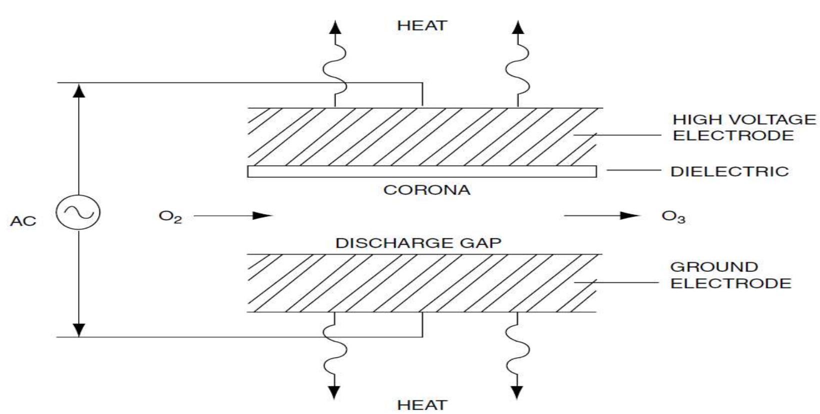


Figure 2.14. Corona discharge [39]

2.7.3.3. The electrochemical method

Electrochemical method is the usage of a direct current (DC) power supplying electrolytic oxygen-containing electrolyte (pure water) to produce ozone. This generator is capable of producing a high concentration of ozone water in lower production cost. DC glow discharge by direct current, (10^2 - 10^3V), DC glow discharge can be at low pressure under 10^{-2} - 10^2 Torr (1 Torr = 1.333 x 10^2Pa) between two conductive electrodes and a very wide frequency range (0 - 2.45 GHz) channel formed by the current. Under the low-pressure glow discharge, it is a stable self-sustained discharge. The structure is placed in two parallel electrode plates in a closed vessel, and then electrons excited neutral atoms and molecules. Particles may occur from an excited state turn to the ground state which is released with light energy. However, the characteristics of DC glow discharge plasma has it own limits on practical application, due to the fact that the DC glow discharge needs to be exposed terminals and the discharge characteristics will be affected by the discharge cavity geometry.

2.7.3.4. The dielectric barrier discharge (DBD).

Although the uniformity of the plasma processing of the low-frequency alternating current discharge plasma can be changed, the exposed terminals of the plasma cannot solve the pollution problem. Low pressure dielectric barrier discharge (DBD) technology comes into being, upcoming bare electrode electrically insulating barrier material live. The dielectric barrier discharge can be discharged only at high frequency in the case of direct current and low-frequency alternating current discharge cannot be formed.

2.7.3.5. The radio-frequency discharge (High-frequency discharge plasma).

Radio frequency power supply is a plasma supporting power source. It is composed of a radio frequency power source, constructed by a impedance dispenser and a impedance power meter. The radio frequency transceiver core circuit uses the technology of the radio frequency, therefore the abbreviation is RF. When the radiation can reach the electromagnetic frequency level of the space, the general frequency range is from 300 kHz – 30 GHz. It is a high frequency alternating current (AC) change electromagnetic wave in short. The principle of the plasma generation by RF power supply which is in a closed vacuum pressure vessel and uses a vacuum pump to obtain a certain degree of vacuum. The RF feeds between the two plates of the vacuum chamber and generates a variable electric field between the two plates. The gas is ionized in the electric field, then charged ions are produced. Then the charged ions accelerated by the continuous collision of gas molecules produces cascading effects. This creates a glow and plasma is created. Among the current classifications we can distinguish low-frequency or high-frequency commonly based on the frequency alternating number, less than 1,000 times per second is called a low-frequency current, vice versa, which is more than 10,000 times counted as high-frequency current. The usual frequency of RF is 13.56 MHz. When the frequency of AC power is less than 50 kHz, there is no change in the situation of gas discharge compared with DC. However, when the frequency exceeds 50 kHz, the discharge process begins to change, it counts as high frequency. Therefore, the material electrode does not require being a conductor, and since the power supply is radiofrequency, the RF current can flow through the capacitance between the two sides of the insulator, which can be used to splash the insulator. It needs extra care to avoid an accident.

2.7.3.6. The microwave discharge

The microwave discharge can always be found in household devices, such as heating appliances in the kitchen. This frequently makes a suitable supply readily available. When the microwave discharge is compared with other methods of generating plasma, the fundamental theory is similar but the microware discharge is more difficult to sustain at lower pressures (<1 Torr) than DC or RF discharges [40].

2.7.4. The plasma effects on textiles material

The low temperature plasma is commonly used in the textile industry which is simply called "cold plasma". The plasma used for the benefit of the surfaces with, for example, hydrophobic, hydrophilic or dirt-repellent properties. By generating additional functions such as flame retardants and self-cleaning the, plasma treatment can achieve new properties. While the high temperature plasma is applied to energy production, cold plasma is focused on the modification of biomaterial surfaces.

Plasma pretreatment additionally enhances the wettability, sliding properties and color capacity of materials. It is commonly used for achieving below effects [41].

- Activation – The textile fibre can be modified by the activation effect of the plasma treatment. Under the plasma treatment, the textile fibre surface can be activated by the chemical reaction to form hydroxyl, carboxyl carbonyl and amine groups etc. [42].
- Surface modification and treatment – This step can be applied to greige cotton fabric. Through the plasma treatment, the impurities such as natural wax in the surface of the cotton fibre can be removed. This will in turn enhance the wettability. Due to the fact that the affinity is improved, the cotton material will have good dyeability. It can use at least an amount of dyes to achieve the desired color.
- Bombardment **-** The bombardment of the textile material with plasma leads to the breakdown of covalent bonds. As a consequence, the low molecular weight species such as contaminants or thin layers of the textile substrate are removed, leads to extremely "clean" surfaces, modifications in the surface area, or controlled reduction of weight of the exposed substrate.
- Cleaning – In many polluted water treatment plants, the plasma treatment is adopted to enhance the waste water treatment performance. Since the plasma provides the breakdown effect of covalent bonds, therefore, the particles in contaminants can be removed easily.

2.7.5. Plasma treatment obstacle

In this project, four parameters and the application of "G2" devices are studied, which are the treatment time, the moisture content, the gas concentration and the dye concentration. All these parameters will influence the plasma treatment. However, there are still other parameters affecting such as the frequency and power of the generator, the variation in gas pressure, the capacity of the reaction chamber, the steady supply of the electrodes on industry washing factory, etc.

2.7.6. Ozone mechanism

Oxygen (O_2) is taken from the atmosphere into an ozone generator that transforms air into ozone molecules (O_3) through electric shocks. Electronic shocking releases high-energy electrons, it reacts with many components in the air. Therefore, the oxygen molecules, the moisture molecules, etc. are included. Through the different path reactions, the admixture of radicals is generated. It can be described as Equations 1 and 2.

Equation 1 : high-energy electrons vs oxygen molecules,

$$\mathbf{H_2O \xrightarrow{e} \cdot OH + e^-_{aq} + \cdot H + H_2O_2 + H_3O + H_2}$$

Equation 2 : high-energy electrons vs moisture molecules

$$\mathbf{O_2 \xrightarrow{e} 2 \cdot O \xrightarrow{H_2O} 2 \cdot OH}$$

The ozone is able to import into water. After injected into water, it can be preserved in water from 3 - 20 minutes. Ozone is readily dissolved in the moisture of air. The reaction of the ozone decomposition is the major process to generate hydroxyl radical. Hydroxyl radical is an effective oxidant. It is a core element in the entire process on fading out color. The entire process is described from Equations 3 to 6.

Equation 3 : $$O_3 \rightarrow O_2 + O\cdot$$

Equation 4 : $$O\cdot + H^+ + e \rightarrow \cdot OH$$

Equation 5 : $$O_3 + H_2O_2 \rightarrow \cdot OH + O_2 + HO_2\cdot$$

Equation 6 : $$O_3 + HO_2\cdot \rightarrow \cdot OH + 2O_2$$

Besides, the ozone is catalyzed by the ultraviolet radiation, forming a variety of free radicals, including hydroxyl radicals. The process was described in Equation 7 and Equation 8 respectively.

Equation 7 : $$O_3 + hv + H_2O \rightarrow H_2O_2 + O_2$$

Equation 8 : $$H_2O_2 + hv \rightarrow 2\cdot OH$$

In entire the plasma generation process, among many free radicals, the hydroxyl radical is the one that has most oxidative function. It is used for de-coloring the reactive dyeing particles in textiles material. The key factor responses for de-coloration. The organic hydroxyl radical is generated while the reactive dye molecules are oxidized by the hydroxyl radical. Equations 9 to 11 can further explain the process and the result on the reactive dyeing particles for de-coloration are obtained.

Equation 9 : $$RH + \cdot OH \rightarrow H_2O + R\cdot$$

Equation 10 : $$R\cdot \rightarrow \text{fragmentation of } R\cdot$$

Equation 11 : $$R\cdot + O_2 \rightarrow ROO\cdot$$

2.8. Specification of “G2” machinery

“G2” is a waterless color fading machine, this machine can fade down color by using controllable high concentrated ozone plasma. Figure 2.15 shows the washing processes between the conventional and the G2 processes. The G2 process could save 61.15% Kw/h on energy aspect, 46.15% on water and 62.5% chemical consumptions. The production lead time can increase by 50%. Tables 2.4 and 2.5 shows the process differences and the amount of resources saved in the conventional bleach process versus the ozone bleach process. Figure 2.16 shows the finishing effects between the conventional method and the G2 machinery method.

Table 2.4. Energy saving indication comparison between conventional method and the G2 machinery method [43]

Consumption per garment	**Standard process**	**G2 Process**	**% Savings**
Water	7.81	4.21	46.15%
Chemicals	40 g	15 g	62.50%
Energy	0.97w	0.35kw	61.21%
Time	116'	58'	50%

STANDARD PROCESS	G2 PROCESS
LASER + MANUAL SCRAPING + PREWASH + ENZYME WASH 60’ + RINSE x2 + SOAPING 10’ + RINSE x2 + DRY + SPRAY PP (Potassium permanganate) + NEUTRALIZE + RINSE x2 + SOFTENING	LASER + MANUAL SCRAPING + PREWASH + G2 15’ + SOAPING 5’ + RINSE x2 + SOFTENING

Figure 2.15. Process steps of conventional method versus G2 machinery method

Table 2.5. Comparison chart of conventional washes versus ozone

Conventional Formula	**Wet Ozone Formula**	**Dry Ozone Formula**
Pre-wash	Pre-wash	Pre-wash
Rinse	Rinse	Rinse
Stone Wash	Stone Wash	Stone Wash
Rinse	Rinse	Rinse
Bleach	Ozone - Bleach	Extract
Neutralization	Rinse	Ozone
Rinse	Reducer	Clean up
Reducer	Rinse	Rinse
Rinse	Tinting/Softening	Tinting/Softening
Rinse	n/a	n/a
Tinting/Softening	n/a	n/a

Figure 2.16. Effects comparison between conventional method and using G2

2.9. Color fading measurement

In this project, the color fading effect of the ozone plasma treatment on reactive dyed cotton knitted fabric will be studied, this section is to review different color measurement technique.

2.9.1. Measurement device

In order to obtain the data from the different parameters, a color measurement instrumental is used, the Macbeth Color Eye 7000A spectrophotometer device (Figure 2.17), will be adopted for measuring the properties of the treated specimens. The requirement for measuring the seculars included with 10° observe angle and illuminant D65.

Figure 2.17. Spectrophotometer ColorEye 7000A from GretagMacbeth

2.9.2. Apparatus calibration

The calibration should be given before measuring the specimens. Calibration steps of the Macbeth Color Eye 7000A spectrophotometer use the provided calibrators, the light trap cover and the ceramic calibration tile, both are shown in Figure 2.18. the light trap goes about as standard of 0% reflectance and the ceramic alignment tile goes about as standard of 100% reflectance. In order to achieve accurate result on a spectrophotometer, the above mentioned tools were used as upper and lower standards. During the color measurement process, large aperture and light source of D65 are used. The reflectance (R in percentage) is measured in wavelengths within 400 and 700nm.

Figure 2.18. Light trap cover (Left) and Ceramic calibration tile (Right)

To derive out the reflectance value, K/S values and CIELAB values from specimens, each specimen was mounted onto the spectrophotometer by the viewport passage handle and completely hooded the viewport gap for reflectance measurement. Four locations will be selected randomly on each specimen. In this project, the reflectance value measured was analysed in two approaches, the relative unlevelness index (RUI) and the reflectance (R%).

2.9.3. Relative unlevelness index (RUI) and Reflectance curve

RUI is developed to assess the degree of levelness of the dyed samples in quantitative terms [44] according to the following Equation 12 and Table 2.6.

Equation 12 :

$$\mathrm{RUI} = \sum_{\lambda=390}^{700} (s_\lambda / \bar{R}) V_\lambda$$

Where

S_λ= standard deviation of reflectance values measured related wavelength.

$\bar{R}$= mean of reflectance value.

V_λ= coefficients of variation of reflectance values.

RUI value in smaller value is represent better levelness on specimen [44]

Table 2.6. Indicates the interpretation of RUI

RUI	<0.2	0.2 - 0.49	0.5 – 1.0	>1.0
Visual appearance of levelness	Excellent levelness (unlevelness not detectable)	Good levelness (noticeable unlevelness under close examiantion)	Poor levelness (apparent unlevelness)	Bad levelness (conspicuous unlevelness)

2.9.3.1. Reflectance curve

The reflectance can be defined as the proportion, percentage of the reflected light and the incident light. The color reflectance values exist independently, which are not affected by staining, fibre properties or light effects. Thus digitized color standards can apply to any conditions and fibre materials. In any conditions for example, the peaks of the reflectance curves were located at around 400 - 430nm which implies that all the specimens are in blue color tone. The different degrees of reflectance value (R%) from different the depth of the color will be reflected from the specimen (Table 2.7 and Figure 2.19). It shows from light to dark, from high to low reflectance values. When the color of specimen is light or bright, such as white color, it can reflect over 80% of the reflectance value, while the color in the darkest black, the reflectance can reach to 0 to 4%. On the other side, the shape of reflectance curves provides a broad indication, "Brightness or Saturation" known as "relative purity", which by comparing the half peak width of reflectance curve. The lower purity always has greater reflectance in the curve shape and vice versa.

Table 2.7. Colors of wavelengths [45].

400 - 430	430 - 480	480 - 520	520 - 570	570 - 600	600 - 630	630 - 700
Violet	Blue	Cyan	Green	Yellow	Orange	Red

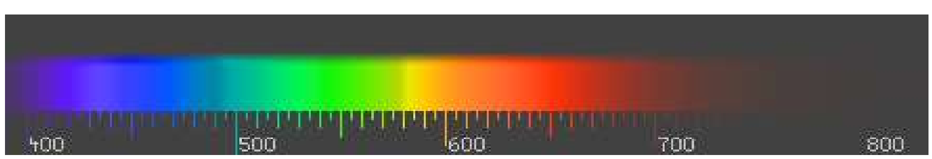


Figure 2.19 Visible spectrum [46]

2.9.4. K/S value (Kubelka-Munk Theory)

The hypothesis test was derived from Kubelka-Munk in 1931. It depicts the ingestion and dissipating coefficients from the deliberate reflectance over the obvious range. The relative shading yield and shading quality (K/S values) which K and S remain for the adsorption and disseminating coefficient, separately, is getting through the reflectance bend, going from the unmistakable range wavelength of 400 - 700nm with 10nm intervals inside the noticeable range is figured by the accompanying Kubelka-Munk condition:

$$K/S = (1-R)^2/2R$$

Where K=coefficient of absorption, depended on the concentration of colorant

S=coefficient of scattering, caused by the color substratum

R=reflectance value of specimen.

After calculating the K/S values, the K/S sum value is obtained by summing up all individual K/S values over the visible spectrum ranging from wavelength 400 - 700/nm according to the following equation:

$$K/S\ SUM = K/S_{400} + \ldots\ldots K/S_{700}$$

Subsequently, the higher K/S SUM value is the better shading yield and the higher grouping of colorant contained in the substrate medium is spoken to.

2.9.5. CIELAB Color Space (L*, a*, b*)

CIE (International Commission on Illumination) system has found in 1976, which is another color specification system most widely accepted by the color-related industries. CIE system provides three-dimensional color space, as shown in Figure 2.20, includes hue, lightness and saturation (chroma).

2.9.5.1. The CIELAB color space, the L*, a* and b* values

CIE L*a*b* is a device-independent color space that includes all perceivable color and its gamut exceeds those of RGB and CMYK color model. This allows CIE L*a*b* to serve as an intermediary color space where values from a particular gamut are re-encoded as CIE L*a*b* values and other devices can convert the resulting CIE L*a*b* values into their own specific color gamut [47].

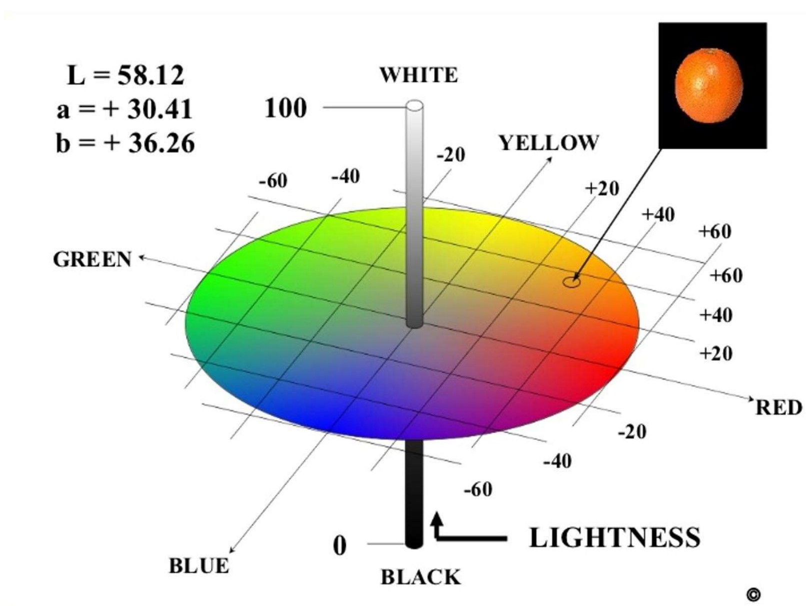


Figure 2.20 Model of CIE LAB Color Space [48]

L*: Lightness, 0-100, where 0 = yields dark and 100 = indicates white

a*: Redness to Greenness, no restriction, when (+)a* = red and (-)a* = green

b*: Yellowness to Blueness, no limit, when (+)b* = yellow and (-)b* = blue

2.9.6. ΔE

To obtain the results between the ozone plasma treated samples and untreated samples in the CIE LAB colorimetric system, ΔE is applied. The ΔE is a single value, below equation is taking into account the relationship between the L*, a* and b* of the ozone plasma,

$$\mathbf{\Delta E} = [\ (\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\ ]^{1/2}$$

As a result, when increases the value of ΔE, difference between the treated and untreated samples are increased in relevantly. Formulae measuring the shading contrasts between regarded specimens and counteract are as follow:

$$\Delta L = L_{Standard} - L_{Sample}$$
$$\Delta a = a_{Standard} - a_{Sample}$$
$$\Delta b = b_{Standard} - b_{Sample}$$

2.9.7. Summary

In the recent two to three decades, the vintage culture becomes a trend. Many techniques on finishing have been developed. On the fading color finishing aspect, both chemical and physical aspects have developed more new application methods. All new application methods purpose to achieve the desired color fading effect of textile products. However, due to the production difficulty and the large number of defective products produced the use pf the plasma technology can provide a track able technique for this un-formal process to become and to have a formality. Moreover there is a the desire of the global market trends on environmental friendly production preference. The plasma technology can significantly reduce the water consumption. It becomes the most ideal substitution method for the conventional color fading application. In this project, the results of ozone on the fading color of reactive dyes on cotton, as well as the effects of gas concentration, water content and treatment time on the color characteristics of textile materials were studied. The result will provide guidance reference for garment manufacturers and industrial washing factories. This study will provide a better understanding on the color fading induced by plasma treatment and will promote the plasma treatment to become practically for industrial use. At the end, the plasma treatment specimens will be used as a guided reference material.

Chapter 3. Experimental

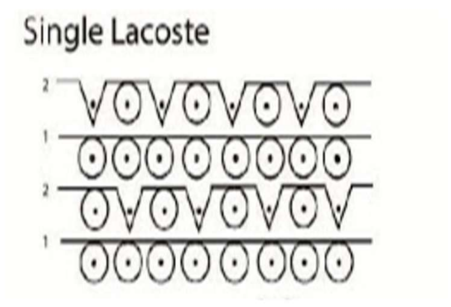
3.1. Introduction

To prepare materials for experimental studies, study the effects of various plasma parameters on the treatment of reactive dyes, and the process of discoloration in the treatment of cotton materials. 75 specimens pieces were prepared, which 32s/2 100% were cotton knitted single pique (Lacoste) in 220 g/m^2 were dyed in different dye concentrations (0.5%, 1.5% and 3%). Specimens with different dyeing concentrations were processed in different parameters of low temperature in the atmospheric plasma treatment.

3.2. Specimens material

In this study, 32s/2 cotton single pique (Lacoste) knitted fabric pieces with a weight of 220g/m^2 were used for dyeing. 30 kgs knitted cotton material on each color dye concentrations specimens. Its specification is shown in Table 3.1. The fabric was conditioned at 65º±2% relative humidity and to temperature 20°±2°C at least 24 hours prior to use. Specimens were dyed by the reactive dye of Levafix Brilliant Yellow CA (provided by Dystar China) as received.

Table 3.1. Specification of material used in this study

Materials	32s/2 100 % cotton	
Fabric Weight	220 g/m^2	
Fabric Structure	Weft knitting - Single Pique	

3.3. Dyeing

The fabric was dyed in three groups of dye concentrations, 0.5%, 1.5% and 3.0% with liquor-to-goods ratio of 10:1. Soda ash and as an auxiliary sodium chloride were added in the dye bath to enhance the exhaustion and fixation properties of dyeing on the fibres.

Table 3.2. Recipe of dyeing process with Reactive Dyes (3 dye concentration)

Dye concentration (%)	Sodium Chloride (NaCl) (g/l)	Soda Ash (Na_2CO_3) (g/l)	Fixation Time (min)
0.5	20	7	30
1.5	42.5	11.5	45
3.0	60	15	60

Temperature rise curve from 25ºC to 60ºC

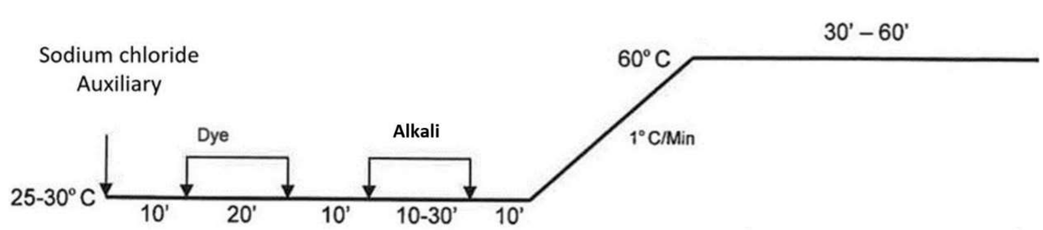


Figure 3.1 Dyeing profile [49].

In the dyeing process, model ALLFIT-30 high temperature Jigger dyeing machine by Fong's National Engineering Company Limited has been used. This is a model suitable for the industry small and medium batch. Jigger dyeing machine was used and the dyeing was carried out according to the dyeing conditions as shown in Figure 3.1. Dyeing recipes are seen in Table 3.2.

3.4. Plasma treatment

In this project, a commercial ozone plasma machine, G2 (Standard model form Jeanologia, Spain) was used (Figure 3.2.).

Figure 3.2. G2 ozone machine from Jeanologia [50]

3.4.1. Equipment specification

Compared with conventional rotary washing machines, the G2 has a similar space with dimension of 240 W x 215 D x 205 H (cm). The dimension of inside tumbler is 120 x 160 (cm). Based on the size of tumbler, the recommended loading capacity is 50 kgs at any condition. The detail of G2 is shown in Table 3.3.

Table 3.3. Technical specifications of G2 machine.

Electricity power demand	9 kw per hour
Ozone generator power	400 g per hour
Ozone gas concentration	0-180 g/Nm^3
Machine loading capacity	50 kgs
50 kgs convert to garments	80-100 denim jeans or 160 knitted t-shirts
Tumbler measurement	1200 x 1600 m/m

The G2 machine only requires electricity power for operating, because inside the machine there is an ozone generator. Meanwhile, there is another device which is a pressure swing adsorption device (PSA device). Through the pressure swing adsorption process, the air from periphery is extracted and pressure can be added. An oxygen filter function to generate sufficient pure oxygen gas is supplied for the ozone generator. After that pure oxygen gas goes through the ozone generator by high voltage electrical current to charge oxygen molecules from O_2 to O_3 [51] . The periphery breathes air at normal conditional, oxygen percentage is only occupied approximately 22 - 23% [52] [53].

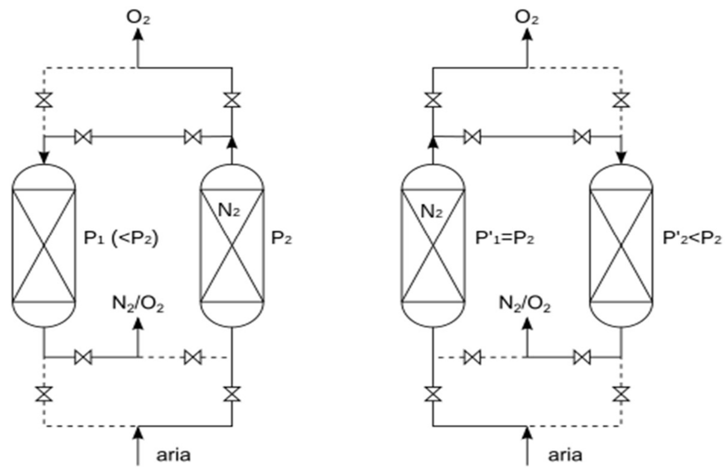


Figure 3.3 Pressure swing adsorption processes [54] .

Based on Table 3.3, the G2 standard model, with sufficient pure oxygen supply, the ozone generator can generate ozone in 400g of ozone per hour. To generate sufficient ozone, it requires steadily and sufficient supply of pure oxygen for the ozone generator. It needs to have a device to enhance sufficient supply of pure oxygen so the ozone generator can generate ozone continuously that is the function from pressure swing adsorption device. As shown in Figure 3.3., after the color fading process, the remaining ozone plasma gas can be extracted through the chamber with six metal tubes. The metal tubes with heat at a 280˚c temperature. While the ozone plasma gas goes through the tube inside, the ozone plasma molecules will then be decomposed by a higher temperature before it is exhausted.

3.4.2. Plasma condition

The reactive dyeing products dyed specimens with three dye concentrations were treated by various parameters in the atmospheric ozone plasma treatment. The plasma treatment conditions were shown in Table 3.4 for Levafix Brilliant Yellow CA reactive color.

Table 3.4. Arrangement of specimens in the plasma handling

No	**Dye concentration (%)**	**Gas Concentration (%)**	**Water Content (%)**	**Time (min)**
Levafix Brillant Yellow CA				
Control	1.5	0	0	0
Y1	1.5	10	35	10
Y2	1.5	10	35	20
Y3	1.5	10	35	30
Y4	1.5	10	45	10
Y5	1.5	10	45	20
Y6	1.5	10	45	30
Y7	1.5	30	35	10
Y8	1.5	30	35	20
Y9	1.5	30	35	30
Y10	1.5	30	45	10
Y11	1.5	30	45	20
Y12	1.5	30	45	30
Y13	1.5	50	35	10
Y14	1.5	50	35	20
Y15	1.5	50	35	30
Y16	1.5	50	45	10
Y17	1.5	50	45	20
Y18	1.5	50	45	30
Y19	1.5	70	35	10
Y20	1.5	70	35	20
Y21	1.5	70	35	30
Y22	1.5	70	45	10
Y23	1.5	70	45	20
Y24	1.5	70	45	30
Control	3	0	0	0
Y25	3	10	35	10
Y26	3	10	35	20
Y27	3	10	35	30
Y28	3	10	45	10
Y29	3	10	45	20

Y30	3	10	45	30
Y31	3	30	35	10
Y32	3	30	35	20
Y33	3	30	35	30
Y34	3	30	45	10
Y35	3	30	45	20
Y36	3	30	45	30
Y37	3	50	35	10
Y38	3	50	35	20
Y39	3	50	35	30
Y40	3	50	45	10
Y41	3	50	45	20
Y42	3	50	45	30
Y43	3	70	35	10
Y44	3	70	35	20
Y45	3	70	35	30
Y46	3	70	45	10
Y47	3	70	45	20
Y48	3	70	45	30
Control	0.5	0	0	0
Y49	0.5	10	35	10
Y50	0.5	10	35	20
Y51	0.5	10	35	30
Y52	0.5	10	45	10
Y53	0.5	10	45	20
Y54	0.5	10	45	30
Y55	0.5	30	35	10
Y56	0.5	30	35	20
Y57	0.5	30	35	30
Y58	0.5	30	45	10
Y59	0.5	30	45	20
Y60	0.5	30	45	30
Y61	0.5	50	35	10
Y62	0.5	50	35	20
Y63	0.5	50	35	30
Y64	0.5	50	45	10
Y65	0.5	50	45	20
Y66	0.5	50	45	30
Y67	0.5	70	35	10
Y68	0.5	70	35	20
Y69	0.5	70	35	30

Y70	0.5	70	45	10
Y71	0.5	70	45	20
Y72	0.5	70	45	30

3.5. Specimens measurement

All specimens treated by the ozone plasma were conditioned at 65º±2% relative humidity and 20±2ºC for at least 24 hours before taking measurement. The condition for color measurement of Macbeth Color Eye 7000A was set under specular which included large aperture value, 10º observe angle and illuminant D65. The color measurement instrument was calibrated with loading black light trap and loading white light trap. The fabric was semi-folded and the edge was sewn for ensuring the opacity and measured the 4 designated points (Figure 3.4). The first measurements were taken and then after turning the fabric to 90 degree and the second readings were taken. Therefore, both warp and weft directions were measured. The captured data of Reflectance %, K/S values, CIE L*, a* and b* value were obtained from the computing system will be collected by the spectrophotometer.

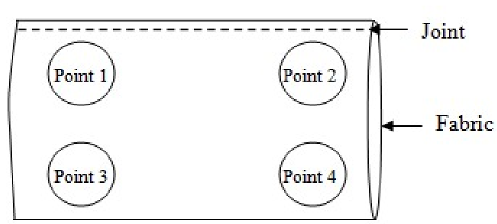


Figure 3.4 Point locations on fabric for color measurement

3.6. Regression model

SPSS was used for obtaining the regression model and correlation of the coefficient of the study. The regression analysis is a predictive modeling technique, it is one of the most well-known modeling techniques and commonly used for predictive analysis or causality relationships between the dependent variable (target) and the independent variable (predictor). The linear regression is usually one of the preferred technologies to learn from predictive models. Under this model, the dependent variable is continuous, the independent variable can be continuous; or discrete. By using a formula equation, the value of the target variable based on the given predictor can be predicted. In the project, since the independent variable is more than one the multiple linear regression technique was selected to use.

Chapter 4. Results and discussion

4.2. Introduction

In this project, the aim is to understand clearly the advance of color fading techniques observed on cotton knitted material carried out by the ozone plasma treatment. After preparing the specimens they were dyed in three dye concentrations. The specimens were arranged to go through the plasma treatment and color data was collected by the spectrophotometer. The statistical software was used for determining the relationship between different processing parameters and relative unlevelness index (RUI), the reflectance curve, K/S value, CIE L*, CIE a*, CIE b* and ΔE value.

4.3. Color fading effect

As shown in Table 3.5, the specimens are divided into four sub-groups based on the dye concentration, the treatment time, the gas concentration and the fabric moisture content. Dye concentrations were ordered into three conditions which are 0.5% in light shade, 1.5% in medium shade and 3% in dark shade. The gas concentration was arranged in 10%, 30%, 50% and 70%, the moisture content arranged in 35% and 45% and the treatment time in 10, 20 and 30 minutes. Specimens without going through the plasma treatment were used as checking reference.

4.4. Color depth

To characterize the color quality of a specimen, color depth is commonly used on demonstrating the relationship between the reflectance (R) of light of a given wavelength. K/S sum can demonstrate the color yield of the specimen and a higher

K/S represents better dye adsorption on a fabric. However, low K/S sum value result is more desired in case of color fading process because it represents the specimen has more color faded out. For evaluating the case of ozone plasma fading, the results of K/S sum value of different specimens under different conditions are shown in Figures 4.1 to 4.6.

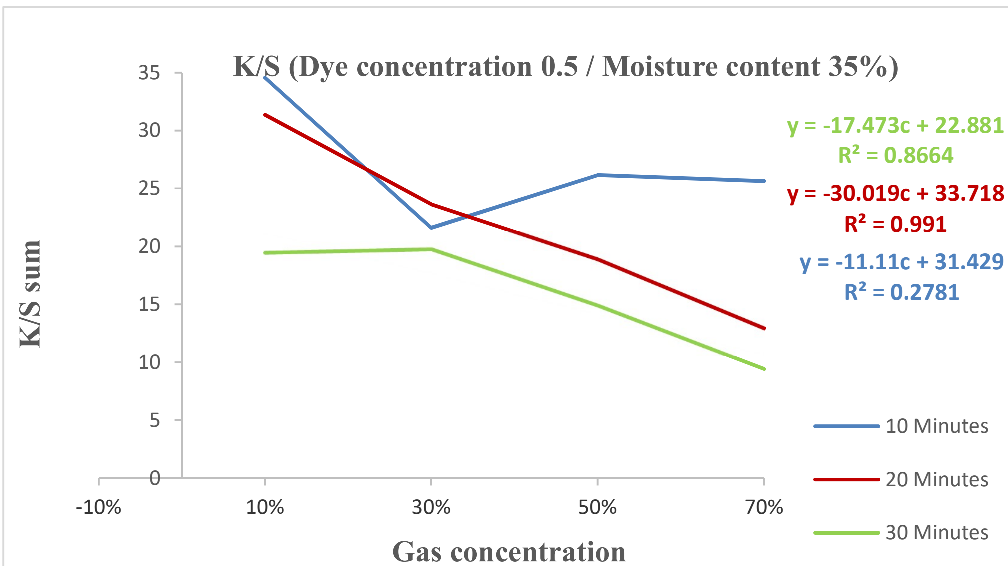


Figure 4.1. The relationship between K/S sum and gas concentration (0.5% dye concentration and 35% moisture content).

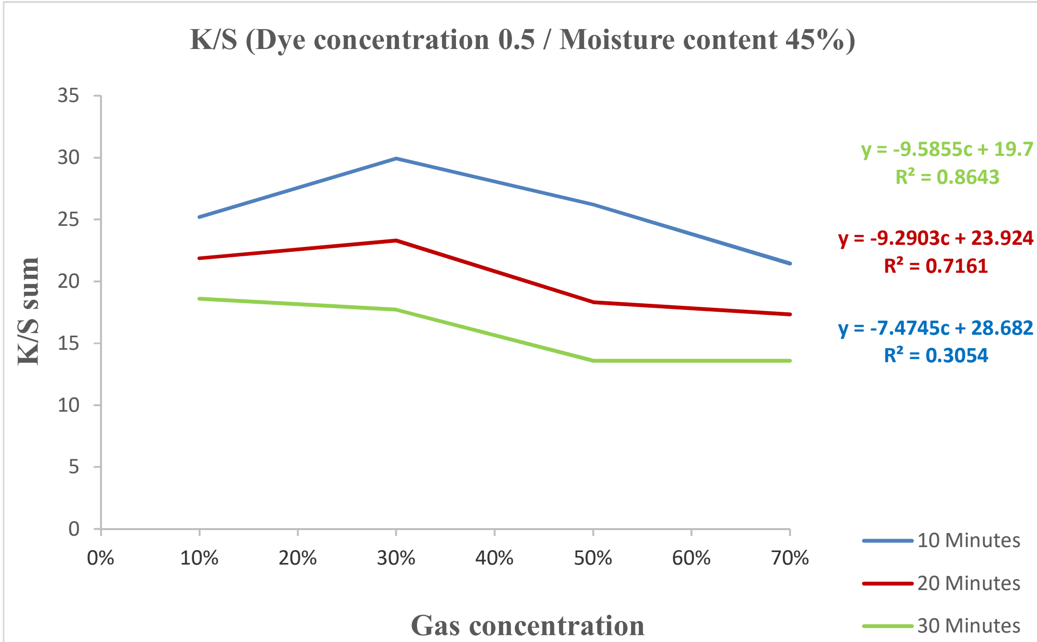


Figure 4.2. The relationship between K/S sum and gas concentration (0.5% dye concentration and 45% moisture content).

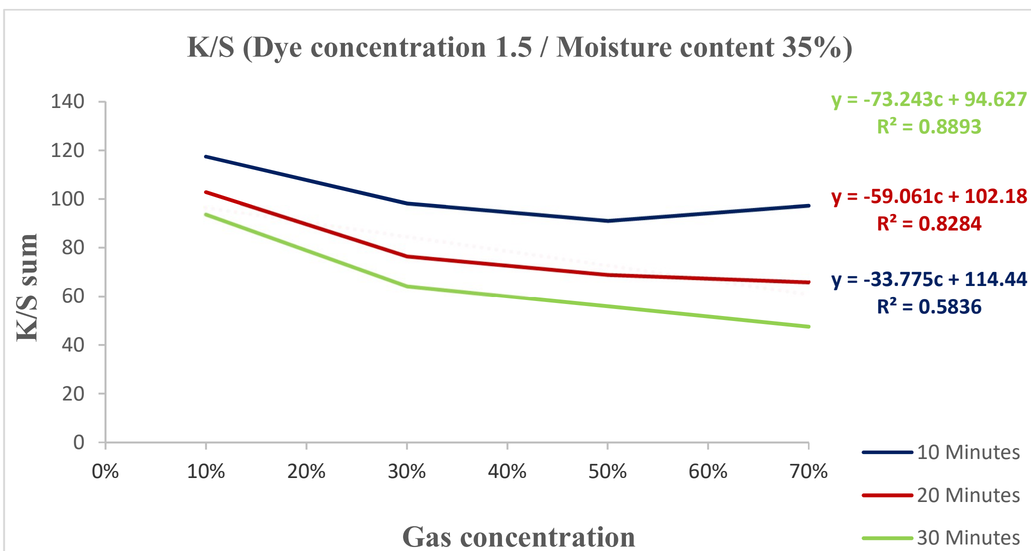


Figure 4.3. The relationship between K/S sum and gas concentration (1.5% dye concentration and 35% moisture content).

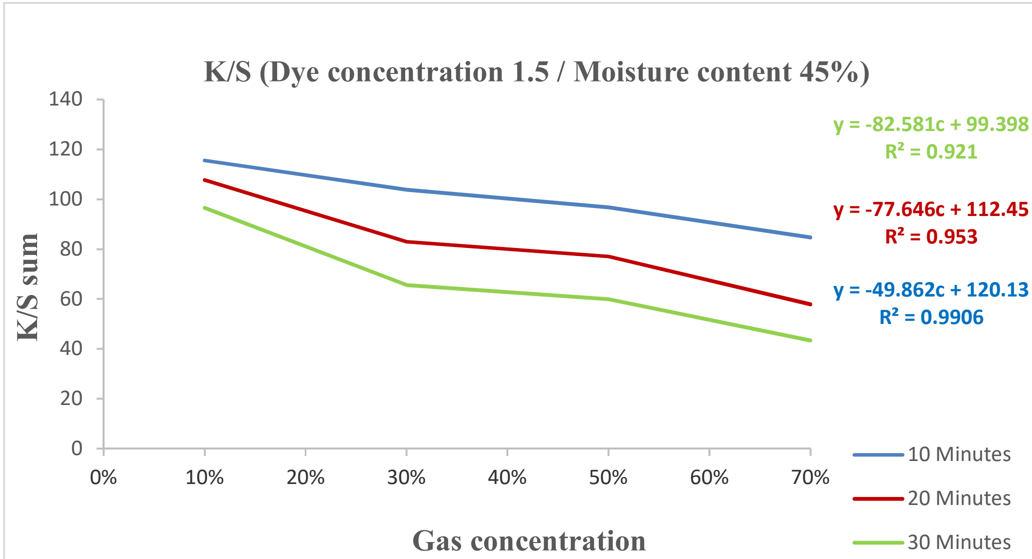


Figure 4.4. The relationship between K/S sum and gas concentration (1.5% dye concentration and 45% moisture content).

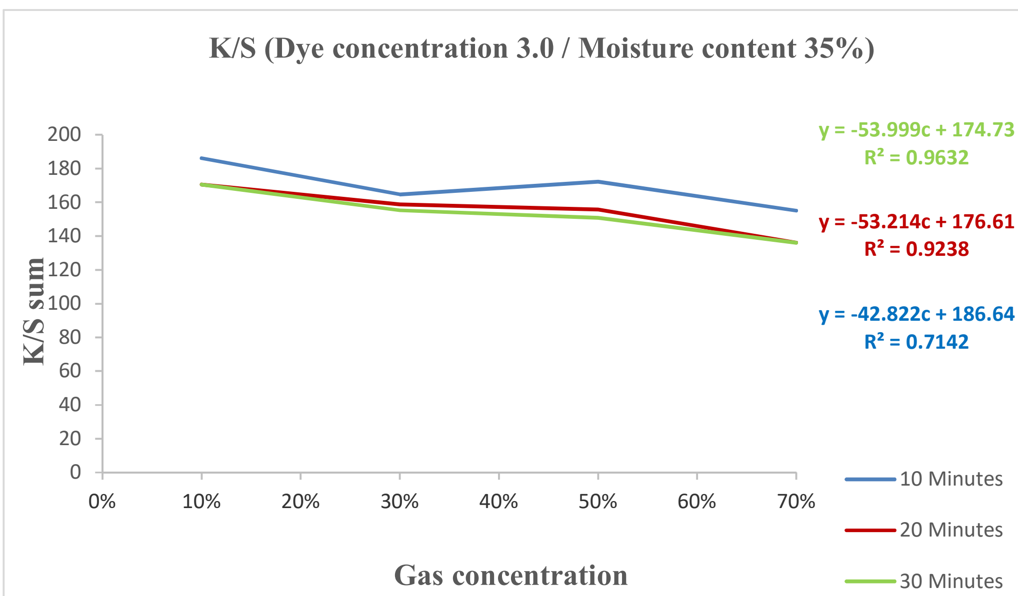


Figure 4.5. The relationship between K/S sum and gas concentration (3.0% dye concentration and 35% moisture content)

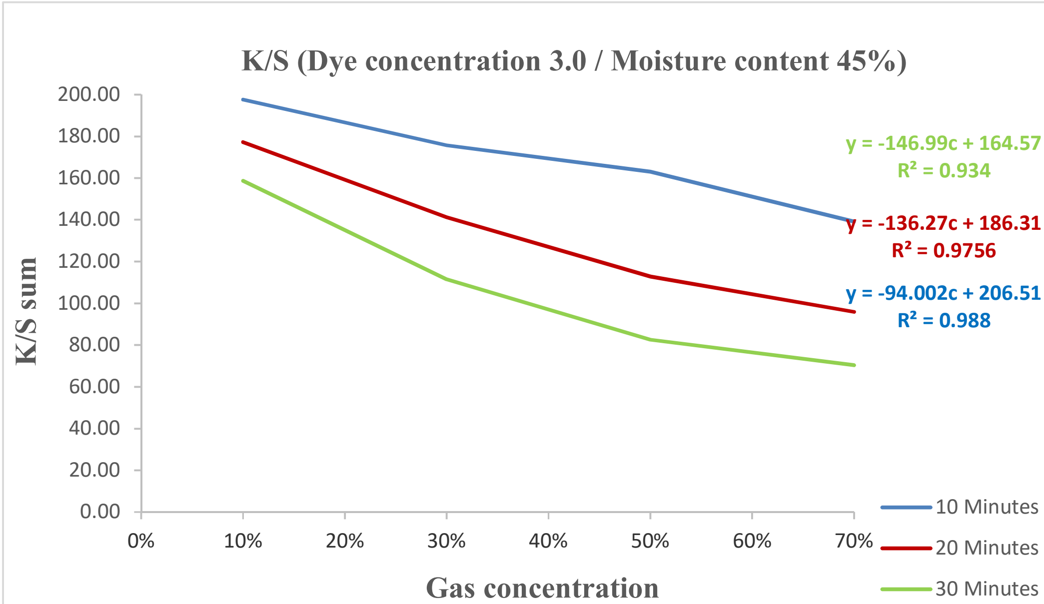


Figure 4.6. The relationship between K/S sum and gas concentration (3.0% dye concentration and 45% moisture content)

From Figure 4.1 to Figure 4.6, it is found that the K/S sums values are increased when the dye concentration increase. As mentioned in Chapter 2, Kubelka-Munk theory assumes a linear relationship between the colorant characteristic and the colorant concentration [55]. Therefore, the increase of color yield is related to the increase in K/S sum values.

4.4.1. Moisture content

In case of the effect of moisture content, from Figure 4.1 to Figure 4.6, the K/S sum does not have large difference between moisture contents in 35% and 45%. Water is a kind of media between plasma species and dyes to enhance and speed up oxidation process. However, too much moisture content does not lead to a significant increment of oxidation. Conversely, it makes result inhibiting the production of hydroxyl radicals, and it may impose negative effect to color fading process [42].

4.4.2. Treatment time

From Figure 4.1 to Figure 4.6, the time of processing has a direct relationship in affecting the K/S sum results. The K/S sum of specimens decreases while the treatment time increases. It can be illustrated that with long treatment time, more amount of dye particles in specimens would be oxidized [42]. Since the amount of dyes decreased after oxidation, the color yield decreases accordingly. Therefore, the K/S sum values decrease. However, under dye concentration of 3%, it does not appear so much difference for treatment times of 20 and 30 minutes in moisture content of 35%, as shown in Figure 4.5. This reflected that the decrease of the amount of reactive dye would reach an equilibrium stage at treatment times of 20 minutes. Therefore, more hydroxyl radicals generate after the equilibrium point may not be utilized for color fading even prolonging the treatment time.

4.4.3. Gas concentration

With higher plasma gas concentration, more hydroxyl radicals could be produced [42]. Due to the interaction between the hydroxyl radicals to the dye particles in the specimens, more oxidizing effect would be observed and hence decreased the K/S sum values.

4.4.4. Regression modelling

4.4.4.1. Linear regression of K/S sum value

In Figure 4.1 to Figure 4.6, linear regression of K/S sum in change of gas concentration (C) under different treatment conditions are calculated and are shown in

Table 4.1. In Table 4.1, it shows that the coefficient of determination (R^2) values. However, no significant relationship could be obtained between the K/S sum and gas concentration under different conditions because the R^2 values are not consistent. In order to have a better understanding between K/S sum values and different processing parameters, multiple linear regression would be used for predicting the relationship between K/S sum values and different processing parameters.

Table 4.1. Linear regression of K/S sum value

Dye concentration (%)	**Moisture content (%)**	**Treatment time (min)**	**Linear regression of K/S sum with gas concentration (C) change**	**R^2**
0.5	35	10	K/S sum10 = -11.11C + 31.42	0.278
		20	K/S sum20 = -30.01C + 33.71	0.991
		30	K/S sum30 = -17.47C + 22.88	0.866
0.5	45	10	K/S sum10 = -7.47C + 28.68	0.305
		20	K/S sum20 = -9.29C + 23.92	0.716
		30	K/S sum30 = -9.59C + 19.70	0.864
1.5	35	10	K/S sum10 = -33.77C + 114.40	0.921
		20	K/S sum20 = -59.06C + 102.10	0.828
		30	K/S sum30 = -73.24C + 94.62	0.828
1.5	45	10	K/S sum10 = -49.86C + 120.10	0.990
		20	K/S sum20 = -77.64C + 112.40	0.953
		30	K/S sum30 = -82.58C + 99.39	0.921
3	35	10	K/S sum10 = -42.82C + 186.60	0.714
		20	K/S sum20 = -53.21C + 176.60	0.923
		30	K/S sum30 = -53.99C+ 174.70	0.963
3	45	10	K/S sum10 = -94.00C + 206.50	0.988
		20	K/S sum20 = -136.20C + 186.30	0.975
		30	K/S sum30 = -146.90C + 164.50	0.934

4.4.4.2. **Multiple linear regression for K/S sum**

In order to find out the relationship between K/S sum values and different processing parameters, multiple linear regression is considered. The regression coefficients between different parameters on K/S sum value are obtained (Table 4.2) and through t-test analysis, the significance of the relationship between different processing paremeters and K/S sum values can be obtained (Table 4.3).

Table 4.2. Model Summary of multiple linear regression for K/S sum

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.965[a]	.931	.927	15.2826210

a. Predictors: (Constant), Treatment time, Moisture content, Gas concentration, Dye concentration

Table 4.3. Coefficients of multiple linear regression for K/S sum

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	82.126	15.787		5.202	.000
Dye concentration	49.987	1.753	.914	28.514	.000
Gas concentration	-.549	.081	-.219	-6.817	.000
Moisture content	-.791	.360	-.070	-2.195	.032
Treatment time	-1.416	.221	-.206	-6.417	.000

a. Dependent Variable: K/S sum

In Table 4.2, the R^2 is 0.931 which shows that K/S sum has 93.1% influenced by dye concentration, gas concentration, moisture content and treatment time. According to

Table 4.3, the p-values of the t-tests for each regression coefficients are 0.000, 0.000, 0.032 and 0.000 respectively.

In dye concentration aspects, P value < 0.05, it represents there has a significant linear relationship with K/S sum at a significant level of 0.05.

In gas concentration aspect, P value < 0.05, it represents there has a significant linear relationship with K/S sum at a significant level of 0.05.

In moisture content aspect, P value > 0.05, it represents there is no a significant linear relationship with K/S sum at a significant level of 0.05.

In treatment time aspect, P value < 0.05, it represents there has a significant linear relationship with K/S sum at a significant level of 0.05.

Based on analyses result, a regression equation can be generated as follow:

K/S sum = 82.126 + dye concentration (49.987) + gas concentration (-0.549) + moisture content (-0.791) + treatment time (-1.416). Equation 4.1.

4.4.4.3. **Verification of equation for K/S sum**

In order to verify the Equation 4.1, five sets of parameters are selected for verification and shown in Table 4.4. As show in Table 4.4, the difference between predicted values and measured values is on average less than 10%. Therefore, it can verify that the Equation 4.1 is validated if processing parameters are input for prediction.

Table 4.4. Verification for K/S sum

Parameters	Measured value	Predicted value	Difference %
0.5C/ 70G / 35M / 20T	12.94	12.68	1.98%
1.5C/ 10G / 35M / 10T	117.39	109.77	6.49%
1.5C/ 30G / 45M / 20T	82.94	76.72	7.50%
3.0C / 10G / 45M / 30T	158.69	148.52	6.41%
3.0C / 70G / 35M / 30T	136.01	123.49	9.20%

Parameter interpretation

“C” represents for dye concentration

“G” represents for gas concentration

“M” represents for moisture content

“T” represents for treatment time

4.5. Relative unlevelness Index (RUI)

The RUI values of ozone plasma treated specimens (under different conditions) are shown in Figure 4.7 to Figure 4.12. In Figures 4.7 to 4.12, the dye concentration and moisture content are selected as constant and the results are analysed based on the change of parameters in gas concentration and treatment time.

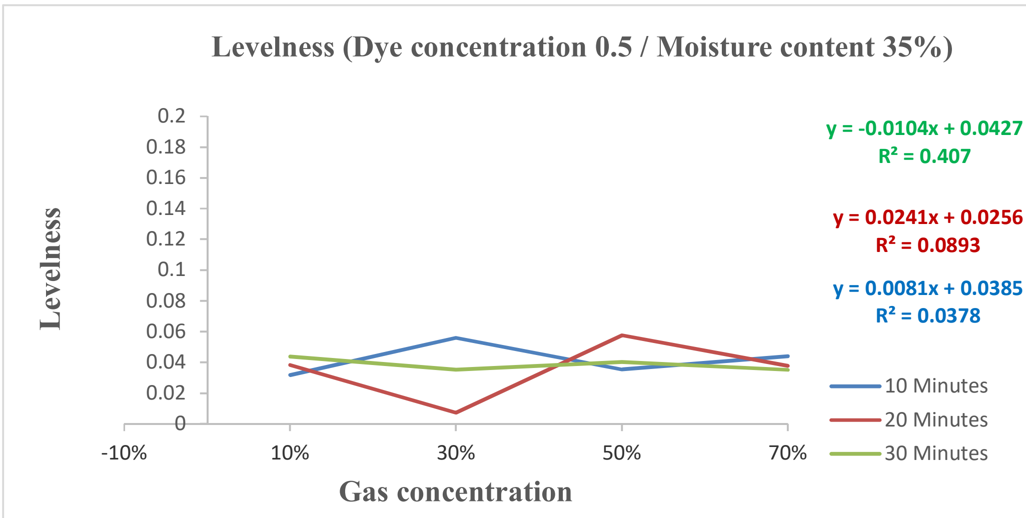


Figure 4.7. The relationship between RUI and gas concentration (0.5% dye concentration and 35% moisture content)

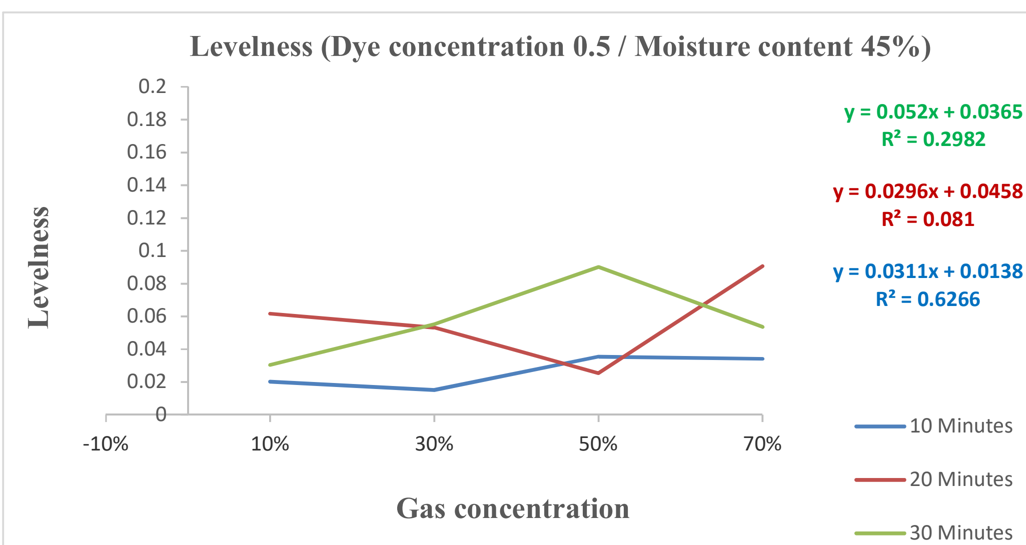


Figure 4.8. The relationship between RUI and gas concentration (0.5% dye concentration and 45% moisture content)

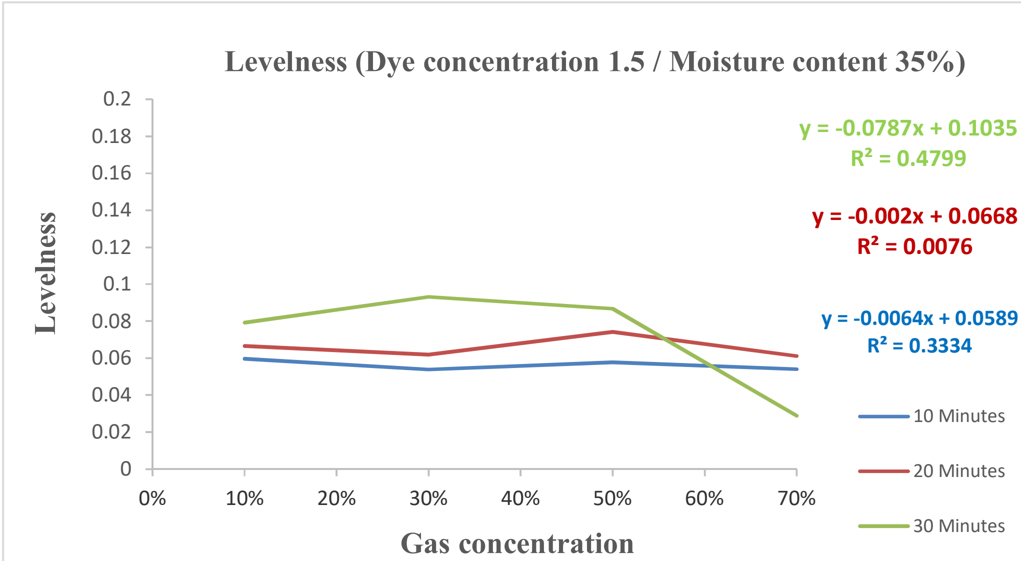


Figure 4.9. The relationship between RUI and gas concentration (1.5% dye concentration and 35% moisture content)

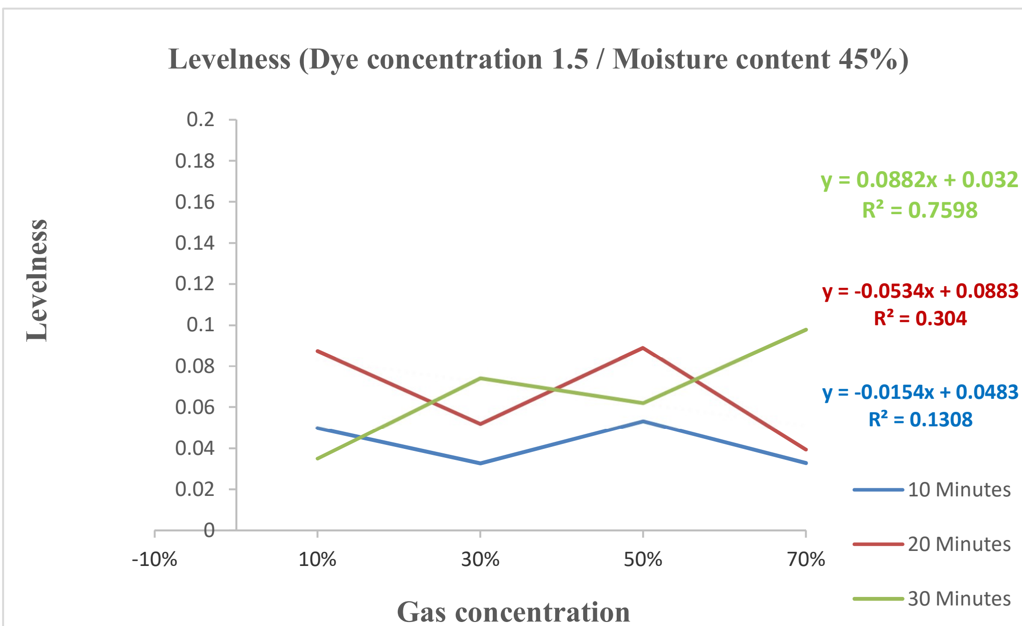


Figure 4.10. The relationship between RUI and gas concentration (1.5% dye concentration and 45% moisture content)

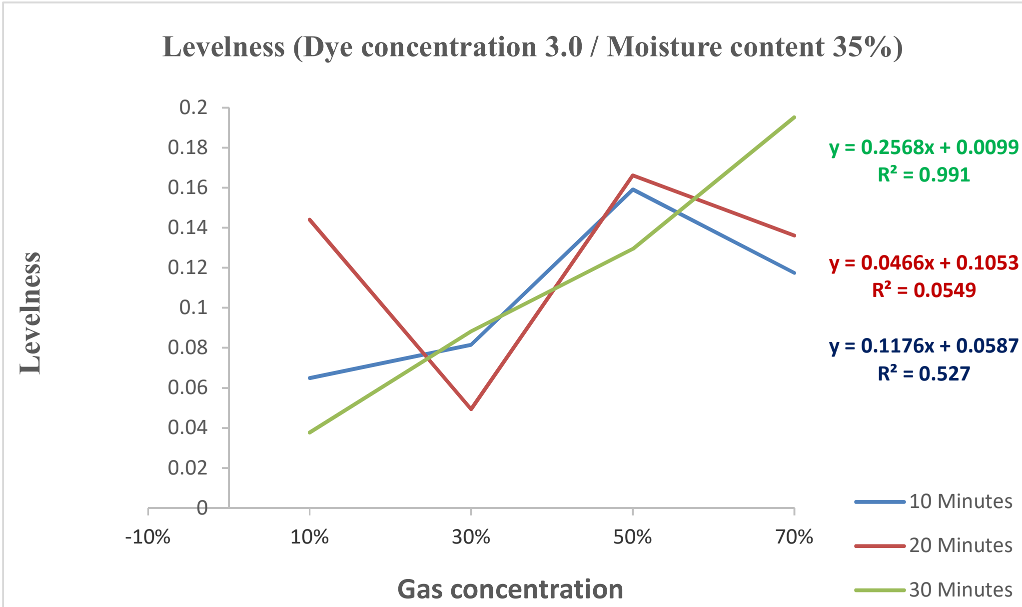


Figure 4.11. The relationship between RUI and gas concentration (3.0% dye concentration and 35% moisture content)

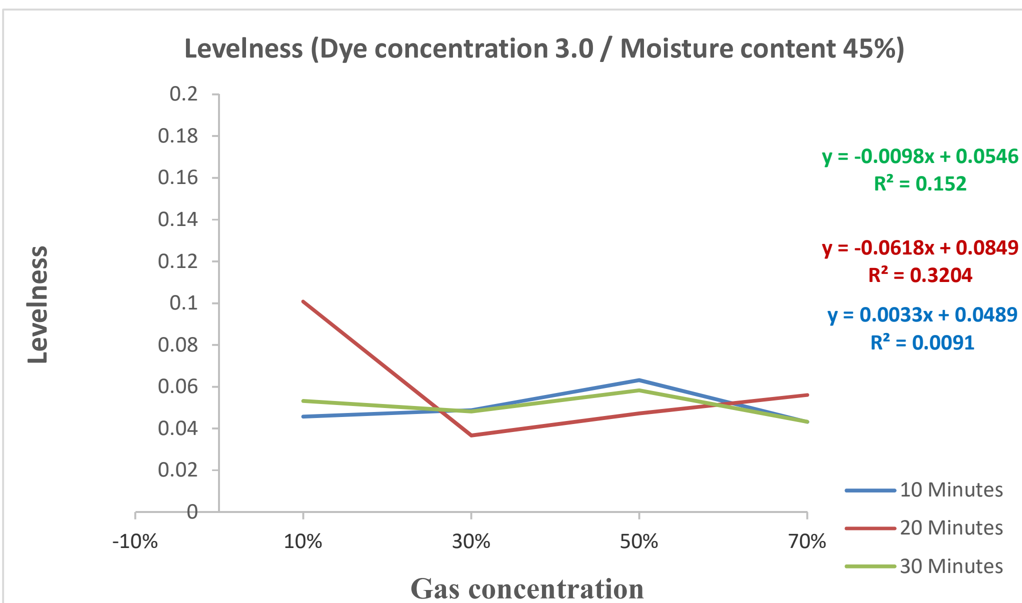


Figure 4.12. The relationship between RUI and gas concentration (3.0% dye concentration and 45% moisture content)

4.5.1. Dye concentration

In the study, spectrophotometer is used for identifying the color change as well as the levelness. In the three dye concentrations, it is found that the color fading treatment with lower moisture content would lead to a better levelness gently. This can have explained that during oxidation process, dyes are being oxidized and leads color yield becomes lower. At the beginning of oxidizing stage, specimen contains more dyes to be oxidized. However, the amount of dyes to be oxidized would become less when reaching later stage of oxidation. In case of 3% dye concentration, more dyes would be available for oxidation which may increase the chance for unlevelness after color fading process. Therefore, the levelness is increased when the dye concentration is decreased. However, it has not appeared variations of levelness between the three dye concentrations equally. When the moisture content reaches to 45%, as shown in Figure 4.8, Figure 4.10 and Figure 4.12, the color fading effect does not increase much with moisture content. This can be explained that the moisture content may reach an equilibrium stage and increases in moisture content would induce dilution effect of hydroxyl radicals [41]. Therefore, high moisture content may inhibit the color fading process.

4.5.2. Moisture content

In this study, two moisture contents are used 35% and 45% and the results are shown in Figures 4.7 to 4.12. When the moisture content of the treatment is up to 45%, i.e. Figure 4.8, Figure 4.10 and Figure 4.12, there is no significant variation between the levelness of three different dye concentrations. As shown in Figure 4.7 to Figure 4.12, it can see that the RUI values of the plasma-treated dyed specimens are below 0.2 which can be classified as very good levelness according to the interpretation of RUI (Table 2.6. in Chapter 2) [44]. When reviewing all the plasma-treated specimens, where the dye concentration is 0.5% and moisture content is 35%. There is an optimum levelness with RUI values of 0.01 and while the treatment time is 20 minutes and the plasma gas concentration in 30%.

4.5.3. Treatment time

When specimens treated under different conditions, different RUI results are produced. It is noted that too long treatment time may not achieve a better levelness. Since the reaction between hydroxyl radicals and treatment time may reach the equilibrium, the efficiency of color fading effects will slow down with prolonged treatment time [41]. Since hydroxyl radical is key element to make color fading process, the treatment time and gas concentration may affect the volume of hydroxyl radicals produced during the color fading process. As per Figure 4.9, it shows that with dye concentration of 1.5% and moisture content of 35%. Shorter treatment time makes levelness increase while the plasma gas concentration increase. However, when plasma gas concentration over 50%, the levelling effect decrease. This may be due to higher gas concentration can produce more hydroxyl radicals. It appears that longer treatment time can enhance hydroxyl radicals leveling distribution on the fabric.

4.5.4. Gas concentration

According to Figures 4.7 to Figures 4.12, it is found that the gas concentration affects the levelness differently in various treatment conditions. For example, in the dye concentration of 3% with moisture content of 35%, the levelness results are fluctuating but when the moisture content is increased to 45%, the levelness results are within a small range.

4.5.5. Regression modelling

4.5.5.1. Linear regression of RUI

Based on Figure 4.7 to Figure 4.12, the linear regression of RUI in change of gas concentration (C) under different treatment conditions are shown in Table 4.5. It is shown that the coefficient of determination (R^2) values of different linear regression relationship are not significant. Therefore, the relationship between RUI and different treatment conditions cannot be predicted by linear regression. As a result, the multiple linear regression would be used for predicting the relationship between RUI and different processing parameters.

Table 4.5. Linear regression of RUI

Dye concentration (%)	Moisture content (%)	Treatment time (min)	Linear regression of RUI with gas concentration (C) change	R^2
0.5	35	10	$RUI_{10} = 0.01C + 0.04$	0.037
		20	$RUI_{20} = 0.02C + 0.03$	0.089
		30	$RUI_{30} = -0.01C + 0.04$	0.407
0.5	45	10	$RUI_{10} = 0.03C + 0.01$	0.626
		20	$RUI_{20} = 0.03C + 0.05$	0.081
		30	$RUI_{30} = 0.05C + 0.04$	0.298
1.5	35	10	$RUI_{10} = -0.01C + 0.06$	0.333
		20	$RUI_{20} = -0.00C+ 0.07$	0.007
		30	$RUI_{30} = -0.08C + 0.10$	0.479
1.5	45	10	$RUI_{10} = -0.02C + 0.05$	0.130
		20	$RUI_{20} = -0.05C + 0.09$	0.304
		30	$RUI_{30} = 0.09C + 0.03$	0.759
3	35	10	$RUI_{10} = 0.12C + 0.06$	0.527
		20	$RUI_{20} = 0.05C + 0.11$	0.054
		30	$RUI_{30} = 0.26C + 0.01$	0.991
3	45	10	$RUI_{10} = 0.00C + 0.05$	0.009
		20	$RUI_{20} = -0.06C + 0.09$	0.320
		30	$RUI_{30} = -0.01C + 0.06$	0.152

4.5.5.2. **Multiple linear regression for RUI**

In order to find out the relationship between RUI and different processing parameters, multiple linear regression is considered. The regression coefficients between different parameters on RUI were obtained (Table 4.6) and with the use of t-test analysis, the significance of their relationships can be obtained (Table 4.7).

Table 4.6. Model Summary of multiple linear regression for RUI

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.582[a]	.339	.300	.0299339

a. Predictors: (Constant), Treatment time, Moisture content, Gas concentration, Dye concentration

Table 4.7. Coefficients of multiple linear regression for RUI

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.091	.031		2.936	.005
	Dye concentration	.016	.003	.472	4.752	.000
	Gas concentration	.000	.000	.147	1.477	.144
	Moisture content	-.002	.001	-.271	-2.733	.008
	Treatment time	.001	.000	.146	1.466	.147

a. Dependent Variable: RUI

Based on Table 4.6, it is noted that only 33.9% RUI values are relying in the influence of dye concentration, gas concentration, moisture content and treatment time and this explains why the results in Figures 4.7 to 4.12 are fluctuating. According to Table 4.7, the p-values of the t-tests for each regression coefficients are 0.000, 0.144, 0.008 and 0.147 respectively.

In dye concentration aspects, P value < 0.05, it represents there has a significant linear relationship with RUI at a significant level of 0.05.

In gas concentration aspect, P value > 0.05, it represents there is no significant linear relationship with RUI at a significant level of 0.05.

In moisture content aspect, P value < 0.05, it represents there has a significant linear relationship with RUI at a significant level of 0.05.

In treatment time aspect, P value > 0.05, it represents there is no significant linear relationship with RUI at a significant level of 0.05.

Based on analyses result, a regression equation can be generated as follow,

RUI = 0.091 + dye concentration (0.016) + gas concentration (-0.000) + moisture content (-0.002) + treatment time (-0.001). Equation 4.2.

4.5.5.3. **Verification of equation for RUI**

In order to verify Equation 4.2, five sets of parameters are used for the verification and the results are shown in the Table 4.8. As shown in Table 4.8, the difference between predicted values and measured values is on average less than 10%. Therefore, it can verify that Equation 4.2 is validated if processing parameters are considered for prediction.

Table 4.8. Verification for RUI

Parameters	Measured value	Predicted value	Difference %
0.5C / 10G / 45M / 10T	0.020	0.019	5.98%
1.5C / 10G / 35M / 20T	0.067	0.065	2.42%
1.5C / 50G / 35M / 10T	0.058	0.055	4.83%
3.0C / 30G / 35M / 10T	0.082	0.079	3.07%
3.0C / 50G / 45M / 10T	0.063	0.059	6.55%

Parameter interpretation

"C" represents for dye concentration

"G" represents for gas concentration

"M" represents for moisture content

"T" represents for treatment time

4.6. Reflectance curve

The reflectance curves of different specimens are shown in Figures 4.13 to 4.18. Based on the shape of the reflectance curves, it is observed that there is no change in the shape of the curves. This indicates that after the color fading process, there is no chromaticity change in the final shade but it is noted that the control fabric located in lower reflectance values range. The reflectance curves, thus, provides the information that after the color fading process, the final shade of treated specimens are paler than the control fabric.

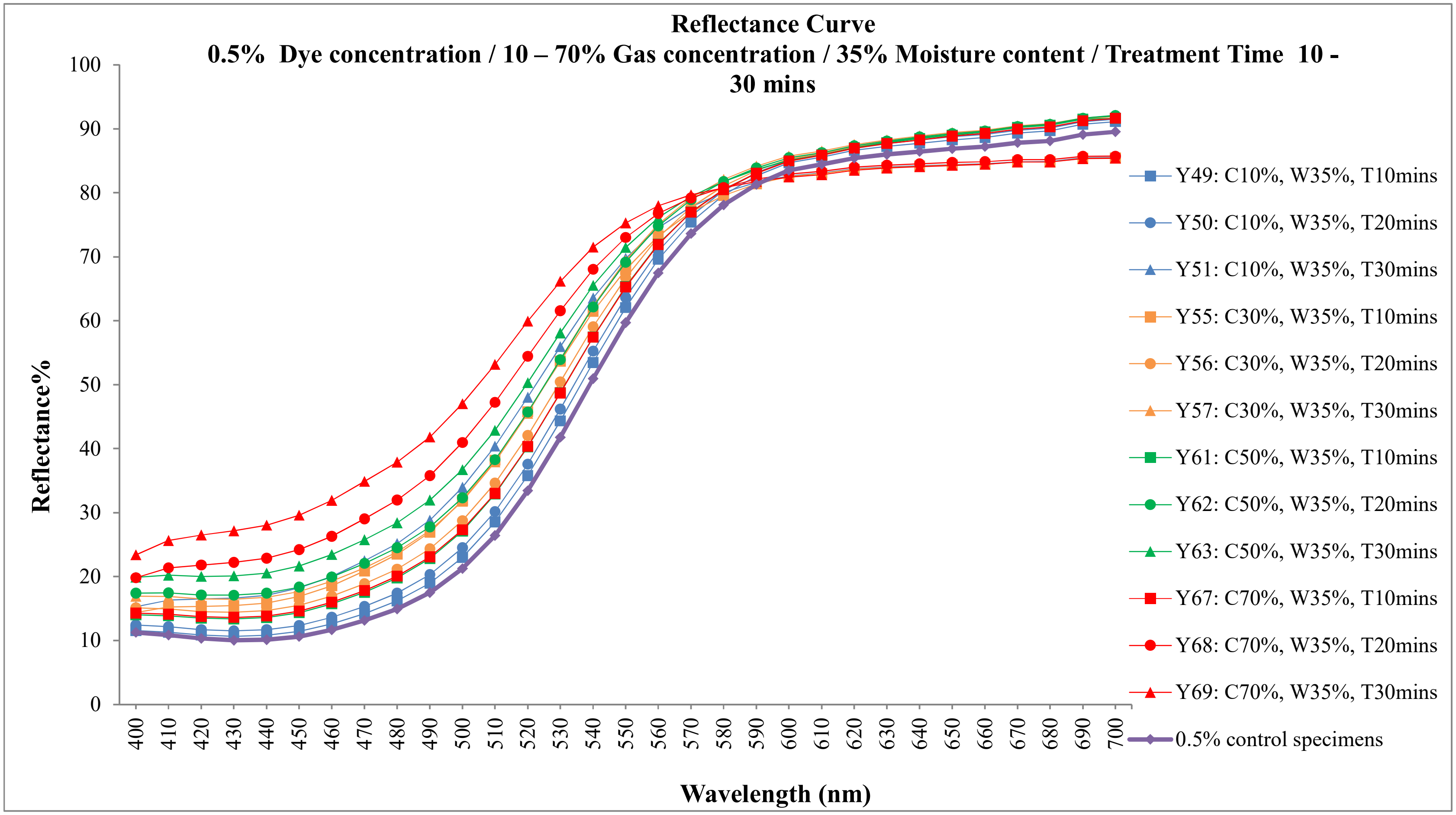


Figure 4.13. Reflectance curve of 0.5% dye concentration with 35% moisture content

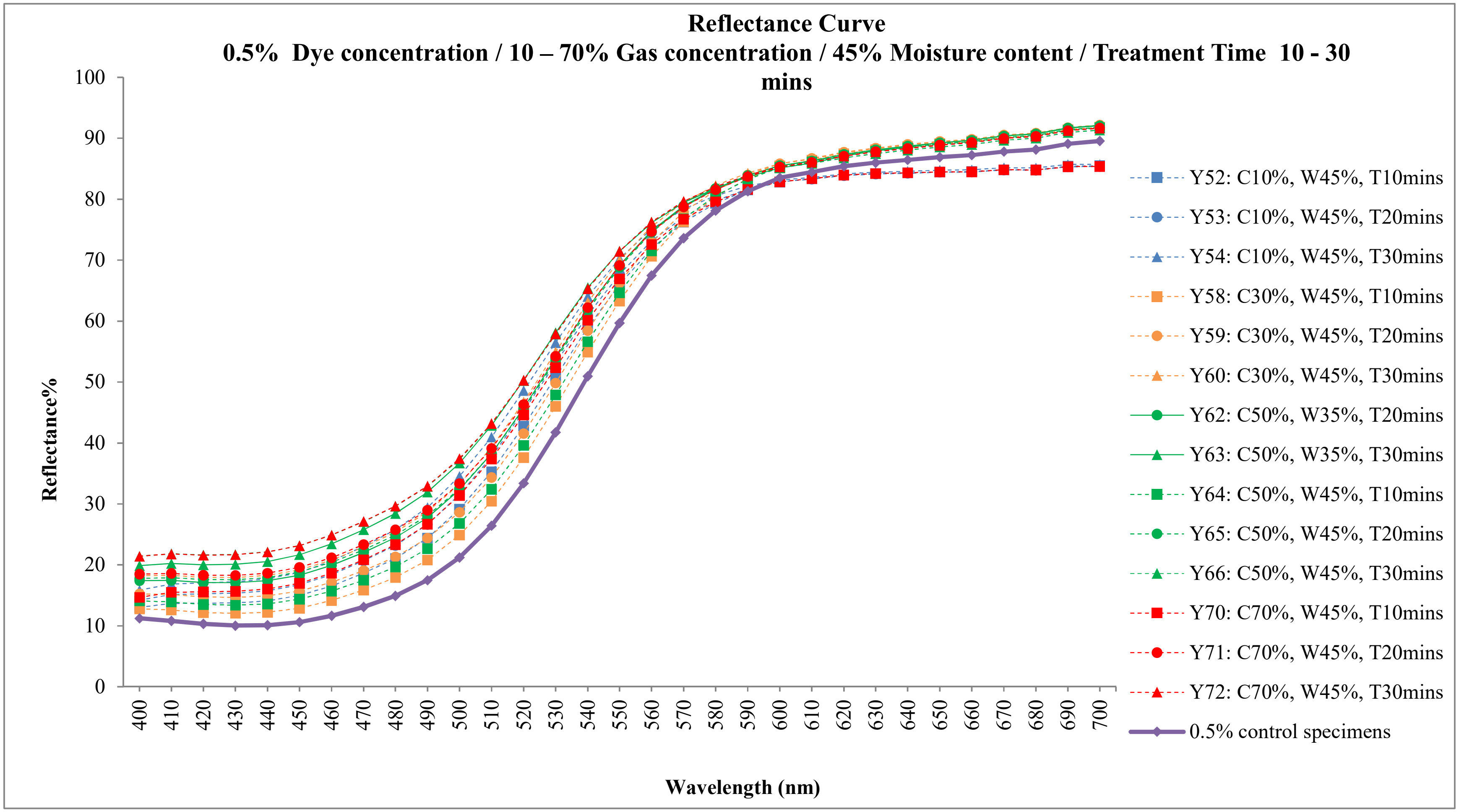


Figure 4.14. Reflectance curve of 0.5% dye concentration with 45% moisture content

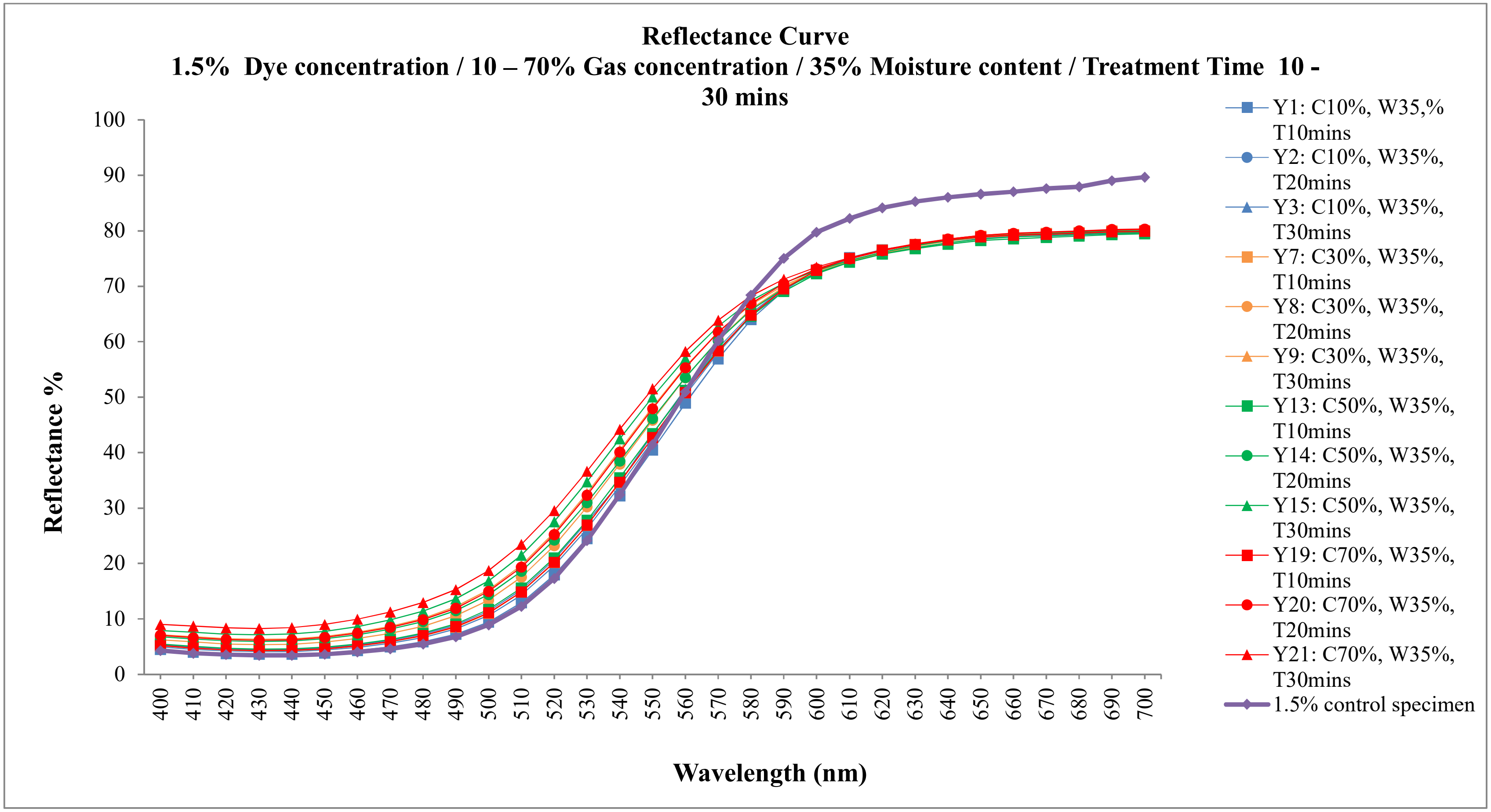


Figure 4.15 Reflectance curve of 1.5% dye concentration with 35% moisture content

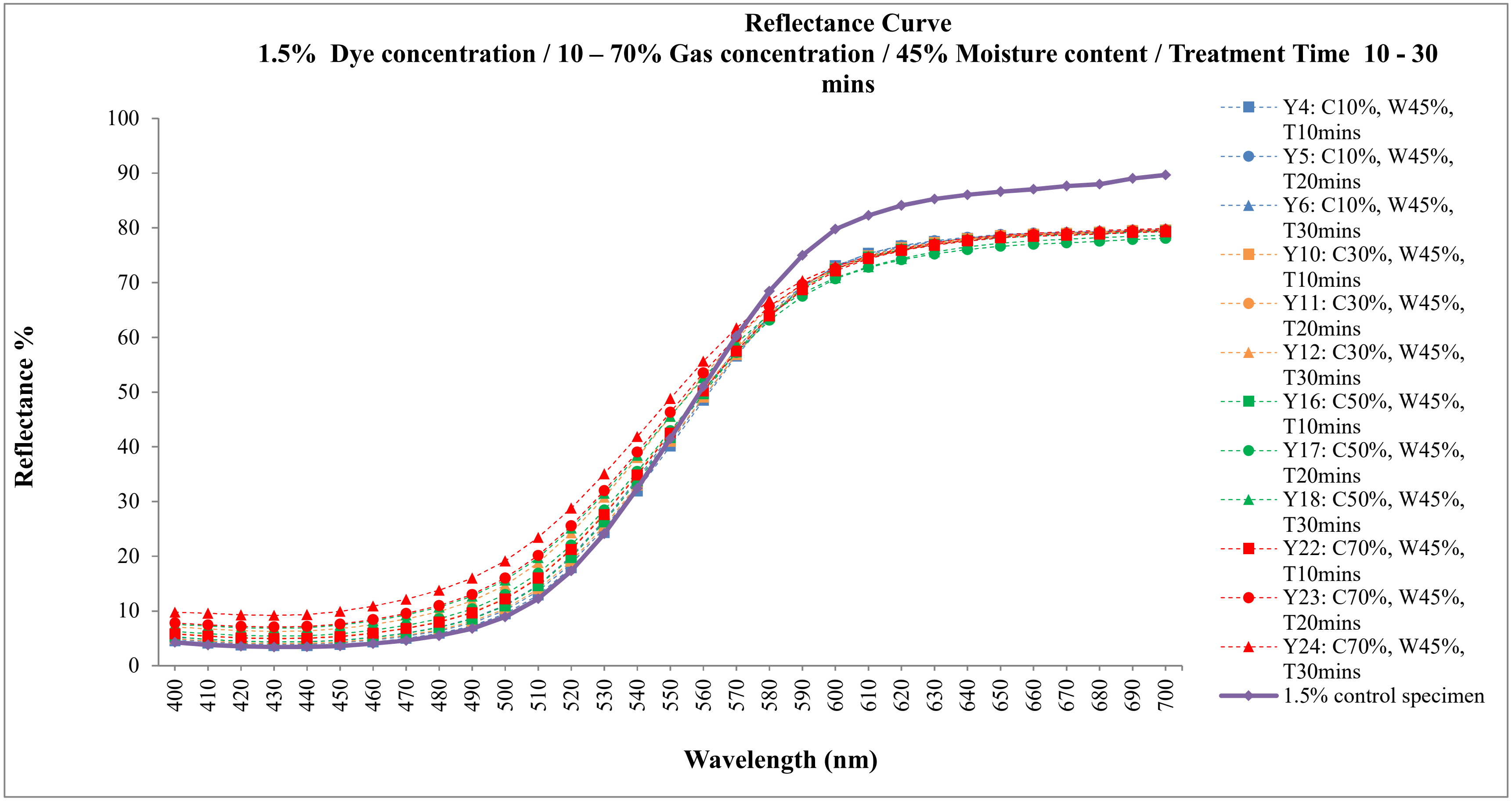


Figure 4.16. Reflectance curve of 1.5% dye concentration with 45% moisture content

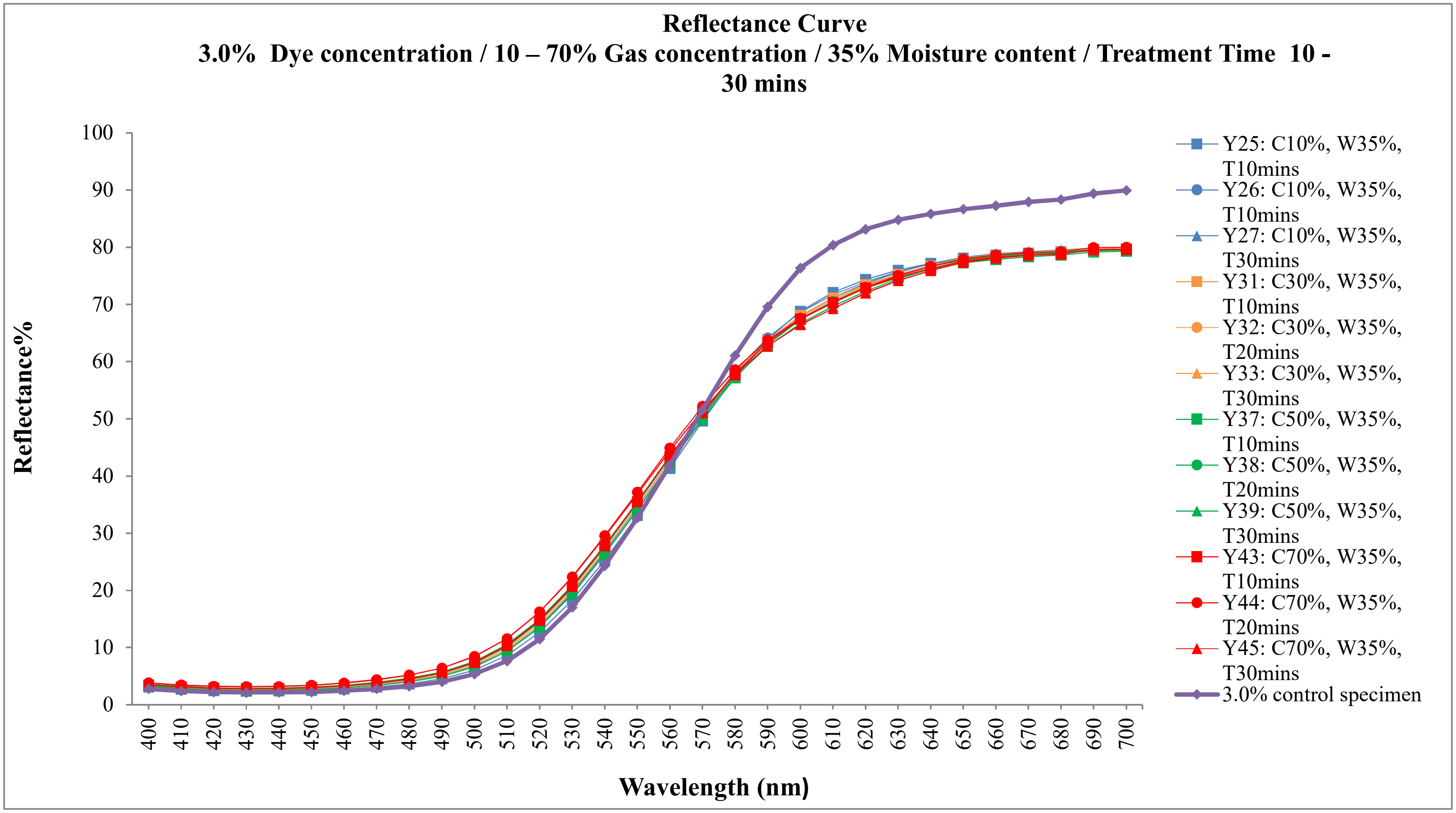


Figure 4.17 Reflectance curve of 3.0% dye concentration with 35% moisture content

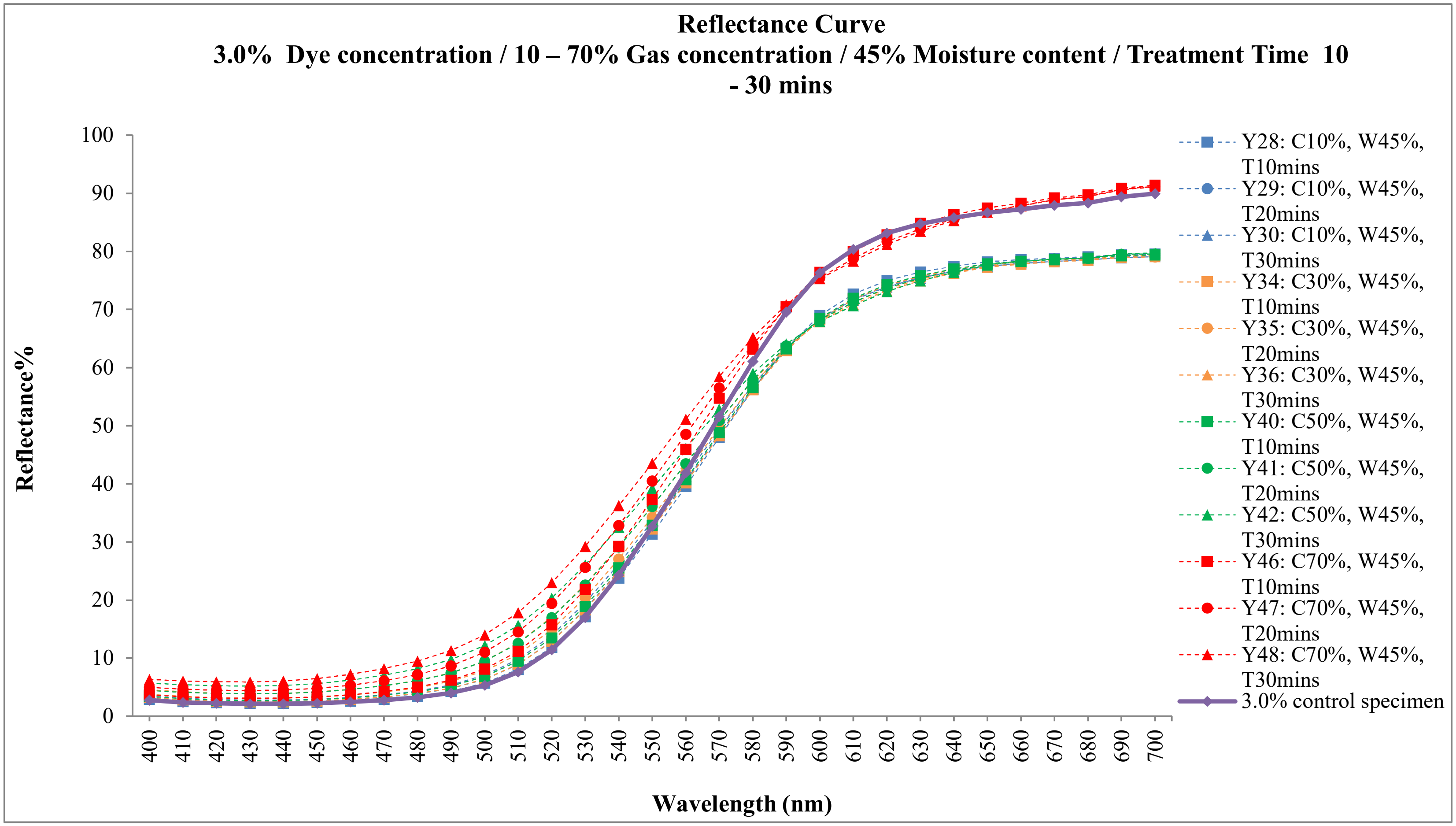


Figure 4.18. Reflectance curve of 3.0% dye concentration with 45% moisture content

4.6.1. Dye concentration

For better discussion of dye concentration, Figure 4.19, which picks the parameters from "gas concentration = 30%; moisture content = 45% and treatment time = 20 minutes" from each depth (Y11, Y35 and Y59), is plotted.

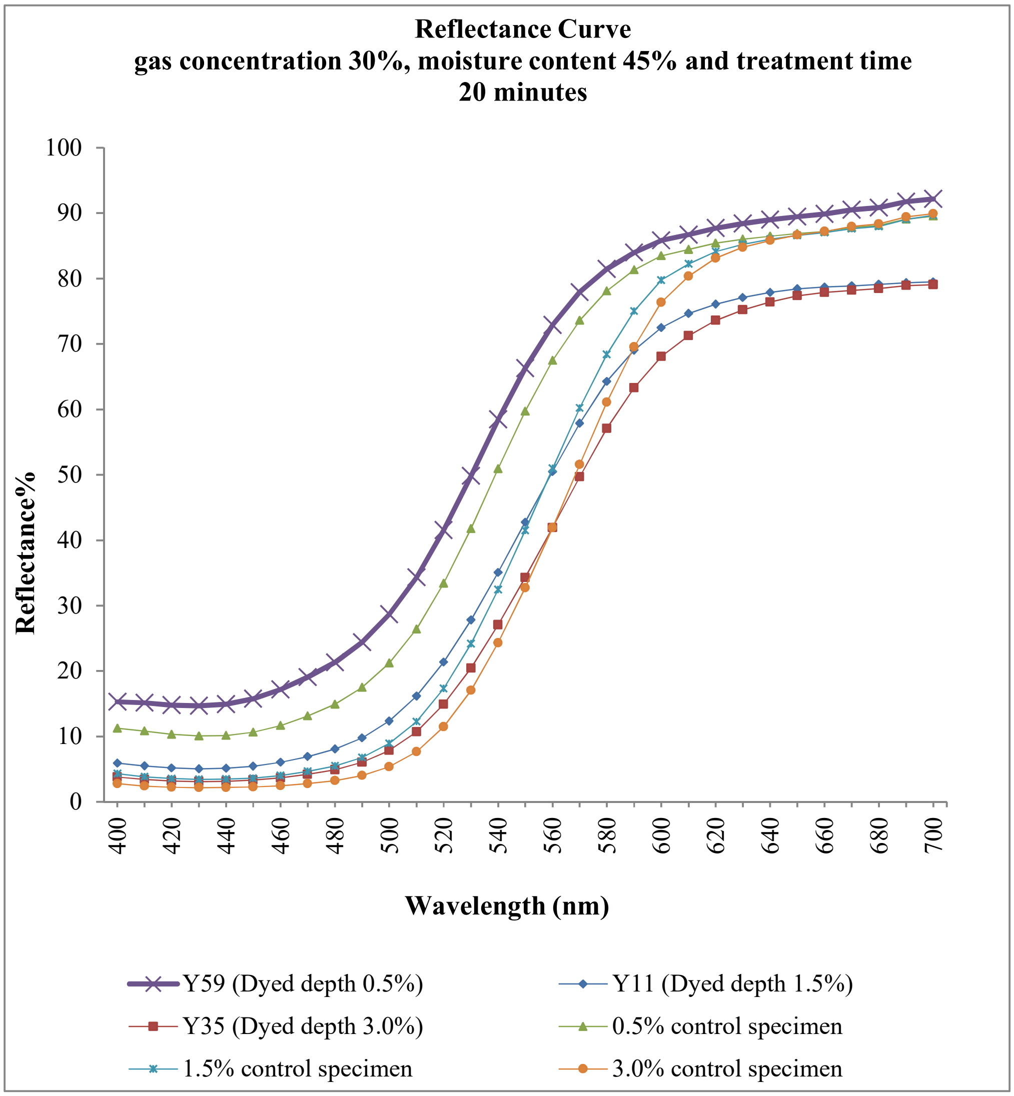


Figure 4.19. Reflectance curve of 0.5%, 1.5% and 3.0% dye concentration with 45% moisture content

Firstly, based on the comparison of reflectance curve of each depth, it can see clearly all curves have similar shape but in different location which indicates that the color fading process do not affect final shade of the product. For 3.0% dye concentration, it located in the lowest location but 0.5% is located in the highest location. After color fading process, the related curves are moved upward which show that the final shade is paler than original one after color fading process.

4.6.2. Moisture content

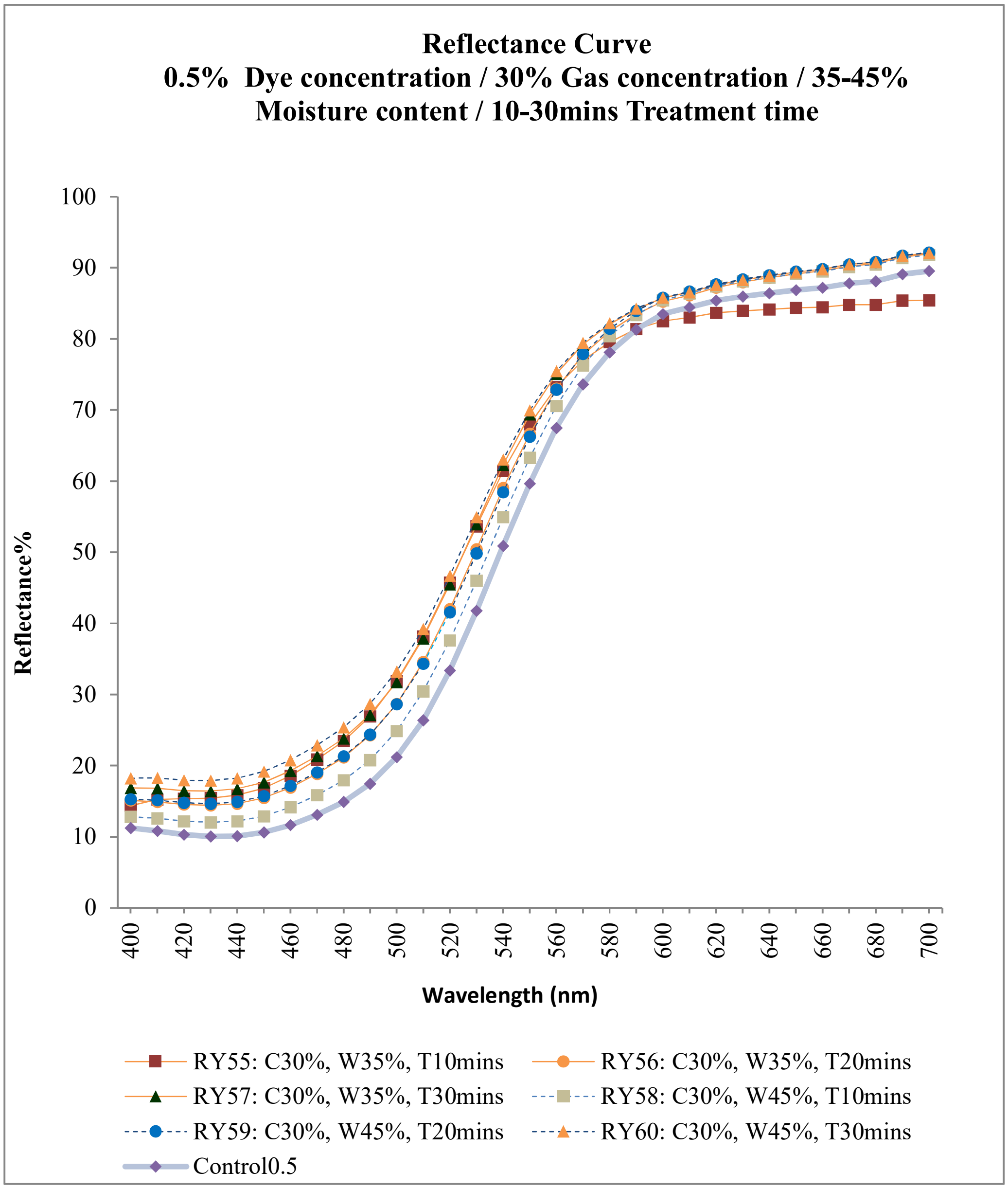


Figure 4.20. Reflectance curve of 0.5% dye concentration with 35% and 45% moisture content

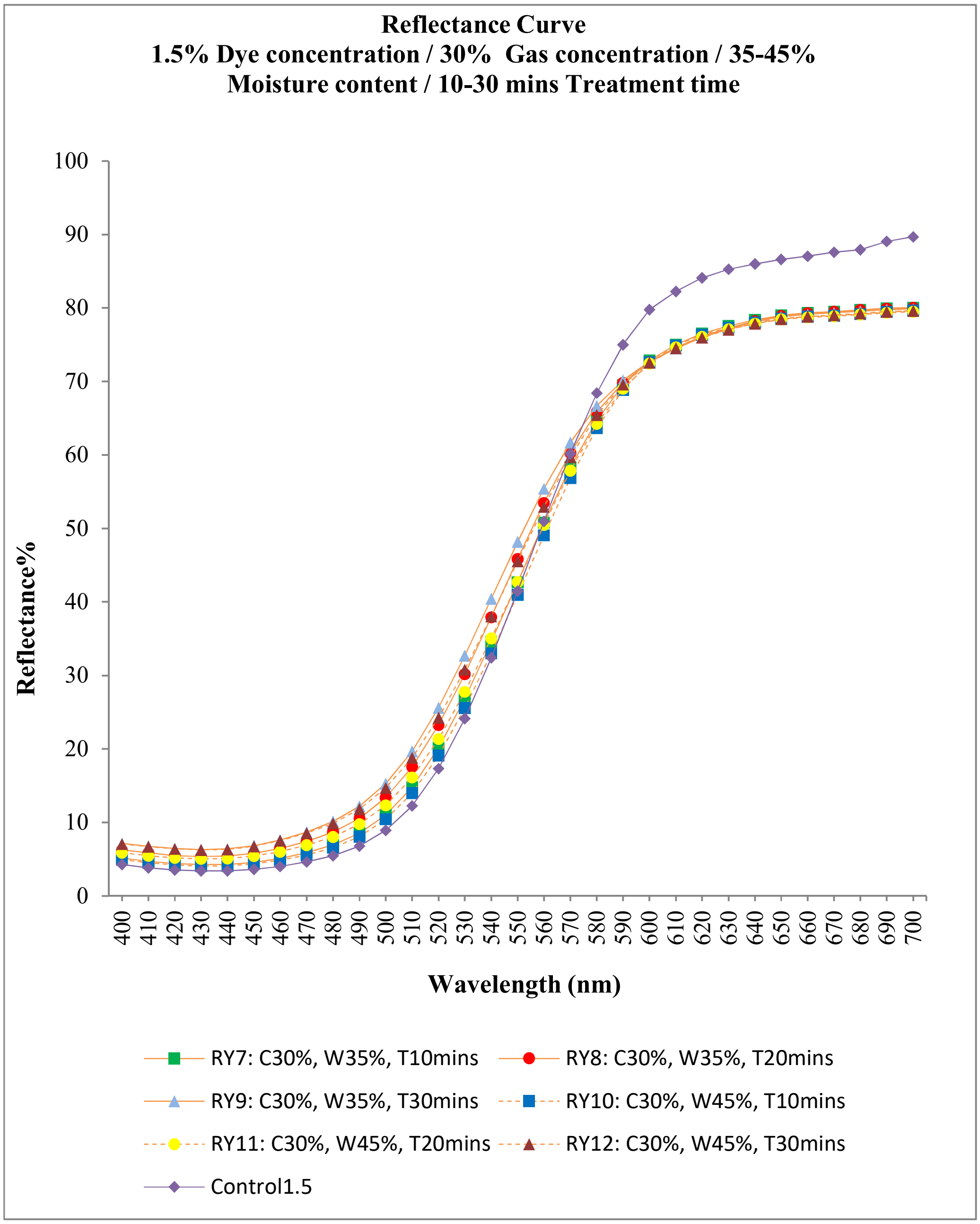


Figure 4.21. Reflectance curve of 1.5% dye concentration with 35% and 45% moisture content

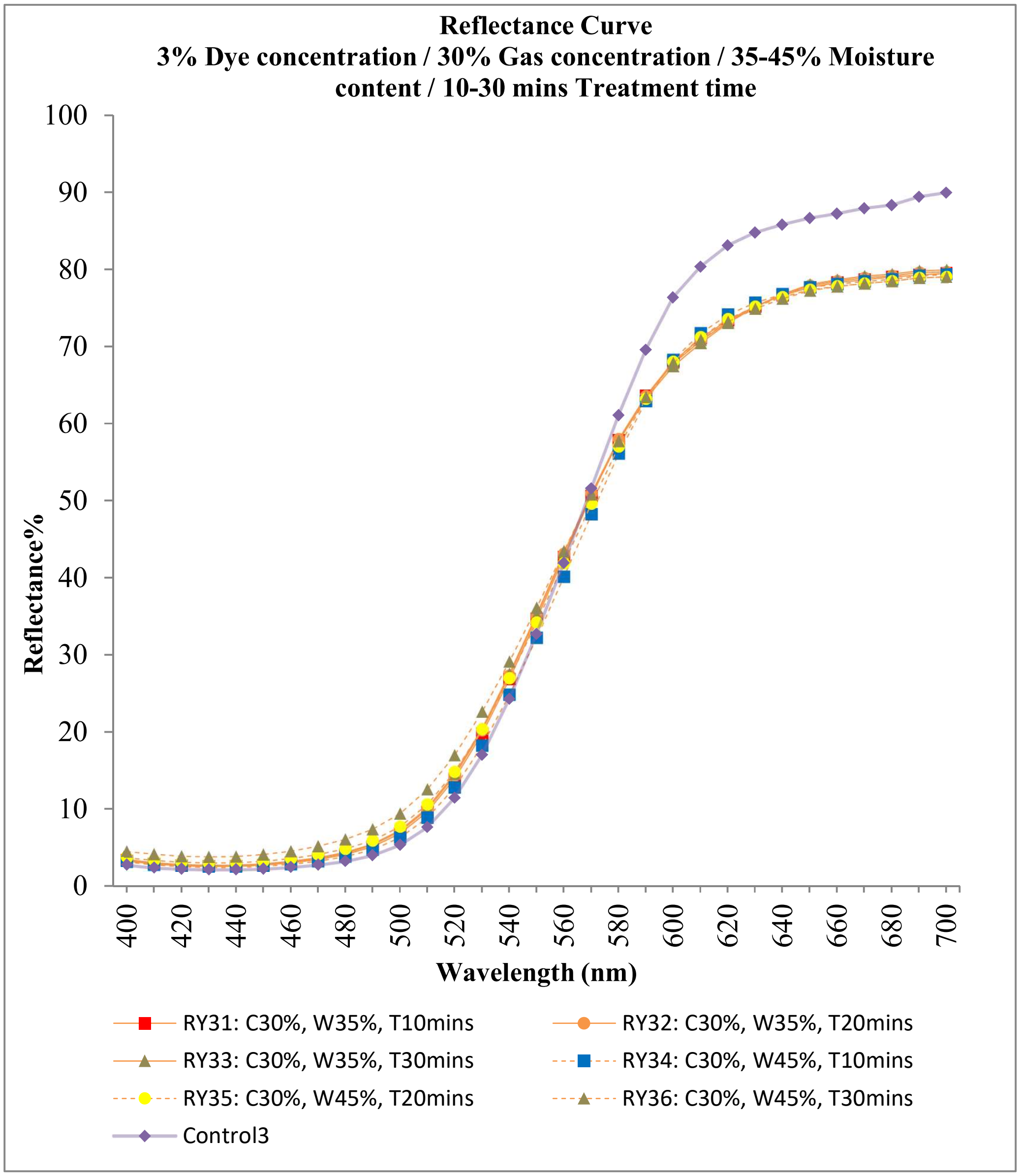


Figure 4.22. Reflectance curve of 3.0% dye concentration with 35% and 45% moisture content

Reflectance curves of specimens of dye concentration of 0.5%, 1.5% and 3% are shown in Figures 4.20, 4.21 and 4.22 respectively. When compared with the control specimens, all treated specimens would reflectance curves at higher position indicating that a paler shade is obtained after color fading process. However, the reflectance curves of specimens treated with 35% moisture content is located in a higher position than 45% moisture content. This may be due to the dilution effect at high moisture content and the hydroxyl radicals are diluted which in fact affecting their color fading power [41].

4.6.3. Treatment time

The impact of treatment time can be considered to have a direct relationship in affecting the reflectance value. The reflectance values increase with increase in treatment time because a longer treatment time may oxidize more dye particles in specimens resulting in paler shade. In fact, after 20 minutes, the color fading may not be further enhanced because equilibrium may reach and hydroxyl radicals generated after the equilibrium point may not be utilized for color fading even prolonging the treatment time.

4.6.4. Gas concentration

For the discussion of effect of gas concentration on the reflectance value, moisture content 35%, treatment time 10, 20 and 30 minutes and gas concentration 30% and 50% are selected as the studied factors.

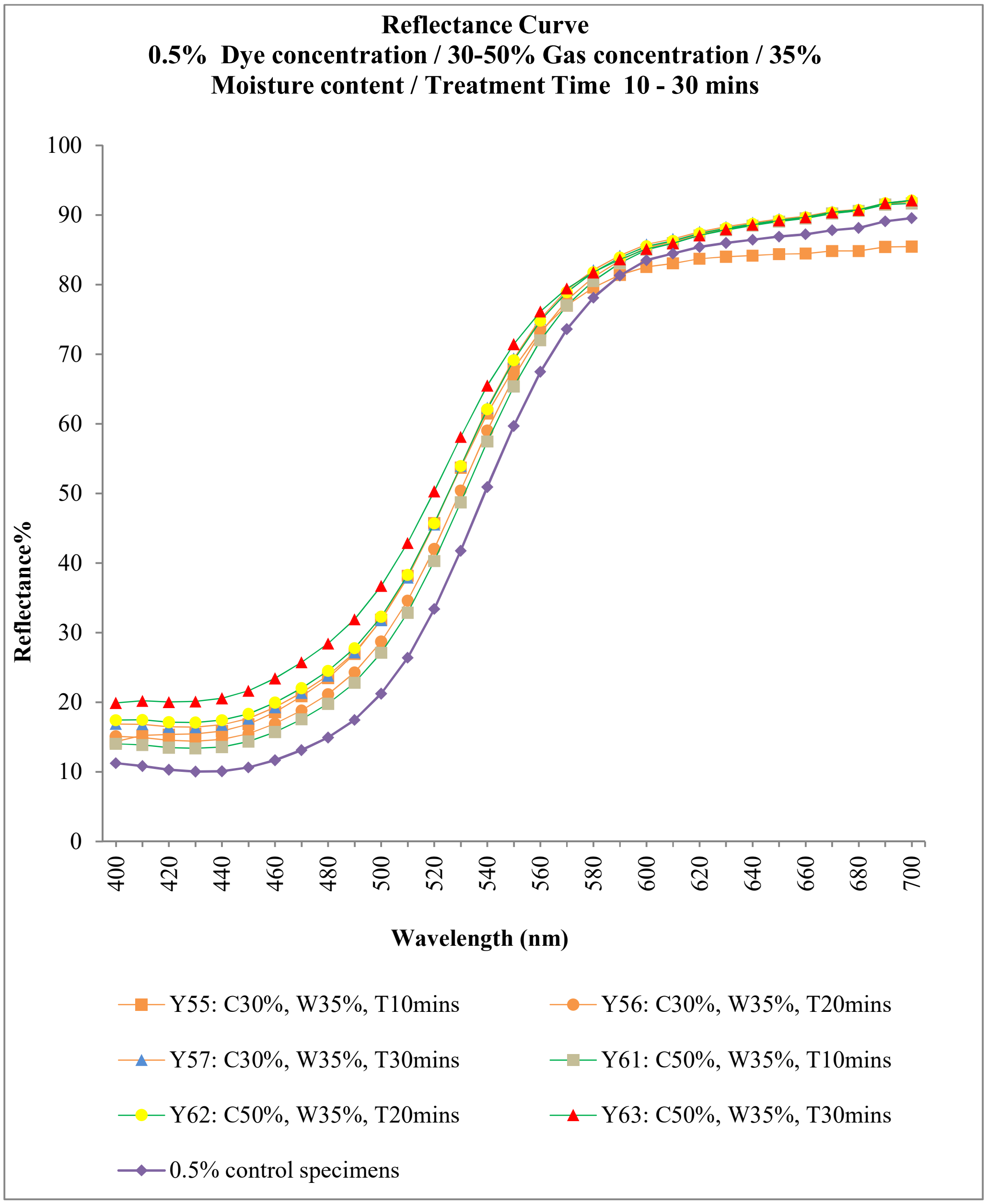


Figure 4.23. Reflectance curve of 0.5% dye concentration with 30 and 50% gas concentration

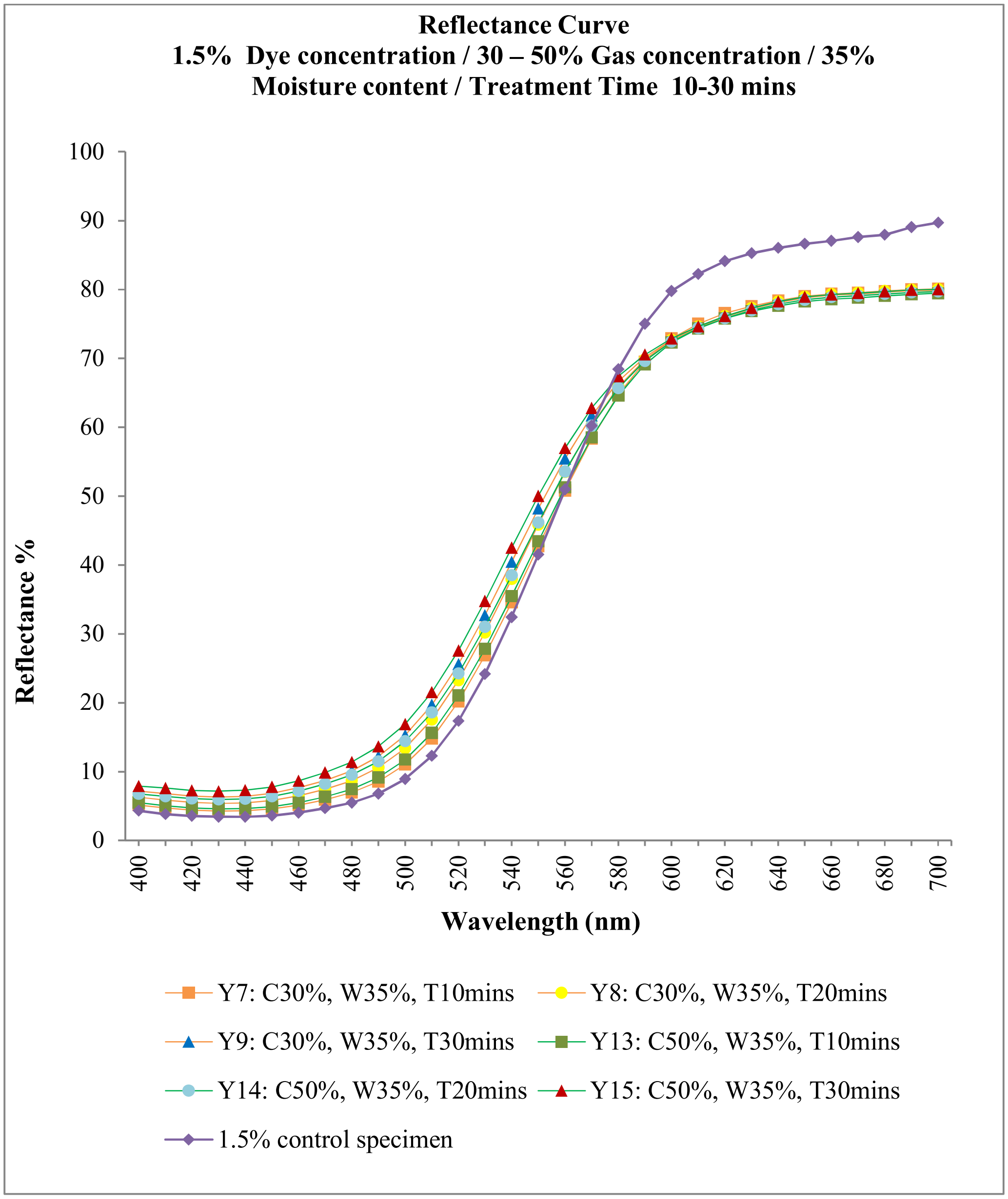


Figure 4.24. Reflectance curve of 1.5% dye concentration with 30 and 50% gas concentration

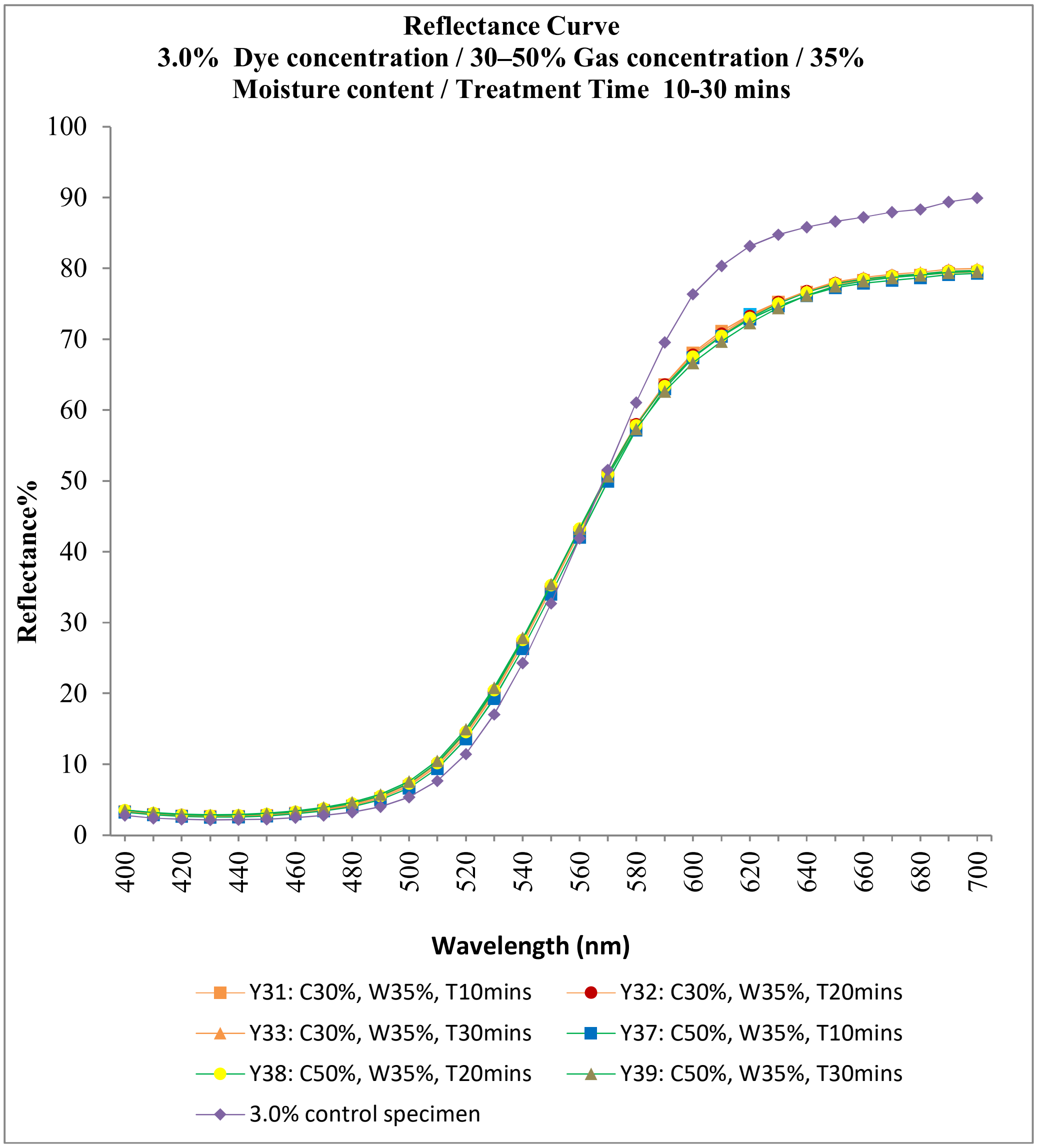


Figure 4.25. Reflectance curve of 3.0% dye concentration with 30 and 50% gas concentration

In case of gas concentration, the reflectance curves are similar between Figures 4.23, 4.24 and 4.25 indicating the gas concentration will not introduce any chromaticity change in the final color. However, the effect of gas concentration in 1.5% and 3% dye concentration is small but the gas concentration effect in 0.5% dye concentration is obvious. Since the hydroxyl radicals are the reactive species for color fading, for low dye concentration like 0.5%, small amount of dye particles is available in the specimens, thus the oxidation effect of the hydroxyl radicals and the dye particles are more obvious.

4.7. CIE LAB

The CIE L*, a* and b* values of different samples are shown in Tables 4.9, 4.10 and 4.11

Table 4.9. CIE L*, a* and b* values of specimens in dye concentration 0.5%

Sample	Dye concentration	Gas concentration	Moisture content	Treatment time	L*	a*	b*
Control	0.5	N/A	N/A	N/A	79.558	18.721	65.909
Y49	0.5	10	35	10	80.596	17.443	65.311
Y50	0.5	10	35	20	81.259	16.383	63.933
Y51	0.5	10	35	30	83.582	8.682	54.449
Y52	0.5	10	45	10	82.091	11.939	58.813
Y53	0.5	10	45	20	82.811	10.471	56.232
Y54	0.5	10	45	30	83.858	8.577	53.789
Y55	0.5	30	35	10	82.893	10.047	56.053
Y56	0.5	30	35	20	82.602	13.778	58.758
Y57	0.5	30	35	30	83.723	11.808	55.956
Y58	0.5	30	45	10	81.299	16.669	62.706
Y59	0.5	30	45	20	82.585	14.364	58.278
Y60	0.5	30	45	30	84.069	11.309	53.652
Y61	0.5	50	35	10	82.022	14.784	60.390
Y62	0.5	50	35	20	83.697	11.763	54.651
Y63	0.5	50	35	30	84.790	9.243	50.280
Y64	0.5	50	45	10	81.848	15.352	60.124
Y65	0.5	50	45	20	83.643	11.949	53.696
Y66	0.5	50	45	30	84.863	9.419	47.955
Y67	0.5	70	35	10	82.027	14.766	59.833
Y68	0.5	70	35	20	85.338	5.705	46.736
Y69	0.5	70	35	30	86.595	3.092	40.665

Y70	0.5	70	45	10	82.633	11.016	55.446
Y71	0.5	70	45	20	83.804	11.506	52.505
Y72	0.5	70	45	30	84.905	9.476	48.033

Table 4.10. CIE L*, a* and b* values of specimens in dye concentration 1.5%

Sample	Dye concentration	Gas concentration	Moisture content	Treatment time	L*	a*	b*
Control	1.5	N/A	N/A	N/A	72.185	32.267	81.732
Y1	1.5	10	35	10	70.627	28.905	77.680
Y2	1.5	10	35	20	71.336	27.268	75.918
Y3	1.5	10	35	30	71.847	26.134	74.654
Y4	1.5	10	45	10	70.533	29.107	77.213
Y5	1.5	10	45	20	70.838	28.410	76.111
Y6	1.5	10	45	30	71.421	26.983	74.596
Y7	1.5	30	35	10	71.571	26.744	75.230
Y8	1.5	30	35	20	72.864	23.680	71.606
Y9	1.5	30	35	30	73.830	21.528	68.929
Y10	1.5	30	45	10	70.892	27.891	75.352
Y11	1.5	30	45	20	71.737	25.817	71.515
Y12	1.5	30	45	30	72.983	23.165	67.939
Y13	1.5	50	35	10	71.772	25.620	73.854
Y14	1.5	50	35	20	73.068	22.878	69.354
Y15	1.5	50	35	30	74.637	19.915	66.812
Y16	1.5	50	45	10	71.174	27.093	74.288
Y17	1.5	50	45	20	71.561	24.417	69.415
Y18	1.5	50	45	30	72.855	21.887	65.341
Y19	1.5	70	35	10	71.596	26.669	75.088
Y20	1.5	70	35	20	73.784	22.030	69.537
Y21	1.5	70	35	30	75.446	18.654	64.074
Y22	1.5	70	45	10	71.572	25.847	71.724
Y23	1.5	70	45	20	73.432	22.143	65.506
Y24	1.5	70	45	30	74.737	19.790	60.263

Table 4.11. CIE L*, a* and b* value of specimens in dye concentration 3.0%

Sample	Dye concentration	Gas concentration	Moisture content	Treatment time	L*	a*	b*
Control	3	N/A	N/A	N/A	68.182	38.950	85.258
Y25	3	10	35	10	66.848	34.232	80.773
Y26	3	10	35	20	67.454	32.739	80.054
Y27	3	10	35	30	67.193	32.867	79.587
Y28	3	10	45	10	66.224	35.719	80.880
Y29	3	10	45	20	66.583	34.093	79.326
Y30	3	10	45	30	67.110	32.906	77.950
Y31	3	30	35	10	67.424	32.236	79.250
Y32	3	30	35	20	67.596	31.730	78.818
Y33	3	30	35	30	67.621	31.430	78.367
Y34	3	30	45	10	66.516	34.267	79.037
Y35	3	30	45	20	67.437	31.826	75.995
Y36	3	30	45	30	68.356	29.501	72.342
Y37	3	50	35	10	67.001	32.543	79.403
Y38	3	50	35	20	67.608	31.419	78.393
Y39	3	50	35	30	67.542	30.806	77.536
Y40	3	50	45	10	66.859	33.651	78.079
Y41	3	50	45	20	68.402	29.767	72.592
Y42	3	50	45	30	69.831	26.230	67.721
Y43	3	70	35	10	67.663	31.151	78.324
Y44	3	70	35	20	68.426	29.559	76.828
Y45	3	70	35	30	68.103	29.228	76.159
Y46	3	70	45	10	70.211	34.246	80.421
Y47	3	70	45	20	71.545	30.293	74.338
Y48	3	70	45	30	72.948	26.939	69.25

4.8. CIE L*

CIE L* describes the lightness of specimens which is in the range from pure black to pure white. CIE L* can help to understand the change in lightness of color faded specimens and the results of different specimens are shown in Figure 4.26 to Figure 4.31.

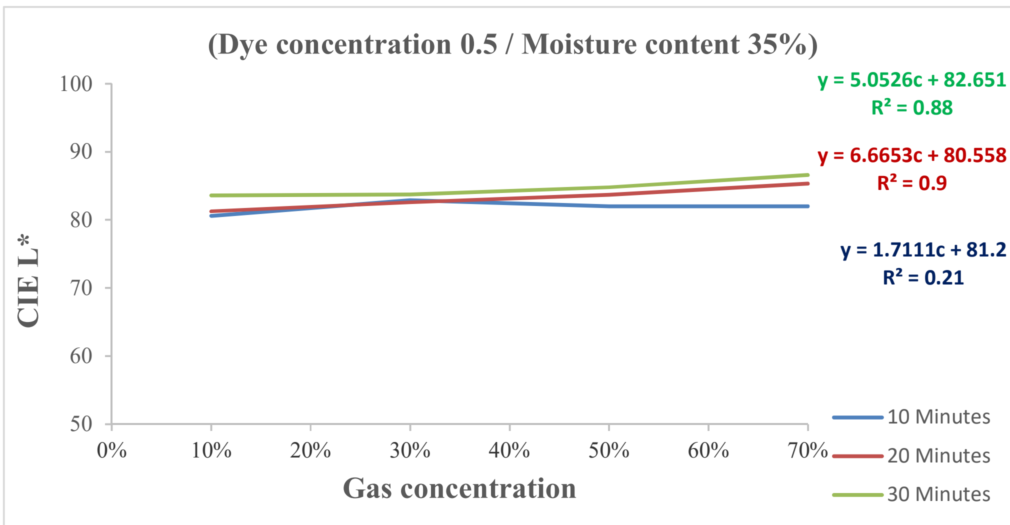


Figure 4.26. Relationship between CIE L* and gas concentration (0.5% dye concentration and 35% moisture content)

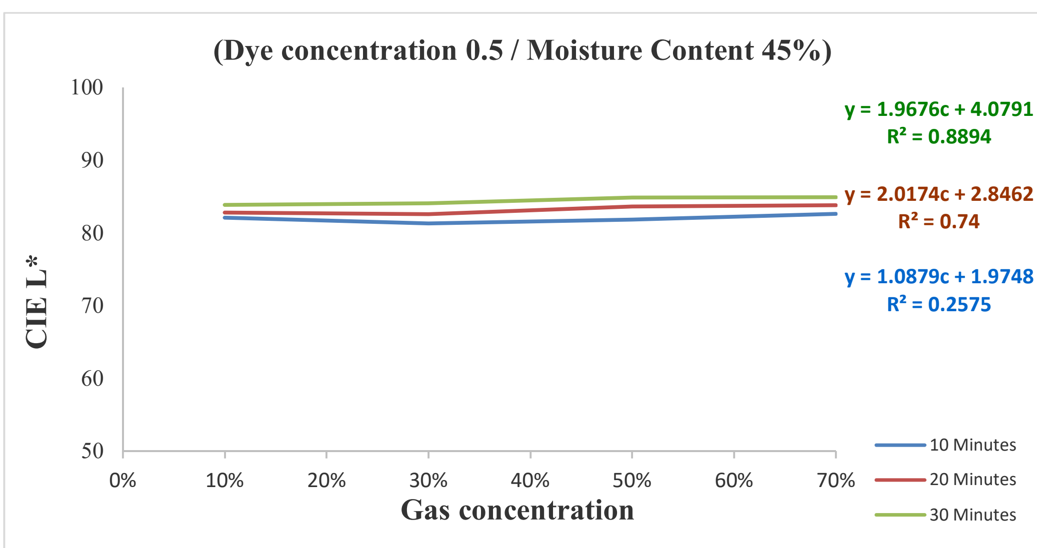


Figure 4.27. Relationship between CIE L* and gas concentration (0.5% dye concentration and 45% moisture content)

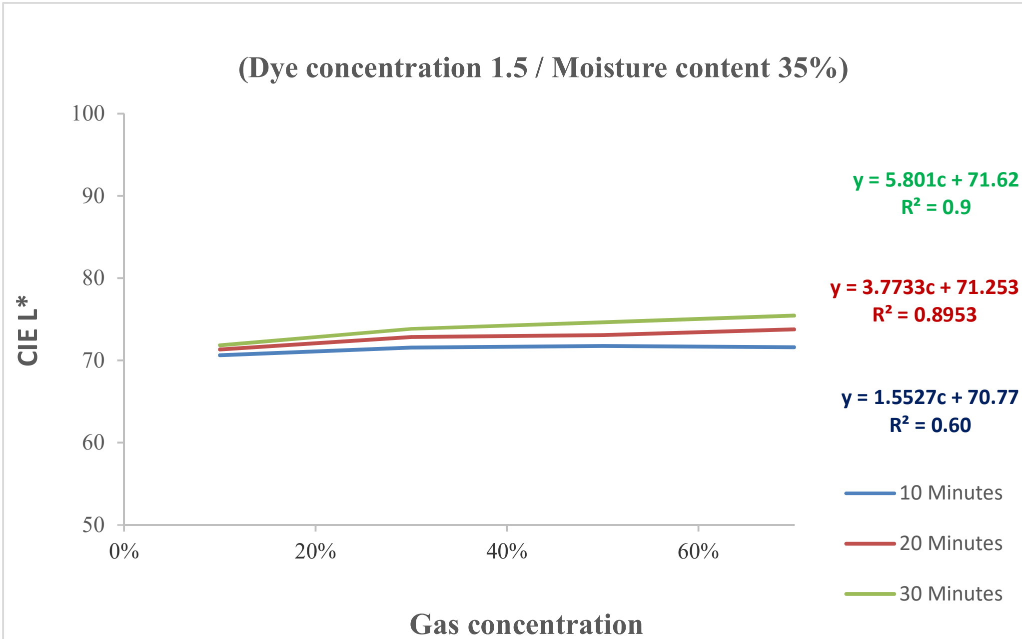


Figure 4.28. Relationship between CIE L* and gas concentration (1.5% dye concentration and 35% moisture content)

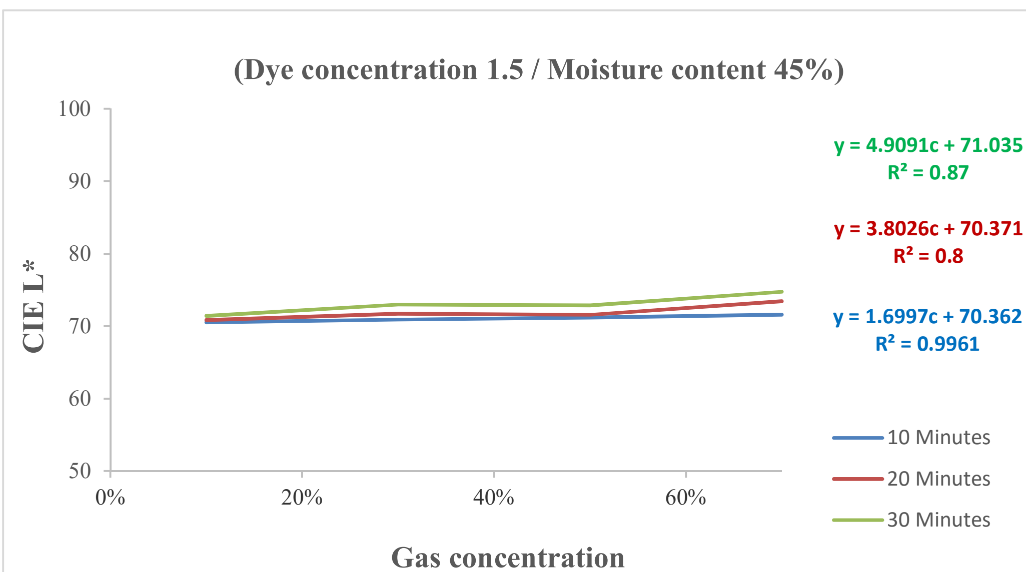


Figure 4.29. Relationship between CIE L* and gas concentration (1.5% dye concentration and 45% moisture content)

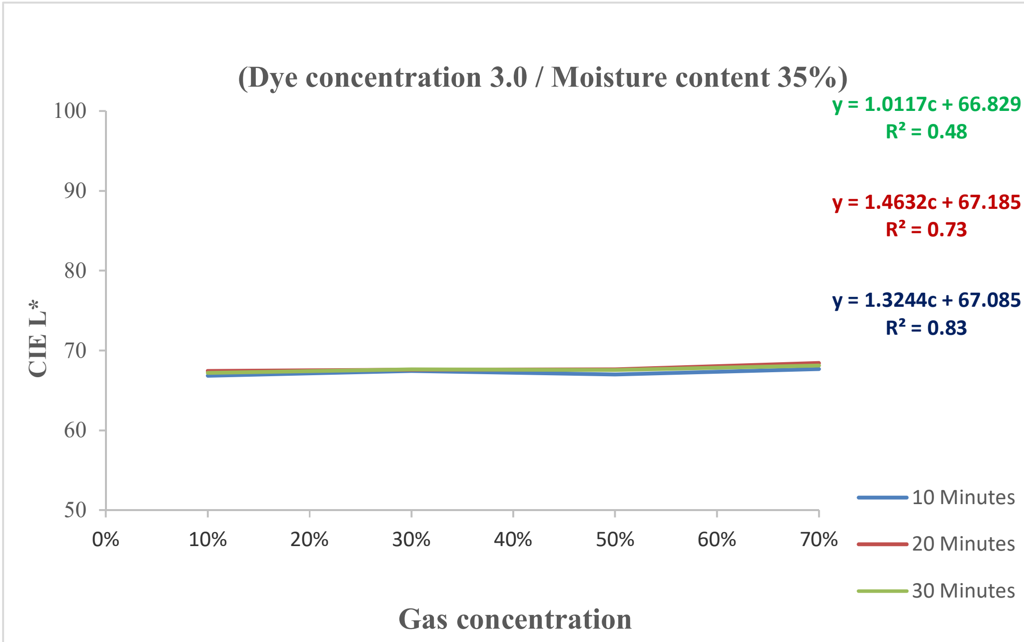


Figure 4.30. Relationship between CIE L* and gas concentration (3.0% dye concentration and 35% moisture content)

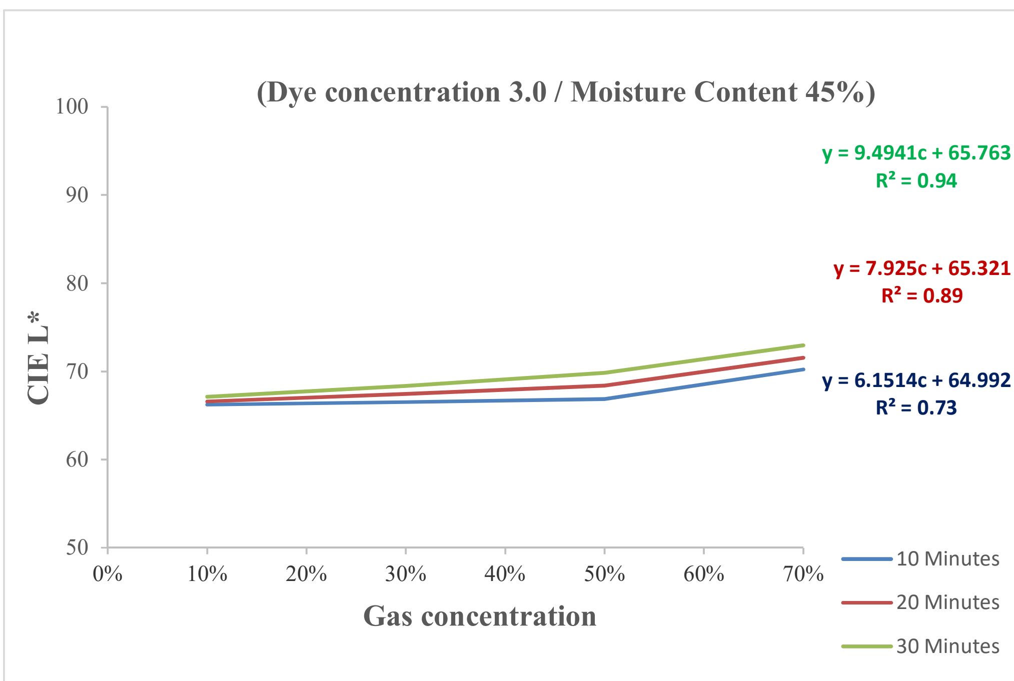


Figure 4.31. Relationship between CIE L* and gas concentration (3.0% dye concentration and 45% moisture content)

4.8.1. Dye concentration

With the view of the 3 different dye concentrations (Figure 4.13 to Figure 4.18), it is found that the CIE L* value increases while the decrease of dye concentration, i.e. the 0.5% dye concentration has the highest CIE L* values. The results are obvious because the dark shade (3.0%) would have the lowest CIE L* value while the light shade (0.5%) would have the highest L* value. Upon the influence during the ozone plasma treatment, the light shade will become palest when compared with other depths.

4.8.2. Moisture content

Based on the CIE L* results, the influence of moisture content is not significant. However, most cases from Tables 4.8 to 4.10 indicate that the 35% of the moisture content has achieved smaller CIE L* values when compared with 45% of the moisture content. This may be due to the dilution effect of the hydroxyl radicals lowering the color fading effect [42].

4.8.3. Treatment time

Generally speaking, from Figure 4.26 to Figure 4.31, the increase in the treatment time will further enhance the color fading effect as indicated by the increased CIE L* value. However, the difference between 20 minutes and 30 minutes is small which implies that the equilibrium stage may reach it and a further color fading process may not be a significant process as from 10 minutes to 20 minutes.

4.8.4. Gas concentration

In all the dye concentrations, the CIE L* values increase when gas concentration increases. This can be explained due to the increased gas concentration that would allow the generation of more hydroxyl radicals for fading the color of the specimens.

4.8.5. Regression modelling

4.8.5.1. Linear regression of CIE L*

The linear regressions of the CIE L* values with different processing parameters are shown in Table 4.12 and the coefficient of the determination (R^2) values of the relationships are varied. Thus, based on the linear regression, it is difficult to determine the relationship between the CIE L* value to different the processing parameters. Thus, multiple linear regression will be used for studying the relationship between the CIE L* values and different processing parameters.

Table 4.12. Linear regression of CIE L* values

Dye concentration (%)	**Moisture content (%)**	**Treatment time (min)**	**Linear regression of CIE L* with gas concentration (C) change**	**R^2**
0.5	35	10	CIE L*10 = 1.7111c + 81.2	0.216
		20	CIE L*20 = 6.6653c + 80.558	0.994
		30	CIE L*30 = 1.7111c + 81.2	0.216
0.5	45	10	CIE L*10 = 1.9676c + 4.0791	0.889
		20	CIE L*20 = 2.0174c + 2.8462	0.747
		30	CIE L*30 = 1.9676c + 4.0791	0.889
1.5	35	10	CIE L*10 = 1.5527c + 70.77	0.601
		20	CIE L*20 = 3.7733c + 71.253	0.895
		30	CIE L*30 = 5.801c + 71.62	0.942
1.5	45	10	CIE L*10 = 1.6997c + 70.362	0.996
		20	CIE L*20 = 3.8026c + 70.371	0.800
		30	CIE L*30 = 4.9091c + 71.035	0.872
3	35	10	CIE L*10 = 1.3244c + 67.085	0.833
		20	CIE L*20 = 1.4632c + 67.185	0.731
		30	CIE L*30 = 1.0117c + 66.829	0.484
3	45	10	CIE L*10 = 6.1514c + 64.992	0.732
		20	CIE L*20 = 7.925c + 65.321	0.892
		30	CIE L*30 = 9.4941c + 65.763	0.949

4.8.5.2. **Multiple linear regression for CIE L***

Table 4.13 shows the t-test result of the multiple linear regression of CIE L* with different processing parameters. Table 4.14 shows the significance of the effect of different processing parameters on the relationship with CIE L*.

Table 4.13. Model Summary multiple linear regression of CIE L*.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.930[a]	.865	.857	2.4953300

a. Predictors: (Constant), Treatment time, Moisture content, Gas concentration, Dye concentration

Table 4.14. Coefficients[a] of multiple linear regression of CIE L*

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	80.467	2.578		31.217	.000
	Dye concentration	-5.831	.286	-.913	-20.371	.000
	Gas concentration	.037	.013	.128	2.848	.006
	Moisture content	.006	.059	.005	.103	.918
	Treatment time	.102	.036	.127	2.832	.006

a. Dependent Variable: CIE L*

Based on Table 4.13, the dye concentration, the gas concentration, the moisture content and the treatment time can influence an 86.5% of the CIE L* values in this study. While Table 4.14 shows the p-values of the t-tests for each regression coefficients 0.000, 0.006, 0.918 and 0.006 respectively.

In dye the concentration aspects, P value < 0.05, represents a significant linear relationship with L* at a significant level of 0.05.

In gas the concentration aspect, P value < 0.05, represents a significant linear relationship with CIE L* at a significant level of 0.05.

In the moisture content aspect, P value > 0.05, represents no significant linear relationship with CIE L* at a significant level of 0.05.

In the treatment time aspect, P value < 0.05, represents a significant linear relationship with CIE L* at a significant level of 0.05.

Based on the analysis result, a regression equation can be generated as follows:

CIE L* = 80.467 + dye concentration (-5.831) + gas concentration (0.37) + moisture content (0.006) + treatment time (0.102).   Equation 4.3

4.8.5.3. **Verification of equation for CIE L***

In order to verify the Equation 4.3, five sets of parameters are selected for analysis and the results are shown in Table. 4.15. It is noted that the predicted and measured values are with an average difference of less than 5%. This indicates that CIE L* values in the color fading process can be predicted by the Equation 4.3 under the condition with the input of processing parameters.

Table 4.15. Verification for CIE L*

Parameters	Measured value	Predicted value	Difference(%)
0.5C / 50G / 45M / 10T	81.85	80.69	1.41%
0.5C / 70G / 35M / 10T	82.03	81.37	0.80%
3.0C / 10G / 35M / 30T	67.19	66.61	0.86%
3.0C / 10G / 45M / 30T	67.11	66.67	0.65%
3.0C / 70G / 35M / 20T	68.43	67.81	0.89%

Parameter interpretation

“C” represents the dye concentration

“G” represents the gas concentration

“M” represents the moisture content

“T” represents the treatment time

4.9. CIE a*

CIE a* value that indicates the redness and greenness of a color. Figure 4.32 to Figure 4.37 are the analysis of specimens under different color fading conditions.

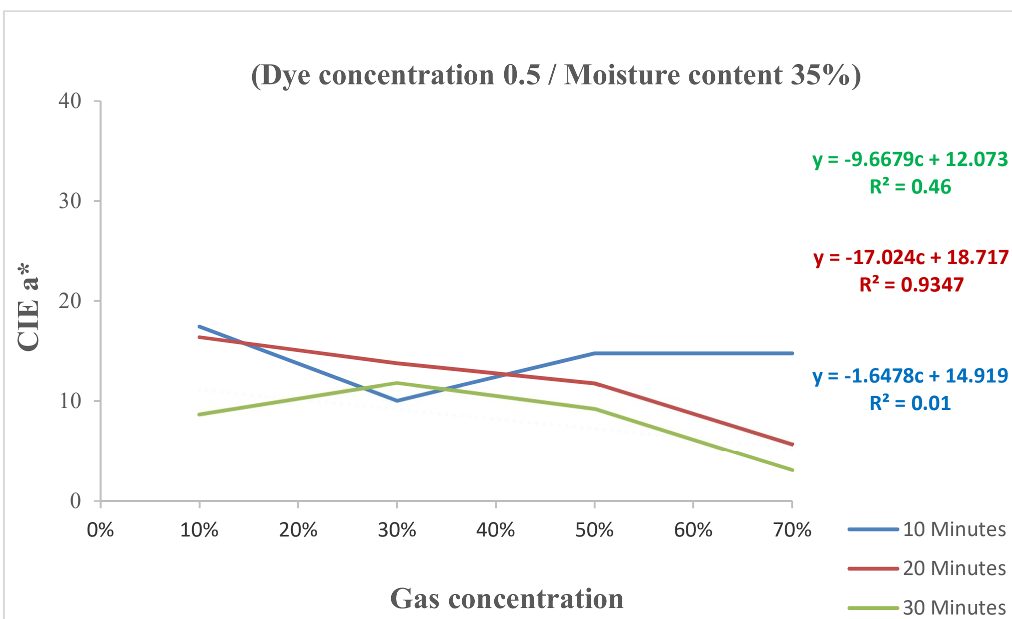


Figure 4.32. The relationship between CIE a* and gas concentration (0.5% dye concentration and 35% moisture content)

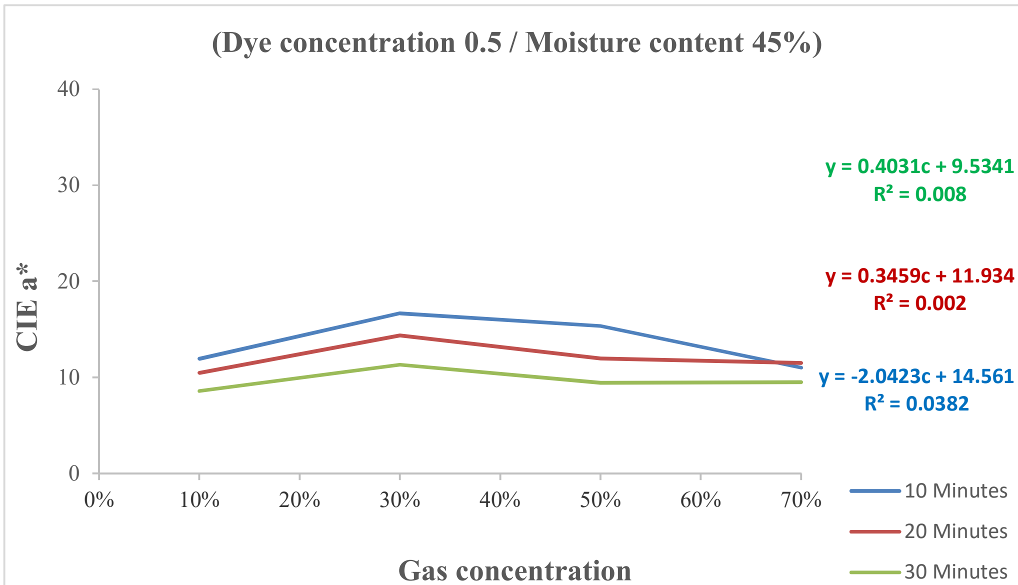


Figure 4.33. The relationship between CIE a* and gas concentration (0.5% dye concentration and 45% moisture content)

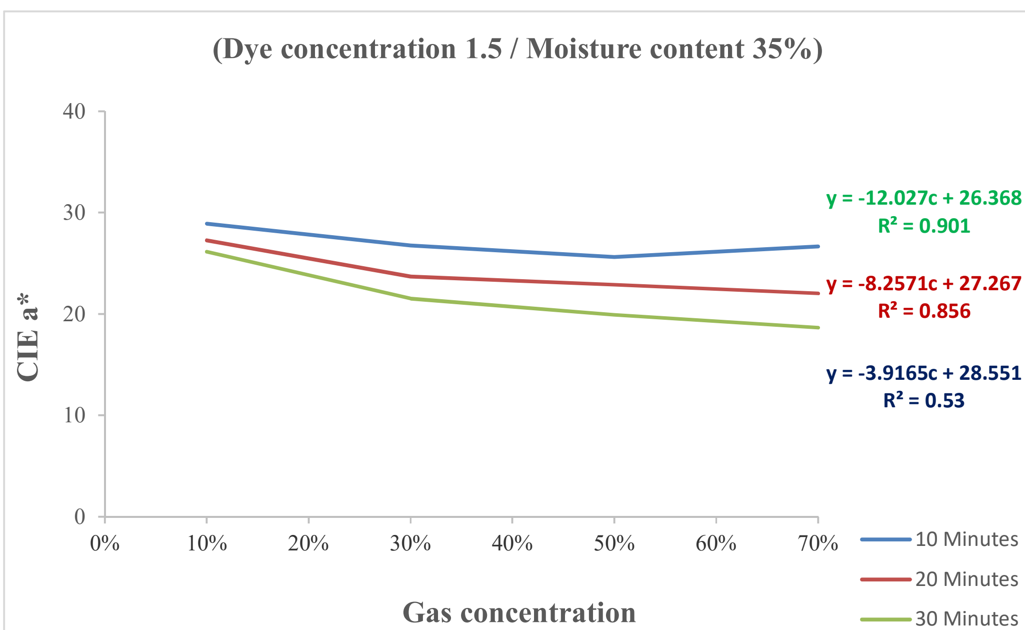


Figure 4.34. The relationship between CIE a* and gas concentration (1.5% dye concentration and 35% moisture content)

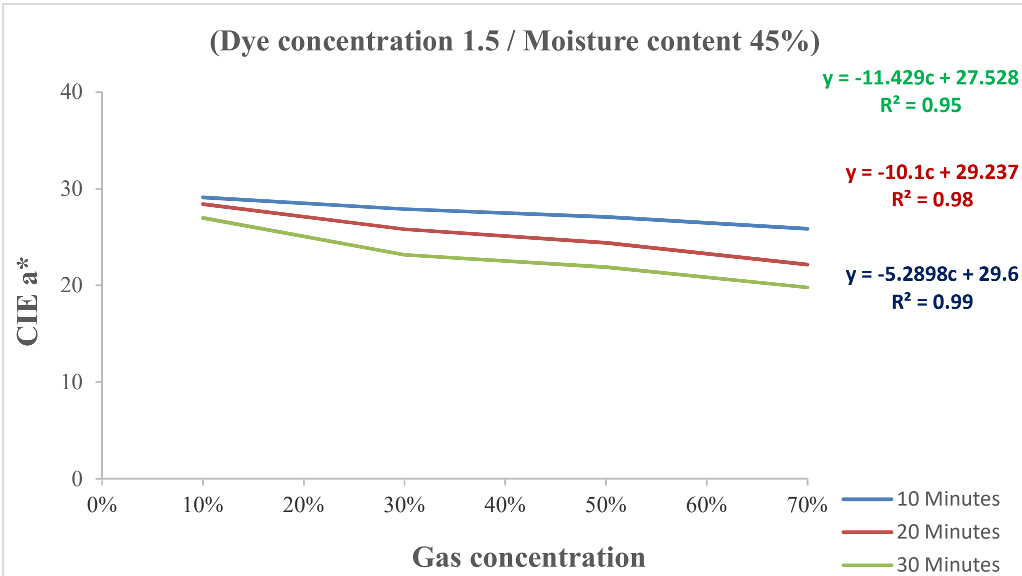


Figure 4.35. The relationship between CIE a* and gas concentration (1.5% dye concentration and 45% moisture content)

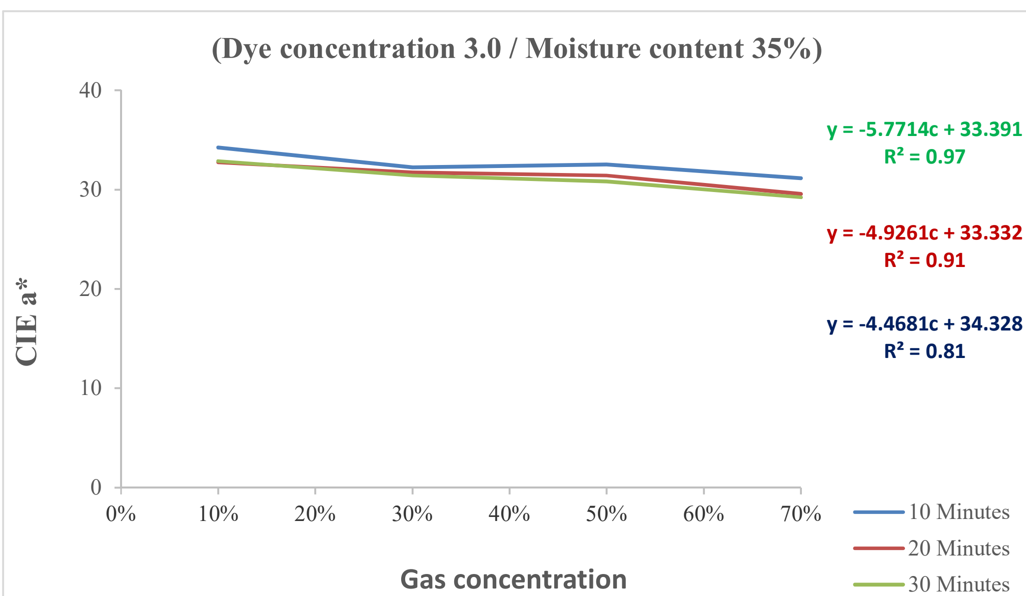


Figure 4.36. The relationship between CIE a* and gas concentration (3.0% dye concentration and 35% moisture content)

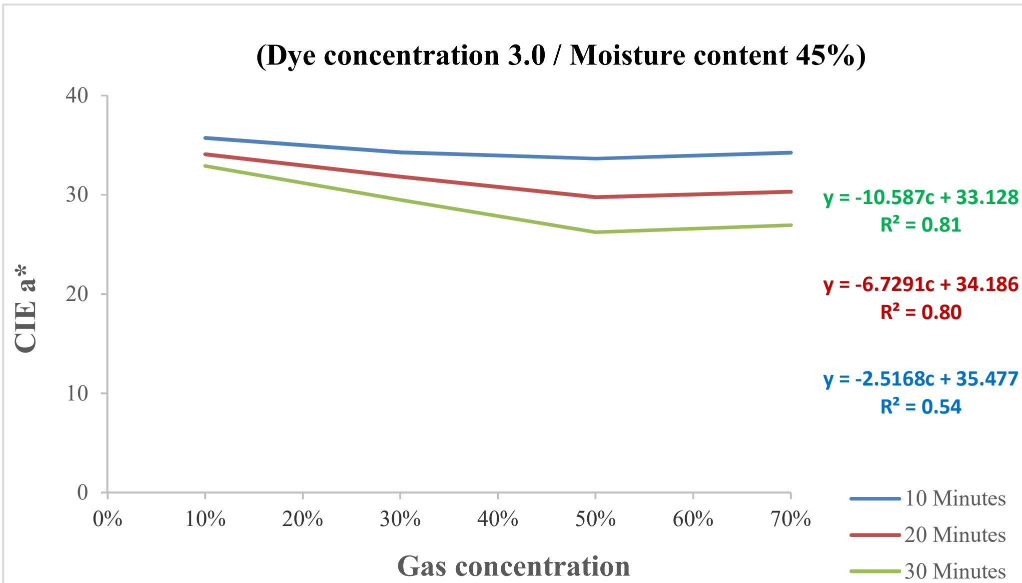


Figure 4.37. The relationship between CIE a* and gas concentration (3.0% dye concentration and 45% moisture content)

4.9.1. Dye Concentration

From Figure 4.32 to Figure 4.37, it is found that the increase treatment time and gas concentration leads to decrease on CIE a* value. Since CIE a* value is referring to tone from redness to greenness, a longer plasma treatment time can provide the conditions to generate more hydroxyl radicals for the oxidation process. A high dye concentration indicates more dye particles in the fabric. With the increase in the treatment time and the gas concentration, more dyes particles on specimens would be faded out and thus relatively, less yellow reactive dyes particle would be available in the fabric leading to a greenish effect.

4.9.2. Moisture content

Based on the CIE a* results in Figure. 4.32. to Figure 4.37, Other than 0.5% dye concentration, which is comparatively fluctuated, CIE a* values of dye concentration of 1.5% and 3.0% decrease orderly but there is no significant difference between two moisture contents.

4.9.3. Treatment time

When the treatment time increases, the CIE a* value decreases. This can be explained by extending the treatment time and therefore it would enable to have more opportunities for the hydroxyl radicals to react with the dye particles in the fabric. Since more dye particles are oxidized on specimens, the redness element would be eliminated resulting in greenish effects. However, in view of a 3% of dye concentration in a 35% of moisture content, when the treatment time increases from 20 to 30 minutes, the color fading effect slows down. This could be explained because when the equilibrium is reached, further treatment time will not bring up and color fading effect.

4.9.4. Gas concentration

When the gas concentration increases, the CIE a* values are generally decreased. With higher gas concentration, more hydroxyl radicals are produced and there are more opportunities to interact with the dye particles in the fabric. Thus, the yellow dyes are removed and leads to a greenish effect [42]. Observing a dye concentration of 3% with a 35% of moisture content, when the treatment time changes from 20 to 30 minutes, no significant change is found in CIE a* values. This is because the equilibrium stage may reached and no further color fading effect goes beyond 20 minutes.

4.9.5. Regression modelling

4.9.5.1. Linear regression of CIE a*

The different linear relationships between CIE a* and the processing parameters are shown in Table 4.16 but the significance of determination (R^2) is varied. Therefore, the linear regression cannot be used for predicting the relationship between the CIE a* value and the processing parameters. Thus, multiple linear regression would be used for determining the relationship between the CIE a* value and the processing parameters.

Table 4.16. Linear regression of CIE a* values

Dye concentration (%)	**Moisture content (%)**	**Treatment time (min)**	**Linear regression of CIE a* with gas concentration (C) change**	**R^2**
0.5	35	10	CIE a*10 = -1.6478c + 14.919	0.019
		20	CIE a*20 = -17.024c + 18.717	0.935
		30	CIE a*30 = -9.6679c + 12.073	0.462
0.5	45	10	CIE a*10 = -2.0423c + 14.561	0.038
		20	CIE a*20 = 0.3459c + 11.934	0.003
		30	CIE a*30 = -2.0423c + 14.561	0.038
1.5	35	10	CIE a*10 = -3.9165c + 28.551	0.537
		20	CIE a*20 = -8.2571c + 27.267	0.857
		30	CIE a*30 = -12.027c + 26.368	0.902
1.5	45	10	CIE a*10 = -5.2898c + 29.6	0.993
		20	CIE a*20 = -10.1c + 29.237	0.988
		30	CIE a*30 = -11.429c + 27.528	0.953
3	35	10	CIE a*10 = -4.4681c + 34.328	0.817
		20	CIE a*20 = -4.9261c + 33.332	0.918
		30	CIE a*30 = -5.7714c + 33.391	0.976
3	45	10	CIE a*10 = -2.5168c + 35.477	0.546
		20	CIE a*20 = -6.7291c + 34.186	0.802
		30	CIE a*30 = -2.5168c + 35.477	0.546

4.9.5.2. **Multiple linear regression for CIE a***

Table 4.17 shows the t-test result of multiple linear regression of CIE a* with different processing parameters. Table 4.18 shows the significance of the effect of different processing parameters on the relationship with CIE a*.

Table 4.17. Model Summary of multiple linear regression for CIE a*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.943[a]	.889	.882	3.0356348

a. Predictors: (Constant), Treatment time, Moisture content, Gas concentration, Dye concentration

Table 4.18. Coefficients of multiple linear regression for CIE a*

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	15.017	3.136		4.789	.000
Dye concentration	7.732	.348	.904	22.204	.000
Gas concentration	-.064	.016	-.164	-4.016	.000
Moisture content	.046	.072	.026	.644	.522
Treatment time	-.226	.044	-.210	-5.153	.000

a. Dependent Variable: CIE a*

Based on Table 4.17, the dye concentration, the gas concentration, the moisture content and the treatment time can influence a 88.9% of the CIE a* values in this study. While Table 4.18 shows the p-values of the t-tests for each regression coefficients are 0.000, 0.000, 0.552 and 0.000 respectively.

In the dye concentration aspects, P value < 0.05, represents a significant linear relationship with CIE a* at a significant level of 0.05.

In the gas concentration aspect, P value < 0.05, represents a significant linear relationship with CIE a* at a significant level of 0.05.

In the moisture content aspect, P value > 0.05, represents no significant linear relationship with CIE a* at a significant level of 0.05.

In the treatment time aspect, P value < 0.05, represents a significant linear relationship with CIE a* at a significant level of 0.05.

Based on the analysis result, a regression equation can be generated as follows:

CIE a* = 15.017 + dye concentration (7.732) + gas concentration (-0.64) + moisture content (0.46) + treatment time (-0.226). Equation 4.4

4.9.5.3. **Verification of equation for CIE a***

Five sets of processing parameters are selected for verifying the Equation 4.4 and the results are shown in Table 4.19. In Table 4.19, the difference between the measured and predicted values of CIE a* is less than 10% which indicates that the Equation 4.4 is validated for predicting the CIE a* values in the color fading process in this study under the condition that processing parameters are input.

Table 4.19. Verification of CIE a*

Parameters	Measured value	Predicted value	Difference %
0.5C / 30G / 35M / 30T	11.8075	11.793	0.12%
0.5C / 70G / 35M / 10T	14.77	13.75	6.86%
1.5C / 30G / 35M / 20T	23.68	21.79	8.00%
3.0C / 10G / 45M / 10T	32.91	32.863	0.13%
3.0C / 30G / 35M / 30T	31.43	31.12	0.98%

Parameter interpretation

“C” represents the dye concentration

“G” represents the gas concentration

“M” represents the moisture content

“T” represents the treatment time

4.10. CIE b*

CIE b* value explicit data for blueness or yellowness, the results of CIE b* values for different specimens treated with different parameters are shown in Figure 4.38 to Figure 4.43.

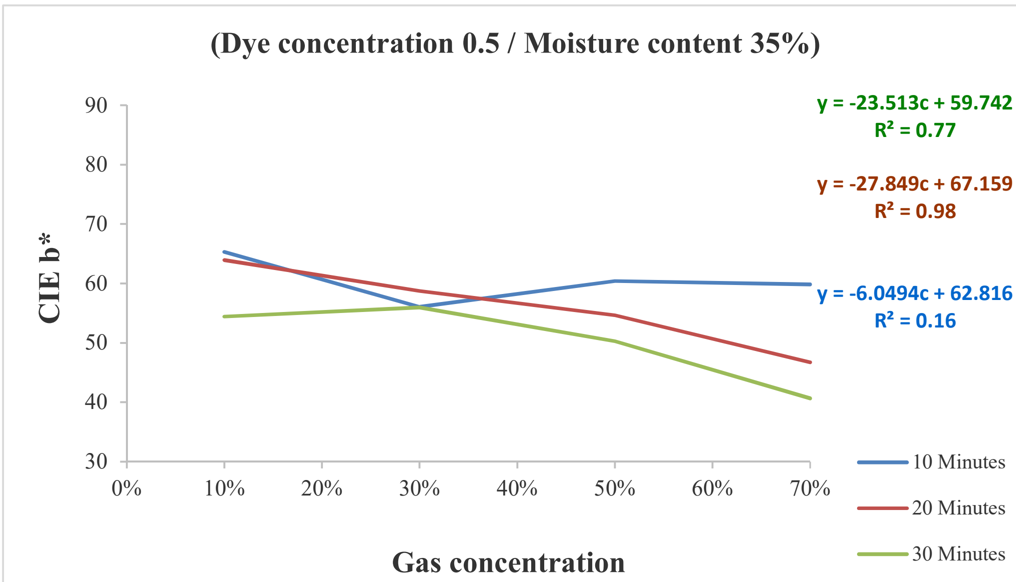


Figure 4.38. The relationship between CIE b* and gas concentration (0.5% dye concentration and 35% moisture content)

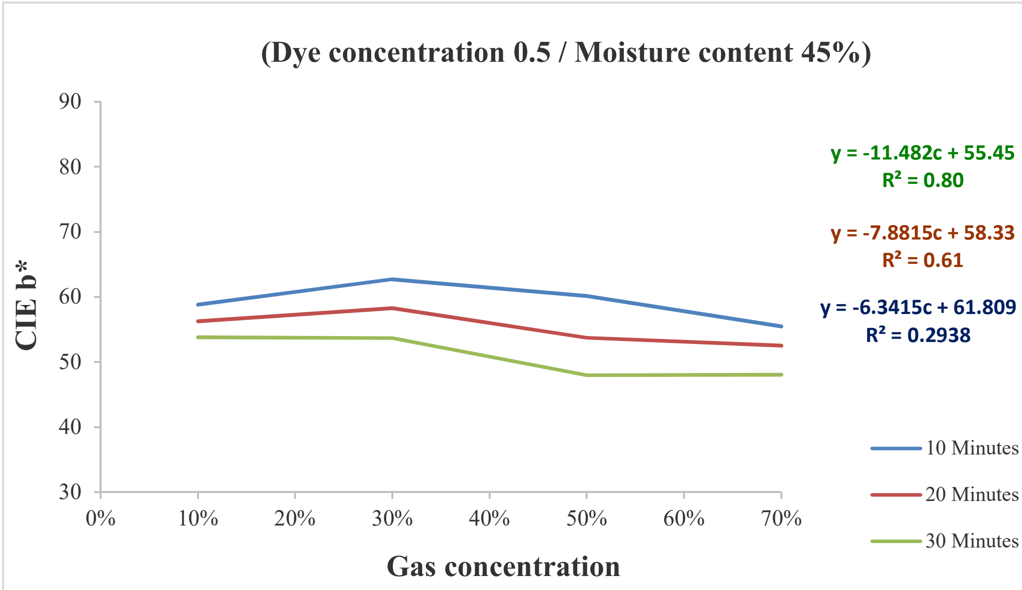


Figure 4.39. The relationship between CIE b* and gas concentration (0.5% dye concentration and 45% moisture content)

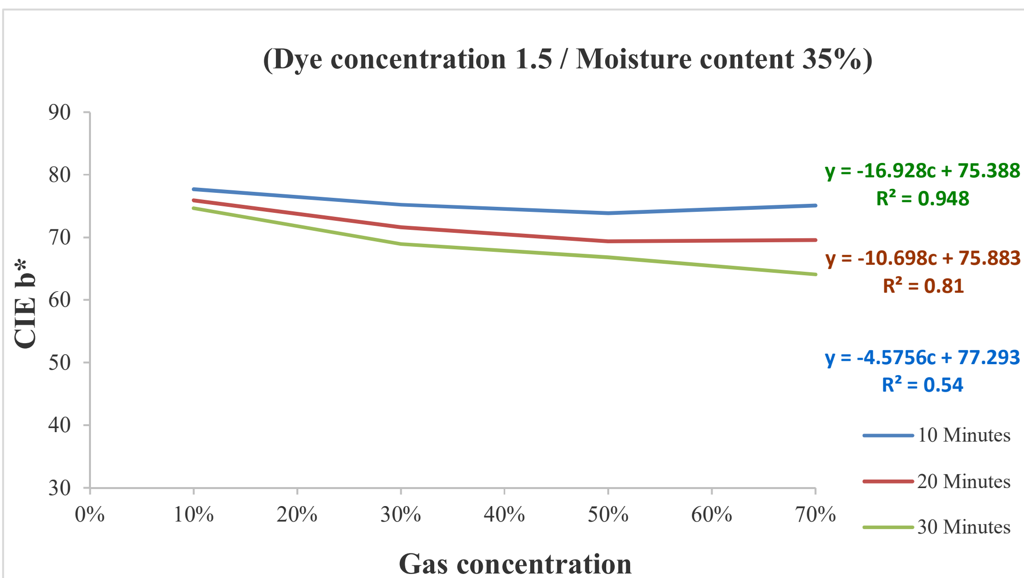


Figure 4.40. The relationship between CIE b* and gas concentration (1.5% dye concentration and 35% moisture content)

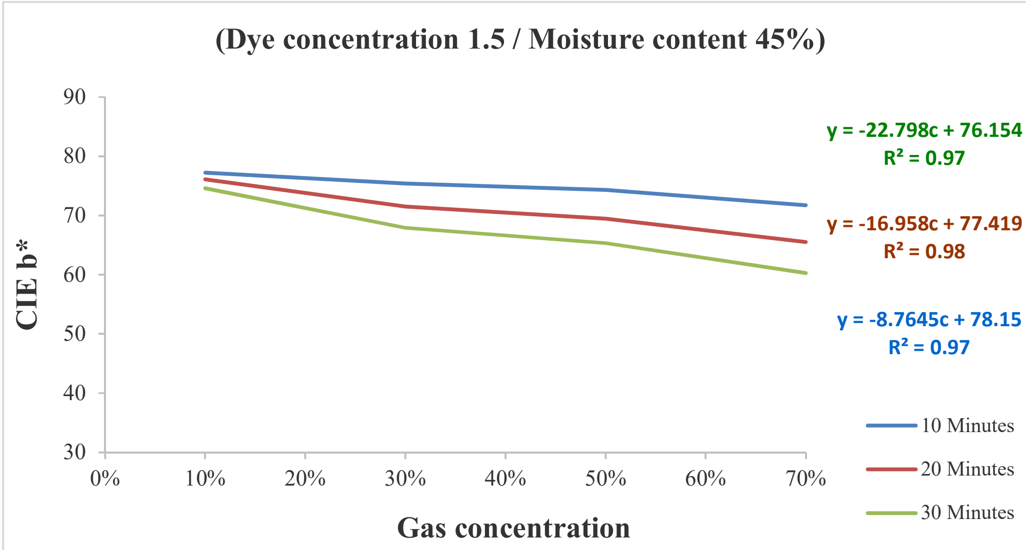


Figure 4.41. The relationship between CIE b* and gas concentration (1.5% dye concentration and 45% moisture content)

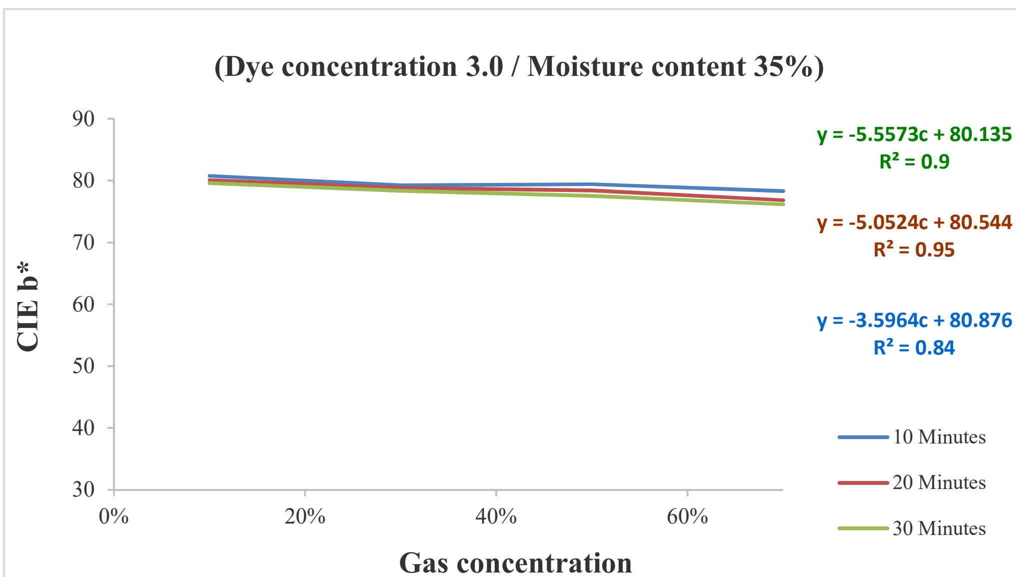


Figure 4.42. The relationship between CIE b* and gas concentration (3.0% dye concentration and 35% moisture content)

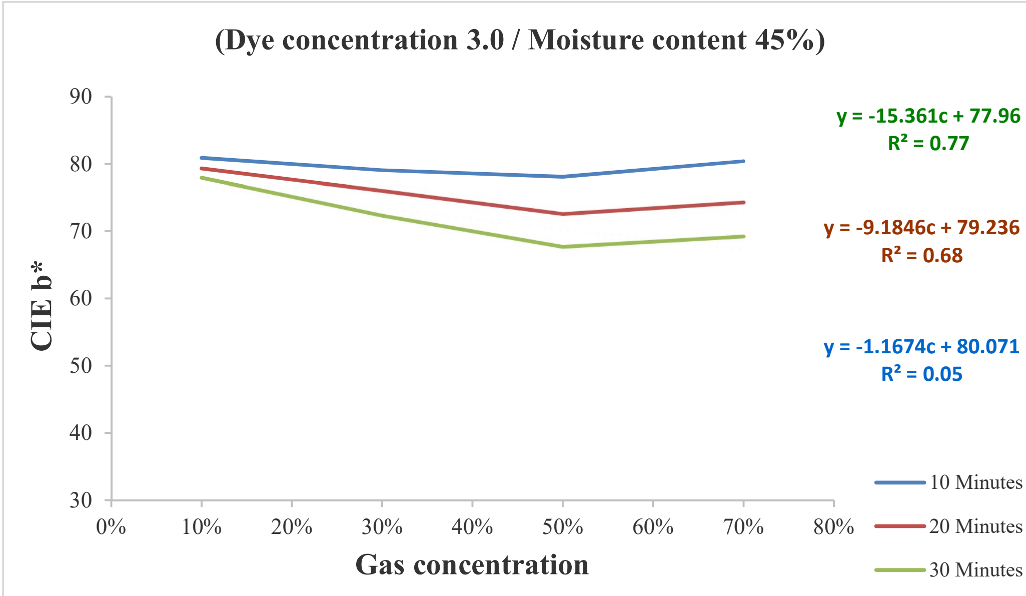


Figure 4.43. The relationship between CIE b* and gas concentration (3.0% dye concentration and 45% moisture content)

4.10.1. Dye concentration

Based on Figure 4.38 to Figure 4.43, the CIE b* value is generally increasing with increased dye concentration. The increase treatment time and gas concentration leads to reduction of the CIE b* value and the specimen color turned to a bluish color. With the increase in the treatment time and the gas concentration, it may produce more hydroxyl radicals that have an oxidation effect on the specimens which will in fact reduce the yellow color in the specimens leading to a bluish tone.

4.10.2. Moisture content

Based on the results of Figure 4.38 to Figure 4.43, it is found that the CIE b* values decreases when the moisture content increased from a 35% to a 45%. Meanwhile, specimens color become bluer and less yellowish as well. However, the situation is reversed when the dye concentration is of 0.5% this may be due to the yellowing effect induced by the plasma and therefore the CIE b* value is increased [42].

4.10.3. Treatment time

When the treatment time increases, the CIE b* values decrease on each dye concentration. This effect can be explained by the fact that a longer treatment time will give hydroxyl radicals more time to oxidize the yellow reactive dyes in the specimens. When more dyes particles are oxidized, less yellow light would be reflected and more bluish effect of the specimens is resulted and the CIE b* values decrease accordingly. However, in Figure 4.42, when the treatment time is changed from 20 and 30 minutes for the 3% of a dye concentration specimen with a moisture content of 35%, there is no change in the CIE b* values. This can be explained because the oxidation (color fading) has already reached the equilibrium stage at treatment time of 20 minutes. A longer treatment time will not further enhance the oxidation of the reactive dyes.

4.10.4. Gas concentration

The CIE b* values of the specimen decrease when the gas concentration is increased for each dye concentration and moisture content. This can be explained because a higher gas concentration would produce more hydroxyl radicals to react with the reactive dyes in the specimens. Since more yellow dyes were oxidized, less yellow light would be reflected and more bluish effect may be produced and this is the reason of the reduction of the CIE b* values. However, in the case of 3% of the dye concentration and 35% of the moisture content, the increase of treatment time from 20 to 30 minutes would not have a significant change in the CIE b* values. This may be due to the reach of the equilibrium stage and the excess hydroxyl radicals and the treatment time would not have further color fading effect on the specimens.

4.10.5. Regression modelling

4.10.5.1. Linear regression of CIE b*

The different linear relationships between CIE b* and the processing parameters is shown in Table 4.20 but the significance of the coefficient of determination (R^2) is varied although some have very good R^2 value. Therefore, the linear regression cannot be used for predicting the relationship between CIE b* value and the processing parameters. Thus, multiple linear regression would be used for determining the relationship between CIE b* value and the processing parameters.

Table 4.20. Linear regression of CIE b* values

Dye concentration (%)	Moisture content (%)	Treatment time (min)	Linear regression of CIE b* with gas concentration (C) change	R^2
0.5	35	10	CIE b*10 = -6.0494c + 62.816	0.169
		20	CIE b*20 = -27.849c + 67.159	0.981
		30	CIE b*30 = -23.513c + 59.742	0.779
0.5	45	10	CIE b*10 = -6.3415c + 61.809	0.294
		20	CIE b*20 = -7.8815c + 58.33	0.619
		30	CIE b*30 = -11.482c + 55.45	0.804
1.5	35	10	CIE b*10 = -4.5756c + 77.293	0.544
		20	CIE b*20 = -10.698c + 75.883	0.819
		30	CIE b*30 = -16.928c + 75.388	0.948
1.5	45	10	CIE b*10 = -8.7645c + 78.15	0.975
		20	CIE b*20 = -16.958c + 77.419	0.982
		30	CIE b*30 = -22.798c + 76.154	0.974
3	35	10	CIE b*10 = -3.5964c + 80.876	0.846
		20	CIE b*20 = -5.0524c + 80.544	0.959
		30	CIE b*30 = -5.5573c + 80.135	0.992
3	45	10	CIE b*10 = -1.1674c + 80.071	0.055
		20	CIE b*20 = -9.1846c + 79.236	0.684
		30	CIE b*30 = -15.361c + 77.96	0.770

4.10.5.2. **Multiple linear regression for CIE b***

Table 4.21 shows the t-test result of the multiple linear regression of CIE b* with different processing parameters. Table 4.22 shows the significance of the effect of the different processing parameters on the relationship with CIE b*.

Table 4.21. Model Summary of multiple linear regression of CIE b*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.912[a]	.832	.822	4.3812269

a. Predictors: (Constant), Treatment time, Moisture content, Gas concentration, Dye concentration

Table 4.22. Coefficients[a] of multiple linear regression of CIE b*

Model		Unstandardized Coefficients		Standardized Coefficients	t	
		B	Std. Error	Beta		
1	(Constant)	71.704	4.526		15.843	.000
	Dye concentration	8.337	.503	.830	16.589	.000
	Gas concentration	-.113	.023	-.245	-4.902	.000
	Moisture content	-.152	.103	-.074	-1.475	.145
	Treatment time	-.352	.063	-.279	-5.567	.000

a. Dependent Variable: CIE b*

Based on Table 4.16, the dye concentration, the gas concentration, the moisture content and the treatment time can influence a 83.2% CIE b* values in this study. While Table 4.17 shows the p-values of the t-tests for each regression coefficients are tested for each regression coefficients and they are 0.000, 0.000, 0.145 and 0.000 respectively.

In the dye concentration aspects, P value < 0.05, represents a significant linear relationship with b* at a significant level of 0.05.

In the gas concentration aspect, P value < 0.05, represents a significant linear relationship with b* at a significant level of 0.05.

In the moisture content aspect, P value > 0.05, represents no significant linear relationship with b* at a significant level of 0.05.

In the treatment time aspect, P value < 0.05, represents a significant linear relationship with b* at a significant level of 0.05.

Based on the analysis result, a regression equation can be generated as follows:

CIE b* = 71.704 + dye concentration (8.337) + gas concentration (-0.113) + moisture content (-0.152) + treatment time (-0.352). Equation 4.5.

4.10.5.3. **Verification of equation for CIE b***

In order to verify the Equation 4.5, five sets of parameters are chosen for analysis and the results are shown in Table. 4.18. It is noted that the predicted and measured values are with an average difference less than 5%. This indicates that CIE b* values in the color fading process can be predicted by the Equation 4.5 under the condition with the input of the processing parameters.

Table 4.23. Verification for CIE b*

Parameters	Measured value	Predicted value	Difference %
0.5C / 70G / 35M / 10T	59.83	59.12	1.19%
1.5C / 50G / 35M / 20T	69.35	66.20	4.55%
1.5C / 70G / 45M / 30T	60.26	58.90	2.26%
3.0C / 30G / 35M / 30T	78.37	77.45	1.18%
3.0C / 70G / 45M / 10T	80.42	78.45	2.46%

Parameter interpretation

“C” represents the dye concentration

“G” represents the gas concentration

“M” represents the moisture content

“T” represents the treatment time

4.11. CIE ΔE

In the CIE LAB system, ΔE is used for explaining the color space distance between color of the CIE L*, a* and b*. It is used to represent the total color difference and the establishment of the quantitative color tolerance. The results of ΔE for the different specimens treated with different parameters are in Figure 4.44 to Figure.4.49.

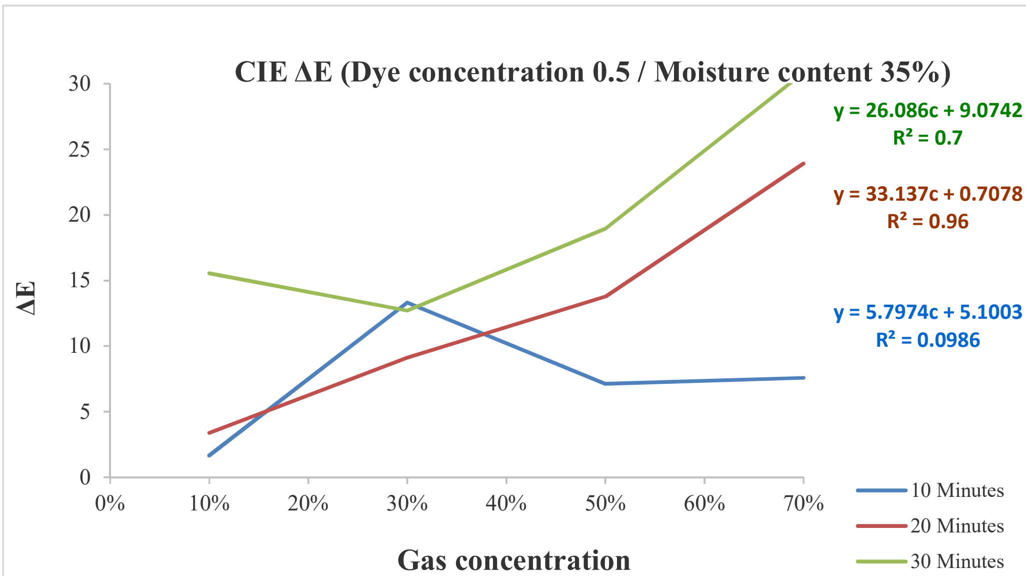


Figure 4.44. The relationship between ΔE and gas concentration (0.5% dye concentration and 35% moisture content)

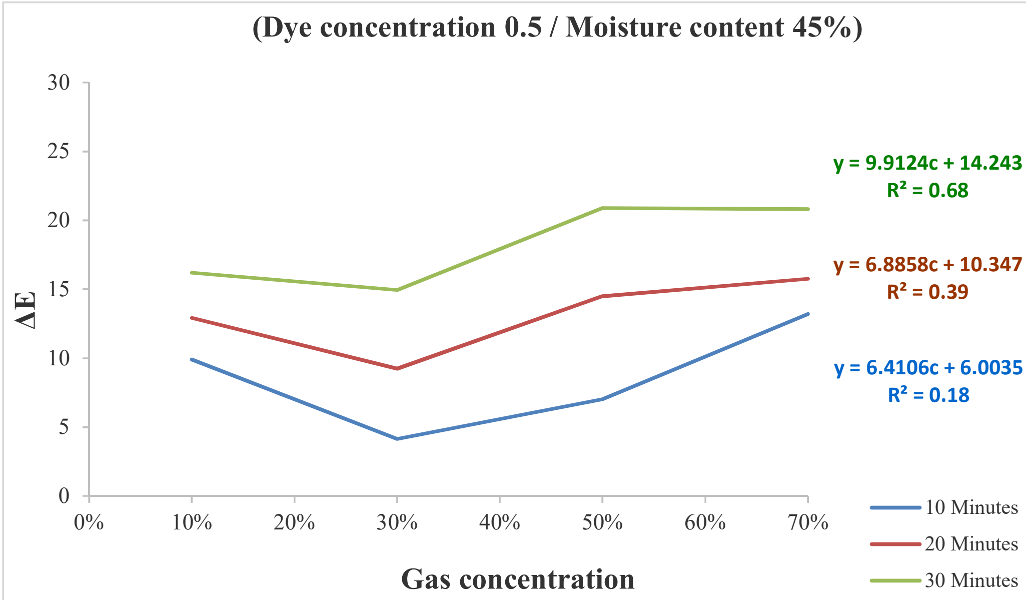


Figure 4.45. The relationship between ΔE and gas concentration (0.5% dye concentration and 45% moisture content)

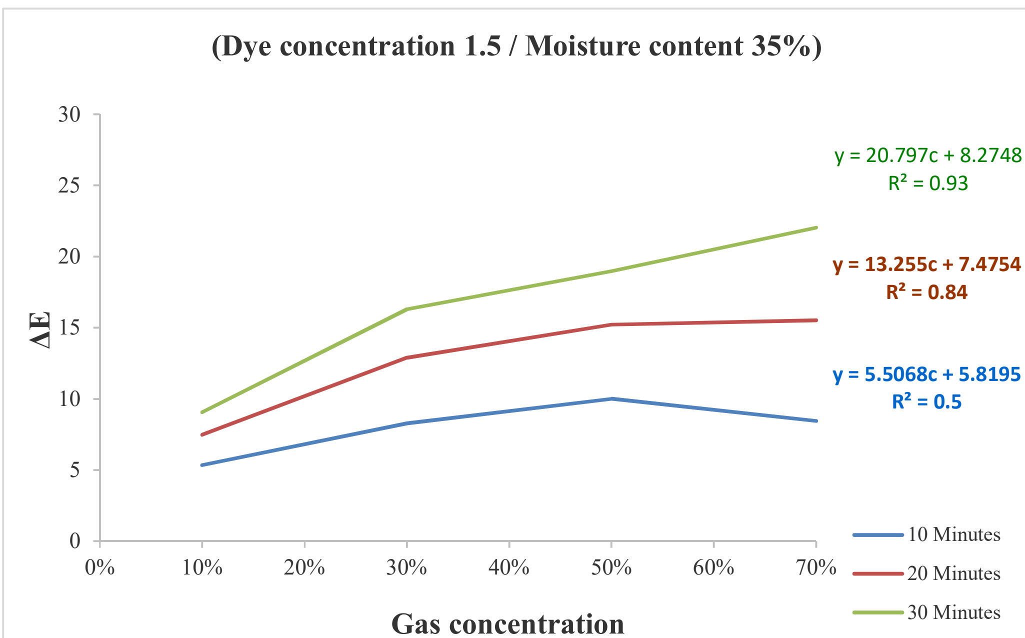


Figure 4.46. The relationship between ΔE and gas concentration (1.5% dye concentration and 35% moisture content)

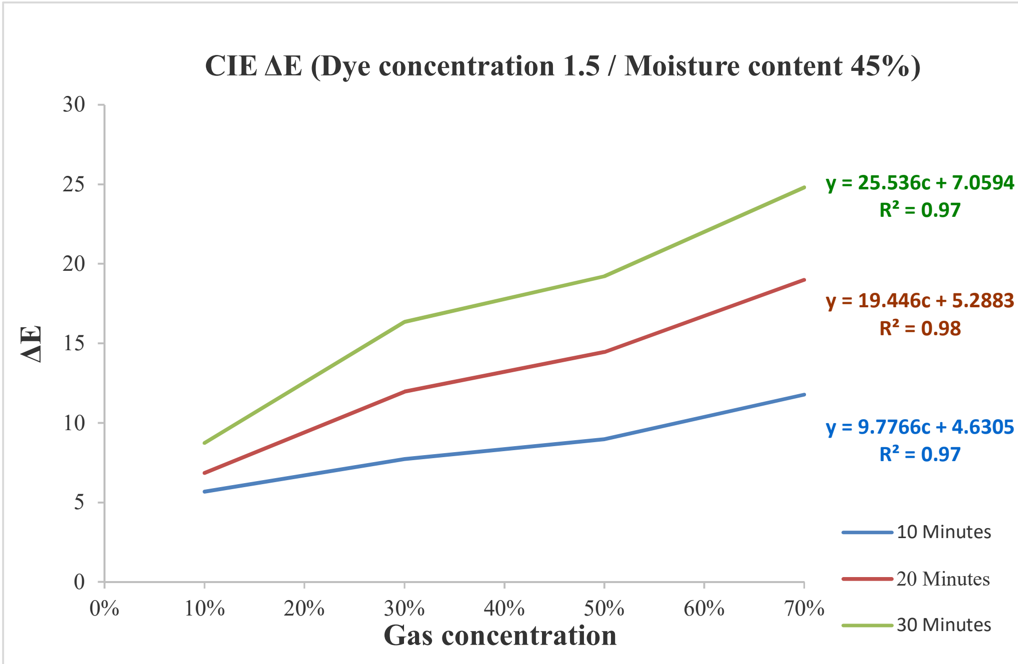


Figure 4.47. The relationship between ΔE and gas concentration (1.5% dye concentration and 45% moisture content)

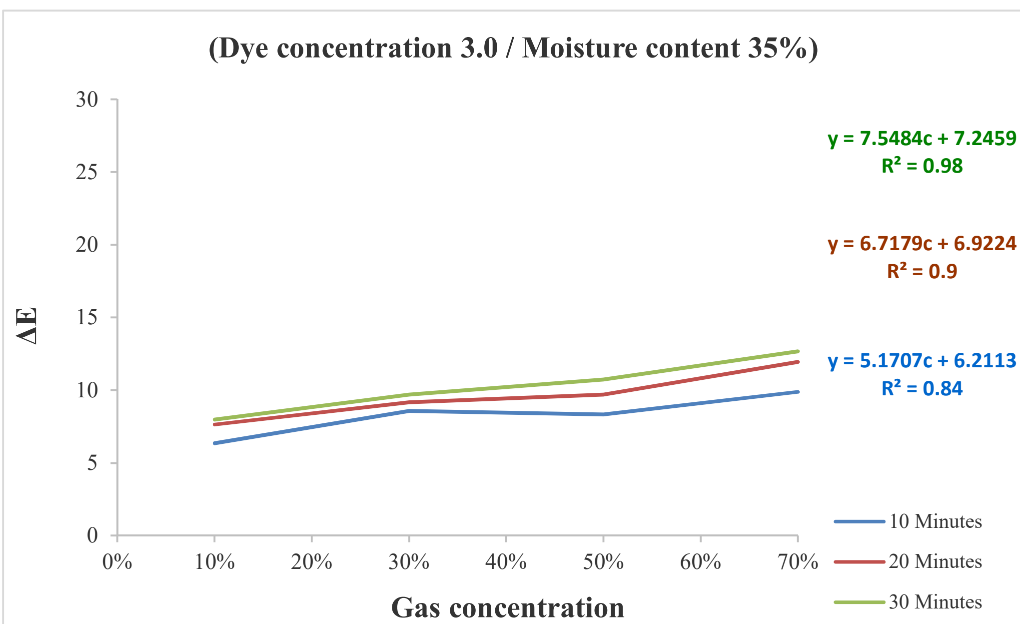


Figure 4.48. The relationship between ΔE and gas concentration (3.0% dye concentration and 35% moisture content)

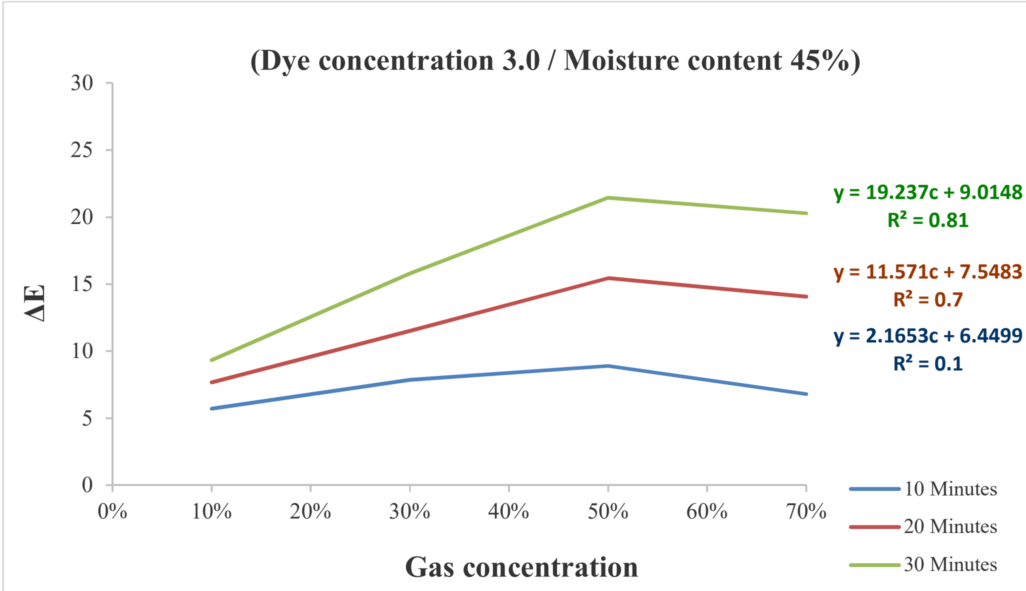


Figure 4.49. The relationship between ΔE and gas concentration (3.0% dye concentration and 45% moisture content)

4.11.1. Dye concentration

By studying Figure 4.43 to Figure 4.49, it is found that the ΔE increases when dye the concentration increase. This can be explained because a higher dye concentration has more dyes in the specimen and it makes a higher color yield on the specimen and the color in dark shade. By ΔE attribute which is used for measuring the color space distance between the color of CIE L*, a* and b*, the dye concentration range increases and the distance of different color in CIE L*, a* and b* are also expanded.

4.11.2. Moisture content

From Figures 4.43 to Figure 4.49, it is found that when the moisture content increases from a 35% to a 45% in the case of the dye concentration a 1.5% and a 3%, of the ΔE value increases. This can be explained due to the fact that the moisture content plays an important role in the color fading in medium to dark shades. In fact, the ΔE increases much in the moisture content of 45%.

4.11.3. Treatment time

The ΔE value increases when the treatment time increases. This can be explained because a longer treatment time can allow the hydroxyl radicals to oxidize the reactive dye particles in the specimens. As more dyes are oxidized, the ΔE value increases accordingly. However, there is not so much change for the treatment time of 20 and 30 minutes in 3% depth and water content of 35%. This can be explained because the oxidation of the reactive dye may reach the equilibrium at a treatment time of 20 minutes. Therefore, the hydroxyl radical provides a limited efficiency on the oxidation of the reactive dyes particles.

4.11.4. Gas concentration

It is found that the ΔE value increases when other factors rose up. This is explained due to the higher gas concentration which can enhance the generation of more hydroxyl radicals. More hydroxyl radicals may in turn oxidize more dye particles. Therefore, the ΔE values are increased.

4.11.5. Regression modelling

4.11.5.1. Linear regression of ΔE

Table 4.17 summarizes the linear regression of the relationship between ΔE and the different processing parameters. The coefficient of the determination (R^2) value is varied which means that the ΔE value cannot be simply determined by the linear regression model. Thus, the multiple linear regression would be used for determining the relationship between ΔE and the different processing parameters.

Table.4.24. Linear regression of ΔE

Dye concentration (%)	Moisture content (%)	Treatment time (min)	Linear regression of CIE ΔE with gas concentration (C) change	R^2
0.5	35	10	$\Delta E_{10} = 5.80C + 5.10$	0.098
		20	$\Delta E_{20} = 33.13C - 0.71$	0.969
		30	$\Delta E_{30} = 26.09C + 9.07$	0.713
0.5	45	10	$\Delta E_{10} = 6.41C + 6.00$	0.181
		20	$\Delta E_{20} = 6.89C + 10.34$	0.396
		30	$\Delta E_{30} = 9.91C + 14.24$	0.683
1.5	35	10	$\Delta E_{10} = 5.51C + 5.82$	0.535
		20	$\Delta E_{20} = 13.25C + 7.48$	0.842
		30	$\Delta E_{30} = 20.79C + 8.27$	0.939
1.5	45	10	$\Delta E_{10} = 9.78C + 4.63$	0.978
		20	$\Delta E_{20} = 19.44C + 5.29$	0.984
		30	$\Delta E_{30} = 25.53C + 7.06$	0.971
3	35	10	$\Delta E_{10} = 5.17C + 6.21$	0.841
		20	$\Delta E_{20} = 6.72C + 6.92$	0.946
		30	$\Delta E_{30} = 7.55C + 7.25$	0.987
3	45	10	$\Delta E_{10} = 2.17C + 6.45$	0.167
		20	$\Delta E_{20} = 11.57C + 7.55$	0.765
		30	$\Delta E_{30} = 19.23C + 9.01$	0.819

4.11.5.2. **Multiple linear regression for ΔE**

In order to find out the relationship between ΔE and the different processing parameters, a multiple linear regression is considered. The regression coefficients between the different parameters on RUI were obtained (Table 4.25) and with the use of t-test analysis, the significance of their relationships can be obtained (Table 4.26).

Table 4.25. Model Summary of multiple linear regression of ΔE

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.841[a]	.706	.689	3.1125780

a. Predictors: (Constant), Treatment time, Moisture content, Gas concentration, Dye concentration

Table 4.26. Coefficients of multiple linear regression of ΔE

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-4.110	3.215		-1.278	.206
	Dye concentration	-1.025	.357	-.190	-2.872	.005
	Gas concentration	.131	.016	.527	7.957	.000
	Moisture content	.110	.073	.100	1.505	.137
	Treatment time	.420	.045	.619	9.351	.000

a. Dependent Variable: ΔE

Based on Table 4.25, the dye concentration, the gas concentration, the moisture content and the treatment time can influence 70.6% ΔE values in this study. While Table 4.26 shows the p-values of the t-tests for each regression coefficients which are 0.005, 0.000, 0.137 and 0.000 respectively.

On the dye concentration aspects, P value < 0.05, represents significant linear relationship with ΔE at a significant level of 0.05.

On the gas concentration aspect, P value < 0.05, represents there is significant linear relationship with ΔE at a significant level of 0.05.

On the moisture content aspect, P value > 0.05, represents no significant linear relationship with ΔE at a significant level of 0.05.

On the treatment time aspect, P value < 0.05, represents significant linear relationship with ΔE at a significant level of 0.05.

Based on the analysis result, a regression equation can be generated as follows:

ΔE = -4.110 + dye concentration (-1.025) + gas concentration (0.131) + moisture content (0.110) + treatment time (0.420).   Equation 4.6

4.11.5.3. **Verification of equation for ΔE**

In order to verify the Equation 4.6, five sets of parameters are chosen for analysis and the results are shown in Table. 4.26. It is noted that the predicted and measured values are with an average difference of less than 5%. This indicates that ΔE values in the color fading process can be predicted by the Equation 4.6 under the condition with the input of the processing parameters.

Table 4.27.   Verification for ΔE

Parameters	Measured value	Predicted value	Difference (%)
0.5C / 50G / 35M / 30T	18.96	18.38	3.08%
1.5C / 30G / 45M / 20T	11.97	11.63	2.81%
1.5C / 30G / 45M / 30T	16.34	15.83	3.10%
3.0C / 30G / 35M / 20T	9.17	9.00	1.93%

3.0C / 10G / 45M / 20T	7.67	7.48	2.58%

Parameter interpretation

“C” represents the dye concentration

“G” represents the gas concentration

“M” represents the moisture content

“T” represents the treatment time

4.12. Material for training

The purpose and target of this section was mentioned in Chapter 1. In order to obtain more understanding on applying the plasma technology in the color fading process and make less water consumption in the washing factory. Based on the four selected parameters, the dye concentration, the gas concentration, the moisture content and the treatment time, 72 cotton specimens have gone through the color fading process by the ozone device (G2) in different parameters combination. It appears a color fading trend on the specimens. The color fading technology by ozone, that is the new application in the washing factory, in order to achieve the purpose of the color fading applied on different materials. To set up a training procedure is necessary. The result of the training will generate specimens reflecting the color fading trend from the plasma parameter setting versus the adopted material and color. From this project, 72 specimens can provide concrete view for a color fading direction guidance.

A couple of factors need to be considered during the use of the reference guideline. This project is focused on cotton knitted material made of a 100% cotton 32s/2. If the same condition is applied to another material, different results may be obtained, but this guideline can give color fading direction. Other than the three preliminary factors, the gas concentration, the moisture content and the treatment time, different material properties, dyes, fabric constructions, etc, will also affect the result. The reference specimens in this study are still able to provide direction on the color fading from the parameters which can be applied in bulk production.

Table 4.28 shows the parameters conversion recommendation from sampling to bulk production and Figure 4.50 shows the specimens color fading trend. This assists the user to get more understanding for determining the standard procedure for the operating.

Table 4.28. Sample specimen and Bulk production working condition comparison table

Sample specimen and Bulk production working condition comparison table				
Device parameter	**Specimen**	**G2 production (50 KG)**	**G2 production (30 KG)**	**G2 production (50 KG) in dry**
Gas power	25%	100%	100%	25%
Concentration	= 40g/Nm^3	= 90g/Nm^3	= 90g/Nm^3	= 90g/Nm^3
Gas Flow	50%	50%	50%	50%
Gas generator pressure	7 psi / 0,5 bar	7 psi / 0,5 bar	7 psi / 0,5 bar	7 psi / 0,5 bar
PSA pressure	60 - 70%	60 - 70%	60 - 70%	60 - 70%
Treatment Time	5	15	10	5
Treatment Time	10	30	20	10
Treatment Time	20	60	40	20
Treatment Time	30	90	60	30

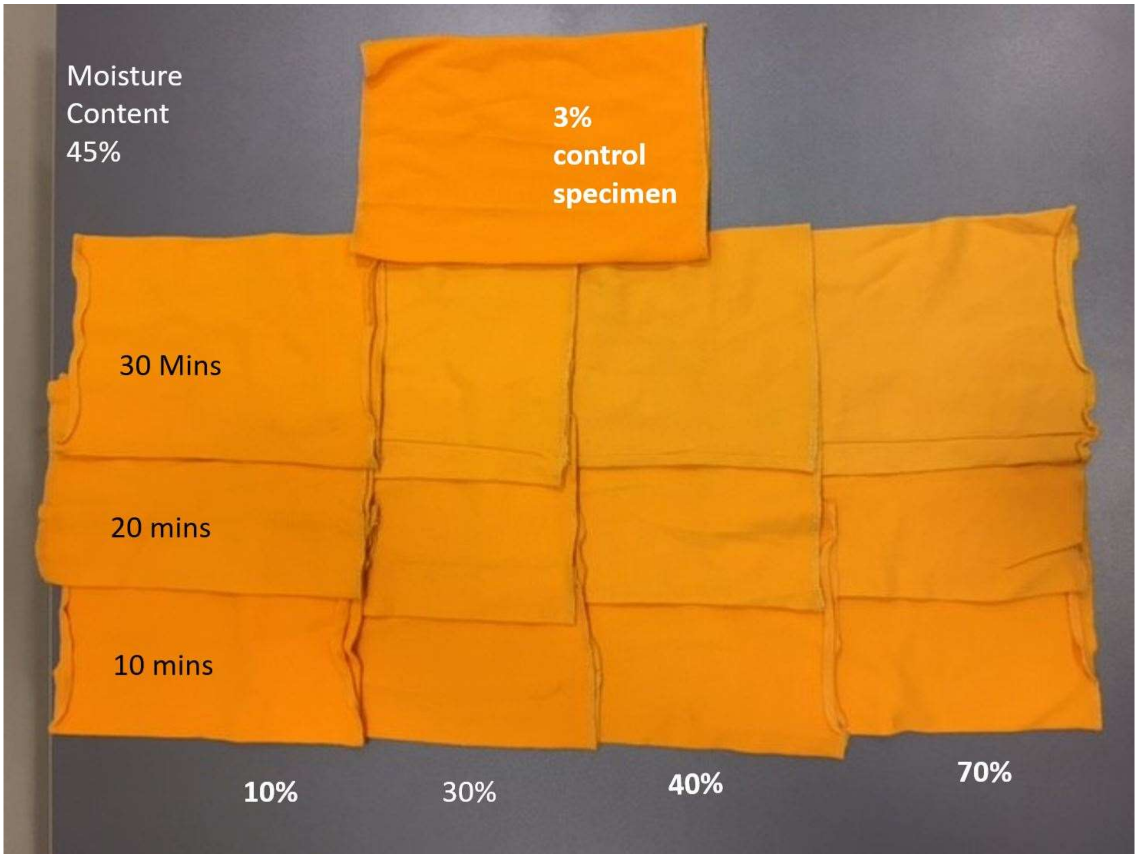


Figure 4.50. Color fading effects on overview specimens in 3% dye concentration and moisture 45%

Chapter 5. Conclusion and future recommendations

5.1. General conclusion

The G2 generator is a machine designed for the color fading of garments under atmospheric pressure which is done by using a plasma-induced ozone treatment in an environmentally friendly and energy-reducing way. It allows a significant reduction of water and energy and eliminates the consumption of toxic chemical used in bleaching and permanganate processes. An oxygen gas from the atmosphere is feed into the G2 generator. The high energy electrons generated by the plasma discharge and it leads to the formation of ozone (O^3). The work flow of the G2 generator process is shown in Figure 5.1. Ozone is an efficient oxidizing agent to oxidize dye particles in the textile surface. For the consideration of occupational safety and healthy issues, the use of the plasma gas will go through a burner to breakdown the used ozone before release the reminded gas to the atmosphere. That is reason why the G2 generator can obtain a certificate in ecology (Figure 5.2).

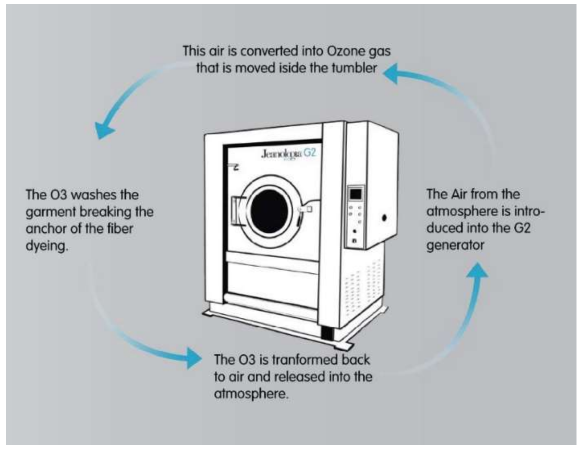
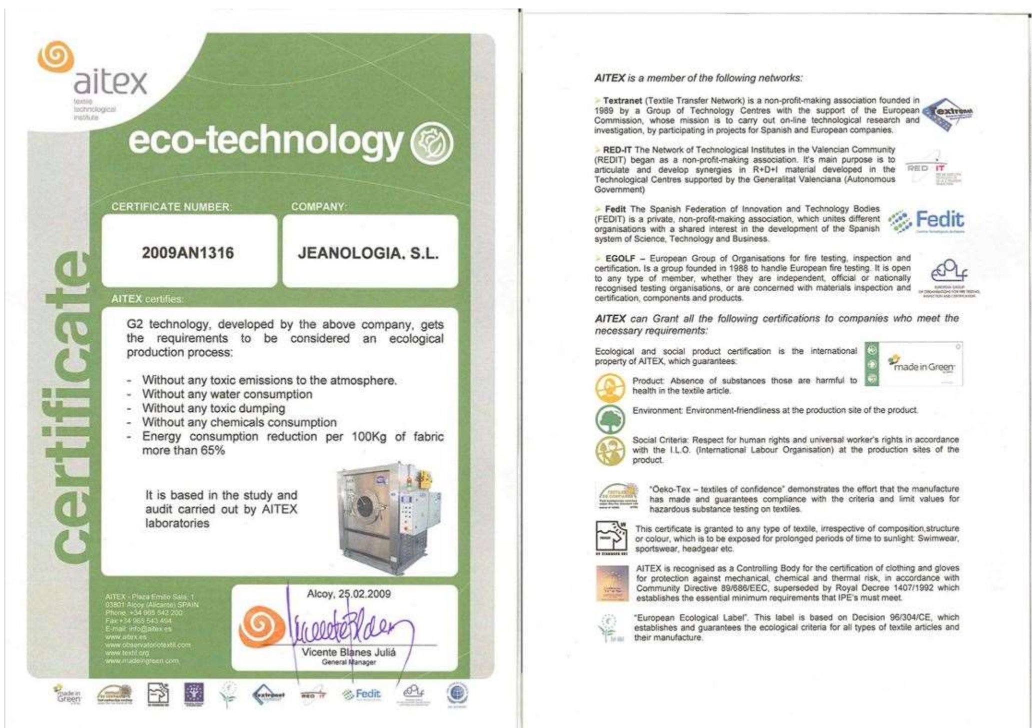


Figure 5.1. G2 generator brief work flow process.

This study used the G2 generator to study eco-de-coloration method under different parameters such as the dye concentration, the moisture content, the treatment time and the gas concentration. 72 knitted cotton specimens were dyed with yellow reactive dye with a dye concentration of 0.5%, 1.5% and 3%.

Those specimens were treated with different combinations of the processing parameters in order to study the color fading effect. The result of color fading effectiveness was based on the RUI, K/S value, CIE L*, CIE a*, CIE b*, and ΔE value, other than spectrophotometer measurement. Statistical analysis was conducted to determine the relationship of different processing parameters with the different color properties. Experimental results revealed that the treatment time and the gas concentration certainly have correlation with the color fading effect, based on the K/S sum process. Both process parameters increase would lead to the enhancement of the color fading effect. However, as observed in the dye concentration aspect, it was found that color fading effectiveness decreased when the dye concentration increased.

Meanwhile, for the moisture content aspect, the increase in moisture content could not lead to enhancement of the color fading effect because the increased moisture could lead to a diluting effect which would inhibit the color fading action. Based on an statistical analysis, the linear regression could not show the relationship between the color properties of different processing parameters. However, the analysis of the multiple linear regressions could determine the relationship between the color properties and the different processing parameters effectively and the good verification results.



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eco-technology

certificate

CERTIFICATE NUMBER: 2009AN1316

COMPANY: JEANOLOGIA, S.L.

AITEX certifies:

G2 technology, developed by the above company, gets the requirements to be considered an ecological production process:

- Without any toxic emissions to the atmosphere.
- Without any water consumption
- Without any toxic dumping
- Without any chemicals consumption
- Energy consumption reduction per 100Kg of fabric more than 65%

It is based in the study and audit carried out by AITEX laboratories

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Vicente Blanes Juliá
General Manager

AITEX is a member of the following networks:

Textranet (Textile Transfer Network) is a non-profit-making association founded in 1989 by a Group of Technology Centres with the support of the European Commission, whose mission is to carry out on-line technological research and investigation, by participating in projects for Spanish and European companies.

RED-IT The Network of Technological Institutes in the Valencian Community (REDIT) began as a non-profit-making association. It's main purpose is to articulate and develop synergies in R+D+I material developed in the Technological Centres supported by the Generalitat Valenciana (Autonomous Government)

Fedit The Spanish Federation of Innovation and Technology Bodies (FEDIT) is a private, non-profit-making association, which unites different organisations with a shared interest in the development of the Spanish system of Science, Technology and Business.

EGOLF – European Group of Organisations for fire testing, inspection and certification. Is a group founded in 1988 to handle European fire testing. It is open to any type of member, whether they are independent, official or nationally recognised testing organisations, or are concerned with materials inspection and certification, components and products.

AITEX can Grant all the following certifications to companies who meet the necessary requirements:

Ecological and social product certification is the international property of AITEX, which guarantees:

Product: Absence of substances those are harmful to health in the textile article.

Environment: Environment-friendliness at the production site of the product.

Social Criteria: Respect for human rights and universal worker's rights in accordance with the I.L.O. (International Labour Organisation) at the production sites of the product.

"Oeko-Tex – textiles of confidence" demonstrates the effort that the manufacture has made and guarantees compliance with the criteria and limit values for hazardous substance testing on textiles.

This certificate is granted to any type of textile, irrespective of composition,structure or colour, which is to be exposed for prolonged periods of time to sunlight: Swimwear, sportswear, headgear etc.

AITEX is recognised as a Controlling Body for the certification of clothing and gloves for protection against mechanical, chemical and thermal risk, in accordance with Community Directive 89/686/EEC, superseded by Royal Decree 1407/1992 which establishes the essential minimum requirements that IPE's must meet.

"European Ecological Label". This label is based on Decision 96/304/CE, which establishes and guarantees the ecological criteria for all types of textile articles and their manufacture.

Figure 5.2 G2 certificate in ecology

5.2. Recommendations for future work

The following works are recommended to be conducted in the future.

(i) In the study, only the color fading effect of reactive dye was considered. It is recommended that the color fading effect of indigo dye, direct dyes, sulphur dyes as well as fluorescent color dyes could be studied in the future.

(ii) The G2 is a very powerful machine for color fading for textile material. However, only the effect of the gas concentration, the moisture content and the treatment time on the color fading was studied. Other machine parameters such as power and rotating / tumbling speed could be studied in future works.

(iii) In this study, only the color properties of lacoste type knitted fabric was studied. Woven fabrics and other types of knitted fabrics could be studied in the future.

(iv) The G2 generator is a machine designed for the color fading of garments mode, the color fading in fabric mode could be studied in the future.

(v) Other than color properties, physical (e.g. tensile strength) and chemical properties (e.g. surface chemical analysis) would be studied in order to have a more comprehensive picture about the effect of the ozone plasma treatment on dyed cotton fabric.

(vi) In order to illustrate the plasma process, further experimental method will be launched, such as he morphology of the fabric surface could be identified to describe the interaction between the plasma and the cotton materials

(vii) To apply it in a commercial aspect, through the cost and consumption (water, energy, chemicals, production turn time etc) analysis, to find out an equation on economical and ecological profile of the ozone treatment is needed in the future work.

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