# การชุบมันผ้าฝ้ายด้วยสารละลายโซเดียมไฮดรอกไซด์ความเข้มข้นต่ำที่อุณหภูมิต่ำ

นางสาววรวรรณ อัศเวศน์



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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# MERCERIZATION OF COTTON FABRIC WITH LOW CONCENTRATION SODIUM HYDROXIDE SOLUTION AT LOW TEMPERATURE

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for the Degree of Master of Science in Applied Polymer Science and Textile Technology
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# บทคัดย่อวิทยานิพนธ์

นางสาววรวรรณ อัศเวศน์ : การชุบมันผ้าฝ้ายด้วยสารละลายโซเดียมไฮดรอกไซด์ความเข้มข้นต่ำที่อุณหภูมิต่ำ. (MERCERIZATION OF COTTON FABRIC WITH LOW CONCENTRATION SODIUM HYDROXIDE SOLUTION AT LOW TEMPERATURE) อ. ที่ปรึกษา : ดร. อุษา แสงวัฒนาโรจน์, 99 หน้า. ISBN 974-334-875-1.

โดยทั่วไปการชุบมันผ้าฝ้ายจะทำการชุบมันในอ่างซึ่งบรรจุสารละลายโซเดียมไฮดรอกไซด์ความเข้มข้นสูงประมาณ 20-30% หลังจากทำการชุบมันแล้ว น้ำเสียที่เกิดจากสารละลายโซเดียมไฮดรอกไซด์ จะถูกทำให้เป็นกลางด้วยกรดในกระบวนการบำบัดน้ำเสีย งานวิจัยนี้เสนอถึงความเป็นไปได้ในการชุบมันผ้าฝ้ายด้วยสารละลายโซเดียมไฮดรอกไซด์ความเข้มข้นต่ำกว่า 20% โดยผ่านการชุบมันที่อุณหภูมิต่ำ ผ้าฝ้ายทอและผ้าฝ้ายถัก ถูกชุบมันด้วยสารละลายโซเดียมไฮดรอกไซด์ความเข้มข้น 10-30% ที่อุณหภูมิ 5-40°C และถูกนำไปทดสอบหาระดับการชุบมัน การดูดซับสีย้อม ความแข็งแรงและความเป็นกรดด่าง ผ้าที่ถูกชุบมันด้วยสารละลายโซเดียมไฮดรอกไซด์ 10% จะให้ระดับการชุบมันใกล้เคียงกันกับผ้าที่ไม่ผ่านการชุบมัน แต่ให้การดูดซับสีย้อม ความแข็งแรงและการยืดตัวสูงกว่า ขณะที่ผ้าชุบมันด้วยสารละลายโซเดียมไฮดรอกไซด์ความเข้มข้น 15-30% ให้ระดับการชุบมัน การดูดซับสีย้อม ความแข็งแรงและการยืดตัวดีกว่าผ้าที่ไม่ผ่านการชุบมัน เพื่อให้ได้ผลการชุบมันที่ยอมรับได้ ผ้าฝ้ายควรถูกชุบมันด้วยสารละลายโซเดียมไฮดรอกไซด์ที่ความเข้มข้นไม่ต่ำกว่า 10% ผลการทดลองนี้ได้เสนอแนะภาวะการชุบมันที่เหมาะสมคือ ชุบมันด้วยสารละลายโซเดียมไฮดรอกไซด์ความเข้มข้น 15% ที่อุณหภูมิ 10-20°C โดยใช้ระยะเวลาในการชุบมัน 30 วินาที



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# AN ABSTRACT

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Generally cotton mercerization is conducted in a mercerizing bath containing high concentration of caustic soda or sodium hydroxide solution such as 20-30%. After mercerization, the alkali waste solution is often treated with an acid for neutralization of the waste treatment process. This project is proposing a possibility of mercerization of cotton fabric with lower caustic soda concentration than 20% through a mercerization at low temperature. Cotton woven and knitted fabrics were mercerized with 10-30% caustic soda solutions at various temperature of 5-40°C and were tested for the degree of mercerization, dye absorption, strength, and pH. Fabrics mercerized with 10% solution showed same degree of mercerization as the unmercerized fabric but they obtained better dye absorption ability and higher fabric strength and elongation. While fabrics mercerized with 15-30% solution showed higher degree of mercerization, dye absorption, and fabric strength and elongation than the unmercerized fabric. To obtain an acceptable mercerizing outcome, cotton fabrics need to be mercerized at concentrations not lower than 10%. The recommended mercerizing condition is to mercerize at 15% caustic soda solution at 10-20°C for 30 seconds.

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ลายมือชื่ออาจารย์ที่ปรึกษา ..................

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# CHAPTER I

# INTRODUCTION

Cellulose is the most abundant of all naturally occurring organic polymers. Although exploited in the forms of cotton, flax, wood and other textile fibers, the purest form of cellulose found in nature is cotton. Cotton is widely available and is the most important natural fiber used for clothing. To dye cotton to deeper shade and to improve cotton luster, a mercerizing process is needed. Cotton mercerization is a process of treating cotton fibers with sodium hydroxide solution under a controlled tension to alter their molecular orientation, crystalline structure, degree of crystallinity and morphology[1]. These changes increase sorption ability, tensile strength, extensibility, luster and roundness of fiber and also affect the handle and drape of the resulting fabrics. To obtain good mercerizing results, four major factors containing alkali concentration, temperature, time, and tension need to be controlled properly during mercerization.

Generally cotton mercerization is conducted in a mercerizing bath containing high concentration of sodium hydroxide solution such as 20-30%. After each treatment, the alkali waste solution is either reused or treated with an acid for neutralization in waste treatment process. To save cost in this waste treatment, alkali concentration used in mercerization should be decreased if possible. Several evidences have shown that using same alkali concentration, mercerization at low temperature provides fabric with higher degree of mercerization than conducting at high temperature[2]. An evidence indicate that sodium hydroxide behaves as a stronger base when it is cold than it is warm[3]. Therefore, it might be possible to mercerize cotton at low temperature using low alkali concentration. The lower the alkali uses in mercerizing process, the saver the cost of chemicals, water, and possibly the energy.

The main objective of this project is, therefore, to study a possibility of decreasing the amount of sodium hydroxide used in mercerizing process, to study the effect of cotton mercerization at low concentration of sodium hydroxide solution at low temperature and to search for an optimum mercerizing condition.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Cellulosic Fiber

### 2.1.1 Molecular Structure of Cellulose

Cellulose is the most abundant of all naturally occurring organic polymers. It is a pure plant cell material consisting of macromolecules of at least several hundred to several thousands of anhydroglucose units[4]. Cellulose is a polymer of β-D-glucopyranosyl units which are linked together by 1,4-β-D glycosidic bond, with the elimination of water, to form chains of 2000-4000 units, as shown in Figure 2.1.

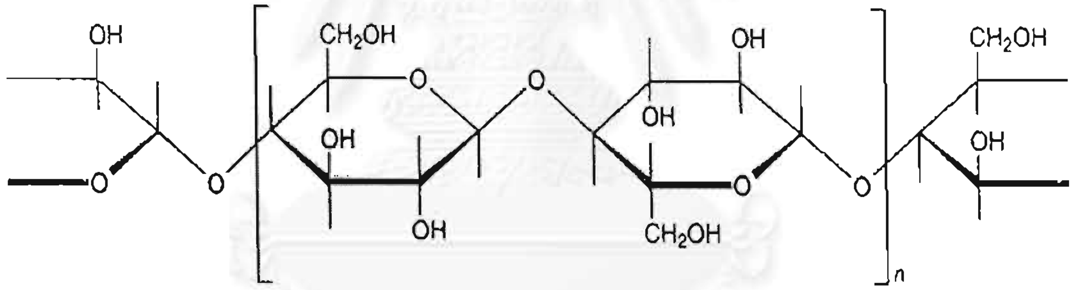



Figure 2.1 Structure of cellulose polymer [5].

The degree of polymerization (DP) of cellulose varies with its sources and is usually expressed as an average, since a wide distribution is found in most samples. In native cellulose it may be as high as 14000, but alkali purified cellulose is usually low to about 1000-2000. The DP of cellulose regenerated by the older methods is about 250-300, but that of modal fibers is higher (about 500-700)[6].

Cellulose I, Cellulose II, Cellulose III, and Cellulose IV are designations that characterize the physical structure of the unit cell of the cellulose configuration.

Native cellulose, Cellulose I, may be derived from such plants as cotton, flax, ramie, jute and hemp[2]. The amount of cellulose in fibers varies according to sources and it is associated with other materials such as water, pectin, protein, wax, lignin, and mineral substances.

Cellulose II is a product from the treatment of native cellulose with strong alkali solutions, such as sodium hydroxide (NaOH), lithium hydroxide (LiOH), potassium hydroxide (KOH) and ammonium hydroxide. Transformation of Cellulose I to Cellulose II usually occurs very rapidly.

Cellulose III and IV are not as well characterized as its other forms. Cellulose III results from treating cellulose I in liquid ammonia or ethylamine and carefully removing it. Cellulose IV is formed on heating cellulose II in glycerol at 200°C [7,8].

## 2.2 Cotton Fiber

Cotton is the most important and the most widely used textile fiber. It is a seed fiber. A mature raw cotton fiber viewed through an optical microscope resembles a flattened twisted tube (Figure 2.2). In cross section, it looks like a lima bean with a collaped inner hollow (Figure 2.3). After treatment in a swelling agent, as in the mercerization process, cotton fiber is almost straight and the hollow becomes rounded[9] (Figures 2.4).

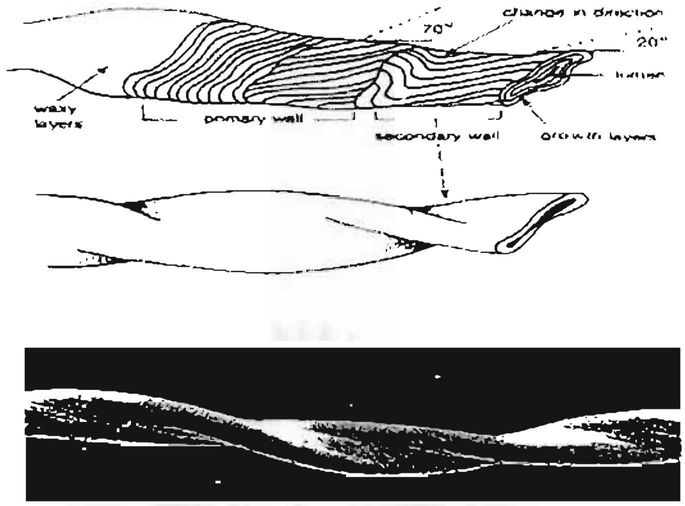



Figure 2.2 Structure of a cotton fiber, (above) diagrammatically and (below) in a photomaticrograph[5]

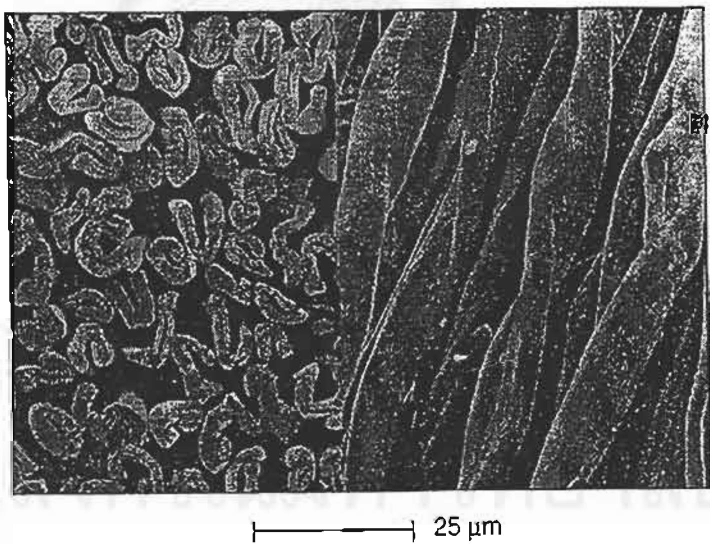



Figure 2.3 Scanning electron micrographs of raw cotton fibers[6].

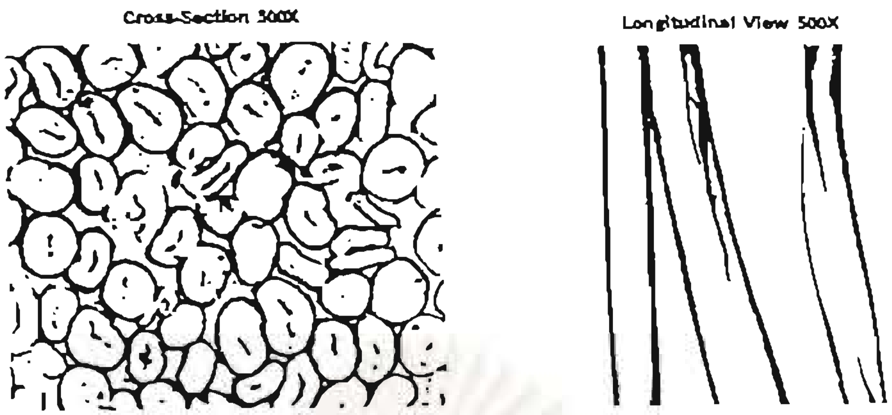



Figure 2.4 Cross-section and longitudinal view of mercerized cotton fibers[2].

## 2.3 Composition of Cotton Fiber

### 2.3.1 Morphology

Cotton fiber has a fibrillar structure. Their morphology, illustrated in Figure 2.5, exhibits three main features : primary wall, secondary wall and lumen.

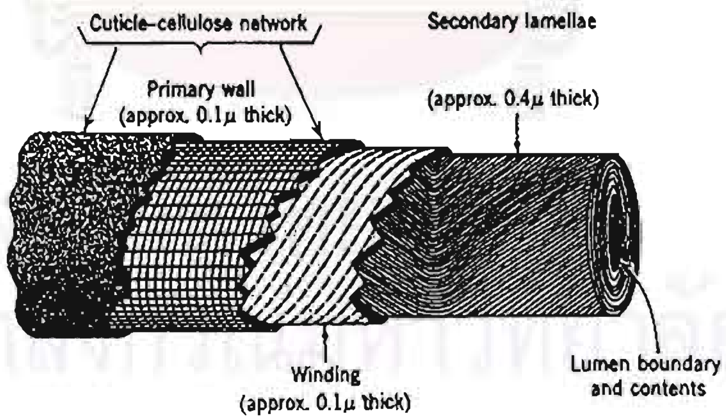



Figure 2.5 Schematic diagram of cotton fiber structure[5].

Primary wall consists of a network of cellulose fibrils covered with an outer layer, or cuticle, of pectin, protein, mineral matter and wax. Wax makes the fiber impermeable to water and aqueous solutions unless a wetting agent is used. Primary wall was found to contain a bulk of noncellulosic constituents of cotton fiber as displayed in Table 2.1. It gives comparative data for a typical cotton. The other substances are mostly water-soluble organic acids and sugars.

Table 2.1 Composition of cotton fibers[6].

| Constituent | Proportion of dry weight % | |
|---|---|---|
| | Whole fibers | Primary wall |
| Cellulose | 94.0 | 54.0 |
| Protein (%N x 6.25) | 1.3 | 14.0 |
| Pectin | 1.2 | 9.0 |
| Wax | 0.6 | 8.0 |
| Ash | 1.2 | 3.0 |
| Other substances | 1.7 | 12.0 |

Secondary wall constitutes a bulk of mature fibers and consists almost entirely of cellulose fibrils arranged spirally around the fiber axis. The direction of the spiral reversing (i.e., changing between s and z twists) many times along a single fibril[6].

Lumen is the central cavity or canal at the fiber center. It is highly irregular in both size and shape. Because of the twisted and wrinkled condition of the dried fiber, it often does not appear to be openned the full length of the fiber, but shows intermittently along the length. When fibers are dissolved in a strong sulphuric acid, lumen often remains as a complete entity and can be rendered visible with basic dyes. In alkaline swelling agents, fibers are usually dispersed[10].

2.3.2 Properties

The properties of cotton fiber are shown in Table 2.2.

Table 2.2 Properties of cotton fiber[11].

| | |
|---|---|
| **Molecular Structure** | Long cellulose polymer chains |
| **Microscopic Features** | |
| Length: | 25 to 60 mm. |
| Width: | 12 to 20 μm. |
| Cross-section: | Bean-shaped |
| Color: | Usually a creamy off-white color |
| Light reflection: | Low luster, dull appearance |
| **Physical Properties** | |
| Tensile Strength: | 96,700 pound/inch. |
| Elongation: | 4 to 13% elongation at break |
| Tenacity (g/den.): | 3 to 5 (dry), 3.6 to 6 (wet) |
| Density ($g/cm^3$): | 1.54 to 1.62 |
| Moisture content at 65% RH, 21°C: | 8.5% |
| Resiliency: | Low |
| Toughness and stiffness: | High |
| Abrasion resistance: | Fair to good |
| **Chemical Properties** | |
| Sunlight and heat: | May be heated in the dry state to a temperature of 150°C without undergoing decomposition but can be damaged by excessive light. |
| Organic solvents: | Resistant to most organic solvents. |
| Bleaches: | Can be bleached without fiber damage. |

| | |
|---|---|
| Acids and alkalis: | Highly resistant to alkalis. Strong mineral acids cause fiber damage readily and organic acids do a little damage. |
| Stains: | Poor resistance to water-born stains. |
| Dyeability: | Good affinity for various types of dyes. Dyeable with direct, vat, sulphur and reactive dyes. |
| **Biological Properties** | |
| Microorganisms: | Vulnerable to action by bacteria and mold. |
| Insects: | Starched cotton is attacked by silverfish. |
| **Optical Properties** | |
| Axial refraction: | 1.596 |
| Transverse refraction: | 1.534 |
| Double refraction | 0.062 |
| **Electrical and thermal conductivity** | Good heat conductor |
| **Flammability behavior** | Burns very readily and once ignited, a fabric will carry flame. |

## 2.4 Mercerization

Mercerization usually refers to the treatment of cotton yarn or fabric with sodium hydroxide solution (caustic soda solution). The process taking its name from John Mercer who, in 1850, observed that there was a general swelling and shrinking effect when cotton was treated with caustic soda solution[12, 13, 14].

The technological advantages of high luster of the mercerized product were not realized until a little later when Horace Lowe demonstrated in 1890 that this property was developed by maintaining the tension during the treatment. Considerable quantities of cotton yarns and clothes are nowadays mercerized to improve luster and/or dye uptake, and more recently without tension to produce "Stretch" material[15]. The main changes occurring in the alkaline treatment of cotton are[12, 13, 14] :

- to increase the solubility of cotton in solvents such as CUEN.
- to reduced the length of cotton yarn or area of cotton cloth.
- to increase the tensile strength of cotton.
- to increase the dye absorption of cotton.
- to increase the physical compactness and density of cotton.
- to increase the water absorption of cotton.
- to increase the reactivity of cotton with oxygen (air).
- to increase the reactivity of cotton at lower temperatures.
- to increase the luster of cotton.
- to increase the rate of oxidation causing cotton degradation.
- to remove the immature dead cotton.

2.4.1 Important Factors in Mercerizing Process

Mercerization process is a permanent alteration in the X-ray diffraction pattern of cellulose, changing it from that typical of native cellulose (Cellulose I) to that of Cellulose II. The degree of mercerization and the degree of change depend on fiber type, tension, temperature, time and concentration of alkali solution as follows.

2.4.1.1 *Fiber type*

Scoured yarns are mercerized but bleached yarns are seldom mercerized. 100% synthetic fibers do not need mercerization. Cotton yarns are more completely mercerized than cotton fabric due to their high surface area[3].

2.4.1.2 *Tension*

The degree of tension is important to the formation of luster when yarn or fabric is mercerized. Sodium hydroxide solution with appropriate concentration causes fiber to swell. When fiber swells, it shrinks in length. When cotton is mercerized with no tension, fiber surfaces show creases, wrinkles and less luster than cotton mercerized under tension.

When tensions are applied during mercerization, fiber shrinkage tends to reduce and fiber internal pressures increase causing the changes to be more profound on the morphological structure of cotton as well as causing the fibers to become glass-like in appearance.

2.4.1.3 *Temperature*

Mercerizing temperature has an effect on the degree of mercerization of cotton. It is generally recognized that a decrease of mercerizing temperature leads to higher swelling of cellulose fiber[16]. There was an evidence shows that hot mercerization can produce better results than normal mercerization for three reasons. First, hot sodium hydroxide solution can penetrate fiber surface throughly with the result that a greater proportion of cellulose may be modified. Second, at higher temperatures, concentrated sodium hydroxide solution causes the fabric to be stretched easier. Last, the stretch/tension variable can be easily set at any desired level when mercerization is conducted at high temperature, which in turn controls the fabric properties[12]. However, there are some drawback on processing hot mercerization. For instance, hot concentrated sodium hydroxide solution can degrade cotton fiber within minutes.

2.4.1.4 *Time*

During mercerization, fibers swell largely in cross-section axis and this leads to shrinkage of fiber length. Increasing the mercerizing time will increase the degree of swelling and shorten the fiber length. Such as when cotton is mercerized at 30°C using 19% sodium hydroxide solution and the time is changed from 1 to 30 minutes, fiber shrinkage can be increased from 19 to 29%. The degree of fiber swelling and fiber shrinkage usually increase with mercerizing time until fiber swells to its maximum controlling by the primary cell wall. Luster is unchanged with increasing mercerization time[3].

#### 2.4.1.5 *Concentration*

Yarn or fabric mercerization process usually uses strong caustic soda solution of 20 to 25% concentrations[7, 17]. It is interesting to note that the mercerization concentration varies with the atomic weight of the alkali used. In other words, either sodium, potassium or lithium hydroxides can be used for mercerizing cotton at 23%, 33% and 9% concentrations, respectively. Calculations indicate that at these concentrations all of the available hydroxyl groups in the cellulose become saturated with the alkaline earth element employed[12].

### 2.4.2 Swelling of Cellulose with Alkaline Solution

When cellulose is immersed in a solution of alkali, water and alkali diffuse in and the material swells. The theory to explain the swelling of cellulose is the hydroxyl groups in the anhydroglucose units behave as weak acids which dissociate independently of each other. In alkaline media, these will become dissociated to and extent dependent on caustic soda concentration, and the presence of ions in cellulose gives rise to an osmotic pressure causing water to enter, until counterbalanced by elastic forces of swollen polymer.

When alkaline solution is replaced by water, undissociated hydroxyl groups are reformed ; the osmotic pressure therefore falls leaving the cellulose in its original chemical state. If the osmotic pressure has been high enough, the polymer will however be permanently distorted.

On an atomic scale, the charged groups will be surrounded by an atmosphere of ions ($Na^-$ and $OH^-$ ) and the distribution of the latter will not be uniform. However on a macroscopic scale such short distance variations may be ignored and the whole treated as being at a uniform potential, different in general from that of the external phase.

The cellulose phase acquires a negative charge with respect to the external phase due to the difference in dielectric constants, but more important in this case is the presence of charged groups in cellulose[15].

Generally, swelling is determined by microscopy, dye sorption, iodine adsorption and moisture regain measurements. Cellulose swelling is a physical reaction occurring during mercerization. Noncrystalline regions are swollen by alkali solution rapidly, but longer times are required to swell crystalline regions. Penetration of the crystalline regions of cellulose depends on the size of the appropriate alkali hydrate being small enough[3].

2.4.3 Sodium Hydroxide Mercerization

Sodium hydroxide is also called caustic, soda lye, and sodium hydrate. In aqueous solution, depending on concentrations, caustic soda can form five hydrates containing 1, 2, 3, 5 and 7 molecules of water respectively. Hydrate formation is an exothermic reaction. Sodium hydroxide has a fairly large dipole hydrate in mercerization. It can induce intracrystalline swelling of cellulose by molecules penetrating between the 110 planes of the crystallites. Intrafibrillar swelling in sodium hydroxide mercerization is higher than in liquid ammonia mercerization. Sodium hydroxide uptake is an adsorption process, not a chemical reaction, similar to a normal adsorption isotherm, and not S-shaped. One mole of sodium hydroxide and five or six moles of water are adsorbed per anhydroglucose unit, in the form of a hydrated ion and free water molecules, in solution of 14-23% sodium hydroxide. Sodium cation ($Na^+$) carries its associated hydration water molecules penetrating into the fiber. Fiber must swell sufficiently to accommodate the diffusion of $Na^+$ with its water molecules. Hydrogen-bonds within the sheets of chains are broken and the sheets are pushed farther apart by the entrance of $Na^+$ and its cluster of water molecules[3].

2.4.4 Mechanism of Sodium Hydroxide Mercerization

When sodium hydroxide (caustic soda) solution enters the amorphous interface regions of ramie cellulose (see Figure 2.6), it rearranges the amorphous regions, located between parallel-up and parallel-down chains in the crystalline regions, into antiparallel soda cellulose I with very little movement of the chain segments and very little effect on the crystalline regions. Sodium hydroxide swells cellulose and creates high chain-segment mobility within the swollen areas. The formation of soda cellulose I proceeds and the energetic and entropic factors probably favor the formation of soda cellulose I. Thus, the crystalline regions of cellulose I gradually diminish in size while the crystallites of soda cellulose I increase. This change proceeds through the removal, by the action of the alkali, of individual chains from the surface of cellulose I crystallites and their incorporation onto the surface of soda cellulose I crystallites. The chain conformation in soda cellulose I is probably close to a twofold helical because of the constraints exerted by such a conformation in the adjacent unconverted cellulose I crystallites. When all constraints due to the uncoverted crystalline cellulose phase have been removed, soda cellulose I absorbs more sodium hydroxide and converts to a crystal structure based on a threefold helical chain conformation and one in which all contacts between adjacent chains in the unit cell are removed. Soda cellulose IIA or IIB is formed and it could be the lowest energy soda cellulose intermediate occurring during mercerization. It is stable both in contact with sodium hydroxide solution and in dry state (soda cellulose IIB is probably the more stable of the two because it is formed when the fibers are under the least amount of lateral constraint). After sodium hydroxide has been removed, the cellulose chains revert to a twofold helical conformation which is a lower energy structure in the absence of sodium hydroxide, and the structure crystallizes in the lowest-energy cellulose II polymorph (see Figure 2.6).

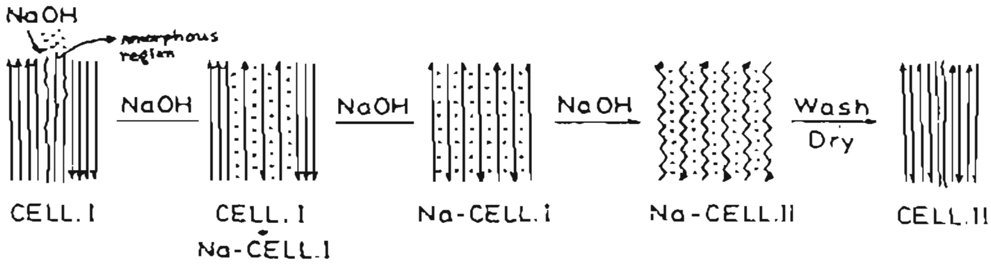



Figure 2.6 Possible mechanism of sodium hydroxide mercerization[3].

When water molecules are removed on drying, swollen structure collapses. More hydrogen-bonds are formed between the chains and they lock up the structure more tightly than it is before mercerization.

There are many proposed reactions of cellulose and sodium hydroxide in mercerization as shown in equations 2.1-2.5.

1. $[C_6H_7O_2(OH)_3]_n + nNaOH \longrightarrow [C_6H_7O_2(OH)_3{\bullet}NaOH)_n$ (2.1)

or $[C_6H_7O_2(OH)_3]_n + nNaOH \longrightarrow [C_6H_7O_2(OH)_2ONa]_n + nH_2O$ (2.2)

It is assumed that, in alkali cellulose, sodium hydroxide is in the form of an adduct being in equilibrium with the alcoholate form:

$$C_6H_{10}O_5{\bullet}\ NaOH \bullet xH_2O \leftrightarrow C_6H_9O_4ONa + (x+1)H_2O \quad (2.3)$$

2. $Na^+OH^- \bullet nH_2O + R_{cell}(OH)_3 \leftrightarrow R_{cell}(OH)_3{\bullet}NaOH(n\text{-}3)H_2O + 3H_2O$ (2.4)

Three hydroxyl groups per anhydroglucose unit replace three molecules of water from the pair of solvated ions, and one molecule of sodium hydroxide is fixed per anhydroglucose unit. But it is quite impossible to react the three hydroxyl groups of cellulose in the same anhydroglucose unit with a single ion-pair hydrate. One of the three hydroxyl groups plays the part of an acid to solvate the ion pair $Na^{+}OH^{-}$.

$$R_{cell}\text{-}OH + NaOH \longrightarrow R_{cell}\text{-}O^{-}Na^{+} + H_2O \qquad (2.5)$$

One $NaOH \bullet H_2O$ is associated with each anhydroglucose unit.

## 2.5 Previous Research Works on Sodium Hydroxide Mercerization of Cellulosic Fibers at Various Temperature

Several researchers have conducted many studies on mercerization using sodium hydroxide solutions and liquid ammonia. The following works are some examples:

An attempt done by Niaz and Tahir was to treat cotton fabrics with solutions of sodium hydroxide at specific concentrations at various temperatures under controlled tension and to study for the change of their molecular orientation, crystal structure, degree of crystallinity and morphology. These changes increase sorption, tensile strength, extensibility, luster and roundness of fibers, and also effect the handle and drape of the resulting fabrics [1]. They found that mercerization conducting at temperature between 15-20$^{\circ}$C provides high luster fabric and increases in dye uptake.



A study by Clifford [18] indicates that the best mercerizing concentration and temperature are 13$^{\circ}$Be$'$-37$^{\circ}$Be$'$ (8.75-31%) and 15-20$^{\circ}$C. At high temperature, caustic soda solution causes less swelling in cotton fibers than at low temperature or room temperature.

Andrew and Wilson [19] studied the caustic treatment of wood pulp and other types of cellulosic materials and found that, mercerization normally starts at a caustic soda concentration of about 5 to 7 percent at room temperature and will be substantially complete at about 9 to 12 percent. Experience has shown that the most effective action is attained with from about 8 to 14 percent caustic soda present based on the weight of the solution. These percentages can be raised and lowered somewhat by variations in origin of the cellulose and by variations in temperature. Normally, mercerization increases with rising concentration and decreases with rising temperature. Therefore, as the temperature of the solution is raised the caustic soda concentration in the mercerizing solution must also be raised to obtain an equivalent effect on the cellulosic material being treated. On the whole, however, the foregoing range holds very well for normal cold caustic soda treatment presently employed.

Edelstein[20] studied the relationships between the factors in mercerization process and the properties of the resultant material. The effect of the mercerizing caustic concentration on the properties of 40/2 cotton yarn of balanced twist held at a constant position during the treatment with the mercerizing caustic solution was studied. In this work, it was found that the higher the concentration of the mercerizing caustic solution, the greater was the tension necessary to hold the yarn at the constant position and the higher was the luster of the finished yarn. The author also found that the lower the mercerizing temperature was for a particular caustic solution, the greater was the tension necessary to prevent the yarn from shrinkage and the greater was the dye affinity and barium activity number of the mercerized yarn.

Angelo[21] studied the alkali treatment of cellulosic fiber goods. The author carried out the alkali treatment of cotton goods with an intermediate drying step between the step of treatment with the alkali solution and the final rinsing and drying. However, when the conventional strength of caustic soda is used, i.e. from 28° –33° Baume′, an alkali process with an intermediate drying caused damage to the fibers.

It was found that good results (particularly for knitted cotton goods) were obtained in an alkali-dry process with an intermediate drying by operating at an alkali strength of only 18°-26° Baume′, a strength at which it was previously believed that no significant improvement in properties could be obtained.

The alkali-dry process according to the invention gave a smooth appearance to the goods and increased gloss, properties which are of particular importance for cotton knitted goods. The goods also had better tear strength, wash-shrinkage values, elongation strength and stability and gave deeper dyeing than those treated by a conventional alkali process. The alkali-dry process of the invention caused no fall of the average degree of polymerization of cellulose or only an unsignificant fall.

Pusic, Grancaric, Soljacic and Ribitsch[22] studied the effect of mercerization on the electrokinetic potential of cotton and found that mercerization can changes the electrokinetic behaviour of cotton. Mercerization also change the fine structure, morphology and conformation of cotton cellulose chain (cellulose I to cellulose II), resulting in a variation in fiber strength and luster as well as adsorption properties.

Nishiyama and Okano[23] studied the morphological changes of ramie fiber during mercerization. This change due to swelling in alkali solution and twisting and changes in the cross-sectional shape of the fibers could be explained as a geometrical alteration caused by lateral expansion of coiling fibrils, as the unmercerized ramie fiber showed an S-helix structure. The fibril angle of ramie fibers was estimated to be 3 degrees. Although the swollen fiber untwisted to some extent on washing with water, the shape of the twisted ribbons as observed by scanning electron microscopy was retained even after drying. Concentrated 8N NaOH produced only a moderate change in morphology, whereas swelling with 3.5N NaOH at 0°C expanded the cross sections about 30 times over the initial ones accompanied by a drastic change in the shape of fiber.

Sao, and Jain[24] studied the mercerization effect of various concentrations of aqueous NaOH solutions on the isolated ultimate cells and the fiber strands of jute. It is observed that the treatment with higher concentration of alkali (12% and above) results in a decrease in crystallinity index and a deterioration in overall molecular orientation along with the change in crystalline lattice from cellulose I to cellulose II. The changes in the supermolecular structure and morphology of cellulose in the ultimate cells appear to be mainly responsible for the development of crimp in jute. A qualitative mechanism for the three-dimensional crimp formation in jute has also been discussed in terms of rearrangement of internal molecular forces in cellulose on mercerization.

Taylor[25] has studied the mercerizing process of lyocell. The lyocell fiber may be subjected to mercerization in the form of staple fiber, tow, continuous filaments, spun yarn or lyocell fabric. It was found that lyocell fiber can satisfactorily be treated with strong alkali in a mercerization process. Other man-made cellulose fibers, for example viscose rayon suffer severe damage under such condition. Treated lyocell fiber was dyed and showed a good color fastness and retained this property on repeated laundering.

## 2.6 A Study of the Mercerization of Cotton Fabric with Low Concentration Sodium Hydroxide Solution at Low Temperature

The mercerization of cotton yarn and fabric is carried out mainly to increase the dye affinity, strength and luster of the material. The increase in one or all of these properties may be of particular importance to the processer. There may also be secondary considerations of change in "handle", increase in evenness, elasticity and chemical reactivity of the material.

In the mercerizing process, cotton yarn or fabric is immersed in a strong solution of caustic soda under a controlled tension to prevent shrinkage. If the mercerized material is to have luster with low shrinkage, it must be stretched before the caustic soda solution is washed out. It means that, a considerable force must be applied to the material. After the caustic soda has been washed out of the material, the force may be removed. The material may then be neutralized with acid, washed and then processed in other ways or it may be finished and dried.

Although the literature on mercerization is extensive, the results of one researcher cannot usually be related to that of another chiefly because such conditions as kind of cotton, yarn, caustic strength, tension, etc. are not the same. Also most researcher usually have had only one or two particular factor or properties under study.

Generally cotton mercerization is conducted in a mercerizing bath containing high concentration of sodium hydroxide solution such as 20-30%. After each treatment, the alkali waste solution is either reused or treated with an acid for neutralization in waste treatment process. To save cost in this waste treatment, alkali concentration used in mercerization should be decreased if possible. Several evidences have shown that using same alkali concentration, mercerization at low temperature provides fabric with higher degree of mercerization than conducting at high temperature. An evidence indicate that sodium hydroxide behaves as a stronger base when it is cold than it is warm. Therefore, it might be possible to mercerize cotton at low temperature using low alkali concentration. The lower the alkali uses in mercerizing process, the saver the cost of chemicals, water, and possibly the energy.

# CHAPTER III

# EXPERIMENTAL

## 3.1 Materials

| | | |
|---|---|---|
| Samples | : | Bleached knitted cotton fabric, yarn count 32/1, single jersey, weigh 1.37 g/100 $cm^2$ |
| | : | Bleached cotton knitted fabric, yarn count 20/1(body size), single jersey, weigh 1.98 g/100 $cm^2$ |
| | : | Bleached cotton woven fabric, yarn count 20/1, plain, weigh 1.08 g/100 $cm^2$ |
| Standard Sample | : | Unmercerized cotton yarn 40/2, supplied by Test Fabrics, Inc., USA |
| Dye | : | Direct dye, Benzopurpurine 4B, supplied by Tokyo Chemical Industry Co., Ltd., Japan |
| Chemicals | : | Analytical grade chemicals (see Table 3.1) |

Table 3.1 Chemicals used in this project.

| Chemicals | Company |
|---|---|
| Sodium hydroxide pellets 98% | Fluka |
| Formic acid 98% | Fluka |
| Barium hydroxide octahydrate powder | Fluka |
| Hydrochloric acid 36.5-38.0% | JT.Baker |
| Petroleum ether solvent ACS, boiling range 40-60°C | Becthai |
| Ethanol 95% | Fluka |
| Phenolphthalein indicator powder, pH 8.2-9.8 | Merck |

Table 3.1 (Continue)

| Chemicals | Company |
|---|---|
| Sodium carbonate powder 99.5% | Merck |
| Nonionic surfactant solution | U.N.T. Chemical Co., Ltd. |
| Amylase enzyme (Termamyl 120 L), activity 120,000 units/g | Novo Nordisk |

## 3.2 Equipment

1. Laboratory exhausted dyeing machine, Ahiba Polymat®
2. Bursting strength tester, Osaka Koho Co., Ltd. Model SD-223
3. Tensile strength tester, LR 5 K, LLOYD Instrument
4. Macbeth reflectance spectrophotometer, Color-eye 7000
5. pH meter, Orion model 720 A
6. Heating mantle, Electromantle MA
7. Hot plate, Framo-Geratetechnik M21/1
8. Oven, Memmert 854 Schwabach
9. Electrical analytical balance, Precisa 1000C-3000D
10. Magnetic stirrer, Framo-Geratetechnik, M21/1
11. Ice bath
12. Water bath, Memmert 854 Schwabach
13. 2 x 2 $ft^2$ stainless steel frame
14. Temperature control bath, Eyela CA-101 Cool Ace
15. Pilot scale mercerizing machine for knitted fabrics
16. Tension meter, ZBF, Tetko mat™F

### 3.3 Fabric Mercerizing Processes

Fabrics were treated with sodium hydroxide solution as follows.

3.3.1 Woven Fabric Mercerizing Process

Woven fabrics were each immersed in various concentrations of sodium hydroxide solutions (10%, 15%, 20%, 25%, 30%) at various temperatures (40°C, 30°C, 20°C, 15°C, 10°C, 5°C) for 30 seconds. Then each of them was stretched for 10 minutes on a 2 x 2 $ft^2$ stainless steel frame (Figure 3.1) under a constant tension of 6 N/cm measured by a tension meter (Figure 3.2) and was rinsed with tap water to remove excess alkali solution after stretching. The fabric was removed from the frame, immersed in 1% formic acid solution for neutralization, rinsed with tap water until neutral pH, squeezed and dried. Untreated and treated fabrics were tested for degree of mercerization, dye absorption, tensile strength, and pH.

Figure 3.1 2 x 2 $ft^2$ Stainless steel frame

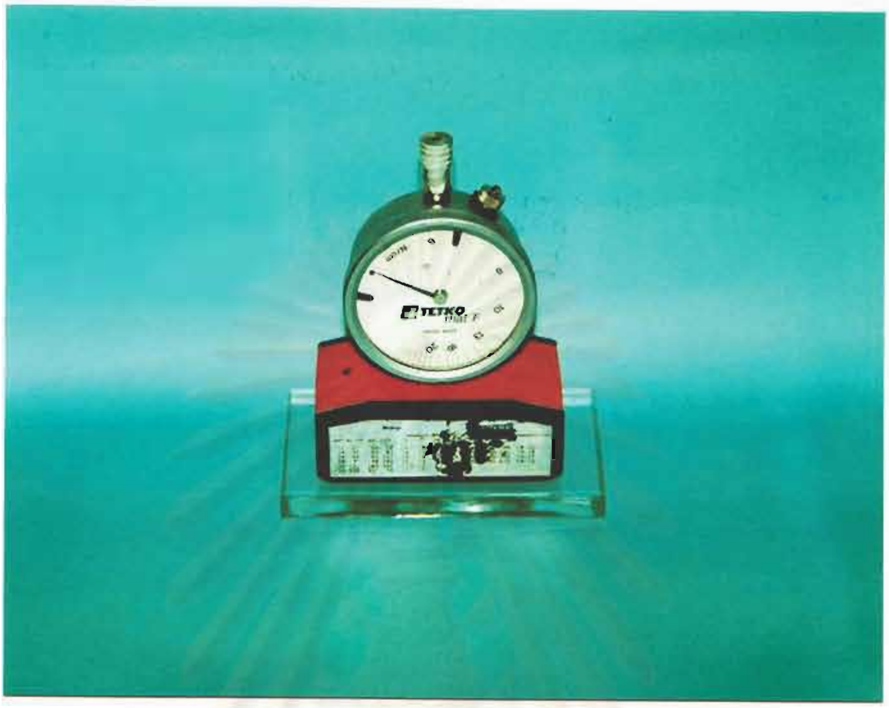



Figure 3.2 Tension meter (ZBF, Tetko mat™F)

3.3.2 Knitted Fabric Mercerizing Processes

3.3.2.1 *Processing on the Stainless Steel Frame*

Knitted fabrics were each immersed in various concentrations of sodium hydroxide solutions (10%, 15%, 20%, 25%, 30%) at various temperatures (40°C, 30°C, 20°C, 15°C, 10°C, 5°C) for 30 seconds. Then each of them was stretched for 10 minutes on a 2 x 2 $ft^2$ stainless steel frame under an appropriate tension and was rinsed with tap water to remove excess alkali solution after stretching. The fabric was removed from the frame, immersed in 1% formic acid solution for neutralization, rinsed with tap water until neutral pH, squeezed and dried.

An additional experiment was conducted in order to study the effects of immersion time and stretching time on mercerizing results. Knitted fabrics were each immersed in 20% sodium hydroxide solutions at 5°C. Time for fabric immersion was increased from 30 seconds to 40 and 60 seconds and time for stretching was changed from 10 minutes to 5, 15, and 30 minutes.

Untreated and treated fabrics were tested for degree of mercerization, dye absorption, bursting strength, and pH.

3.3.2.2 *Processing on the Pilot Scale Mercerizing Machine*

Knitted fabrics were each mercerized on the pilot scale mercerizing machine (Figure 3.3) at 15% and 20% sodium hydroxide solution at 10°C and 30°C respectively. These conditions were chosen based on mercerizing results processing on the stainless steel frame mentioned in section 3.3.2.1.


Figure 3.3 Pilot scale mercerizing machine

Knitted fabric was first immersed, under tension controlled by the machine speed, into the first bath containing sodium hydroxide solution for 30 seconds. Then the fabric was continuously rinsed in three bath of 90°C water for neutralization, squeezed and dried. Treated fabrics were tested for degree of mercerization, dye absorption, bursting strength and pH.

### 3.4 Test Procedures

All unmercerized and mercerized cotton woven and knitted fabrics were tested for properties. The test procedures are described as follows.

3.4.1 Degree of Mercerization Measurements

Both woven and knitted fabrics were measured for the degree of mercerization using the barium number test, AATCC Test Method 89[26] "Mercerization in Cotton." This test method gives the degree of mercerization of cotton yarns and fabrics and indicates the completeness of the reaction between cotton sample and mercerizing agent. All samples are required to pass a two steps extraction. Firstly, each cotton sample and a skein of standard unmercerized cotton yarn are refluxed together for 1 hour with petroleum solvent, 1 hour with alcohol and 1 hour with distilled water. Secondly, they are desized in an enzyme solution for 1 hour, boiled in a solution of soap and soda ash for another hour and washed throughly with water until neutral pH. After they are dried, they are separately soaked in barium hydroxide solutions for at least 2 hours. In case cotton sample is fabric, it is required to be cut into small pieces before soaking in barium hydroxide solution. After 2 hours, 10 ml is drawn from each solution and blank solution to be titrated with hydrochloric acid solution. The titration result determines the ratio of barium hydroxide absorbed by the sample to that absorbed by the standard. Then multiply this ratio by 100 to obtain the barium activity number (BAN). BAN in the range of 100-105 indicates no mercerization, above 150 indicates substantially complete mercerization, and intermediate number (106-150) indicates incomplete mercerization.

3.4.2 Tensile Strength Measurements

Woven fabrics were tested for breaking load and breaking elongation by The Standard for Method of Testing for Textiles, volume 9 [27], "Breaking load and elongation of woven fabrics." This test method covers raveled strip and cut strip test procedures for determining the breaking load and breaking elongation of woven fabrics. Each sample is cut along warp and weft sides to the amount described in the test method and clamped to the testing machine (Figure 3.4). The sample is then extended with a constant rate of 100 ± 10 mm per minute until breakage. The breaking load and elongation are recorded.


Figure 3.4 Tensile strength tester (LR 5 K, LLOYD Instrument)

### 3.4.3 Bursting Strength Measurements

The strength of knitted fabrics was measured using the Standard for Method of Testing for Textiles, volume 19 [28]. "Diaphragm Bursting Strength and Bursting Distension Tester Method." This test method covers the determination of the bursting strength and bursting distension of knitted fabrics. Each sample is securely clamped to the machine (Figure 3.5) without tension. When the machine is started, a force is exerted against the sample through a diaphragm until rupture occurs. The rupture force minus the residual force of the clamp when knitted fabrics was removed is the bursting strength.

Figure 3.5 The Hydraulic Diaphragm Bursting Strength Tester (Osaka Koho Co., Ltd. Model SD-223)

3.4.4 pH Measurements

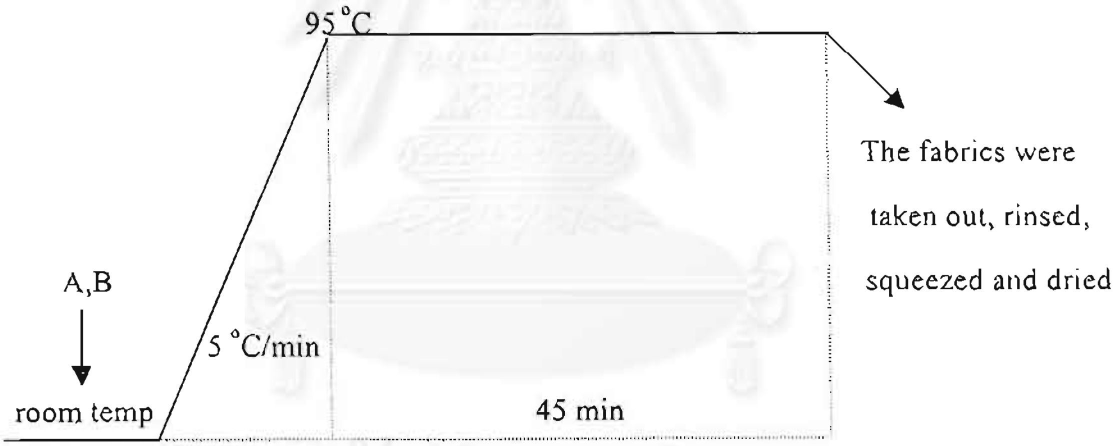
The procedure to determine pH of textile products is "pH of the Water-Extract from Bleached Textiles", AATCC Test Method 81 [29]. The test result indicates the efficiency of textile washing operation after various wet treatments. pH value of textile product is an important factor in further treatments such as dyeing or finishing. Each sample is boiled in distilled water at a moderate rate for 10 minutes. Then let all contents cool to room temperature. Remove the sample and measure the pH of water-extract by a pH meter (Figure 3.6). The pH of water-extract depends on the chemical treatment previously given to the sample, the pH of the wash-water, and the efficiency of the washing operation. Normally, pH of the water-extract will be higher after caustic boiling than after bleaching. If the material is scoured after bleaching, the pH may be lower.


Figure 3.6 pH meter (Orion 720 A)

3.4.5 Dye Absorption Measurements

Woven and knitted fabrics were dyed with direct dye, Benzopurpurine 4B 1% o.w.f. (of weight of fabric) in the Ahiba Polymat® laboratory dyeing machine (Figure 3.7) at a liquor ratio of 30:1. The dyeing process was commenced at room temperature, raised to 95 °C (5°C/minute) and maintained at this temperature for 45 minutes. The dyed fabrics were then removed from dye solution, rinsed throughly in running tap water, squeezed and dried.

The dyeing process is illustrated in Diagram 3.1.




where A = Woven or knitted fabric

B = Dye solution

Diagram 3.1 The dyeing process


Figure 3.7 Ahiba Polymat® laboratory dyeing machine

After dyeing, samples were measured for color strength by using an Instrumenta Color System (I.C.S.) Macbeth reflectance spectrophotometer (Figure 3.8) to measur the reflectance values of the samples at 520 nm. Increasing the concentration or strengtl of the dye on the fabric results in a decrease in the fabric reflectance (R) at th wavelength of maximum absorption ($\lambda_{max}$). The sample with more dyestuff on give higher color strength. The color strength of the dyed fabric can be expressed as K/! value calculated by the Kubelka Munk equation [5,30] :

$$K/S = \frac{(1-R)^2}{2R}$$

where K is the absorption coefficient.

S is the scattering coefficient.

R is the reflectance of the fabric at the wavelength of maximum absorption ($\lambda_{max}$)


Figure 3.8 I.C.S. Macbeth spectrophotometer (Color-eye 7000)

# CHAPTER IV

# RESULTS AND DISCUSSION

## 4.1 Degree of Mercerization

The degree of mercerization is usually estimated by determining a barium activity number (BAN) according to a method developed by the American Association of Textile Chemists and Colorists (AATCC). Fabric with high BAN also indicates high degree of mercerization. BAN of complete mercerized cotton fabric is above 150 [26] but in general, fabric mercerized in the factory obtains BAN in the range of 130-140 which is acceptable and two samples containing BAN differences of 4-5 indicate no significant difference.

### 4.1.1 Degree of Mercerization of Woven Fabric

Table 4.1 and Figure 4.1 show BAN of unmercerized woven fabrics and mercerized woven fabrics with 10%, 15%, 20%, 25%, and 30% sodium hydroxide (NaOH) solutions at 40°C, 30°C, 20°C, 15°C, 10°C, and 5°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

Results indicate that fabrics mercerized with 10% NaOH solutions have the same BAN as unmercerized fabrics with BAN lower than 130 and fabrics mercerized with 20-30% NaOH solutions obtain BAN above 130 at all temperatures. Thus, NaOH solution at 10% concentration may not be used as the mercerizing agent for this fabric due to providing low degree of mercerization comparable to unmercerized fabric. Mercerization using 15% NaOH solution provides fabrics with BAN approaching 130 when mercerizing temperature is below 20°C. To mercerize this woven fabric to the required BAN, a minimum concentration of 15% NaOH solution is needed. Table 4.1 also indicates that upon mercerization, BAN of mercerized fabric increases with increasing the concentrations of NaOH solutions or the mercerizing agent but it does not change significantly with changing the mercerizing temperatures.

Table 4.1 BAN of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | BAN | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 117.50 | | | | | |
| 10% NaOH | 108.59 | 114.17 | 117.77 | 117.30 | 116.67 | 112.97 |
| 15% NaOH | 111.24 | 117.05 | 121.08 | 129.30 | 122.40 | 125.35 |
| 20% NaOH | 145.83 | 130.03 | 148.62 | 149.74 | 151.72 | 142.98 |
| 25% NaOH | 152.98 | 153.09 | 163.54 | 163.02 | 132.64 | 161.84 |
| 30% NaOH | 168.09 | 159.07 | 164.42 | 172.88 | 170.64 | 163.53 |



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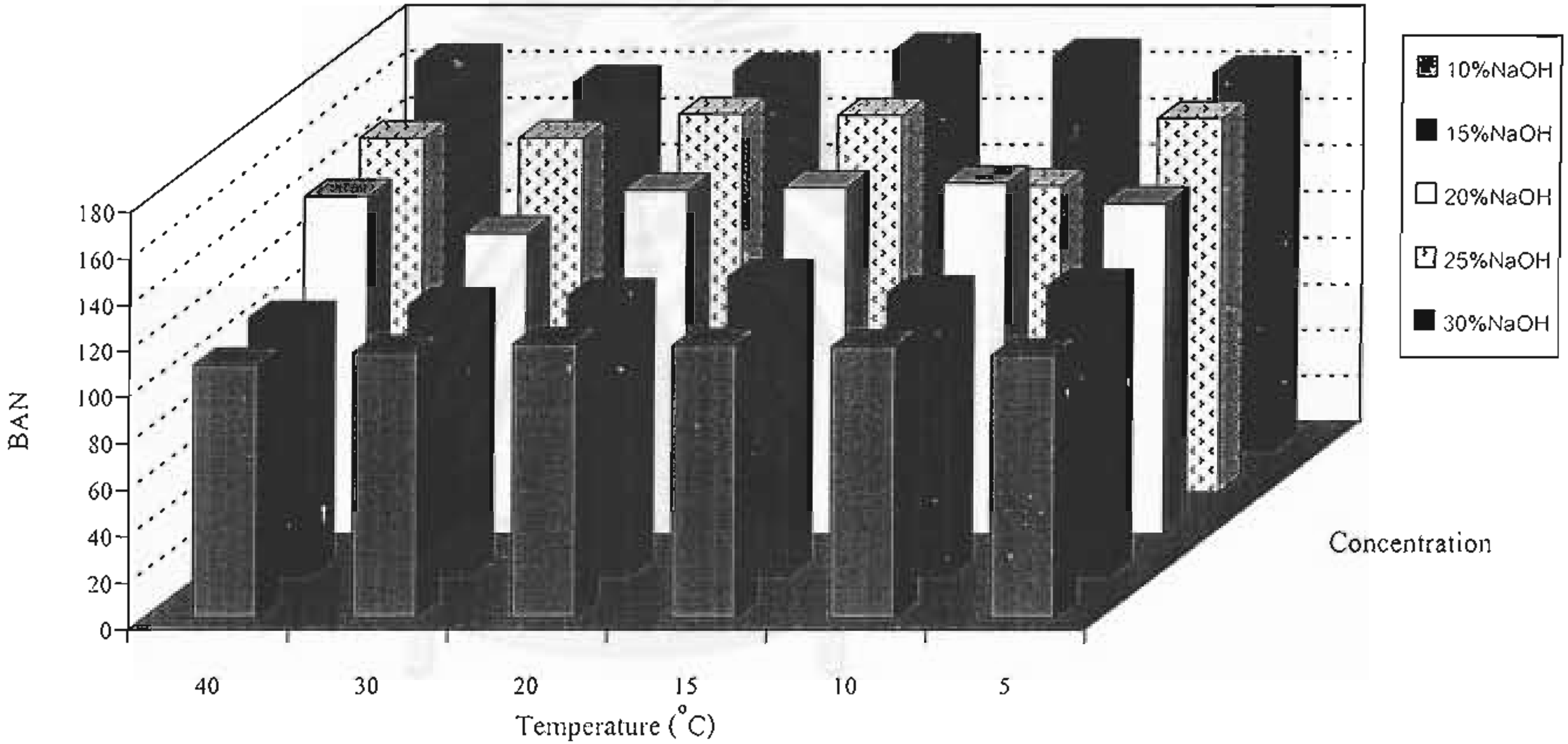


(BAN of unmercerized woven fabric = 117.50)

Figure 4.1 BAN of mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

### 4.1.2 Degree of Mercerization of Knitted Fabrics Mercerized on the Stainless Steel Frame

Table 4.2 and Figure 4.2 show BAN of unmercerized knitted fabrics and mercerized knitted fabrics with 10%, 15%, 20%, 25%, and 30% NaOH solutions at 40°C, 30°C, 15°C, 10°C, and 5°C for 30 seconds under a constant tension for 10 minutes on a stainless steel frame, washed and neutralized with formic acid.

Mercerized knitted fabrics obtain the overall results in the same manner as the mercerized woven fabrics. In addition, knitted fabrics mercerized with 15% NaOH solution at temperatures below 15°C show BAN above 130. When the mercerization is conducted at higher concentrations of NaOH solutions above 15%, changing the mercerizing temperatures does not significantly change the BAN of mercerized fabric.

Results in sections 4.1.1 and 4.1.2 indicate that mercerization of woven and knitted fabrics can be done with acceptable BAN at low concentration of NaOH solutions as 15%. To mercerize at low concentration, mercerizing temperature must be decreased to 15°C or lower.

Table 4.2 BAN of unmercerized and mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| BAN | | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 90.68 | | | | | |
| 10% NaOH | 92.65 | 93.91 | 96.81 | 99.14 | 98.58 | 100.84 |
| 15% NaOH | 117.88 | 112.50 | 126.10 | 125.08 | 135.25 | 132.75 |
| 20% NaOH | 148.92 | 155.73 | 155.65 | 156.44 | 153.82 | 155.53 |
| 25% NaOH | 159.29 | 157.90 | 165.53 | 161.81 | 165.17 | 165.71 |
| 30% NaOH | 167.05 | 164.90 | 166.76 | 168.91 | 167.41 | 168.08 |

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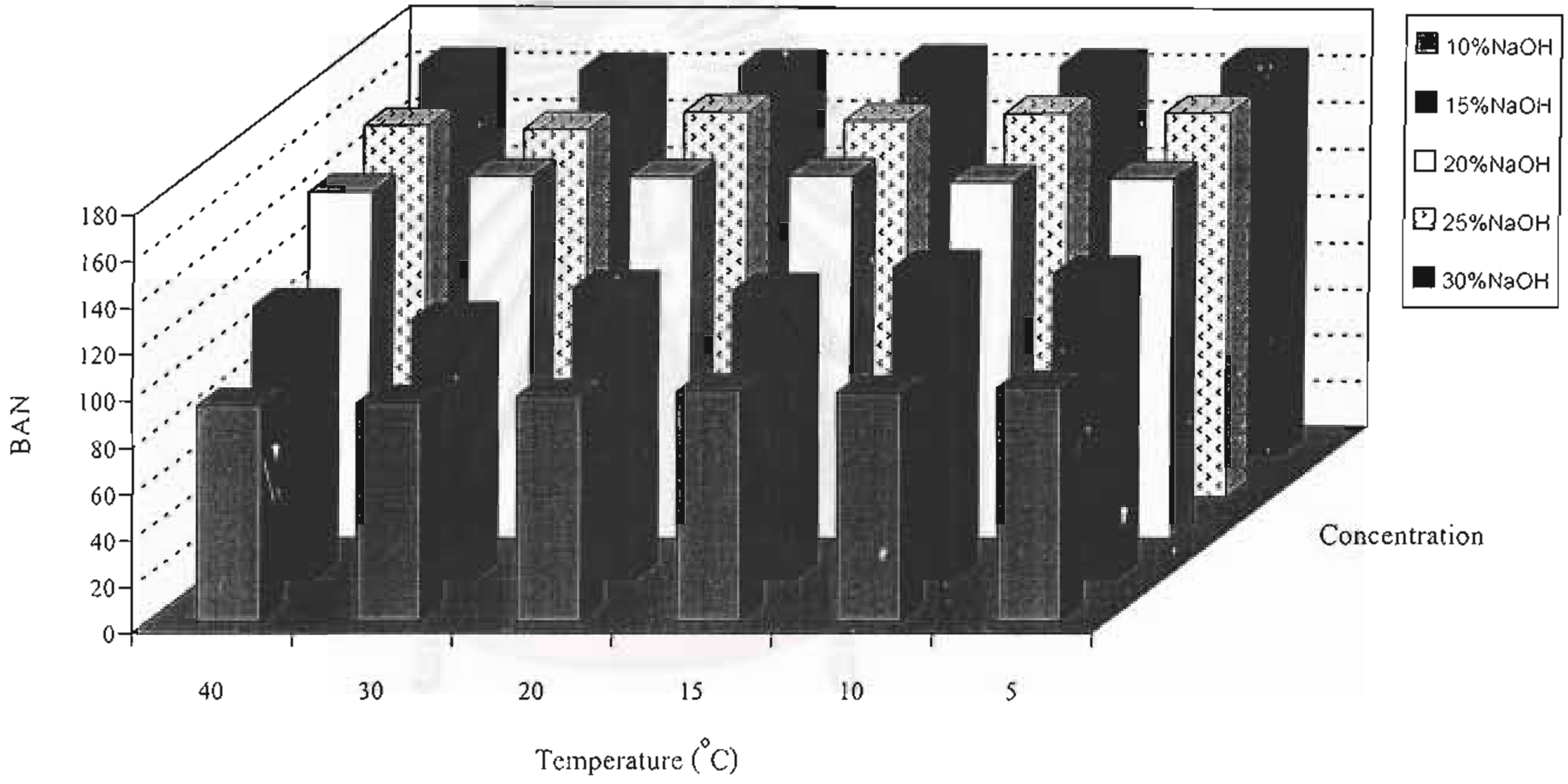


(BAN of unmercerized knitted fabric = 90.68)

Figure 4.2 BAN of mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

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4.1.3 Degree of Mercerization of Knitted Fabric Mercerized on the Pilot Scale Mercerizing Machine

Knitted fabrics were mercerized on the pilot scale mercerizing machine at 15% and 20% NaOH solution at 10°C and 30°C respectively. The first mercerizing condition represents a mercerization with low concentration NaOH solution at low temperature while the second represents a typical mercerization. Both mercerizing conditions provide fabrics with BAN above 130 (see Table 4.3 and Figure 4.3). It demonstrates that the mercerizing condition of 15% NaOH solution at 10°C (low concentration and low temperature) will be an acceptable condition for mercerization in the textile wet process.

Table 4.3 BAN of unmercerized and mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water on the pilot scale mercerizing machine.

| condition | BAN |
|---|---|
| unmercerized | 95.84 |
| 15% NaOH 10°C | 134.56 |
| 20% NaOH 30°C | 146.18 |

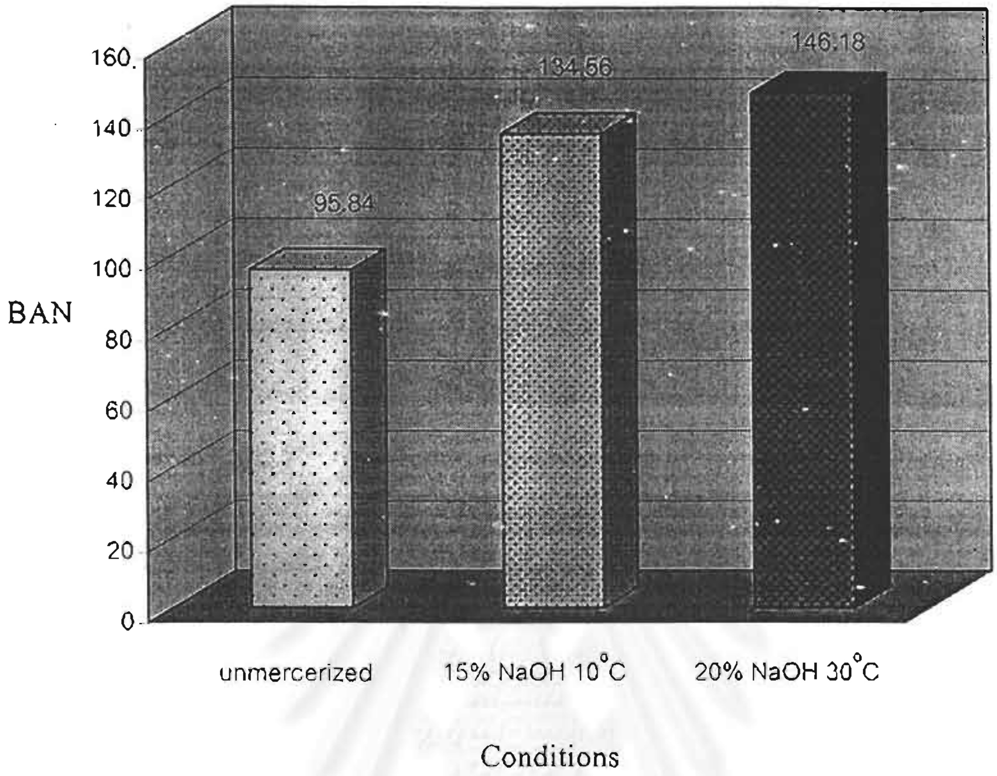


Figure 4.3 BAN of mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water in the pilot scale mercerizing machine.

## 4.2 Fabric Strength

Woven and knitted fabrics were tested for tensile and bursting strength according to the standard test methods mentioned in sections 3.4.2 and 3.4.3. Results are shown as follows.

### 4.2.1 Tensile Strength of Woven Fabric

Tables 4.4-4.7 and Figures 4.4-4.7 show tensile strength of untreated and treated woven fabrics at various conditions. Mercerized fabrics obtain 1-40% higher breaking loads and 25-93% higher elongations than unmercerized fabrics. Mercerization at any mercerizing condition conducted in this experiment increases the fabric strength.

Table 4.4 Breaking load along warp direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| Breaking load (N) | | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 341.57 | | | | | |
| 10% NaOH | 305.70 | 356.97 | 375.23 | 378.27 | 383.75 | 376.10 |
| 15% NaOH | 346.87 | 341.25 | 407.53 | 400.93 | 414.85 | 374.60 |
| 20% NaOH | 422.93 | 369.37 | 438.83 | 451.90 | 419.63 | 439.57 |
| 25% NaOH | 439.70 | 441.37 | 477.87 | 456.77 | 469.95 | 424.57 |
| 30% NaOH | 465.80 | 384.00 | 478.10 | 456.50 | 464.05 | 459.90 |

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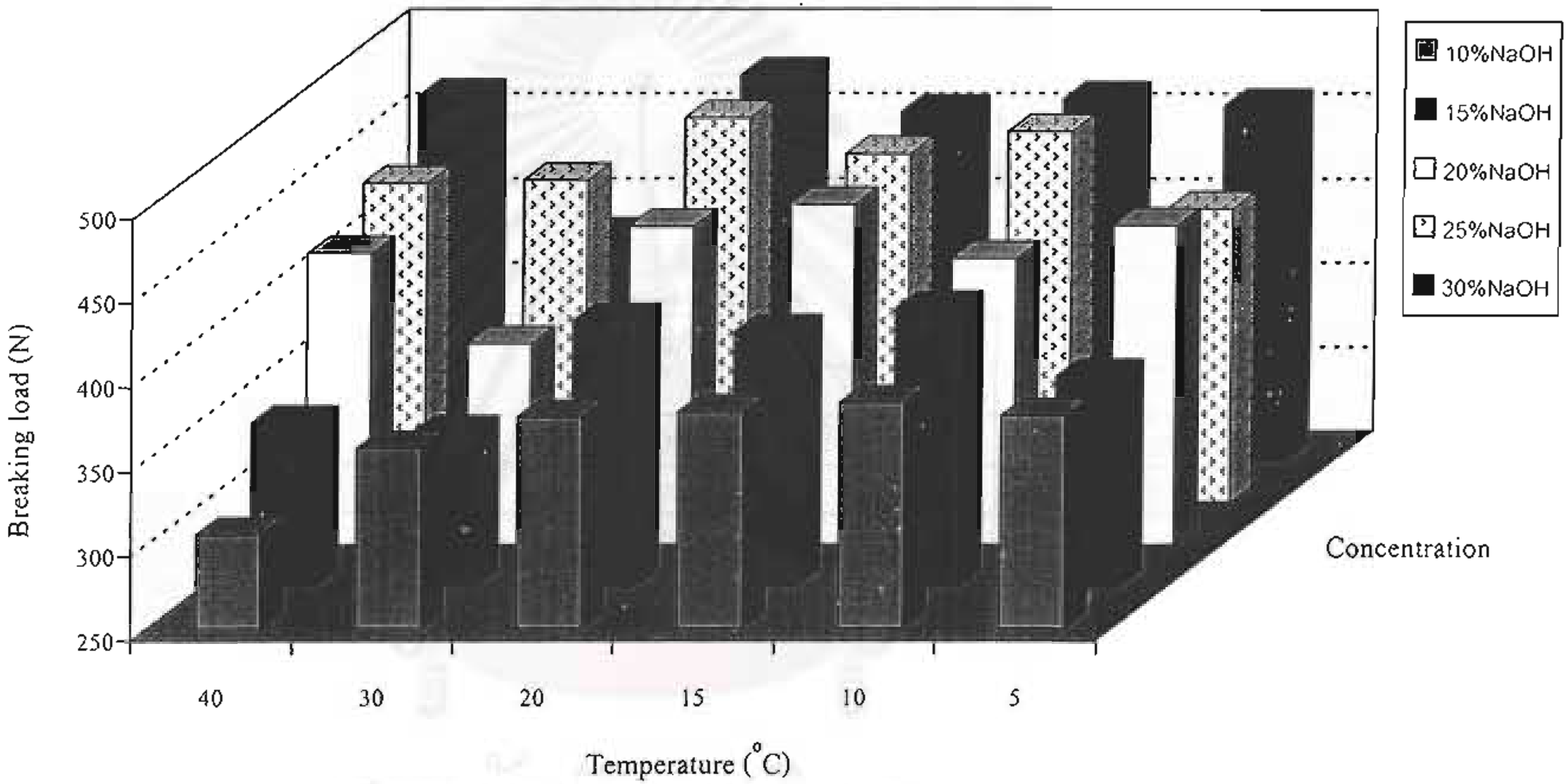


(Breaking load along warp direction of unmercerized woven fabric = 341.57)

Figure 4.4 Breaking load along warp direction of mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

Table 4.5 Breaking load along weft direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | Breaking load (N) | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 240.30 | | | | | |
| 10% NaOH | 300.60 | 299.47 | 309.60 | 373.97 | 353.90 | 337.37 |
| 15% NaOH | 340.00 | 345.10 | 370.40 | 375.75 | 396.37 | 372.93 |
| 20% NaOH | 449.10 | 394.20 | 409.17 | 433.47 | 452.57 | 445.93 |
| 25% NaOH | 382.60 | 402.83 | 447.47 | 439.65 | 419.60 | 412.50 |
| 30% NaOH | 394.30 | 425.63 | 455.50 | 464.50 | 363.67 | 371.93 |

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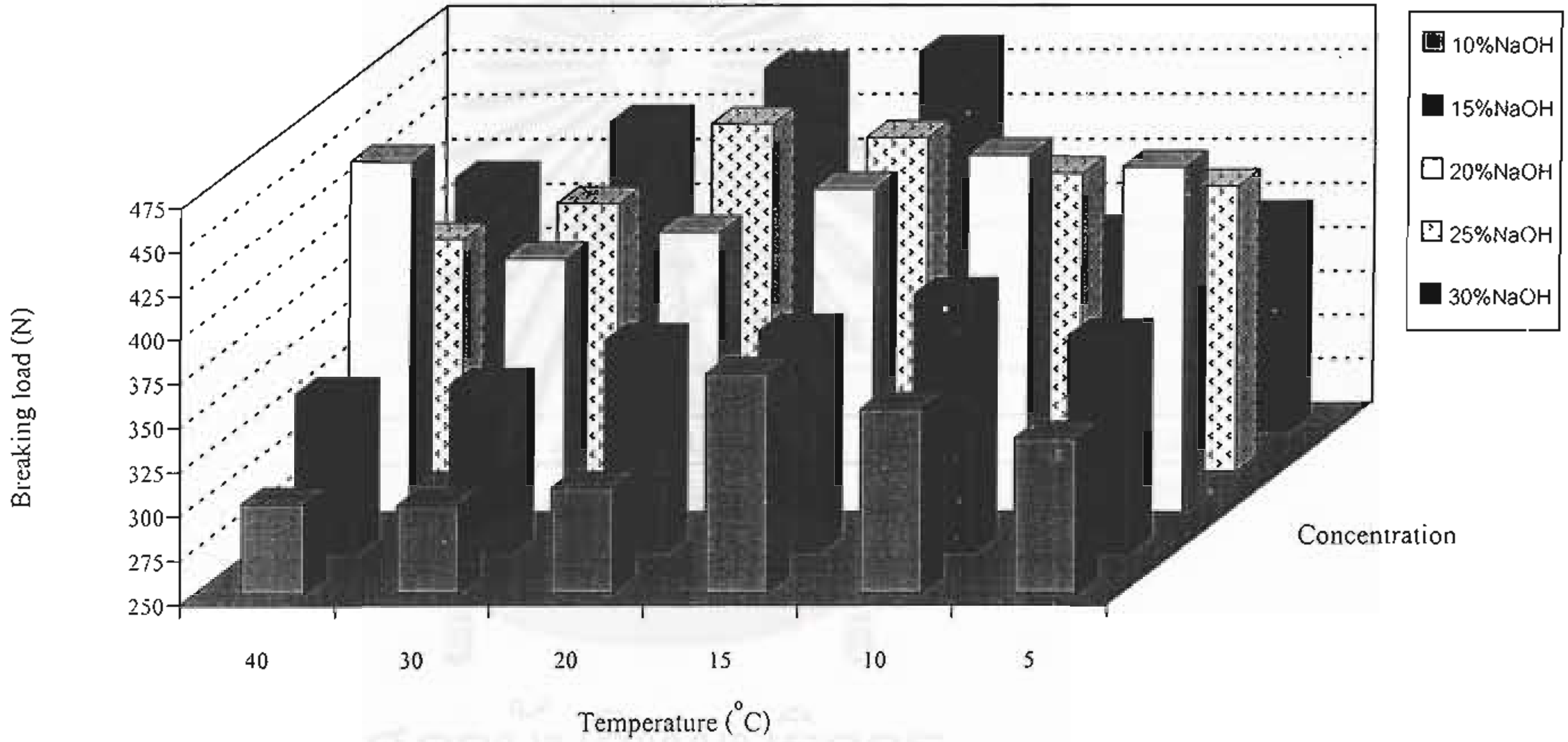


(Breaking load along weft direction of unmercerized woven fabric = 240.30)

Figure 4.5 Breaking load along weft direction of mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

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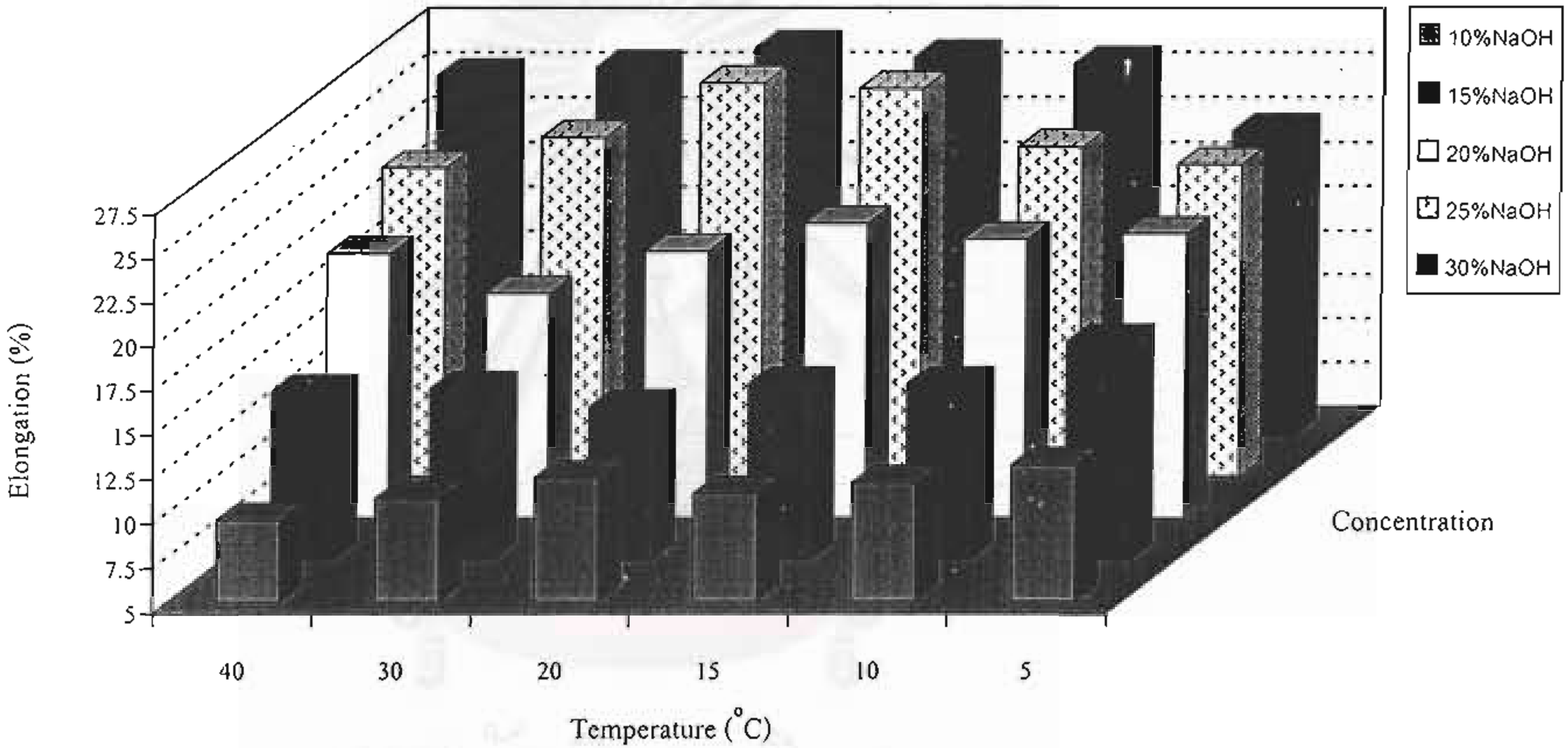
Table 4.6 Elongation along warp direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| Elongation (%) | | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 6.03 | | | | | |
| 10% NaOH | 9.55 | 10.76 | 11.93 | 11.05 | 11.65 | 12.65 |
| 15% NaOH | 14.46 | 14.65 | 13.63 | 14.90 | 14.90 | 17.35 |
| 20% NaOH | 19.99 | 17.74 | 20.12 | 21.69 | 20.80 | 21.13 |
| 25% NaOH | 22.51 | 24.22 | 27.25 | 26.94 | 23.70 | 22.73 |
| 30% NaOH | 25.31 | 25.79 | 26.87 | 26.36 | 26.00 | 22.30 |




(Elongation along warp direction of unmercerized woven fabric = 6.03)

Figure 4.6 Elongation along warp direction of mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

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Table 4.7 Elongation along weft direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| Elongation (%) | | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 21.33 | | | | | |
| 10% NaOH | 18.80 | 17.81 | 20.73 | 22.76 | 18.20 | 18.17 |
| 15% NaOH | 17.89 | 15.60 | 23.45 | 22.07 | 19.10 | 17.07 |
| 20% NaOH | 21.19 | 18.37 | 23.45 | 21.82 | 20.20 | 19.70 |
| 25% NaOH | 22.14 | 22.02 | 25.26 | 22.36 | 20.40 | 19.00 |
| 30% NaOH | 22.39 | 20.80 | 28.61 | 24.91 | 19.37 | 21.43 |



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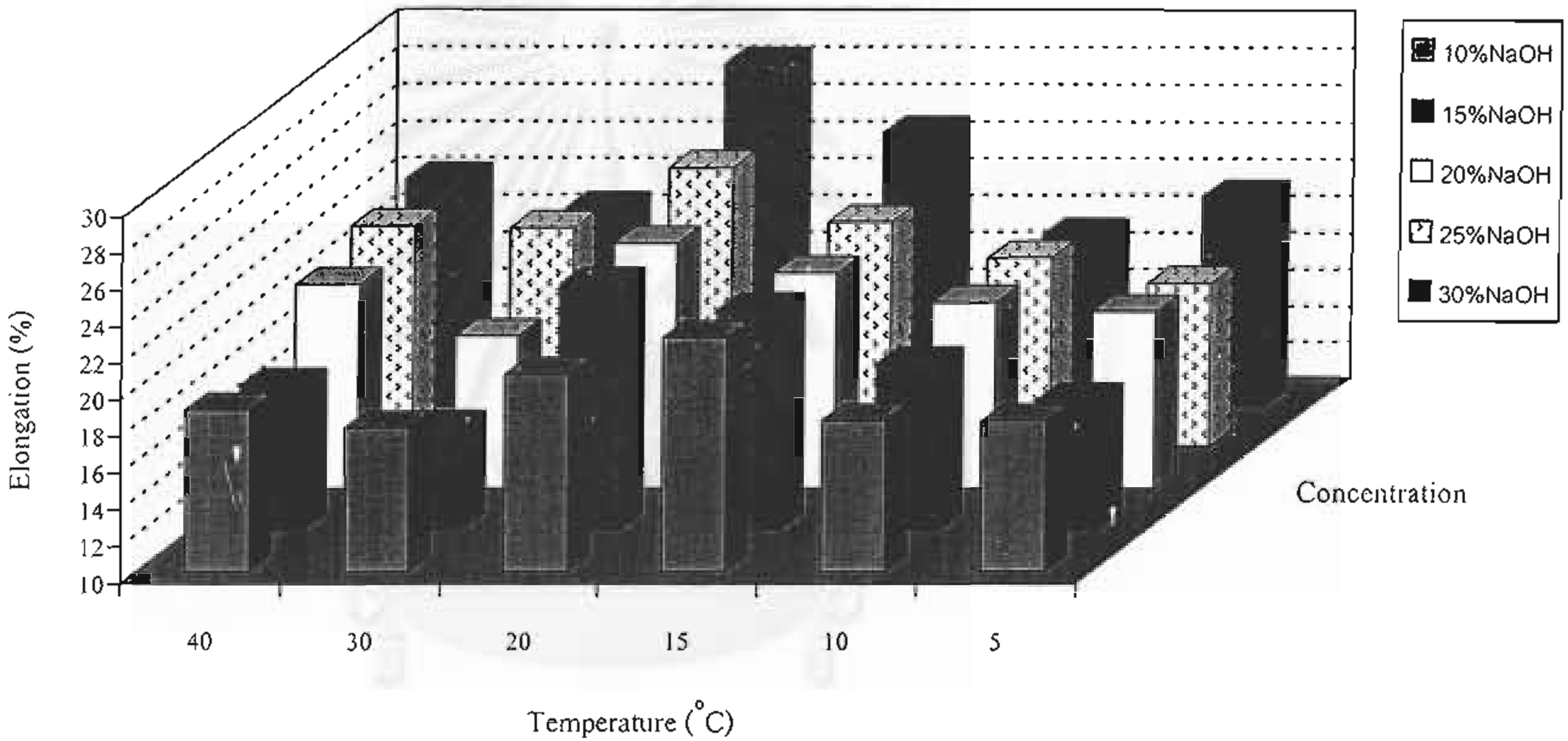


(Elongation along weft direction of unmercerized woven fabric = 21.33)

Figure 4.7 Elongation along weft direction of mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

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4.2.2 Bursting Strength of Knitted Fabric Mercerized on the Stainless Steel Frame

Unmercerized and mercerized knitted fabrics were tested for bursting strength according to The Standard for method of Testing for Textiles, volume 19, "Diaphragm Bursting Strength and Bursting Distension Tester Method."

Table 4.8 and Figure 4.8 reveal that mercerized fabrics obtain 3-26% higher bursting strength than unmercerized fabrics. Mercerization at any mercerizing condition conducted in the experiment increases the fabric strength.

Table 4.8 Bursting strength of unmercerized and mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| Bursting strength (kg/cm$^2$) | | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 5.38 | | | | | |
| 10% NaOH | 5.60 | 5.66 | 5.58 | 5.78 | 5.78 | 5.84 |
| 15% NaOH | 5.83 | 5.98 | 6.22 | 6.22 | 6.54 | 6.42 |
| 20% NaOH | 6.24 | 6.28 | 6.44 | 6.48 | 6.56 | 6.58 |
| 25% NaOH | 6.38 | 6.54 | 6.48 | 6.52 | 6.56 | 6.58 |
| 30% NaOH | 6.34 | 6.34 | 6.64 | 6.46 | 6.62 | 6.78 |

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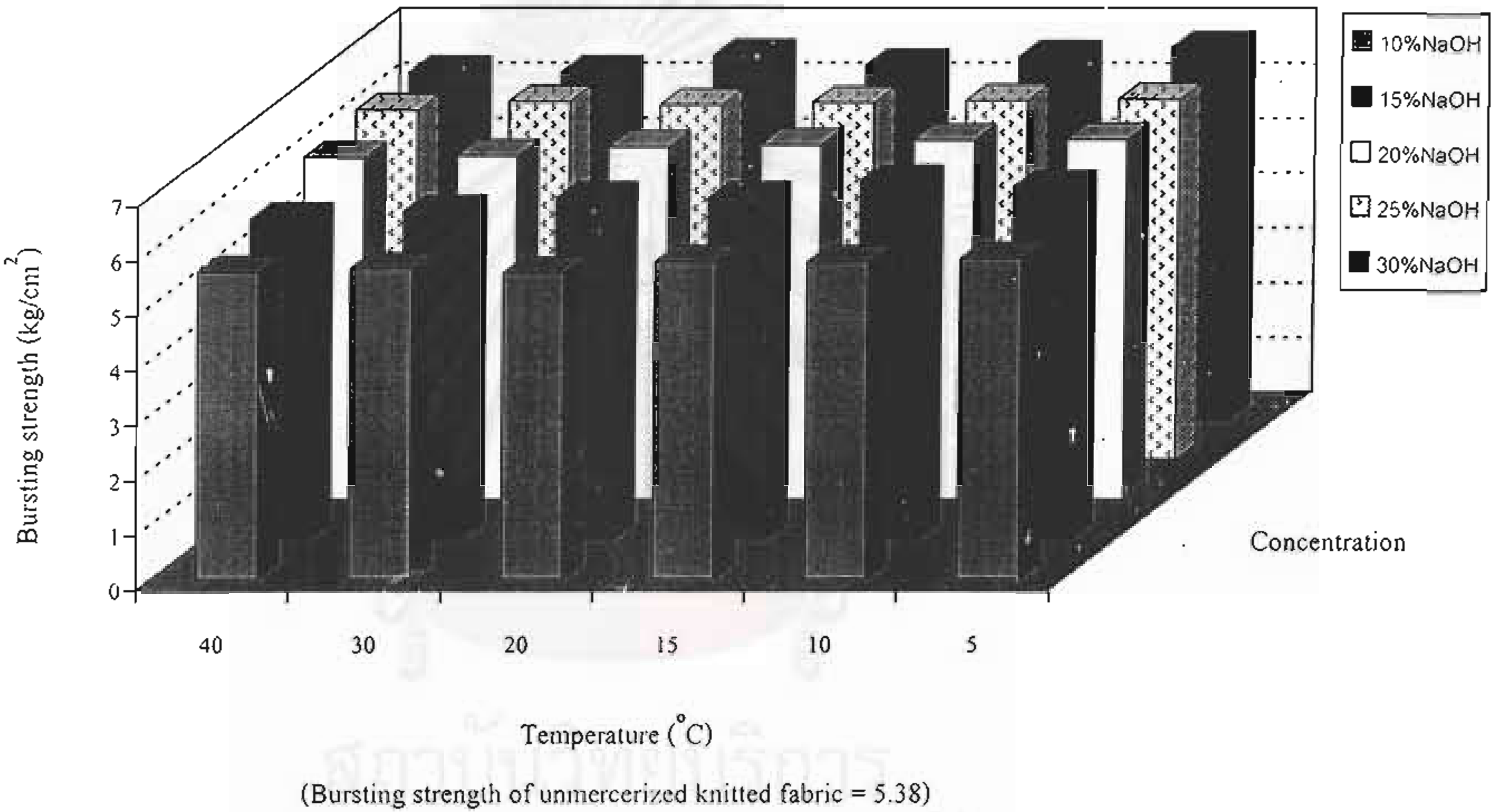


Figure 4.8 Bursting strength of mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

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4.2.3 Bursting Strength of Knitted Fabric Mercerized on the Pilot Scale Mercerizing Machine

Bursting strengths of mercerized fabrics are higher than those of unmercerized fabrics as shown in Table 4.9 and Figure 4.9. Both mercerizing conditions on the pilot scale machine provide fabrics with better strength than fabrics mercerized on the stainless steel frame.

Table 4.9 Bursting strength of unmercerized and mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water on the pilot scale mercerizing machine.

| condition | Bursting strength ($kg/cm^2$) |
|---|---|
| unmercerized | 5.98 |
| 15% NaOH 10°C | 7.78 |
| 20% NaOH 30°C | 8.14 |

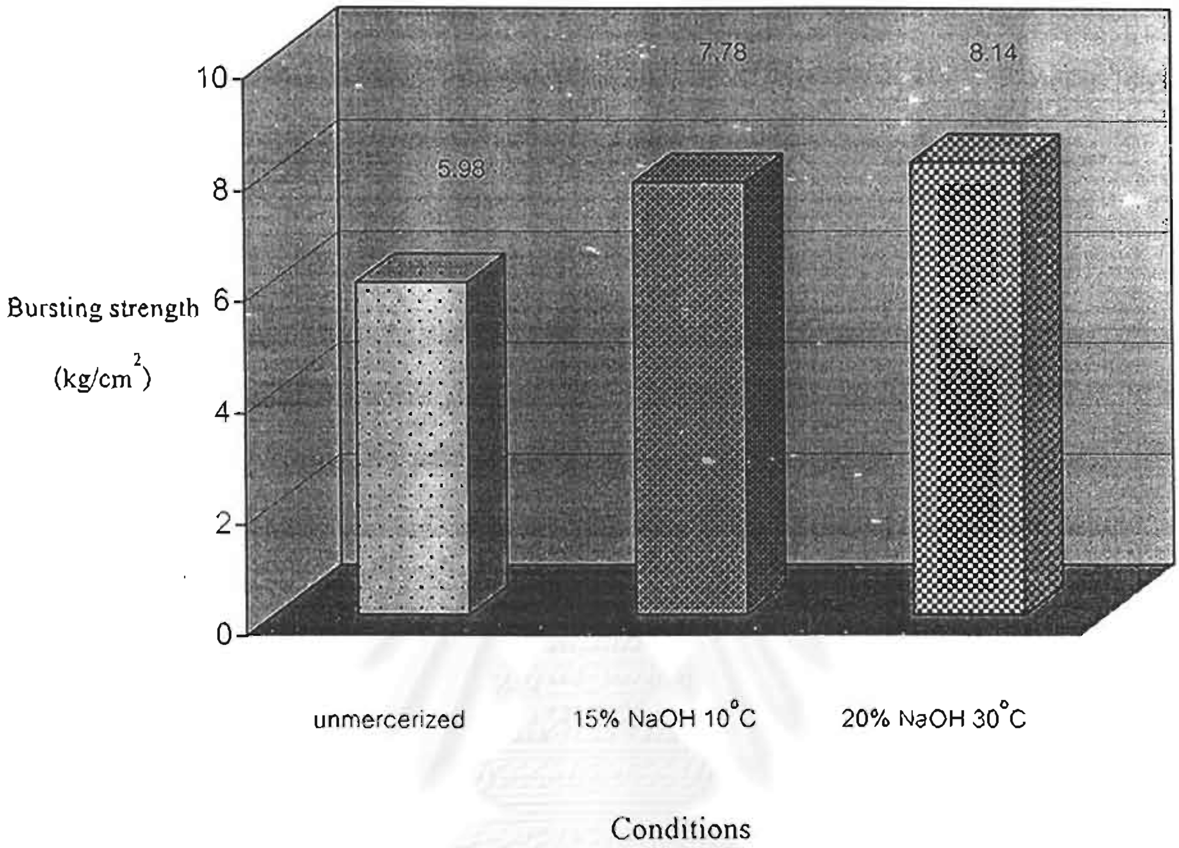


Figure 4.9 Bursting strength of mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water in the pilot scale mercerizing machine.

### 4.3 Fabrics pH

Untreated and treated fabrics were tested for pH of water extract from the fabrics according to a method developed by AATCC Test Method 81, "pH of the Water-Extract from Bleached Textiles." It is to determine the efficiency of fabric washing operation. Normally, pH of water-extract from the finished fabric should be around 6.5-7.5.

4.3.1 pH of Woven Fabric

Table 4.10 and Figure 4.10 show pH of water-extract from unmercerized and mercerized woven fabrics.

pH of water-extract from every sample are in the range of 6.5-7.5. This indicates that the washing operation after mercerizing process is well conducted.

Table 4.10 pH of water-extract from unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | pH | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| distilled water at room temperature | 6.87 | | | | | |
| unmercerized | 6.44 | | | | | |
| 10% NaOH | 6.41 | 7.35 | 6.82 | 6.97 | 6.60 | 6.85 |
| 15% NaOH | 6.60 | 6.92 | 6.55 | 6.85 | 6.64 | 6.66 |
| 20% NaOH | 7.07 | 6.62 | 7.24 | 7.18 | 6.60 | 6.61 |
| 25% NaOH | 7.55 | 6.94 | 7.52 | 7.38 | 6.66 | 6.73 |
| 30% NaOH | 7.54 | 7.29 | 7.55 | 7.38 | 7.35 | 6.77 |

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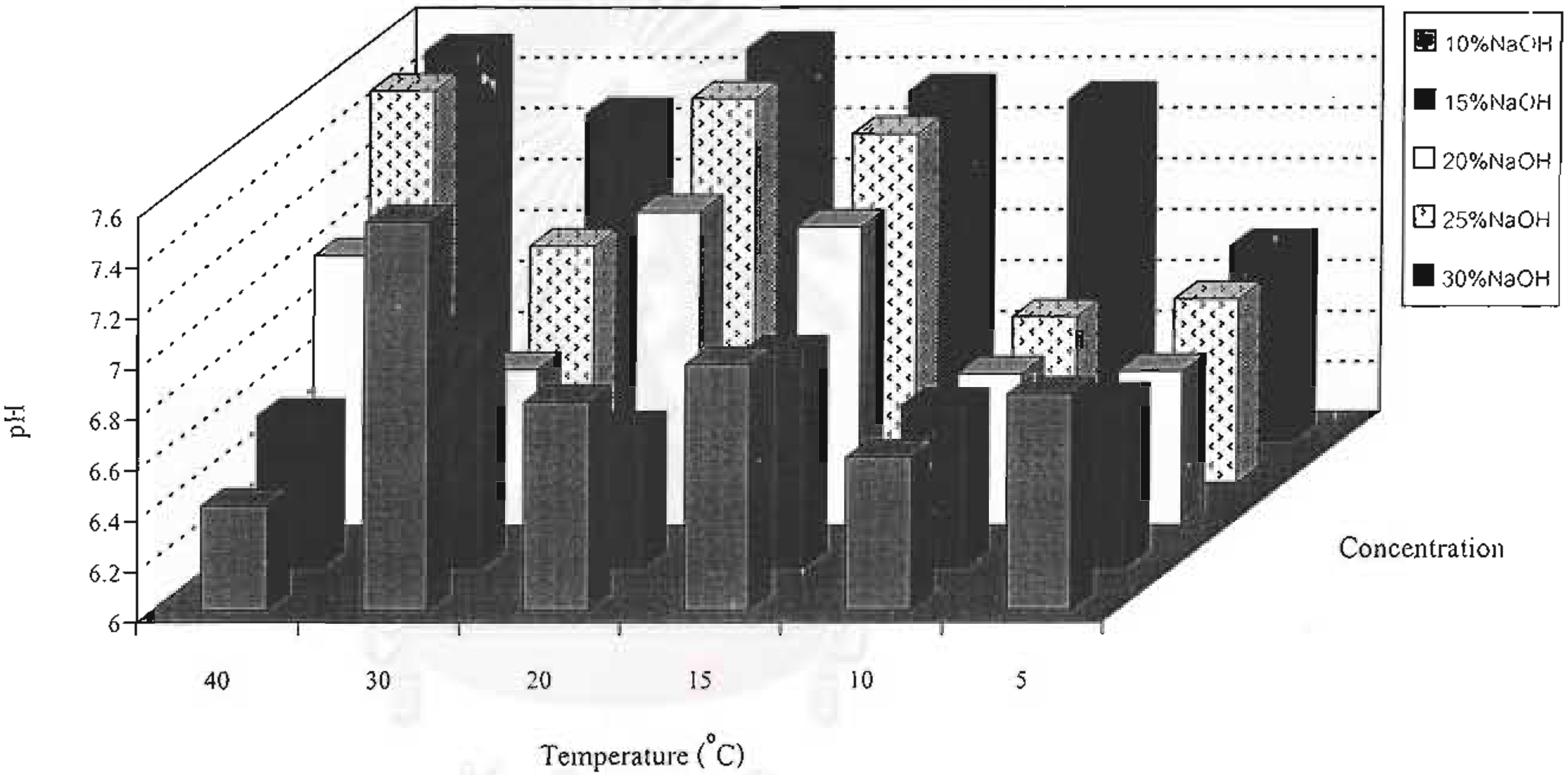



( pH of water-extract from unmercerized woven fabric = 6.44)

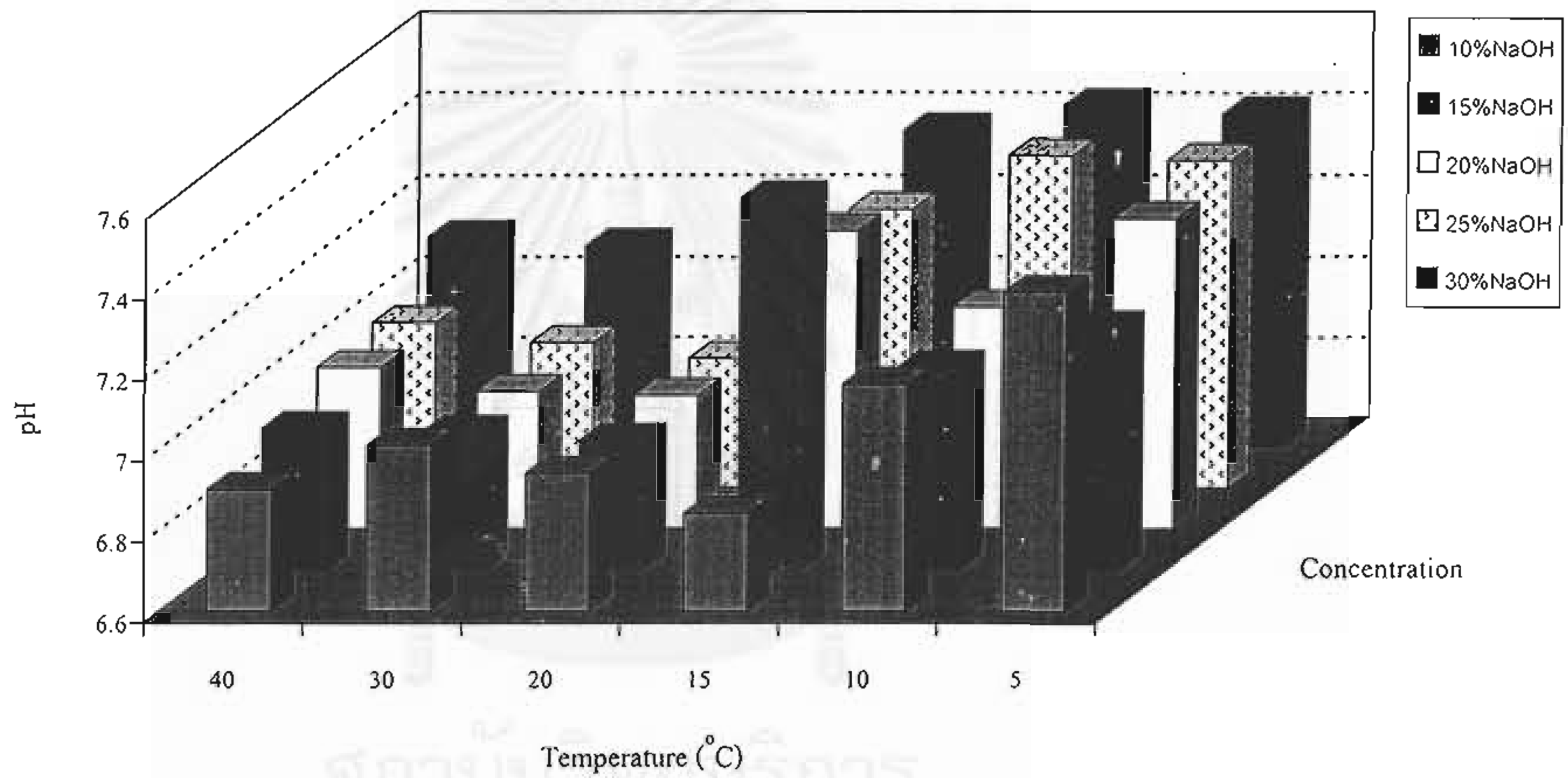
Figure 4.10 pH of water-extract from mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

4.3.2 pH of Knitted Fabric Mercerized on the Stainless Steel Frame

Table 4.11 and Figure 4.11 also show that pH of water extract from knitted fabrics are in the acceptable range of 6.5-7.5. This indicates that the washing operation after mercerizing process of knitted fabrics is well conducted.

Table 4.11 pH of water-extract from unmercerized and mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | pH | | | | | |
|---|---|---|---|---|---|---|
| condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| distilled water at room temperature | 6.83 | | | | | |
| unmercerized | 6.14 | | | | | |
| 10% NaOH | 6.90 | 7.01 | 6.94 | 6.84 | 7.16 | 7.39 |
| 15% NaOH | 6.95 | 6.94 | 6.92 | 7.52 | 7.10 | 7.20 |
| 20% NaOH | 7.00 | 6.94 | 6.93 | 7.34 | 7.15 | 7.37 |
| 25% NaOH | 7.01 | 6.96 | 6.92 | 7.29 | 7.42 | 7.41 |
| 30% NaOH | 7.12 | 7.10 | 6.88 | 7.38 | 7.44 | 7.42 |




(pH of water-extract from unmercerized knitted fabric = 6.14)

Figure 4.11 pH of water-extract from mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

4.3.3 pH of Knitted Fabric Mercerized on the Pilot Scale Mercerizing Machine

Table 4.12 and Figure 4.12 shows that pH of the water-extract from knitted fabrics are also in the range of 6.5-7.5. Although these mercerized fabrics were neutralized with hot water instead of an acid after the mercerizing process, but the pH of water-extract is in the acceptable range. This could indicate that hot water washing can effectively remove excess alkali from the mercerized fabric.

Table 4.12 pH of the water-extract from unmercerized and mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water on the pilot scale mercerizing machine.

| condition | pH |
|---|---|
| distilled water at room temperature | 6.56 |
| unmercerized | 6.89 |
| 15% NaOH 10°C | 7.29 |
| 20% NaOH 30°C | 7.31 |

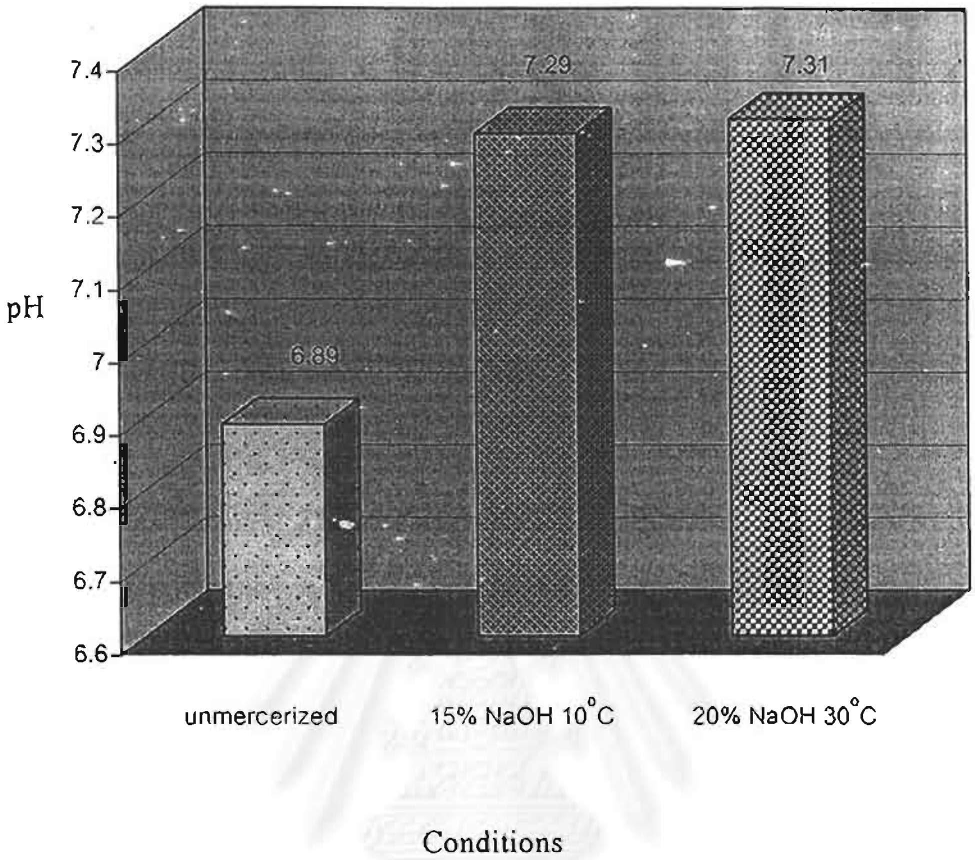



Figure 4.12 pH of water-extract from mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water in the pilot scale mercerizing machine.

## 4.4 Dye Absorption of Fabric

Unmercerized and mercerized fabrics were dyed with direct dye, Benzopurpurine 4B as described in section 3.4.5 to determine for the dye absorption of fabric. The sample with more dyestuff on gives higher color strength which can be expressed as K/S value.

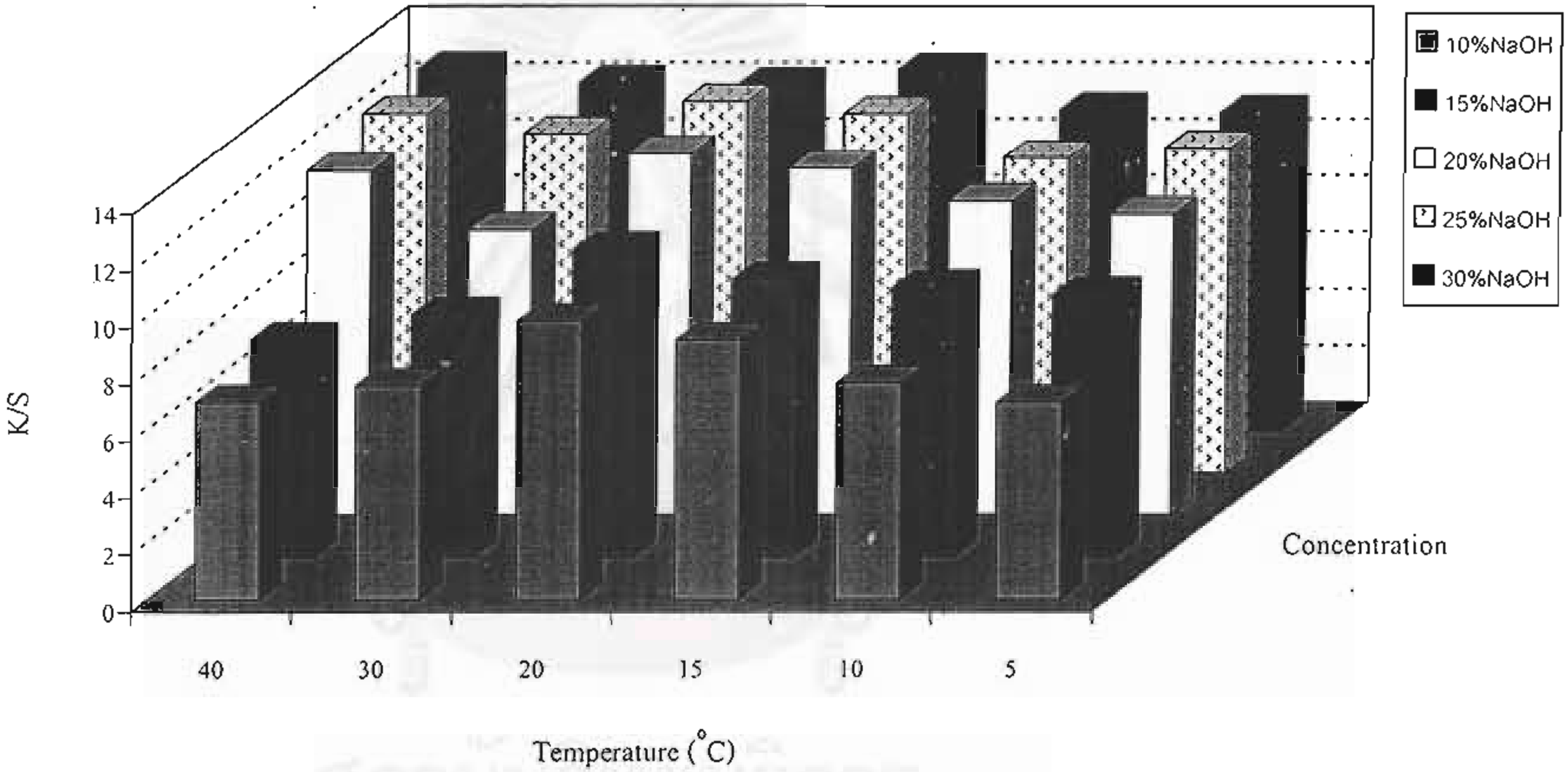
Dyed fabrics were measured for K/S using Macbeth Color-eye 7000 Spectrophotometer.

### 4.4.1 Color Strength of Woven Fabrics

Table 4.13 and Figure 4.13 show that mercerized fabrics obtained 2-80% higher K/S than unmercerized fabrics. Mercerization at any condition in this experiment increases the dye absorption ability of fabric. Comparing the mercerizing condition of 15% NaOH solution at 15°C (low concentration and low temperature) with a typical mercerizing condition of 20% NaOH solution at 30°C, K/S of both conditions is approximately the same. Therefore, it is possible to mercerize this woven fabric with low concentration of 15% NaOH solution at low temperature of 15°C and obtains the same dye absorption of mercerized fabrics.

Table 4.13 K/S of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| K/S | | | | | | |
|---|---|---|---|---|---|---|
| Condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 7.337 | | | | | |
| 10% NaOH | 6.958 | 7.531 | 9.810 | 9.130 | 7.618 | 6.929 |
| 15% NaOH | 7.673 | 8.567 | 10.854 | 9.784 | 9.505 | 9.277 |
| 20% NaOH | 12.151 | 10.055 | 12.758 | 12.241 | 11.078 | 10.609 |
| 25% NaOH | 12.700 | 11.989 | 13.130 | 12.680 | 11.127 | 11.475 |
| 30% NaOH | 12.809 | 12.308 | 12.231 | 12.777 | 11.345 | 11.259 |




(K/S of unmercerized woven fabric = 7.337)

Figure 4.13 K/S of mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

### 4.4.2 Color Strength of Knitted Fabrics Mercerized on the Stainless Steel Frame

Table 4.14 and Figure 4.14 indicate that mercerized fabrics obtain 24-190% higher K/S than unmercerized fabric. Mercerization increases the dye absorption ability of knitted fabric. Results also indicate that it is possible to mercerize this knitted fabric at low concentration of NaOH solution such as 15% at low temperature of 10°C and obtains the same dye absorption as the typical mercerizing condition using 20% NaOH solution at 30°C.

Table 4.14 K/S of unmercerized and mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| K/S | | | | | | |
|---|---|---|---|---|---|---|
| Condition | 40°C | 30°C | 20°C | 15°C | 10°C | 5°C |
| unmercerized | 5.328 | | | | | |
| 10% NaOH | 6.622 | 7.586 | 7.513 | 8.384 | 7.131 | 9.094 |
| 15% NaOH | 9.127 | 10.233 | 13.041 | 12.913 | 13.658 | 14.312 |
| 20% NaOH | 13.112 | 13.571 | 13.935 | 15.490 | 14.534 | 15.197 |
| 25% NaOH | 13.931 | 14.143 | 13.989 | 13.470 | 14.697 | 14.436 |
| 30% NaOH | 13.678 | 14.161 | 14.168 | 14.072 | 14.597 | 14.498 |

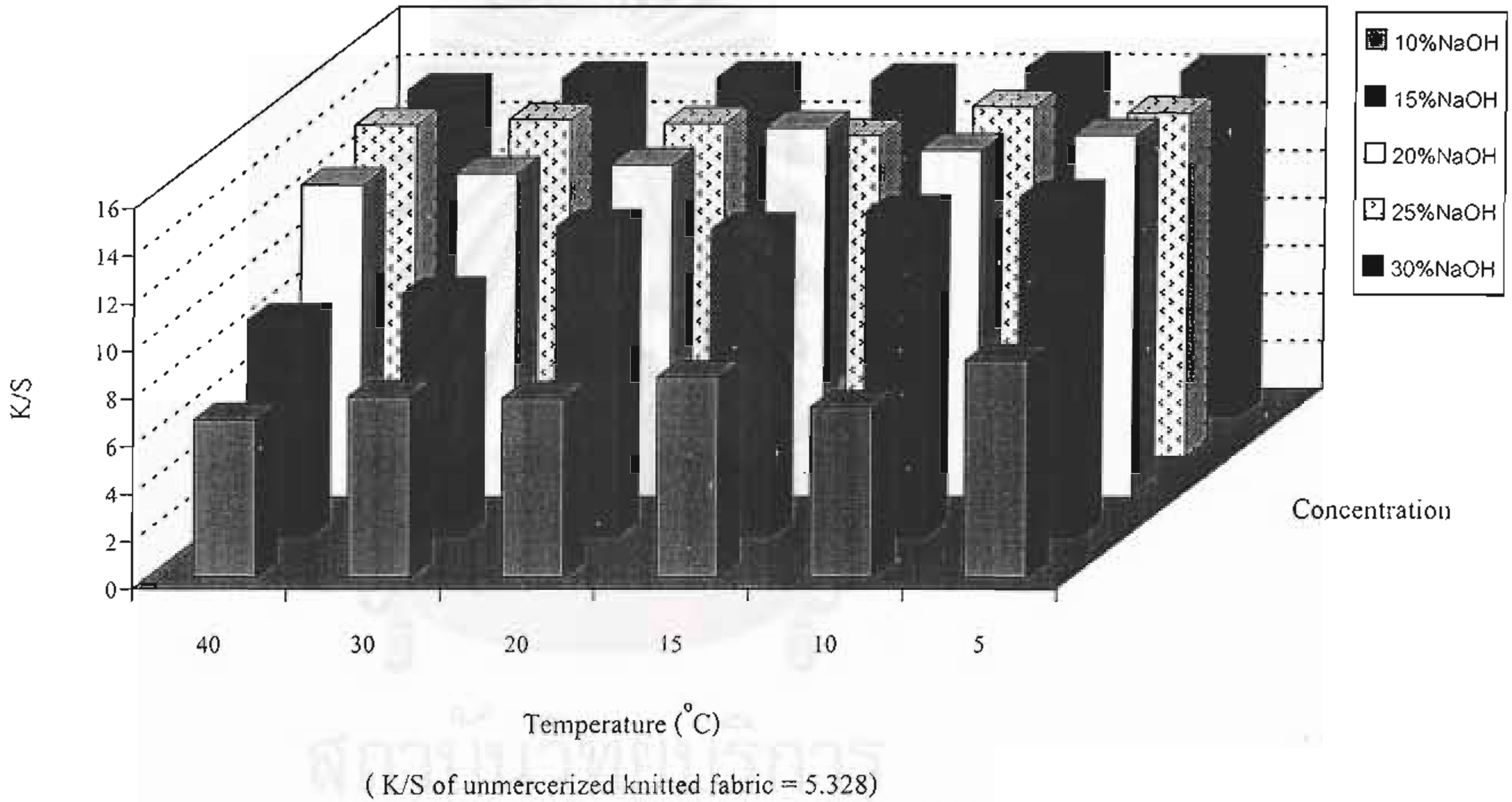



Figure 4.14 K/S of mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

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4.4.3 Color Strength of Knitted Fabrics Mercerized on the Pilot Scale Mercerizing Machine

Results in Table 4.15 and Figure 4.15 show that mercerized fabrics obtain over 50% higher K/S than unmercerized fabric. Mercerization significantly improves the dye absorption of fabric. Comparing the dye absorption of fabrics mercerized by these two mercerizing conditions, it indicates that K/S for both fabrics are the same. Therefore, it is possible to mercerize knitted fabric with low concentration of NaOH solution as 15% at low temperature as 10°C and obtains the same dye absorption of mercerized fabrics.

Table 4.15 K/S of unmercerized and mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water on the pilot scale mercerizing machine.

| condition | K/S |
|---|---|
| unmercerized | 5.49 |
| 15% NaOH 10°C | 12.06 |
| 20% NaOH 30 °C | 12.02 |

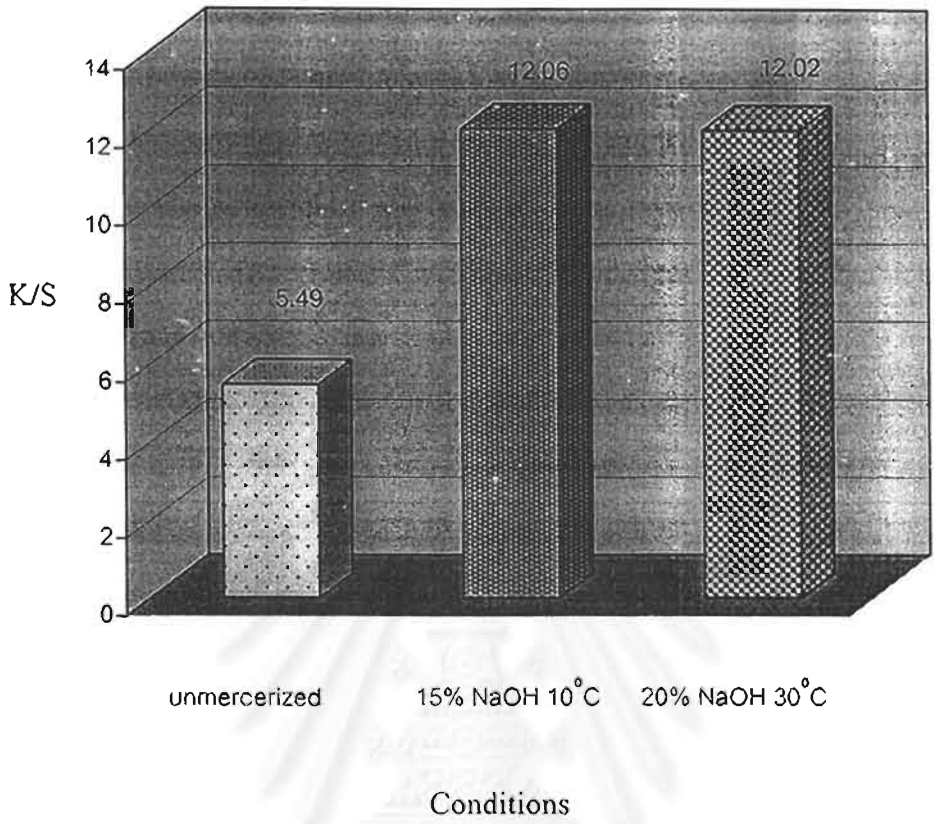


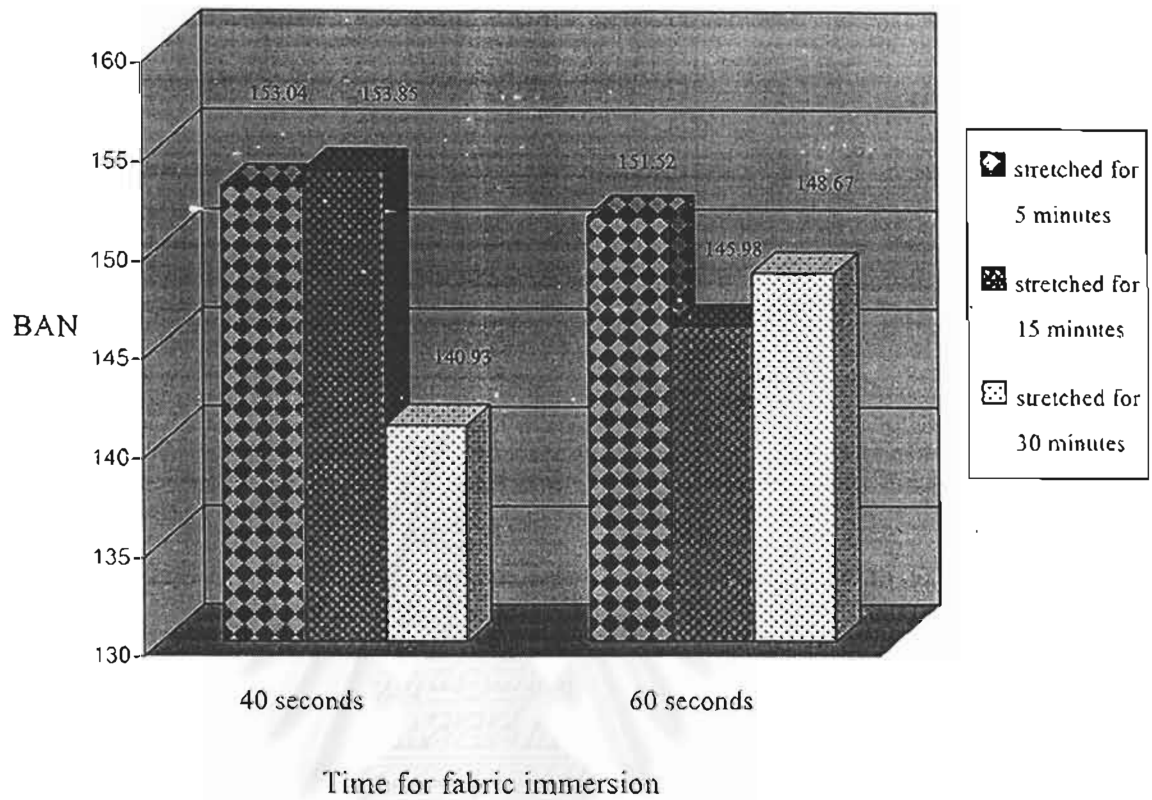

Figure 4.15 K/S of mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water in the pilot scale mercerizing machine.

### 4.5 The Effects of Immersion Time and Stretching Time on Mercerizing Results

Tables 4.16-4.19 and Figures 4.16-4.19 show results of BAN, bursting strength, pH, and K/S of knitted fabric immersed in 20% NaOH solution at 5°C at various times of 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes. This study was conducted in order to study the effects of immersion time and stretching time on mercerizing results and the results indicate that increasing the immersion time from 30 seconds to 40 and 60 seconds and varying the stretching time from 10 minutes to 5, 15, and 30 minutes do not significantly change the degree of mercerization. Bursting strength and K/S of mercerized fabrics increase as previous results and pH of fabrics are located in the acceptable range. One drawback found upon increasing the immersion time was fabrics tended to shrink more when they were immersed into the mercerizing bath for a longer time. Thirty minutes immersion should be enough for the fabric immersion step.

Table 4.16 BAN of unmercerized and mercerized knitted fabrics with 20% sodium hydroxide solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

| K/S | | | |
|---|---|---|---|
| condition | stretched for 5 minutes | stretched for 15 minutes | stretched for 30 minutes |
| unmercerized | 90.68 | | |
| immersed for 40 seconds | 153.04 | 153.85 | 140.93 |
| immersed for 60 seconds | 151.52 | 145.98 | 148.67 |




(BAN of unmercerized knitted fabric = 90.68)

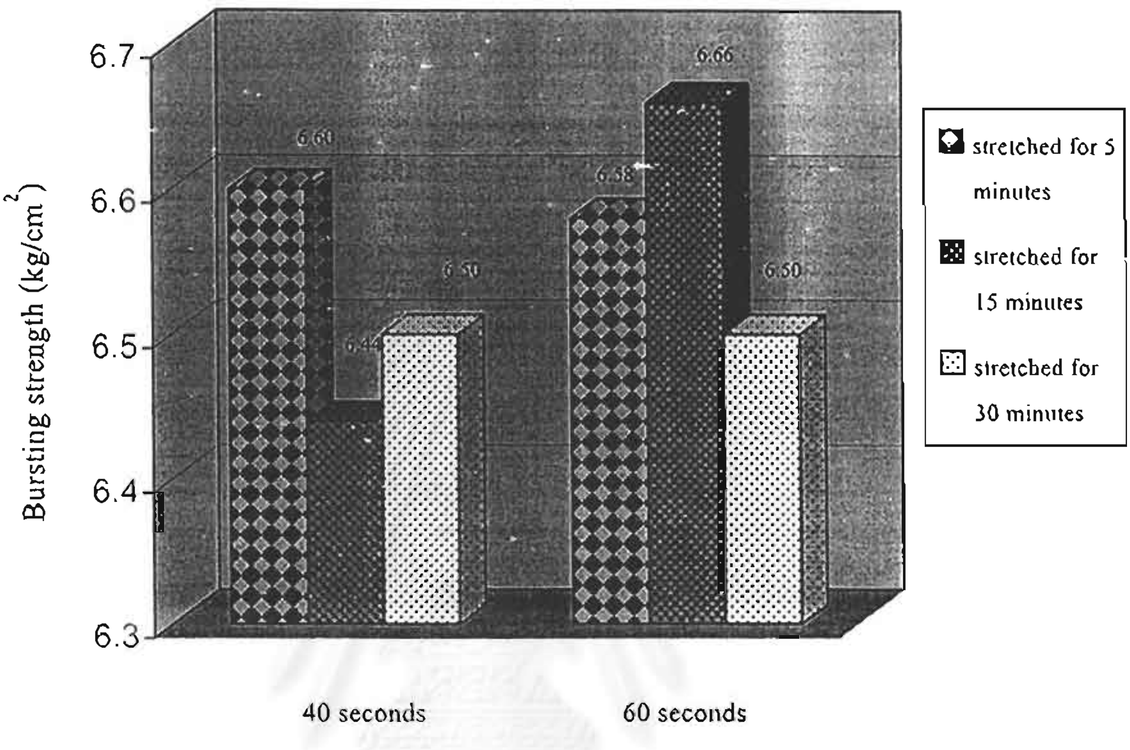
Figure 4.16 BAN of mercerized knitted fabrics with 20% NaOH solutions at $5^{\circ}C$ for 40 and 60 seconds under a constant tension for 5, 15 and 30 minutes, washed and neutralized with formic acid.

Table 4.17 Bursting strength of unmercerized and mercerized knitted fabrics with 20% sodium hydroxide solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

| K/S | | | |
|---|---|---|---|
| condition | stretched for 5 minutes | stretched for 15 minutes | stretched for 30 minutes |
| unmercerized | | 5.38 | |
| immersed for 40 seconds | 6.60 | 6.44 | 6.50 |
| immersed for 60 seconds | 6.58 | 6.66 | 6.50 |

Table 4.18 pH of unmercerized and mercerized knitted fabrics with 20% sodium hydroxide solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

| K/S | | | |
|---|---|---|---|
| condition | stretched for 5 minutes | stretched for 15 minutes | stretched for 30 minutes |
| distilled water at room temperature | | 6.83 | |
| unmercerized | | 6.14 | |
| immersed for 40 seconds | 7.54 | 7.32 | 7.24 |
| immersed for 60 seconds | 7.33 | 7.26 | 7.25 |




(Bursting strength of unmercerized knitted fabric = 5.38)

Figure 4.17 Bursting strength of mercerized knitted fabrics with 20% NaOH solutions at 5 °C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

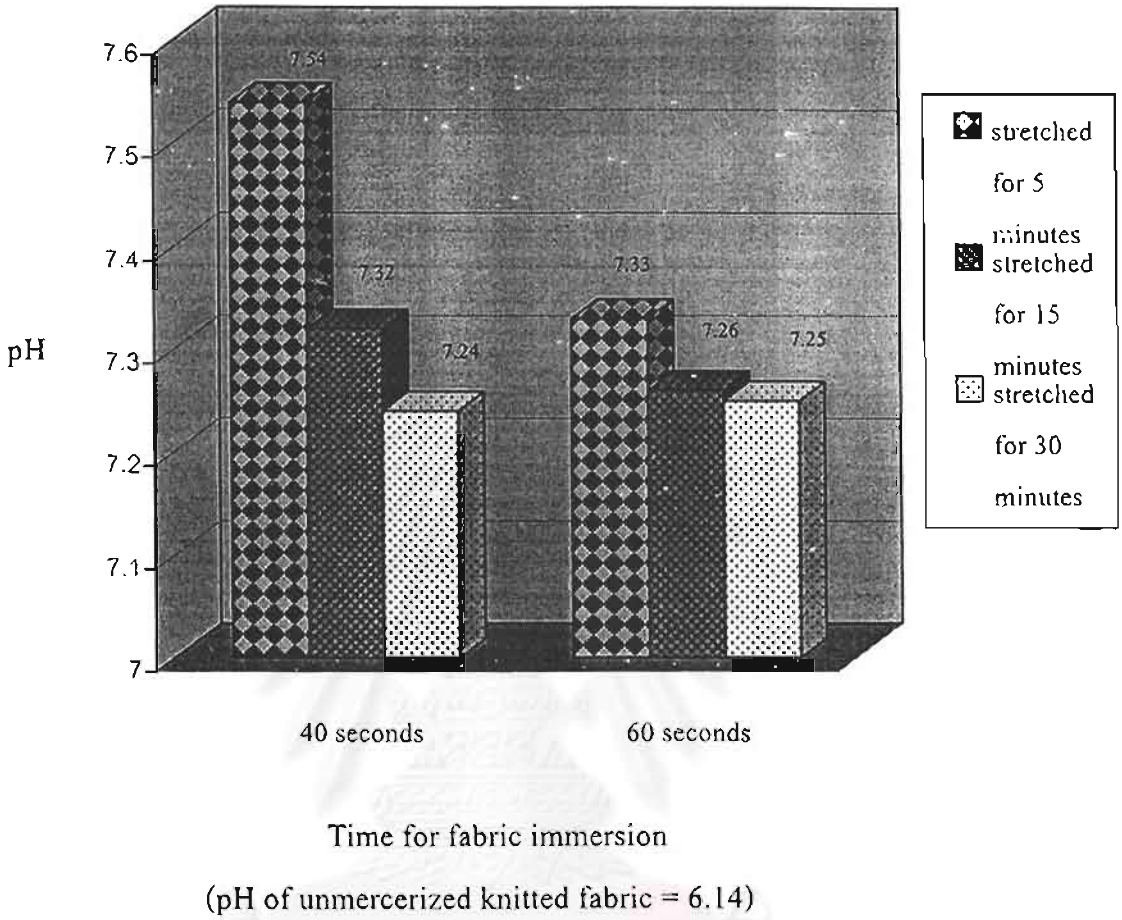
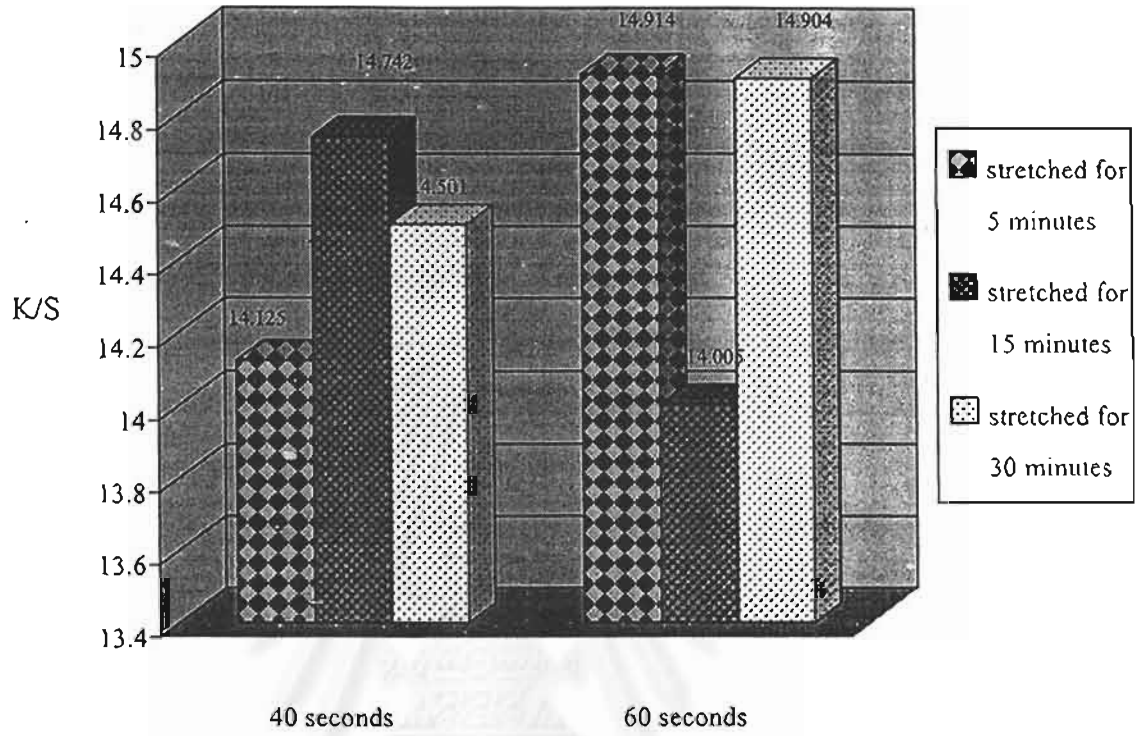



Figure 4.18 pH of mercerized knitted fabrics with 20% NaOH solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

Table 4.19 K/S of unmercerized and mercerized knitted fabrics with 20% sodium hydroxide solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

| K/S | | | |
|---|---|---|---|
| condition | stretched for 5 minutes | stretched for 15 minutes | stretched for 30 minutes |
| unmercerized | 5.328 | | |
| immersed for 40 seconds | 14.125 | 14.742 | 14.501 |
| immersed for 60 seconds | 14.914 | 14.005 | 14.904 |




(K/S of unmercerized knitted fabric = 5.328)

Figure 4.19 K/S of mercerized knitted fabrics with 20% NaOH solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30minutes, washed and neutralized with formic acid.

# CHAPTER V

# CONCLUSIONS

Mercerizing results shown in Chapter IV indicate the following conclusions:

1. Mercerizing process conducted in this experiment increases the degree of mercerization, the strength, and the dye absorption of cotton fabrics.
2. The degree of mercerization of cotton fabric increases with increasing the concentration of NaOH solution used in the process and does not significantly change with changing the mercerizing temperatures at same mercerizing concentration.
3. An optimum time for fabric immersion into the mercerizing bath is 30 seconds.
4. To obtain an acceptable mercerizing result, fabric needs to be mercerized at concentrations not lower than 15% NaOH solution. In terms of chemical saving, mercerization can be conducted at 15% NaOH rather than at 20-30% NaOH.
5. To mercerize at low concentration such as 15% NaOH, mercerizing temperature must be decreased to 10-20°C or lower in order to obtain an acceptable mercerizing result.

# CHAPTER VI

# RECOMMENDATIONS

1. Results indicate that mercerization can be conducted at low concentration of 15% NaOH solution and at low temperatures 10-20°C, it will be more informative to study the cost of chemicals and energy used for low alkali concentration/low temperature mercerization compared with the usual mercerizing condition.
2. Mercerization at low alkali concentration at low temperature should be conducted on the processing machine in the factory and chemicals/energy costs should also be studied.
3. In this experiment, only 2 mercerizing conditions were conducted on the pilot scale mercerizing machine. Other conditions may be processed on the machine as well.

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# Appendix

# APPENDIX A

Raw data of BAN, breaking load,

elongation, bursting strength, and pH of cotton fabrics.

Table A1 BAN of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | BAN | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | 30°C | | 20°C | | 15°C | | 10°C | | 5°C | |
| unmercerized | 117.50 | | | | | | | | | | | |
| 10% NaOH | 113.30 | 103.88 | 114.73 | 113.60 | 119.89 | 115.65 | 115.68 | 118.92 | 114.25 | 119.09 | 113.24 | 112.70 |
| average | 108.59 | | 114.17 | | 117.77 | | 117.30 | | 116.67 | | 112.97 | |
| 15% NaOH | 110.67 | 111.80 | 116.19 | 117.90 | 123.24 | 118.92 | 130.70 | 127.89 | 122.40 | 122.40 | 126.45 | 124.24 |
| average | 111.24 | | 117.05 | | 121.08 | | 129.30 | | 122.40 | | 125.35 | |
| 20% NaOH | 148.13 | 143.52 | 130.85 | 129.20 | 146.96 | 150.28 | 154.69 | 144.49 | 153.14 | 150.29 | 145.68 | 140.27 |
| average | 145.83 | | 130.03 | | 148.62 | | 149.74 | | 151.72 | | 142.98 | |
| 25% NaOH | 154.11 | 151.84 | 153.09 | 153.09 | 165.75 | 161.32 | 163.54 | 162.50 | 149.31 | 155.96 | 161.28 | 162.40 |
| average | 152.98 | | 153.09 | | 163.54 | | 163.02 | | 132.64 | | 161.84 | |
| 30% NaOH | 166.38 | 169.80 | 159.07 | 159.07 | 163.04 | 165.50 | 170.34 | 175.42 | 170.64 | 170.64 | 163.53 | 163.53 |
| average | 168.09 | | 159.07 | | 164.42 | | 172.88 | | 170.64 | | 163.53 | |

Table A2 BAN of unmercerized and mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| BAN | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | 30°C | | 20°C | | 15°C | | 10°C | | 5°C | |
| unmercerized | 90.68 | | | | | | | | | | | |
| 10% NaOH | 92.10 | 93.19 | 94.49 | 93.33 | 98.26 | 95.35 | 99.71 | 98.56 | 98.86 | 98.29 | 100.56 | 101.12 |
| average | 92.65 | | 93.91 | | 96.81 | | 99.14 | | 98.58 | | 100.84 | |
| 15% NaOH | 119.55 | 116.20 | 110.12 | 114.88 | 127.27 | 124.93 | 125.95 | 124.20 | 135.82 | 134.67 | 134.49 | 131.01 |
| average | 117.88 | | 112.50 | | 126.10 | | 125.08 | | 135.25 | | 132.75 | |
| 20% NaOH | 149.46 | 148.37 | 154.22 | 157.23 | 152.17 | 159.13 | 156.73 | 156.14 | 152.97 | 154.67 | 156.98 | 154.07 |
| average | 148.92 | | 155.73 | | 155.65 | | 156.44 | | 153.82 | | 155.53 | |
| 25% NaOH | 158.47 | 160.11 | 158.17 | 157.62 | 166.10 | 164.96 | 160.35 | 163.27 | 165.73 | 164.61 | 165.71 | 165.71 |
| average | 159.29 | | 157.90 | | 165.53 | | 161.81 | | 165.17 | | 165.71 | |
| 30% NaOH | 167.63 | 166.47 | 165.18 | 164.62 | 164.77 | 168.75 | 168.91 | 168.91 | 167.96 | 166.85 | 168.36 | 167.80 |
| average | 167.05 | | 164.90 | | 166.76 | | 168.91 | | 167.41 | | 168.08 | |

Table A3 BAN of unmercerized and mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water on the pilot scale mercerizing machine.

| condition | BAN | |
|---|---|---|
| unmercerized | 96.67 | 95.00 |
| average | 95.84 | |
| 15% NaOH 10°C | 134.28 | 134.84 |
| average | 134.56 | |
| 20% NaOH 30°C | 146.13 | 146.18 |
| average | 146.18 | |

Table A4 Breaking load along warp direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | Breaking load (N) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | | 30°C | | | 20°C | | | 15°C | | | 10°C | | | 5°C | | |
| unmercerized | 341.57 | | | | | | | | | | | | | | | | | |
| 10% NaOH | 316.60 | 303.30 | 297.20 | 372.70 | 346.00 | 352.20 | 365.80 | 389.90 | 370.00 | 382.20 | 375.70 | 376.90 | 372.70 | 394.80 | | 384.10 | 368.10 | |
| average | 305.70 | | | 356.97 | | | 375.23 | | | 378.27 | | | 383.75 | | | 376.10 | | |
| 15% NaOH | 347.90 | 313.90 | 378.80 | 333.80 | 348.70 | | 441.70 | 415.80 | 365.10 | 423.80 | 389.10 | 389.90 | 413.10 | 416.60 | | 393.70 | 355.50 | |
| average | 346.87 | | | 341.25 | | | 407.53 | | | 400.93 | | | 414.85 | | | 374.60 | | |
| 20% NaOH | 439.10 | 413.50 | 416.20 | 387.20 | 379.90 | 341.00 | 415.80 | 455.50 | 445.20 | 465.00 | 466.90 | 423.80 | 416.20 | 425.00 | 417.70 | 436.40 | 433.30 | 449.00 |
| average | 422.93 | | | 369.37 | | | 438.83 | | | 451.90 | | | 419.63 | | | 439.57 | | |
| 25% NaOH | 448.20 | 443.30 | 427.60 | 404.00 | 471.10 | 449.00 | 492.90 | 466.20 | 474.50 | 462.00 | 475.70 | 432.60 | 477.20 | 462.70 | | 410.10 | 415.80 | 447.80 |
| average | 439.70 | | | 441.37 | | | 477.87 | | | 456.77 | | | 469.95 | | | 424.57 | | |
| 30% NaOH | 450.50 | 449.80 | 497.10 | 377.70 | 464.20 | 310.10 | 468.40 | 473.40 | 492.50 | 476.50 | 457.40 | 435.60 | 479.10 | 449.00 | | 474.50 | 450.50 | 454.70 |
| average | 465.80 | | | 384.00 | | | 478.10 | | | 456.50 | | | 464.05 | | | 459.90 | | |

Table A5 Breaking load along weft direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | Breaking load (N) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | | 30°C | | | 20°C | | | 15°C | | | 10°C | | | 5°C | | |
| unmercerized | 240.30 | | | | | | | | | | | | | | | | | |
| 10% NaOH | 275.40 | 334.20 | 292.20 | 309.80 | 228.80 | 299.80 | 353.20 | 246.00 | 329.60 | 397.90 | 386.80 | 337.20 | 388.00 | 340.70 | 333.00 | 330.00 | 320.80 | 361.30 |
| average | 300.60 | | | 299.47 | | | 309.60 | | | 373.97 | | | 353.90 | | | 337.37 | | |
| 15% NaOH | 341.40 | 314.30 | 364.30 | 364.70 | 349.80 | 320.80 | 398.30 | 328.40 | 384.50 | 385.70 | 365.80 | | 406.30 | 369.30 | 413.50 | 364.70 | 410.80 | 343.30 |
| average | 340.00 | | | 345.10 | | | 370.40 | | | 375.75 | | | 396.37 | | | 372.93 | | |
| 20% NaOH | 494.00 | 432.20 | 421.10 | 407.80 | 400.20 | 374.60 | 410.80 | 392.50 | 424.20 | 451.30 | 445.90 | 403.20 | 445.60 | 442.10 | 470.00 | 460.40 | 425.70 | 451.70 |
| average | 449.10 | | | 394.20 | | | 409.17 | | | 433.47 | | | 452.57 | | | 445.93 | | |
| 25% NaOH | 391.00 | 390.60 | 366.20 | 412.00 | 424.90 | 371.60 | 388.30 | 487.90 | 466.20 | 436.00 | 443.30 | | 416.20 | 423.00 | | 366.20 | 431.80 | 439.50 |
| average | 382.60 | | | 402.83 | | | 447.47 | | | 439.65 | | | 419.60 | | | 412.50 | | |
| 30% NaOH | 409.70 | 405.50 | 367.70 | 388.00 | 447.80 | 441.40 | 467.30 | 462.00 | 437.20 | 422.30 | 510.00 | 461.20 | 394.80 | 340.30 | 355.90 | 334.50 | 383.80 | 397.50 |
| average | 394.30 | | | 425.63 | | | 455.50 | | | 464.50 | | | 363.67 | | | 371.93 | | |

Table A6 Elongation along warp direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | Elongation (%) | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | | 30°C | | | 20°C | | | 15°C | | | 10°C | | | 5°C | | |
| unmercerized | 6.03 | | | | | | | | | | | | | | | | | |
| 10% NaOH | 9.68 | 9.88 | 9.10 | 11.55 | 10.41 | 10.32 | 11.42 | 12.24 | 12.12 | 11.08 | 11.07 | 11.01 | 11.00 | 12.30 | | 12.70 | 12.60 | |
| average | 9.55 | | | 10.76 | | | 11.93 | | | 11.05 | | | 11.65 | | | 12.65 | | |
| 15% NaOH | 14.72 | 13.61 | 15.05 | 14.77 | 14.52 | | 14.47 | 13.03 | 13.40 | 15.04 | 13.34 | 16.31 | 14.50 | 15.30 | | 17.50 | 17.20 | |
| average | 14.46 | | | 14.65 | | | 13.63 | | | 14.90 | | | 14.90 | | | 17.35 | | |
| 20% NaOH | 21.02 | 18.72 | 20.24 | 17.18 | 18.75 | 17.28 | 17.55 | 21.32 | 21.50 | 22.26 | 22.01 | 20.80 | 20.30 | 22.60 | 19.50 | 22.00 | 20.50 | 20.90 |
| average | 19.99 | | | 17.74 | | | 20.12 | | | 21.69 | | | 20.80 | | | 21.13 | | |
| 25% NaOH | 21.81 | 22.90 | 22.84 | 22.82 | 26.13 | 23.72 | 27.90 | 26.39 | 27.45 | 26.32 | 28.34 | 26.15 | 23.30 | 24.10 | | 22.20 | 22.80 | 23.20 |
| average | 22.51 | | | 24.22 | | | 27.25 | | | 26.94 | | | 23.70 | | | 22.73 | | |
| 30% NaOH | 25.94 | 22.63 | 27.35 | 25.19 | 26.89 | 25.28 | 27.88 | 26.27 | 26.46 | 26.99 | 24.73 | 27.35 | 27.20 | 24.80 | | 22.50 | 23.30 | 21.10 |
| average | 25.31 | | | 25.79 | | | 26.87 | | | 26.36 | | | 26.00 | | | 22.30 | | |

Table A7 Elongation along weft direction of unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| Elongation (%) | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | | 30°C | | | 20°C | | | 15°C | | | 10°C | | | 5°C | | |
| unmercerized | 21.33 | | | | | | | | | | | | | | | | | |
| 10% NaOH | 19.55 | 19.63 | 17.21 | 16.91 | 16.98 | 19.55 | 21.98 | 19.78 | 20.42 | 23.98 | 22.36 | 21.95 | 19.20 | 18.30 | 17.10 | 17.90 | 19.40 | 17.20 |
| average | 18.80 | | | 17.81 | | | 20.73 | | | 22.76 | | | 18.20 | | | 18.17 | | |
| 15% NaOH | 18.08 | 17.58 | 18.01 | 16.15 | 15.31 | 15.33 | 24.81 | 23.42 | 22.12 | 21.36 | 22.78 | | 21.20 | 18.20 | 17.90 | 16.50 | 17.90 | 16.80 |
| average | 17.89 | | | 15.60 | | | 23.45 | | | 22.07 | | | 19.10 | | | 17.07 | | |
| 20% NaOH | 21.23 | 22.02 | 20.32 | 18.00 | 17.26 | 19.84 | 24.24 | 22.15 | 23.97 | 22.52 | 21.47 | 21.48 | 20.70 | 20.00 | 19.90 | 20.20 | 19.50 | 19.40 |
| average | 21.19 | | | 18.37 | | | 23.45 | | | 21.82 | | | 20.20 | | | 19.70 | | |
| 25% NaOH | 21.50 | 23.05 | 21.88 | 21.82 | 23.87 | 20.36 | 25.16 | 25.28 | 25.35 | 21.48 | 23.24 | | 21.10 | 20.70 | | 18.00 | 20.40 | 18.60 |
| average | 22.14 | | | 22.02 | | | 25.26 | | | 22.36 | | | 20.40 | | | 19.00 | | |
| 30% NaOH | 22.18 | 23.84 | 21.14 | 19.74 | 22.08 | 20.58 | 27.77 | 28.68 | 29.38 | 24.77 | 26.75 | 23.22 | 17.50 | 21.10 | 19.50 | 19.60 | 21.90 | 22.80 |
| average | 22.39 | | | 20.80 | | | 28.61 | | | 24.91 | | | 19.37 | | | 21.43 | | |

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Table A8 Bursting strength of unmercerized and mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| Bursting strength ($kg/cm^2$) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | | | | 30°C | | | | | 20°C | | | | | 15°C | | | | | 10°C | | | | | 5°C | | | | |
| unmercerized | 5.38 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10% NaOH | 5.65 | 5.85 | 5.45 | 5.40 | 5.65 | 5.70 | 5.50 | 5.80 | 5.60 | 5.70 | 5.40 | 5.70 | 5.50 | 5.60 | 5.70 | 6.20 | 5.70 | 5.50 | 5.90 | 5.60 | 5.70 | 5.90 | 5.90 | 5.70 | 5.70 | 5.90 | 5.90 | 6.00 | 5.70 | 5.70 |
| average | 5.60 | | | | | 5.66 | | | | | 5.58 | | | | | 5.78 | | | | | 5.78 | | | | | 5.84 | | | | |
| SD | 0.18 | | | | | 0.11 | | | | | 0.13 | | | | | 0.28 | | | | | 0.11 | | | | | 0.13 | | | | |
| 15% NaOH | 5.70 | 5.80 | 6.10 | 5.90 | 5.65 | 5.70 | 6.30 | 6.00 | 6.00 | 5.90 | 5.80 | 6.20 | 6.80 | 6.60 | 5.70 | 6.30 | 6.30 | 6.30 | 6.20 | 6.00 | 6.50 | 6.20 | 6.90 | 6.40 | 6.70 | 6.40 | 6.60 | 6.30 | 6.40 | 6.40 |
| average | 5.83 | | | | | 5.98 | | | | | 6.22 | | | | | 6.22 | | | | | 6.54 | | | | | 6.42 | | | | |
| SD | 0.18 | | | | | 0.22 | | | | | 0.48 | | | | | 0.13 | | | | | 0.27 | | | | | 0.11 | | | | |
| 20% NaOH | 6.10 | 6.50 | 6.40 | 6.10 | 6.10 | 6.60 | 6.20 | 6.20 | 6.20 | 6.20 | 6.60 | 6.30 | 6.10 | 6.70 | 6.50 | 6.30 | 6.50 | 6.70 | 6.40 | 6.50 | 6.90 | 6.70 | 6.70 | 6.20 | 6.30 | 6.30 | 6.50 | 6.50 | 6.60 | 7.00 |
| average | 6.24 | | | | | 6.28 | | | | | 6.44 | | | | | 6.48 | | | | | 6.56 | | | | | 6.58 | | | | |
| SD | 0.19 | | | | | 0.18 | | | | | 0.24 | | | | | 0.15 | | | | | 0.30 | | | | | 0.26 | | | | |
| 25% NaOH | 6.10 | 6.20 | 6.50 | 6.30 | 6.80 | 6.60 | 6.90 | 6.40 | 6.20 | 6.60 | 6.30 | 6.30 | 6.80 | 6.30 | 6.70 | 6.70 | 6.40 | 6.40 | 6.80 | 6.30 | 6.70 | 6.80 | 6.30 | 6.60 | 6.40 | 6.80 | 6.40 | 6.50 | 6.60 | 6.60 |
| average | 6.38 | | | | | 6.54 | | | | | 6.48 | | | | | 6.52 | | | | | 6.56 | | | | | 6.58 | | | | |
| SD | 0.28 | | | | | 0.26 | | | | | 0.25 | | | | | 0.22 | | | | | 0.16 | | | | | 0.15 | | | | |
| 30% NaOH | 6.10 | 6.30 | 6.50 | 6.20 | 6.40 | 6.70 | 6.50 | 6.10 | 6.10 | 6.30 | 6.30 | 6.30 | 7.10 | 6.70 | 6.80 | 7.00 | 6.20 | 6.20 | 6.50 | 6.40 | 6.80 | 6.80 | 6.60 | 6.70 | 6.20 | 6.40 | 6.70 | 6.80 | 7.00 | 7.00 |
| average | 6.34 | | | | | 6.34 | | | | | 6.64 | | | | | 6.46 | | | | | 6.62 | | | | | 6.78 | | | | |
| SD | 0.18 | | | | | 0.26 | | | | | 0.34 | | | | | 0.33 | | | | | 0.25 | | | | | 0.25 | | | | |

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Table A9 Bursting strength of unmercerized and mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water on the pilot scale mercerizing machine.

| condition | Bursting strength ($kg/cm^2$) | | | | |
|---|---|---|---|---|---|
| unmercerized | 6.20 | 5.70 | 6.10 | 5.80 | 6.10 |
| average | 5.98 | | | | |
| SD | 0.22 | | | | |
| 15% NaOH 10°C | 8.20 | 7.70 | 7.80 | 7.20 | 8.00 |
| average | 7.78 | | | | |
| SD | 0.38 | | | | |
| 20% NaOH 30°C | 7.70 | 8.30 | 7.80 | 8.30 | 8.60 |
| average | 8.14 | | | | |
| SD | 0.38 | | | | |

Table A10 pH of water-extract from unmercerized and mercerized woven fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | pH | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | 30°C | | 20°C | | 15°C | | 10°C | | 5°C | |
| distilled water at room temperature | 6.87 | | | | | | | | | | | |
| unmercerized | 6.44 | | | | | | | | | | | |
| 10% NaOH | 6.47 | 6.35 | 7.39 | 7.31 | 7.13 | 6.51 | 7.08 | 6.86 | 6.59 | 6.61 | 6.84 | 6.85 |
| average | 6.41 | | 7.35 | | 6.82 | | 6.97 | | 6.60 | | 6.85 | |
| 15% NaOH | 6.62 | 6.57 | 7.18 | 6.66 | 6.60 | 6.50 | 6.86 | 6.84 | 6.54 | 6.73 | 6.68 | 6.64 |
| average | 6.60 | | 6.92 | | 6.55 | | 6.85 | | 6.64 | | 6.66 | |
| 20% NaOH | 6.62 | 7.52 | 6.63 | 6.60 | 7.20 | 7.27 | 7.16 | 7.19 | 6.60 | 6.61 | 6.59 | 6.62 |
| average | 7.07 | | 6.62 | | 7.24 | | 7.18 | | 6.60 | | 6.61 | |
| 25% NaOH | 7.66 | 7.44 | 6.84 | 7.05 | 7.47 | 7.56 | 7.36 | 7.41 | 6.71 | 6.61 | 6.65 | 6.82 |
| average | 7.55 | | 6.94 | | 7.52 | | 7.38 | | 6.66 | | 6.73 | |
| 30% NaOH | 7.53 | 7.54 | 7.28 | 7.30 | 7.48 | 7.62 | 7.38 | 7.39 | 7.33 | 7.36 | 6.78 | 6.76 |
| average | 7.54 | | 7.29 | | 7.55 | | 7.38 | | 7.35 | | 6.77 | |

Table A11 pH of water-extract from unmercerized and mercerized knitted fabrics with 10-30% sodium hydroxide solutions at 5-40°C for 30 seconds under a constant tension for 10 minutes, washed and neutralized with formic acid.

| | pH | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | 40°C | | 30°C | | 20°C | | 15°C | | 10°C | | 5°C | |
| distilled water at room temperature | 6.83 | | | | | | | | | | | |
| unmercerized | 6.14 | | | | | | | | | | | |
| 10% NaOH | 6.88 | 6.92 | 7.00 | 7.01 | 6.96 | 6.92 | 6.83 | 6.84 | 7.17 | 7.15 | 7.58 | 7.20 |
| average | 6.90 | | 7.01 | | 6.94 | | 6.84 | | 7.16 | | 7.39 | |
| 15% NaOH | 6.95 | 6.95 | 6.96 | 6.92 | 6.91 | 6.92 | 7.62 | 7.43 | 7.08 | 7.11 | 7.22 | 7.17 |
| average | 6.95 | | 6.94 | | 6.92 | | 7.52 | | 7.10 | | 7.20 | |
| 20% NaOH | 7.01 | 7.00 | 6.92 | 6.96 | 6.95 | 6.91 | 7.35 | 7.33 | 7.15 | 7.14 | 7.35 | 7.39 |
| average | 7.00 | | 6.94 | | 6.93 | | 7.34 | | 7.15 | | 7.37 | |
| 25% NaOH | 7.02 | 7.01 | 6.95 | 6.97 | 6.92 | 6.91 | 7.39 | 7.19 | 7.42 | 7.43 | 7.41 | 7.40 |
| average | 7.01 | | 6.96 | | 6.92 | | 7.29 | | 7.42 | | 7.41 | |
| 30% NaOH | 7.11 | 7.23 | 7.08 | 7.11 | 6.88 | 6.87 | 7.35 | 7.41 | 7.44 | 7.43 | 7.43 | 7.41 |
| average | 7.12 | | 7.10 | | 6.88 | | 7.38 | | 7.44 | | 7.42 | |



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Table A12 pH of the water-extract from unmercerized and mercerized knitted fabrics with 15% NaOH 10°C and 20% NaOH 30°C for 30 seconds under a constant tension, washed and neutralized with 90°C water on the pilot scale mercerizing machine.

| condition | pH | |
|---|---|---|
| distilled water at room temperature | 6.10 | 7.02 |
| average | 6.56 | |
| unmercerized | 6.90 | 6.88 |
| average | 6.89 | |
| 15% NaOH 10°C | 7.13 | 7.45 |
| average | 7.29 | |
| 20% NaOH 30°C | 7.16 | 7.46 |
| average | 7.31 | |

Table A13 BAN of unmercerized and mercerized knitted fabrics with 20% sodium hydroxide solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

| K/S | | | | | | |
|---|---|---|---|---|---|---|
| condition | stretched for 5 minutes | | stretched for 15 minutes | | stretched for 30 minutes | |
| unmercerized | 90.68 | | | | | |
| immersed for 40 seconds | 153.87 | 152.21 | 152.71 | 154.99 | 139.30 | 142.55 |
| average | 153.04 | | 153.85 | | 140.93 | |
| immersed for 60 seconds | 150.14 | 152.89 | 147.13 | 144.83 | 150.00 | 147.34 |
| average | 151.52 | | 145.98 | | 148.67 | |

Table A14 Bursting strength of unmercerized and mercerized knitted fabrics with 20% sodium hydroxide solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

| K/S | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| condition | stretched for 5 minutes | | | | | stretched for 15 minutes | | | | | stretched for 30 minutes | | | | |
| unmercerized | 5.38 | | | | | | | | | | | | | | |
| immersed for 40 seconds | 6.90 | 6.20 | 6.90 | 6.80 | 6.20 | 6.80 | 6.30 | 6.10 | 6.50 | 6.50 | 6.50 | 6.70 | 6.80 | 6.30 | 6.20 |
| average | 6.60 | | | | | 6.44 | | | | | 6.50 | | | | |
| SD | 0.37 | | | | | 0.26 | | | | | 0.25 | | | | |
| immersed for 60 seconds | 7.00 | 6.50 | 6.60 | 6.60 | 6.20 | 6.90 | 9.70 | 6.50 | 6.70 | 6.50 | 6.20 | 6.90 | 6.20 | 6.70 | 6.50 |
| average | 6.58 | | | | | 6.66 | | | | | 6.50 | | | | |
| SD | 0.29 | | | | | 0.17 | | | | | 0.31 | | | | |

Table A15 pH of unmercerized and mercerized knitted fabrics with 20% sodium hydroxide solutions at 5°C for 40 and 60 seconds under a constant tension for 5, 15, and 30 minutes, washed and neutralized with formic acid.

| K/S | | | | | | |
|---|---|---|---|---|---|---|
| condition | stretched for 5 minutes | | stretched for 15 minutes | | stretched for 30 minutes | |
| distilled water at room temperature | 6.83 | | | | | |
| unmercerized | 6.14 | | | | | |
| immersed for 40 seconds | 7.40 | 7.68 | 7.31 | 7.32 | 7.22 | 7.26 |
| average | 7.54 | | 7.32 | | 7.24 | |
| immersed for 60 seconds | 7.34 | 7.32 | 7.26 | 7.26 | 7.25 | 7.25 |
| average | 7.33 | | 7.26 | | 7.25 | |

# CURRICULUM VITAE

Miss Worawan Asaves was born in Septemper 9, 1974 at Chanthaburi. She received her Bachelor degree in General Science from the Faculty of Science, Chulalongkorn University in 1995. She began her Master Degree program in June 1977 and completed the program in April 2000.