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THESIS

THE DEVELOPMENT OF A DYEING MACHINE FOR IMPROVING THE QUALITY OF LOCAL SILK DYEING

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The primary aim of this study was to investigate various local silk dyeing processes in Thailand in relation to the variations in the quality of dyed silk yarns. It also attempted to develop a prototype dyeing machine for improving the local silk dyeing process. The ultimate goal of this study was that the new improved dyeing machine could be proved technically feasible while economically viable as well as environmentally sound and socially accepted so that it could be recommended.

The study selected three local silk dyeing groups from Napho, Buri Rum Province; Sanuan Nai, Buri Rum Province; and Nonmuang, Nong Bua Lam Phu Province for technical investigation. Hence, interview and data collection was conducted to examine the dyed silk yarn quality measured in terms of various indicators. Using local dyeing method (LDM) with labor-intensive, open container, traditional equipment and wood energy, the quality of dyeing methods was then evaluated for color value (L*, C* and h*), colorfastness (dE* values of color change and color staining) and reproducibility (dE* values of the three replication pairs). All LDMs proved their effectiveness in producing quality dyed silk yarn in spite of a low level of reproducibility. At the same time, this study proposed new improved dyeing machines as considered to be the first and second prototype dyeing machines (PDM I and PDM II) as alternative dyeing methods, with technical innovation from heat control, automatic wheel rotary system, liquid petroleum gas energy. In particular, the PDM II which is the improved model of the PDM I in terms of better semi-closed container system and more effective heat measurement produced far better results in the above evaluation indicators, including that obtained color values close to the standard color, relatively higher colorfastness level and more consistent degree of reproducibility. In general, the quality of dyed silk yarn from PDM II was found highest among the dyeing alternatives.

The PDM II was then recommended as the prototype dyeing machine with comparative advantages to be further promoted. Moreover, economic, environmental and social considerations between LDM and PDM II also confirmed the relative feasibility in favor of PDM II despite some further technical improvements of PDM II which could still be possible, as already suggested in the study.

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Student's signature Thesis Advisor's signature

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I am now certain that a good piece of work is often in the hand of a good teamwork. My thesis is completed as good as it can be not only by me but through a number of people whom I owe a great debt in one way or another. I am positive that without their whole efforts spent on the duration of my five years at Kasetsart University as a Ph.D. student, this thesis may not be possible as the way it is supposed to be. In overall, I really realize that because of all my teachers who have taught and trained me about knowledge and life, I then have today when I finish my Ph.D. study.

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Sarunya Kasembunyakorn
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LIST OF ABBREVIATIONS

A	=	amp
cc	=	cubic centimeter
cm	=	centimeter
cm^3	=	cubic centimeter
ºC	=	degree Celsius
g	=	gram
HP	=	horsepower
hr	=	hour
Hz	=	hertz
Kcal	=	kilocalorie
kg	=	kilogram
KWh	=	kilowatt-hour
L	=	liter
LR	=	liquor ratio
m	=	meter
m^2	=	square meter
ml	=	milliliter
mm	=	millimeter
owf	=	on weight of fiber
pt	=	pint
rpm	=	round per minute
%	=	percentage
tpi	=	turns per inch
V	=	volt
vs	=	versus
W	=	watt
wt	=	weight

THE DEVELOPMENT OF A DYEING MACHINE FOR IMPROVING THE QUALITY OF LOCAL SILK DYEING

INTRODUCTION

From historical evidence, it is a fact that cloth has been directly or indirectly involved in the lives of human beings since ancient times. It was found that prehistoric people knew how to weave for more than 3,000 years when earthenware for spinning thread was discovered. Every society and nation have its own roots relating to textile and clothing development as the basic welfare of people. Thailand is no exception in this regard, located as it is on the continental shelf of ancient Asia. Since the New Stone Age and Metal Age, needles made from animal bones were firstly found at Ban Kaow, Kanchanaburi and stones used for extracting fibers were also discovered in Chumphon and Prachuap Khiri Khan. Small pieces of cotton and silk were found attached to bracelets and bronze axes. Such evidence was later used as the pathway to trace the development of textile and clothing in the country. Moreover, they are considered important factors indicating the origins of the country, as well as economic, environmental and societal development so far.

Not only are clothes indicative of the fundamental welfare of people, they also served as reflections of human development and way of life in each period of time. The level of national progress and prosperity can be simply seen from how textile and clothing production and processing advanced. At present, local woven fabric is one of the products that strongly present the culture, wisdom, and unique creativity of Thai people. It is woven by various methods and for multiple purposes from daily wear, ritual use, cultural preservation, artful work, market supply and as a labor of love. In Thailand, where its richness lies on natural biodiversity, Thai fabrics can be woven from three different kinds of materials; namely silk, cotton and synthetic yarn. Generally speaking, each material will be concentrated on in specific geographical location of the country, while representing different culture and tradition. The quality of local fabrics of particular regions in Thailand is, therefore, varied due to many detailed factors.

Among all materials, silk stands alone as the most predominant textile material due mainly to its recognition as a symbol of national pride and its demand in the market. The making of Thai silk products has long been realized, both nationally and internationally, for a long time. Thai silk is regarded as different from Western, Japanese and Korean silks in its texture and complexity. In most pieces of Thai silk, the wefts are usually silk yarns that are domestically reeled. It is the weft that gives Thai silk its sheen and texture and the uniqueness of its beauty. During modern times Thai silk has enjoyed the strong support of Her Majesty the Queen of Thailand. Many of her loyal Thai silk development projects have taken the name of Thai silk to the world market in terms of leading fashion and export earnings. On the other hand, Her Majesty the Queen herself has long been recognized as the most outstanding presenter of Thai silk at the national and international levels. It is without doubt that considerable credit for the modern technical and marketing innovation of Thai silk materials and clothes has deservedly been given to Her Majesty the Queen.

Limitations of Thai silk, however, remain as exists for all other materials. The weakness that can not be denied is that it is rather difficult to wash and care for local Thai silk, and also its color can easily bleed. This results in the relatively low use of Thai silk in daily life. Conversely, Thai silk, which is considerably higher priced compared with other materials, is generally chosen for special purposes and among the higher income class of people.

Moreover, another of the crucial problems of Thai silk production is related to the silk yarn dyeing method which produces diversified dyed silk yarn quality and consequently inconsistent quality of silk products themselves. Such silk yarn dyeing problems are in fact the root of many other problems related to silk quality, market value and thus profitability of the producers. In other words, any possibility in improving silk yarn dyeing techniques would increase not only the dyed silk yarn quality at the end but also improve the cost-effectiveness of the dyeing method, decrease excessive labor use, especially during any labor scarcity season, and thus sustain the silk dyeing method into the future.

Also important is the search for new, improved and appropriate dyeing methods which would in one way or another not deteriorate but would support the development of traditional dyeing methods in the rural areas where the art has been practiced for a long time. Local incubation of Thai wisdom and age-old knowledge in silk dyeing processes should be used to benefit the development of newly improved dyeing methods.

The general description of traditional Thai silk dyeing processes is rather a labor-intensive technology with inconsistent output quality. One can simply see the overall picture that traditional methods of silk dyeing in Thailand are just the dyeing of yarn in the form of hanks or skeins. Silk yarns are simply suspended on wooden poles or hoops and turned by hand. Normally temperature, dyeing cycle time and the amount of chemical substances are not exactly measured but they are approximated by the dyers from their experiences. This inexact proportion really affects the quality of dyed silk in terms of colorfastness and hue despite the fact that all these procedural variations must be closely controlled in dyeing. Obviously, chemical computations and weightings must be made more precise and correct. Reproduction of the dyeing cycle time, dyeing temperature, rate of temperature rise, and agitation of the substrate and dyebath must be controlled for dyeing.

On top of such technical limitations, usage of the labor force in the dyeing process is another limitation of traditional local dyeing methods. Local labor for dyeing tasks, which are mostly the experienced females in rural villages, are scarce, especially during the farming season. At the same time, processes in degumming, bleaching and dyeing silk yarn require a lot of physical strength in turning around the silk yarn for equal heat, so the color is evenly spread. Such hard work together with the experience required for rural females as the local silk dyers has gradually become a discouraging factor for younger women to enter silk dyeing as an occupation thus leaving all activities to the middle-aged females. Sustainability of traditional silk yarn dyeing in rural Thailand is therefore facing a declining trend in terms of both skillful labor and new entrepreneurship.

The search for newly improved dyeing machines is, therefore, one of the key solutions to many problems and limitation in the upstream of the Thai silk business. Accordingly, improving the quality of dyed silk yarn from the newly developed dyeing machines will benefit all stages, leading to better quality silk yarn, more cost-effective production, higher value silk fabrics and then stronger competitiveness in all market levels. At the end, the creation of customer satisfaction and continuity of worldwide recognition of Thai silk will thus be possibly sustained in the competitive market.

This key issue, and also the main objective of this study, is then how the technical aspects in the development of a dyeing machine for improving the quality of local silk dyeing should be experimented upon and conducted. The overall target of this study is to seek for a prototype dyeing machine that can be proved technically feasible and more efficient. Taking a holistic approach under consideration, economic viability, environmental soundness and social acceptance of such a newly improved dyeing machine will also be discussed.

The ultimate goal of this study is that the Thai silk dyeing, processing and marketing will benefit from the development and promotion of the new prototype dyeing machine. It is the key challenge for everyone concerned that only development of a newly improved dyeing machine can possibly lead to promote the growth and prosperity of the Thai silk industry into the future, as it has been from the past to present.

OBJECTIVES

The study basically consists of two main objectives, as follows:

1. To investigate the comparative local dyeing processes and evaluate the efficiency of silk dyeing and the quality of dyed silk yarn.

2. To develop a prototype dyeing machine for improvement of local silk dyeing and to compare the quality of silk yarn by the selected local groups and techniques.

Scope of Research

The scope of research will cover the following aspects:

1. The silk yarns used in the experiment were a hybrid type in white. They were degummed and in the skein form, No.30/32D, 6 ply, 150 tpi. They were produced in the same lot from Jun Mai Thai Company. This kind of fiber has been regularly used as a weft in producing high quality silk fabric.

2. The ‘Lion Playing a Drum’ red dye No.34 of Phua Kiam Seen Company was used in the dyeing experiment. This type of dye is popular in the Northeast of Thailand. The dye used was from one lot.

3. The ‘Lion Playing a Drum’ powdered wetting agent of Phua Kiam Seen Company was suggested to be used in the dyeing process by the company. The agent used was also from one lot.

4. The ‘Lion Playing a Drum’ powdered fixing agent of Phua Kiam Seen Company was suggested to be used after the dyeing process by the company. The agent used was from one lot.

5. There were 3 groups of subjects, namely a Local Handicraft Group from Amphur Napho in Buri Rum; Hangkarok Silk Group from Ban Sanuan Nai in Buri Rum and Agricultural Housewife Group from Ban Nonmuang in Nong Bua Lam Phu. Originally there were 10 groups of silk weavers who joined the collaboration project between Kasetsart University and the Bank for Agriculture and Agricultural Cooperatives (2005) with the purpose to improve silk and packaging. However, these 3 mentioned groups volunteered to participate in this research project.

6. The dyeing procedure used was recommended by Phua Kiam Seen Company. The standard procedure included water ratio of 30:1, 20 sachets of dye, 2 kilograms of fiber, 2% owf. of powdered wetting agent, 2% owf. of fixing agent and 2% owf. of salt. First, the degummed silk was soaked in water. Then, dissolved dye and the wetting agent in 50°C water was poured into the solution in the water. The fiber was wrung and put into the prepared solution at 35°C and the temperature was gradually increased to 90°C (30 minutes duration was used for raising the temperature). The temperature was maintained at 90°C for 30 minutes adding salt during the first 15 minutes. The silk yarn was rinsed in plain water 5 times and soaked in water with the powdered fixing agent in the ratio of 30:1 and the fixing agent 2% owf. The process needed to be done at 60°C for 20 minutes and the dyed silk yarn was then hung dried.

7. The AATCC Test Method 61-2001 Test No.1A was used as the test of colorfastness to laundering.

8. The spectrophotometer Datacolor 650^{TM} of Data Expert Co., Ltd. was used as the color value measurement.

9. The experiment was conducted by using randomized complete block design with 9 treatments and 3 replications. The control process was the dyeing process suggested by Phua Kiam Seen Company and used in the Infra-red dyeing machine. Sample in each replication was randomly selected and tested for the color values before and after washing.

Hypotheses

In order to evaluate the quality of dyed silk yarn (objective 1), the following hypotheses were tested:

1. There was no difference in L* value among silk yarn dyed by the 3 local groups.

2. There was no difference in C* value among silk yarn dyed by the 3 local groups.

3. There was no difference in h* value among silk yarn dyed by the 3 local groups.

4. There was no difference in dE* value among silk yarn dyed by the 3 local groups.

In order to compare the quality of silk yarn dyed by using the prototype dyeing machine I, by using the prototype dyeing machine II and by the local groups (objective 2), the following hypotheses were tested:

5. There was no difference in L* value among silk yarn dyed by the 9 procedures.

6. There was no difference in C* value among silk yarn dyed by the 9 procedures.

7. There was no difference in h* value among silk yarn dyed by the 9 procedures.

8. There was no difference in dE* value among silk yarn dyed by the 9 procedures

Benefits

Expected benefits from the research were as follows:

1. To better understand the local dyeing process which leads to limited quality of dyed silk and relatively low market value.

2. To evaluate the effectiveness of a newly-developed dyeing machine in order to improve the dyed silk quality and thereby increase the value added to various Thai silk products.

3. To comprehend the feasibility of applying the newly-developed dyeing machine among local producers regarding technical, economic, social and environmental considerations.

Framework of Research

The structure of thought in this study can be related and illustrated in the framework of figure 1. It can be seen that from the main research issues, the study will seek rational explanation and analysis. Comparative measurements among three dyeing methods will be tested and concluded. Finally, technical and policy recommendations will be expressed on the selected dyeing machine which has proved holistically feasible, including technical, economic, environmental and social aspects.

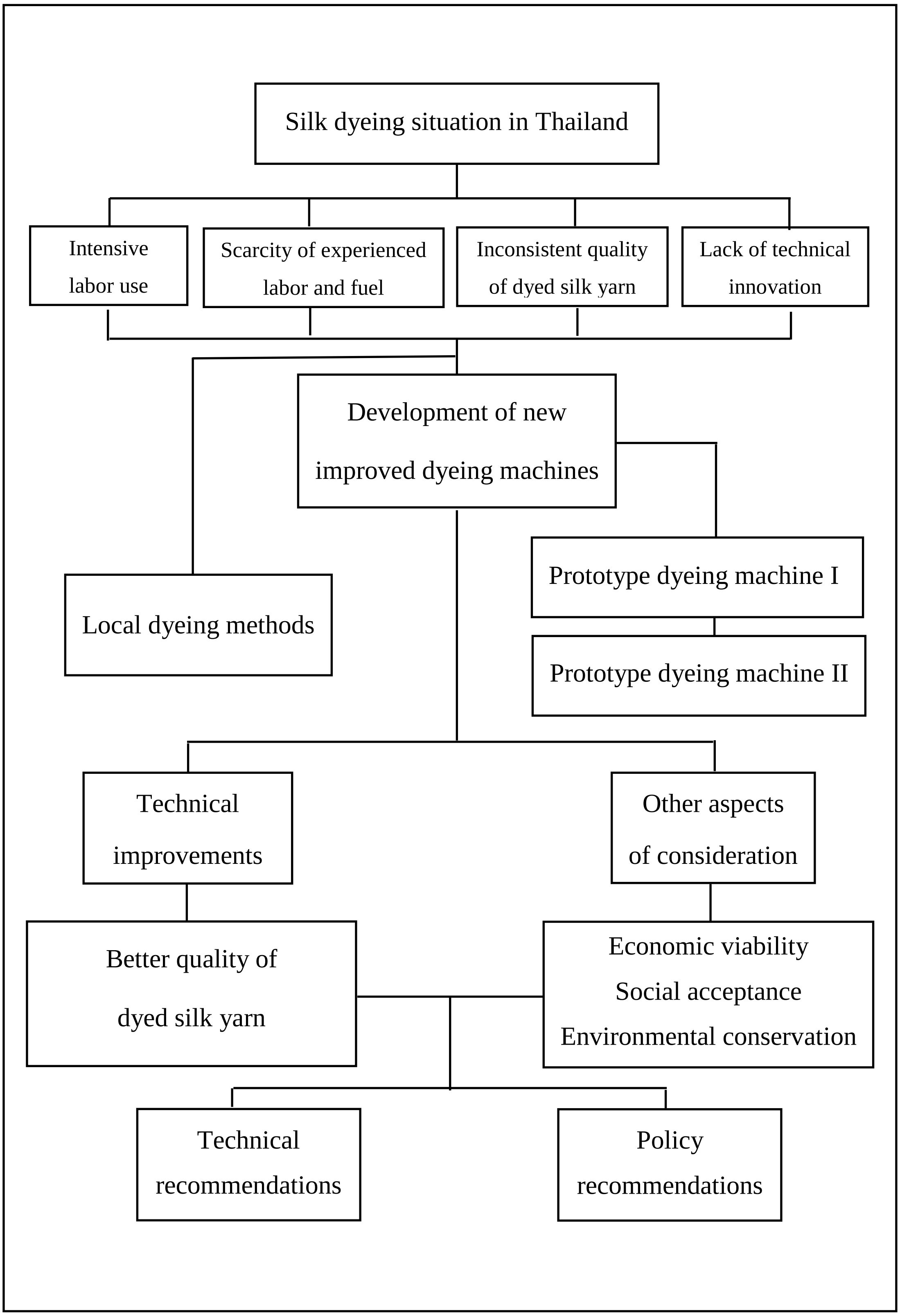


Figure 1 Framework of the study

LITERATURE REVIEW

Silk Fiber

Silk fiber is a continuous protein filament produced by the silkworm in order to form its cocoon. The principal species of caterpillar used in commercial production is the mulberry silkworm which is the larva of the silk moth, Bombyx mori. It belongs to the order Lepidoptera. (Segal, 1972) The caterpillar secretes the silk as a viscous fluid that forms in two large glands in the lateral part of the body. The fluid flows through two ducts to a common exit tube with a spinneret on the under lip. The silk from these two glands is joined by the secretion of sericin from two other glands that quickly hardens and cements the two filaments together. The caterpillar produces this thread and winds it around itself to form the protective covering or cocoon in which it passes the pupa stage. The double silk filament as it exists in the cocoon is known as a bave, and each single filament is called a brin. (Tortora and Merkel, 2003)

1. Physical Appearance

Under a microscope, raw silk fiber shows a smooth, translucent, rod-like filament with occasional swellings along its length. (Segal, 1972) A cross section of silk fiber has a rounded, triangular shape with an uneven diameter. Silk has a diameter of 9 to 11 microns, and filaments may be as short as 300 meters or as long as 3,000 meters. (Hudson *et al.*, 1993; Price *et al.*, 1999)

Natural fiber is normally white, but silk may be gray or yellow due to the color of sericin. Because it is a smooth, translucent filament, silk when processed becomes a smooth, lustrous, and luxurious fabric. (Segal, 1972; Gohl and Vilensky, 1990; Hudson *et al.*, 1993; Collier and Tortora, 2001; Price *et al.*, 1999)

2. Chemical Composition

The structure of silk fiber is made of protein which is composed of fibroin and sericin totaling 97%. The other components are wax, carbohydrate color and organic substances. (Minagawa *et al.,* 1987) Fibroin represents 75-90% of the fiber and sericin 10 to 25%. The chemical formula for fibroin is $C_{15}H_{23}N_5O_6$ and the chemical formula for sericin is $C_{15}H_{25}N_5O_8$. (Segal, 1972)

Fibroin is composed of simple amino acids and contains no disulfide bonds. Without intramolecular cross linking; silk's morphology results from the ionic bonding of amino acid groups. (Cardamone and Marmer, 1995) Fibroin in cultivated silk fiber contains at least 15 amino acids. Up to 90% of the weight of polymer is made up of the four amino acids: glycine, alanine, serine and tyrosine. Besides some amount of polar amino acids has basic or acid side – chain of amino acids. Sericin which wraps up fibroin has a large amount of serine and threonine of oxy amino acids and a lot of aspartic acid and glutamic acid of acid amino acid and arginine and lysine of basic amino acid as Table 1. (Minagawa *et al.,* 1987)

There are three types of sericin. Sericin I, or easily soluble sericin, is around 40%, Sericin II or soluble sericin is 45-50% and Sericin III or insoluble sericin is 10-20%. These three types could be separated by dissolving sericin in water with different temperature. For excellent colorfastness in dyeing it is necessary to dissociate the sericin (glue) which covers silk fibers so that the fibers have more absorbency. Besides the glue other covers as well such as wax, carbohydrate or color substance have to be dissociated. (Sailasute, 1983; Minagawa *et al.,* 1987)

Table 1 The amino acid composition of silk sericin and silk fibroin (grams of amino acid in protein 100 grams)

	Amino acid	**Sericin**	**Fibroin**
Non-polar amino acid	Glycine	8.66	41.25
	Alanine	3.51	28.87
	Valine	3.14	2.63
	Leucine	1.02	0.32
	Isoluecine	0.77	0.44
	Praline	0.66	-
	Phenylalanine	0.50	0.58
Acid amino acid	Aspartic acid	17.03	0.76
	Glutamic acid	7.46	0.69
Basic amino acid	Arginine	6.07	0.86
	Histidine	1.88	-
	Lysine	4.95	0.17
Oxy amino acid	Serine	27.32	13.22
	Threonine	7.48	0.81
	Tyrosine	4.43	10.96
Sulfur-complex amino acid	Methionine	-	-
	Cystine	0.20	-
	Total	95.08	101.56

Source: Minagawa *et al.* (1987)

3. Silk Properties

3.1 Physical and mechanical properties

Segal (1972) and Hollen *et al.* (1979) reported that silk is a strong fiber with a dry tenacity ranging from 3.5-5.0 grams per denier. It loses some strength when it is wet. Its breaking strength can be as high as 65,000 pounds per square inch.

The density of silk is 1.25 g/cm^3 which is lower than wool, cotton and linen, silk is, therefore, lighter in weight than these fibers. Silk can be stretched as much as 20% of its length without breaking. It, therefore, has good elastic recovery and moderate resiliency.

The moisture regain of silk is relatively high. At saturation the regain is about 30%, silk fiber can soak up 30% of weight in moisture and still feel dry. The absorption property of silk helps in the application of dyes and finishes, but, unlike many fibers, silk absorbs impurities in liquids such as metal salts. These contaminants tend to damage silk by weakening the fiber. The specific gravity of silk is less than that of cellulose fiber and is similar to that of wool. (Joseph *et al.*, 1992; Collier and Tortora, 2001)

3.2 Chemical properties

Like other protein fibers, silk is sensitive to strong alkalies and will dissolve in heated caustic soda (NaOH). Weak alkalies such as soap, borax, and ammonia cause little damage to silk unless they remain in contact with the fiber for a long time. (Joseph *et al.*, 1992; Collier and Tortora, 2001)

Mineral acids can dissolve silk and cause fiber contraction and shrinkage. Medium concentrations of hydrochloric acid (HCl) will dissolve silk. On the other hand, organic acids do not damage silk and are used in finishing processes. The molecular arrangement in silk permits rapid absorption of acid but tends to hold the acid molecules so they are difficult to remove. (Joseph *et al.*, 1992; Collier and Tortora, 2001)

Furthermore, cleaning solvents and spot-removing agents do not damage silk, but chlorine bleaches cause fiber disintegration. Therefore, hydrogen peroxide and perborate bleaches are generally used in bleaching silk. Perspiration can have a negative effect on dyestuffs, causing discoloration after repeated exposure. (Joseph *et al.*, 1992; Callier and Tortora, 2001) Sunlight tends to accelerate the decomposition of silk. It increases oxidation and results in fiber degradation and destruction. (Joseph *et al.*, 1992; Collier and Tortora, 2001) When silk fiber is heated to 140°C, the fiber remains unaffected for a long period of time but it decomposes very quickly at 175°C or more. (Sonthisombat, 2004)

The arrangement of polymer within silk may be either random or parallel. A random or unorganized arrangement of long-chain molecule creates an amorphous area within the fiber. On the other hand, orderly, parallel arrangement is known as crystallinity. It is said that amorphous areas are weaker than crystalline areas, and that those fibers with the highest levels of crystallinity are the strongest fibers and have the highest luster. (Gohl and Vilensky, 1990) But amorphous areas are better resilient than crystalline areas. (Kadolh *et al.*, 1993) For color absorption, amorphous areas show excellent performance. (Gohl and Vilensky, 1990)

Silk Coloration

Coloration is a stepwise process that involves attraction of the dye from the liquid or print past to the fiber surface, from where it diffuses into the fiber. Within the fiber, molecules move from one point of attachment to another. Unless they become chemically bonded to the fiber or converted to an insoluble pigment, this process can continue for as long as fiber remains in the dyebath. (Ingamells, 1993)

Dyes are colorants that are applied to, or formed in, a textile substrate in molecularly dispersed form. (AATCC, 2002) Dyes must be soluble or capable of being made soluble in the medium such as the carrier in which they are applied, or they must themselves be molecularly dispersible into the fibers. (Collier and Tortora, 2001) Dyes may combine chemically with fiber molecules, attach themselves to the fiber's surface or be absorbed into the fiber without chemical action. (Hudson *et al.*, 1993) Undissolved particles of dyes stay on the outside and colors then have poor fastness to crocking and bleeding. (Hollen *et al.*, 1979)

1. Preparatory Process of Silk

Preparatory processes are necessary for removing impurities from silk fiber and improving their aesthetic appearance. (Vigo, 1997) Silk is produced by the silk worm as a continuous thread in the form of a double strand of the protein fibroin, covered and commented by a second protein, sericin. The pupa is killed by steam; silk from the cocoons is then graded and reeled into skeins. By imparting the necessary twist to single or multiple strands of the reeled silk, yarns are prepared.

1.1 Silk degumming or boiling-off

Degumming or boiling-off is the process employed to remove the silk gum enveloping the two raw silk fibroins. During the degumming process, soil, stain, oil and fats attached to the material will also be removed. (Karmakar, 1999)

If silk is to be dyed in the yarn stage, it must first be degummed. This process, which removes the sericin from the fiber, is affected by treatment with hot soap or soap and sodium carbonate solution (25-30% on the weight of material) at 90-95°C for 2 hours. No further preparation is required for dyeing dark shades but for pale shades, a second soaping with 15% soap may be given. Degumming is essential for bringing out the true luster of silk and as a preparation for dyeing. Otherwise unleveled shades are produced. The boiled-off liquor containing an alkaline solution of silk gum and its hydrolytic products may be added to the dyebath as a levelling agent. (Segal, 1972)

According to Jarujinda (2005), there are several methods for the degumming process: high pressure water degumming, alkaline degumming, acid degumming, soap degumming, synthetic detergent degumming, enzymatic degumming, foam degumming and partially degumming (half-boiled silk). However, care is required in every method in order to avoid damaging fibroin. Moreover, levelling in degumming is required since it can affect the levelling in dyeing.

The method for degumming silk recommended by Dystar Company of Bayer and Hoechst (2003) contains the following ingredients: 5-10 g/L olive oil soap (green soap), 3 g/L LEVAPON TH liquid, and 1-2 g/L soda ash, 2-3 g/L Calgon T. The pH level is at 9.5-10 and the degumming time is suggested at 1-2 hours at 95°C. The ratio of water and fiber is 1:30. Water at the temperature of 40-50°C is used to rinse the fiber and cold water is applied after that. Ammonia 25% at the ratio of 1 ml for 1 liter of water must be used in the first rinse to enhance the removal of the soap.

According to Division of Textile Industry (2001), there are several methods of degumming using acid, basic, and enzyme. The basic degumming method is a very old method but it is still more popular than other methods because it is easy and yields accurate and quick results. Moreover, the cost is low and the method does not seem to create a bad effect on the fiber. The basic degumming method can be done according to the following procedures.

1) The basic degumming method that uses sunlight soap and soda ash requires the following proportions: the ratio of water : silk at 30:1, sunlight soap 4-6 g/L and soda ash 1.5 g/L. First, prepare 95°C hot water and dissolve sunlight soap and soda ash in the water. Then put the fiber in. Turn the fiber over from time to time for 30-45 minutes. Reduce the water temperature slowly until it reaches 60-70°C. Then wring the fiber or use the spinning machine to remove the gumming. Clean the fiber in 95°C hot water for 20 minutes. Rinse the fiber well in cold water again. (Division of Textile Industry, 2001)

2) The basic degumming method that uses synthetic detergent soap and soda ash requires the following proportions: the ratio of water: silk at 30:1, sunlight soap 15% owf., anionic wetting agent 1 g/L and soda ash 1.5 g/L. Follow the same procedures in the above method. This method is better in the degumming than the first method since it effectively removes dirt from the fiber. The received fiber is soft, shiny, tough and strong. (Division of Textile Industry, 2001)

A popular degumming method usually utilizes basics, which have an effect on the degumming process. (Kittisumpan, n.d.)

1) The pH level should be around 10.0-10.5. If it is lower than the mentioned level, the reaction would be slow. If it is higher, the fiber loses its strength.

2) The usual time length of degumming is around 1-2 hours depending on the nature of the raw silk.

3) Sericin dissolves too slowly when the temperature is lower than 80°C. Therefore, the degumming method is usually done at the temperature of 95-100°C.

The fiber that has gone through the degumming process can be tested by being dyed in the 0.1% Picrocarmine solution. The fibroin will turn yellow while the sericin will become red. (Division of Textile Industry, 2001)

Besides the above method, Amornsri (2005) explained that there are 3 other methods to test the result of the degumming.

1) Dye with 1% Sirius Red F3B. Sericin will become pink.

2) Dye with Neocarmin W. Sericin will become blue, brown-purple, red-purple depending on the types of the fiber. Fibroin becomes gold-yellow.

3) Test with cuprammonium solution. Fibroin is damaged while sericin is not damaged.

All methods mentioned above can test the result of the degumming in terms of quanlity. If the quatity is the focus, this can be done easily by weighting the fiber to observe the missing weight. The constant weight of the fiber will be looked at before and after the degumming. Steps in finding constant weight are as follows: place the uncovered specimen in an oven and maintain the temperature at 105-110°C for 1.5 hours. At the end of the time period, remove the specimen from the oven, immediately put it in the desiccator. When the specimens have cooled down to room temperature, remove them from the desiccator and reweight. Repeat the heating and reweighting process for a period of 30 minutes until the weight is constant to within ±0.001 g. (AATCC, 2002)

1.2 Silk bleaching

For bright color dyes or white, silk could be bleached by peroxide before dyeing. (Sonwalkar, 1993) Because silk is not readily degradable, it can tolerate more severe conditions. Chlorine bleaching produces discoloration so it is never prescribed. This discoloration has been attributed to the degradation of tyrosine residues. (Earland, 1960) A typical peroxide bleach bath includes alkaline hydrogen peroxide with sodium silicate and ammonia, pH 10, with tetrasodium pyrophosphate and EDTA, and processing at 40-60°C for 2-4 hours. (Sonwalkar, 1993; Cardamone and Marmer, 1995)

Minagawa *et al.* (1987) stated that the proper degumming procedure produces the white color in the fiber so bleaching is not necessary. However, the yellow fiber and the fiber from contaminated cocoons still remains yellow or almost brown after the degumming process. Therefore, the oxidation process bleaching with Hydrogen peroxide or the reduction process bleaching with hydrosulfite is required.

1) The oxidation process bleaching with hydrogen peroxide. Prepare a 1% hydrogen peroxide solution (diluted from 35%) and add a little amount of sodium hydrogen carbonate (or ammonia solution). Soak the fiber in the prepared solution at a temperature of 50-60°C. Then rinse in warm water and room temperature water several times. In general, this kind of bleaching does not destroy the peptide bonding but sometimes it reduced the length of the chain of the molecule especially under the condition that the ion of the metal exists. This can reduce the toughness and stretchability of the fiber. (Minagawa *et al.,* 1987)

2) The reduction process bleaching with hydrosulfite. Bleach the fiber in the hydrosulfite solution (1% of the weight of the fiber) at a temperature of 50°C for 2-3 hours. Then rinse with warm and room temperature water several times. (Minagawa *et al.*, 1987)

Division of Textile Industry (2001) proposed 3 methods of bleaching as follows:

1) Reduction method. This method requires the ratio of water: material at 30:1, anionic wetting agent 1 g/L, and sodium hydrosulfite 2-3 g/L. Prepare the solution according to the mentioned proportion and adjust the temperature of the solution to 85-95°C. Put the fiber that has gone through the degumming process in. Turn the fiber over frequently and keep it for 30-45 minutes. Wring by hand or use a spinning machine. Rinse the fiber with water 2-3 times. Then rinse it in 95°C hot water for 15 minutes and rinse again in water. Sodium hydrosulfite is a strong reducing agent so it can yield a good color and is convenient to use because a large amount or high temperature is not required. However, the received whiteness is not permanent and the fiber is coarse, rough and is not quite shiny.

2) Oxidation method. This method requires the ratio of water: material at 30:1, anionic wetting agent 1 g/L, sodium siligate 1.5 g/L, 35% hydrogen peroxide 4-6 cc/L and soda ash or ammonia (to adjust the pH value to 9-9.5). Prepare 85-95°C hot water and dissolve anionic wetting agent and sodium siligate in the water. Then add hydrogen peroxide in and use soda ash or ammonia to adjust the pH value to 9-9.5. Leave the fiber that has gone through the degumming process in the solution for 45-60 minutes. Wring by hand or use a spinning machine. Rinse with water 1-2 times and rinse with 90°C hot water for 15 minutes. Rinse again with water. Hydrogen peroxide is the bleaching substance that yields permanent whiteness. However, it is not popular in Thailand because of its high price. It also requires a complicated process since it needs to be use with other chemical substances, for example sodium siligate which is difficult to rinse off. Care must also be taken when there are heavy metals for example iron and copper in the water because they can

accelerate the reaction and cause damage to the fiber. Consequently, a sequestering agent is needed in the bleaching tub.

3) The bleaching procedure using both reduction method and oxidation method. The fiber must go through the reduction method first and then the oxidation method.

Besides the types of bleaching substance, Riggs and Sherrill (1982) mentioned that factors such as the temperature and the concentration of the bleaching substance also affect the bleaching reaction. The high temperature and the concentration of bleaching substance cause a strong bleaching reaction.

Sonthisombat (2002) mentioned that there are 2 methods used to test the fiber that goes through a bleaching process.

1) The comparison through a naked eye. A comparison can be made among the fibers that go through the bleaching process, those with no bleaching and the standard white fiber of that particular fiber.

2) The measure of tensile strength and tear strength of the fiber.

AATCC (2002) proposed AATCC Test Method 110-2000 as the method to test whiteness of textiles. This test method provides procedures for measuring the whiteness and tint of textiles. Whiteness as measured by this test method is an indication of how white the textile appears to an average viewer. Tint, if other than zero, is an indication of a reddish or greenish hue having shifted away from a bluish hue with a dominant wavelength of 466 nanometer. The spectrophotometer is used to measure the level of whiteness.

2. Color and Process of Silk Dyeing

There are many methods of silk dyeing, useful for different purposes. The cocoon, the yarn or the piece of cloth may be dyed. However, the most popular method is to dye the yarn in the form of a hank or skein. (Sonwalkar, 1993; Division of Textile Industry, 2001) Silk is suitably dyed with acid dye. However, other colors such as direct dyes, basic dyes, acid mordant dyes, reactive dyes, vat dyes and natural dyes can be used. The selection of color depends on the purpose, luster and esthetic maintain of silk. At present, only three kinds of dyes are usually used: acid dyes, metal complex dyes and reactive dyes. (Division of Textile Industry, 2001)

2.1 Acid dyes

Acid dyes are so called because they are usually applied under acidic conditions. (Gohl and Vilensky, 1990) Acid dyes are sufficient to allow direct application from an aqueous solution. (Ingamells, 1993) Most synthesized acid dyes depend on pendant sulfonate salt groups for their solubility as do the direct dyes. (Aspland, 1993)

Acid dyes are water-soluble and contain one or more anionic groups (usually $-SO_3H$). Most acid dyes contain azo groups, but there are a few that are in the anthraquinone or triphenylmethane chemical class. Adsorption of acid dyes is governed by species of polymeric functional groups that exist at different values of pH and by the hydrophobicity of the dye. In neutral solution, the functional amino and carboxyl groups exist as switterions: $^{+}NH_3$--F--COO^{-}. Under acidic conditions, protonation of the carboxyl group occurs, and the fiber exist as $^{+}NH_3$--F--COOH. Conversely, deprotonation of the positively charged amino group occurs in basic solution and the fiber exists in the form of NH_2--F--COO^{-}. Sorption of acid dyes may be most appropriately characterized by the use of Langmuir-type isotherms, but Donnan equilibrium may also be utilized to explain the distribution of ions in the solid and solution phases. (Vigo, 1997)

According to its application, acid dyes may be further subdivided into 3 types: levelling dyes, milling dyes and super-milling dyes. (Vigo, 1997)

The characteristics of these three types of acid dyes are summarized in Table 2.

Levelling dyes are normally applied to wool from a strongly acidic bath (pH of 2-3 with sulfuric acid) to promote good exhaustion. Their good migration and levelling properties, due to their low molecular weight and ability to become unattached and subsequently reattached to another dye site on the fiber, are offset by their poor wetfastness. Levelling dyes applied to polyamides are usually of higher

Table 2 Characteristics of acid dyes

Criteria	Levelling dyes	Milling dyes	Super-milling dyes
1. Fastness to wet treatment	Poor	Good	Very good
2. Dyeing method	Sulfuric acid	Acetic acid	Ammonium acetate
3. pH of dyeing	2-4	4-6	6-7
4. Levelling under own dyeing conditions	Good	Moderate-poor	Very poor
5. Dye characteristics	Low molecular wt High solubility Molecular solutions	High molecular wt Low solubility Colloidal solutions	High molecular wt Low solubility Colloidal solutions
6. Affinity of anions	Low	High	Very high

Source: Vigo (1997)

molecular weight, and are applied at a higher pH than on wool. (Vigo, 1997) Generally, sodium sulphate (Glauber's salt) is applied with this type of dye in a dyebath to increase the levelling properties. (Sirisongtham, 2005)

Milling acid dyes are applied from weakly acidic solutions (usually acetic acid), have higher molecular weight than levelling acid dyes, and contain two or more anionic groups. These dyes have good wetfastness, but possess poor levelling and migration properties. (Vigo, 1997) According to Sirisongtham (2005), sodium sulphate should not be added in the dyebath because it speeds up the process of exhaustion. This leads to the low levelling properties of fiber.

Neutral or super-milling acid dyes are applied from solutions of neutral pH, usually containing only one anionic group. Since they are not levelling, their application must be carried out carefully. If they are properly applied, they exhibit good wet and lightfastness properties. Better fastness of the super-milling and milling dyes compared to that of the levelling dyes may be due to the fact that they have a larger molecular size than the levelling dyes. (Vigo, 1997) In order to increase the qualities of levelling properties, Sirisongtham (2005) pointed out that ammonium salt such as ammonium acetate and ammonium sulphate or ammonium sulphate should be added into the dyebath.

2.2 Metal complex dye

Premetallized or metal complex dyes are normally classified as acid dyes since they usually have azo groups and anionic substituents and possess good substantivity for protein and polyamide fibers. However, the anionic group differs in the ratio of metal to dye. Chromium or cobalt salts are most frequently used as the metal complexing agents. (Vigo, 1997)

There are 2 types of metal complex dyes. (Sirisongtham, 2005)

1) Acid dyeing premetalized dyes or 1:1 metal complex dyes.

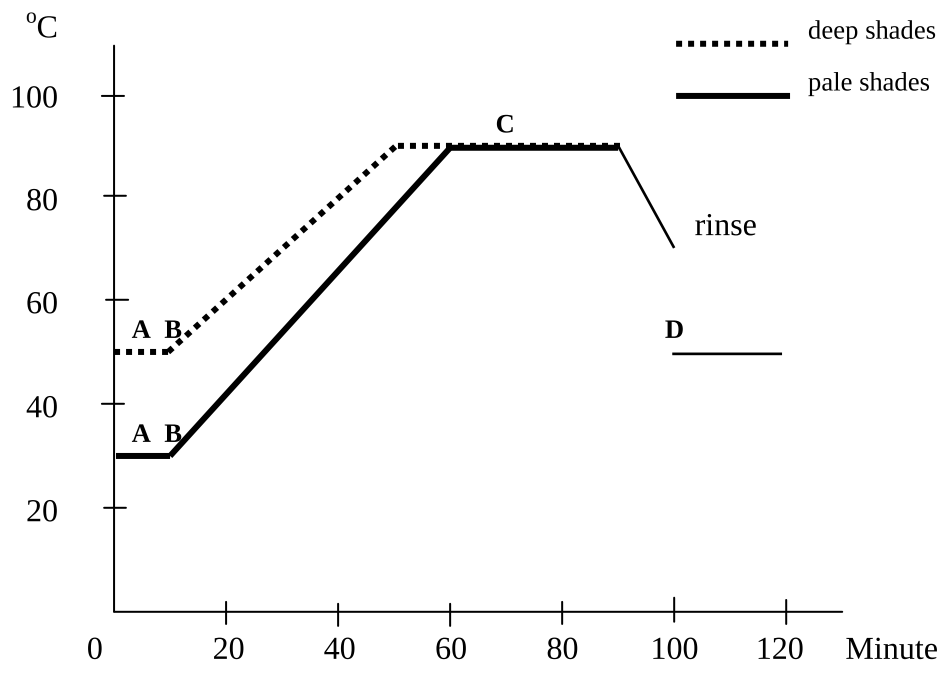
This dye normally contains one or two –SO_3H groups and is applied from strongly acidic solutions (usually 6-8% H_2SO_4 to attain a pH of 2.0-2.4). The dyeing procedure is quite lengthy since the dyebath temperature is raised slowly to the boil for almost an hour. The boiling is maintained for more than an hour to achieve levelling and insolubilization of the metal complex on the fiber.

2) Neutral dyeing premetalized dyes or 1:2 metal complex dyes.

This dye has large molecules and such high substantivity even at neutral pH that it requires levelling agents and pH above 7. It usually has no ionizing groups but contains high polar groups (such as –SO_2CH_3 or –SO_2NH_2) to confer sufficient solubility of the dye in water. These complex are applied from weakly acidic or neutral solutions (pH 6-7), preferably with addition of ammonium salts. Although the dyeing period is also long, the pre-boil temperature is only 40-50°C. This dye possesses excellent fastness.

2.3 Method for dyeing silk with acid dyes and metal complex dyes

A method for dyeing silk with acid dyes and metal complex dyes recommended by Dystar Company of Bayer and Hoechst (2003) is shown in Figure 2.



A 5-10% sodium sulphate anhydrous
0.5-1% levelling agent
X% acetic acid pH 5-7 (depending on the depth of shade)

B Y% dyestuff

C If exhaustion is insufficient, then: 0.5-2% acetic acid 60% pH 5.5-4.5

D Cationic after treatment

Figure 2 Explanation of dyeing silk with acid dyes and metal complex dyes method through graph

Source: Modified from Dystar Company of Bayer and Hoechst (2003)

2.4 Factors affecting acid dyeing

Division of Textile Industry (n.d.) pointed out the factors affecting acid dyeing as follows:

1) An effect of acids

In acid dyeing, acid plays a very important role because it increases the exhaustion rate. Sulfuric acid (H_2SO_4), an inorganic acid, leads to higher exhaustion rate when compared with acetic acid (CH_3COOH).

2) An effect of electrolytes

Salt used in acid dyeing acts as a levelling agent in making the color spread evenly. It acts as a retardant in reducing the rate that the molecules of color stick to the fiber.

3) An effect of temperature

The exhaustion rate of acid dye highly depends on the temperature. At a temperature lower than 39°C, the fiber does not adsorb any color. For the dye in the group milling dyes, the dyeing process must not be done at a temperature lower than 60°C. However, at a temperature higher than 70°C, the adsorption rate is very quick. Therefore, the level of temperature must be carefully controlled to avoid the problem of non-leveling color by slowly increasing the temperature.

2.5 Reactive dyes

Reactive dyes contain anionic substituents, but differ markedly from acid, direct, basic and mordant dyes because their negatively charged groups are primarily for solubilizing the dye and they become substantive to fibers by covalent bond formation. (Vigo, 1997)

The structures, development and application of reactive dyes to textiles contain sulfonic acid groups to increase their solubility in water, chromophoric groups or systems, and a linking group to an electrophilic structure that contains a good leaving group (halogen, sulfate, or methanesulfonate) as shown in Figure 3. (Vigo, 1997)

Most of the electrophilic structures are heterocyclic rings (triazines, pyrimidines, quinoxalines and benzothiazoles) containing one or more halogens as leaving groups. They react with sodium cellulosate or any other negatively charged fiber substituent (-NH groups in wool or polyamides) by nucleophilic aromatic substitution to form covalent bonds. There are also reactive dyes with a hydroxyethylsulfone structure ($B-SO_2-CH_2-CH_2-OSO_3H$) that, in the presence of alkali, are converted into a vinyl sulfone structure ($B-SO_2-CH=CH_2$). This latter structure then reacts with fiber by nucleophilic addition across the double bond to reactive group of fiber. A major class of reactive dyes that has been gaining commercial acceptance is those based on triphenodioxazines due to their excellent alkaline stability and lightfastness. (Vigo, 1997)

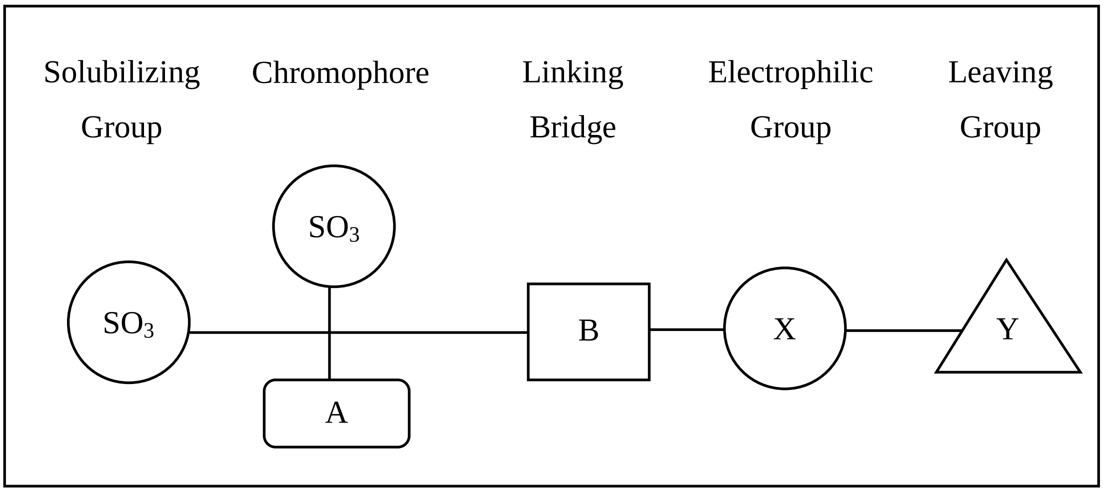


Figure 3 General structure of reactive dyes

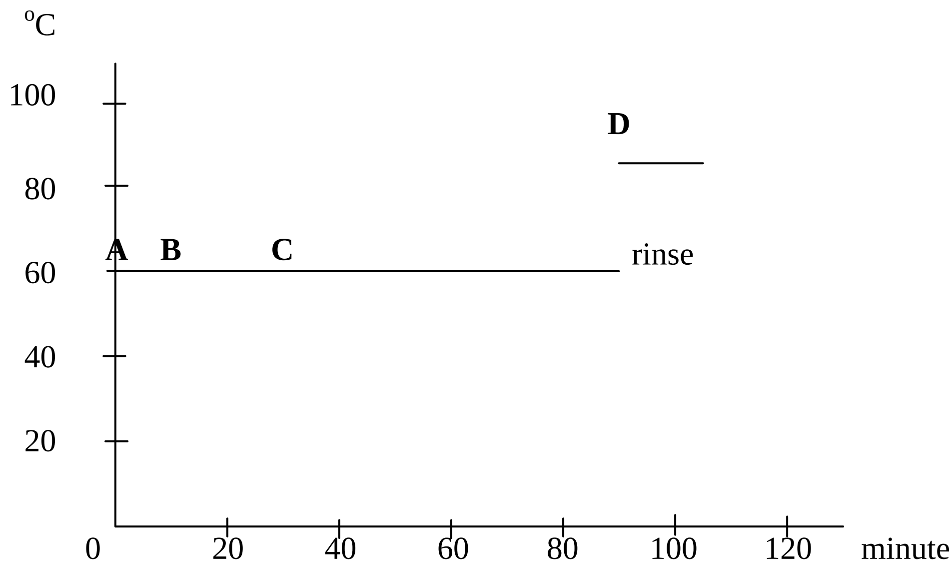
Source: Vigo (1997)

Reactive dyes are most frequently applied to cotton and other cellulosic fibers at an alkaline pH of 9-12 but have also been applied to wool, silk, and polyamide fibers in weakly alkaline dyebaths. In the past, it was believed that strong alkaline solutions such as sodium carbonate or even sodium hydroxide were required to enhance the covalent bond between these dyes and the fibers. However, in later studies and processes, milder alkaline conditions such as sodium bicarbonate are frequently used in reactive dye fixation processes. (Vigo, 1997)

Since reactive dyes cannot migrate once they are affixed to the fiber, the amount of unacceptable dyed fabric tends to be higher with these classes of dyes than for other dye classes. Level dyeings can be obtained by matching the rate of exhaustion of the reactive dye with the two stages of exhaustion (primary and secondary). In the primary exhaustion stage, physical absorption occurs because of dye addition and the presence of inorganic salts. In this stage, migration or levelling is possible. Controlling rate of fixation to form covalent bonds with the fiber is important in the secondary exhaustion stage. Methods have been developed to obtain high reproducibility of dyeing in both shade and depth and better levelness by predicting and controlling the pH of the dyebath to obtain optimum exhaustion and fixation curves for specific reactive dyes. (Vigo, 1997)

2.6 A method for dyeing silk with reactive dyes

A method for dyeing silk with reactive dyes recommended by Dystar Company of Bayer and Hoechst (2003) is shown in Figure 4.



A NaCl 50 g/L

B Y% dyestuff

C Soda ash 2 g/L

D Soaping agent

Figure 4 Explanation of dyeing silk with reactive (Remazol®) method through graph

Source: Modified from Dystar Company of Bayer and Hoechst (2003)

2.7 Factors affecting reactive dyeing

Sailasute (1983) stated that there are six factors influencing the absorption level of reactive dye to the fiber.

1) An influence of affinity. The level of affinity of the color with the fiber depends on the structure of the color. This kind of reaction cannot be controlled by the dyeing procedure so the right color must be chosen to yield the required result.

2) An influence of liquor ratio. Water plays a very important role in increasing the level of affinity of reactive dye. The less the water, the better the level of affinity.

3) An effect of temperature. Reactive dye has small molecules so it can diffuse quickly into the fiber. Generally, the dyeing process is done at a low temperature first and the temperature should then be increased slowly.

4) An effect of electrolyte concentration. When there are a lot of electrolytes in a dyebath, the absorption level of dye to the fiber is high.

5) An effect of alkali. Basic can either increase the chemical reaction or reduce the absorption rate.

6) An effect of fiber. Different types of fiber can absorb different amount of dyes.

Color Measurement and Fastness

The three principle factors which control appearance of an object need a lot of attention. They are the nature of the light, the nature of the object, and the nature of the detector. Light travels in waves and must be reflected from the object and be received by the eye. The focus of light waves on the retina creates impulses which are transmitted via the optic nerve to the brain. There are two light sources. First, natural light varies with latitude, the time of the day, the direction, the presence or absence of cloud season and other variables. Second, daylight simulation that has a spectral energy distribution (SED) by wavelength close to average daylight is the xenon arc lamp. According to Gohl and Vilensky (1990), normally the characteristics of color and appearance demonstrate the three-dimensionality of perceived color and meaning as follows:

Hue is the quality of color for which we reserve the color names: red, yellow, green, blue, and others.

Value relates to property of color generally called darkness or lightness (from 0-100, where 0 is black and 100 is white).

Chroma relates to colorfulness of the sample when compared to nature. It is the dullness, brightness, saturation, intensity, vividness, or purity of the color.

However, the accuracy and precision of color identification depend on sex, age, temperament, and experience including the environment during observation. Color measurement test methods have been developed to provide consistency and precision in measuring color. It is CIE color order system (initial letters of the French word for International Commission on Illumination).

1. CIELAB Color Order System

At present, textile color differences are predominately calculated from CIEL*a*b* 1976 and its color difference space is shown in Figure 5. (Gohl and Vilensky, 1990; Aspland, 1993; Perkins, 1996; Chrisment, 1998)

L* or lightness-darkness axis runs up and down the color space, with value from 0-100, representing black to white respectively.

The a* axis has negative values (green) to positive values (red).

The b* axis has negative values (blue) to positive values (yellow).

Color in a*or b* can also be related to chroma, C* which is the direct distance from the achromatic (0, 0) origin, and hue angle, h*, which is measured in degrees from a 0°-360°scale running counterclockwise from the positive a* axis at yellow

(90°) and on around through green (180°) and blue (270°) and back to red (0°, 360°). (Gohl and Vilensky, 1990; Aspland, 1993; Perkins, 1996; Chrisment, 1998)

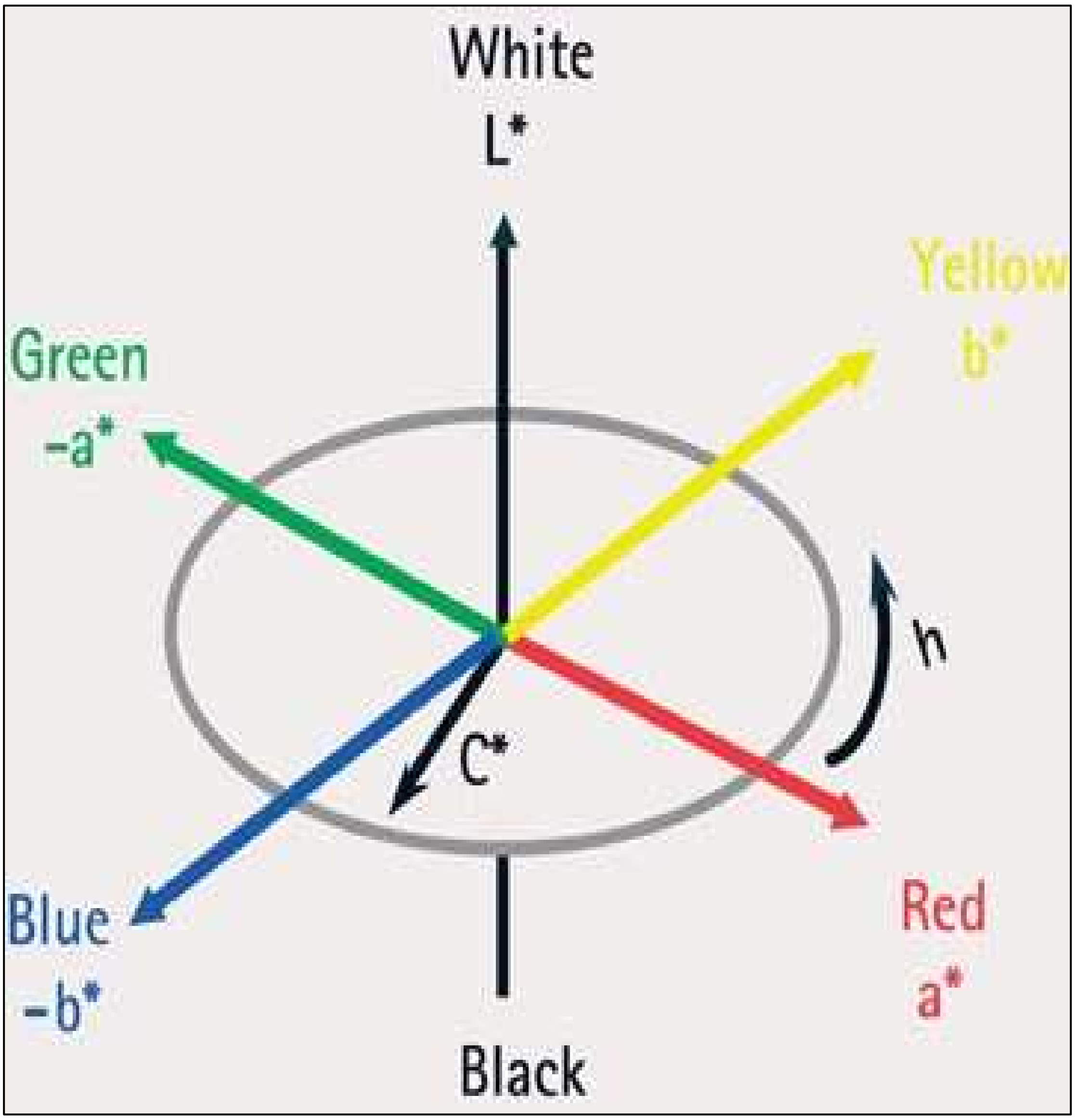


Figure 5 Characteristics of CIEL*a*b* 1976 color space

Source: Burkinshaw (2004)

2. Color Differences

CIEL*C*h* color difference space also has three dimensions at right angles, like CIELAB. The chroma axis, C*, has the orientation of a direct line drawn from the CIEL*a*b* a*, b* origin (0, 0) to the position of the object chosen as the standard. The metric hue axis, h*, runs at right angles to the chroma axis, through the selected standard. This enables color differences to be expressed in terms of the three rectilinear co-ordinates of L*C*h* (similar to Munsell Value, Chroma and Hue). These co-ordinates are normally used in a limited volume of color space around a standard, where the standard is at a new origin with co-ordinates (0, 0) and samples are compared with the standard in terms of the color differences dL*, dC* and dh*. (Gohl and Vilensky, 1990; Aspland, 1993; Perkins, 1996; Chrisment, 1998)

Positive values of dC* indicate more chromic samples while negative values indicate less chromic samples. Positive values of metric hue mean that the colors have moved in the counterclockwise hue direction, of normally increasing hue angle, but the name given to the change depends on the name given to the color of the standard of the origin. (Gohl and Vilensky, 1990; Aspland, 1993; Perkins, 1996; Chrisment, 1998)

For negative values of metric hue, the reverse is true. For example, in an orange standard, positive dh* means yellower, and negative dh* means redder; but in a blue standard, positive dh* means redder, and negative dh* means greener. (Gohl and Vilensky, 1990; Aspland, 1993; Perkins, 1996; Chrisment, 1998)

When two samples (or a trial and the standard) show color differences in all three dimensions, the total color difference is expressed as dE* (Gohl and Vilensky, 1990; Aspland, 1993; Perkins, 1996; Chrisment, 1998), where:

$$dE^{*2} = dL^{*2} + da^{*2} + db^{*2} \text{ or}$$
$$= dL^{*2} + dC^{*2} + dh^{*2}$$

3. Colorfastness Test

For accuracy and precision of fastness test of dyeing the test should be done as the standard of fastness test, AATCC recommendation (American Association of Textile Chemists and Colorists). (AATCC, 2002)

Colorfastness to laundry test as recommended by AATCC Test Method 61-2001 Test No.1A would be at a temperature of 40°C, 0.37% detergent of total volume, total liquor volume 200 milliliters, 10 stainless steel balls, and a test time of 45 minutes. The following procedures are used when the sample is a skein. First, prepare two 110 meters (120 yards) skeins of each yarn. Second, fold the skein so that there is a uniform amount of yarn across a 50 millimeters (2 inches) width with a length appropriate for the procedure to be used. Then, keep one skein of each sample as an unwashed original. Next, sew or staple Crockmeter test cloth squares or squares of bleached cotton test fabric having approximately the same weight folded over each end of the layered yarn specimen. Attach a multifiber test fabric along one 50 millimeters edge of test specimen and in contact with the face of material with the wool on the right. Then evaluate this test by checking the color differences in terms of dL*, da*, db*, dC*, dh* and dE*. (AATCC, 2002)

In addition, Table 3 is shown the comparison of Grey Scale for Color Change and Grey Scale for Color Staining levels of colorfastness in any condition with the total color differences, dE* in CIELAB system. (AATCC, 2002)

In the dyeing industry, the result of total difference, dE* from CIELAB of samples, must be at least 1-2 level but Grey for Color Change is at least 3-4 level and Grey Scale for Color Staining is at least 4-5 for good colorfastness samples.

Table 3 Comparison of Grey Scale for Color Change and Grey Scale for Color Staining with total color differences in CIEL*a*b* system

Grey Scale for Color Change		Grey Scale for Color Staining	
Colorfastness Grade	**Total Color Difference (dE*)**	**Colorfastness Grade**	**Total Color Difference (dE*)**
5	0.0	5	0.0
4-5	0.8	4-5	2.2
4	1.7	4	4.3
3-4	2.5	3-4	6.0
3	3.4	3	8.5
2-3	4.8	2-3	12.0
2	6.8	2	16.9
1-2	9.6	1-2	24.0
1	13.6	1	34.1

Source: AATCC (2002)

Hank Dyeing Machines

GENDAI Advanced Studies Research Organization (1988) revealed that, for hank dyeing, liquor circulating and cascade-type hank dyeing machines are generally used.

1. Liquor Circulating Hank Dyeing Machine

In this type of machine, the yarn is hung on a stick, and liquor is circulated by using an axial pump. In the machines currently used, the sticks are fitted at the upside and the downside of the frame and the flow direction of liquor is reversed alternately many times. The feature of the liquor circulating hank dyeing machines is that the yarn can shrink freely, and its limitation is that the liquor ratio is large and it requires much labor due to its inefficiency.

2. Cascade-Type Hank Dyeing Machine

In this machine, the yarn is hung on a perforated cylinder, and then dyed by injecting liquor from the cylinder while the yarn is rotated intermittently by the rotating stick on the circumference of the cylinder. The liquor at the bottom is fed back to the cylinder by a pump. The liquor ratio can be made smaller than that of a liquor circulating hank dyeing machine, but the machine is not suitable for vat dye and sulphur dyes because it is highly possible that the liquor will contact with the air. The color depth difference between the inner and outer layers of the hank, which occurs in cascade-type hank dyeing machines, can be prevented by using proper selection of an even dyeing dyestuff, using retarding agents, controlling the weight of the yarn, improving the pump capacity, and especially by cleaning the filter thoroughly.

According to National Mulberry and Silk Institute (2006), equipment used in dying should be stainless steel that has enough depth to let the fiber evenly soak in the dyeing solution and at the same time does not let heat directly affect the fiber.

Trotman (1984) said that a good dyeing machine should contain these following characteristics:

1) a good dyeing solution circulation

2) a precise and consistent temperature control system

3) be designed to have a proper liquor ratio which can save water, energy and chemical substances during the dyeing process

4) dyeing solution and chemical substances can be added quickly and conveniently

5) is built from materials that are durable and resistant to chemical substances, have smooth surfaces that can be cleaned easily

Local Silk Dyeing Method

Silk dyeing in the past used colors from nature. (Leesuwan, 1987) However, natural colors require complicated steps for example extraction and the process of reproducing a color is very difficult. (Moeyes, 1993) Chemical dyes are now very popular because the dyeing process is very easy and precise colors can be easily achieved. The color from the dyeing process is also very bright and has colorfastness. (National Mulberry and Silk Institute, 2006) This is very efficient in terms of time and labor. The popular chemical dyes among the local dyers are ‘Lion Playing a Drum’ brand and ‘Airplane’ brand. These acid dyes can be easily found in local stores. (Panurat *et al.*, Nd.)

W. Pansubkul (personal communication, April 9, 2005), Manager of Phua Kiam Seen Company which produces ‘Lion Playing a Drum’ dye and ‘Two Lions’ dye, explained that ‘Lion Playing a Drum’ dye, a popular brand among the local people, are acid dyes except No.1, 11 and 25 which are green, black and golden yellow respectively. They are direct dyes. ‘Lion Playing a Drum’ dye is packaged in a 10 gram sachet. In each sachet, there is dye and sodium sulfate so it is very convenient to use and popular among dyers in the northeastern Thailand. Moreover, the company also produces a powdered wetting agent, powdered fixing agent, degumming chemical substances, and chemical substances for warps.

Mr. Pansubkul mentioned that his dye is very easy to use and the value of colorfastness to laundering is also at an acceptable level. Materials required are water in the ratio of 30:1, 1 sachet of dye, 100 grams of fiber, 2% owf. of wetting agent, 2% owf. of fixing agent and 2% owf. of salt. First, soak the degummed fiber in water. Then dissolve the dye and wetting agent in 50°C warm water and mix the solution in water. Wring the fiber and put it in the prepared water and gradually increase the water temperature to 90°C. Maintain the temperature at 90°C for 30 minutes by adding salt during the first 15 minutes. Make sure that the fiber soaks well in the water. After that, rinse the fiber in plain water 3 times and soak the fiber in water with 2% owf. of the powdered fixing agent in the ratio of 30:1 and the agent. This process needs to done at 60°C for 20 minutes and then hang dry the fiber. However, Mr. Pansubkul described that generally the local dyers inherit the knowledge of dyeing from their ancestors so the techniques of each group might not be exactly the same. These differences might have some effects on the quality of silk. He also mentioned that an agent would help better the colorfastness in acid dyes.

Moeyes (1993) also talked about the dyeing process at the community level in Thailand. He explains that the dyers prefer to do their work outdoors, either in cooking area or in a small space adjoining their cooking area, or in the centre of the action where the animals, the children and the husband, and everybody else can just run through. The dyers build an oven on the ground, made of clay or stones with an opening in the top for the dye pan, and opening in the front for the firewood. They control the temperature through burning wood. The more wood they have burnt, the higher the temperature. If they want to reduce the heat quickly, they pull the wood out from under the dye pan, and push it back as soon as the liquid stops simmering. For dye pans, they use any available big pan, sometimes ordinary steel buckets from the market, but more often they use big cooking pots, of any kind of material. They do not use wooden or glass rods either, but use a stick obtained from the woods. They do not have a notebook, because they do not keep records of their dyeing. Their records pass from mothers to daughters verbally. As for scales, they do not use them. So, the local dyer looks at the color of the dyebath and the yarn that will be dyed.

Moeyes (1993) also suggested that in the dyeing process, gas, electric or propane stoves should be used instead of firewood or charcoal. The dyeing containers should be stainless steel for the best dyeing result. This is because in enamel, ordinary steel or aluminum influence the color of dye. Scales, one or two liter measuring jugs, plastic bowls, measuring spoons, glass jars, a thermometer, a sieve, colander and rubber gloves are also necessary.

Tawanwitchajit (2005) visited a housewife group in Pa-ngad Nuan Pattana Village with staff of ‘Colourway’ Journal and ATSME to offer suggestions on dyeing and weaving silk. She mentioned that the dyeing process requires a lot of labor, which is similar to degumming. The dyers are required to regularly turn the fiber to let the heat flow evenly through the fiber in order to gain an even color in the fiber. Therefore, a question of how to minimize the number of turnings of fiber is frequently asked by the group of housewife. Moreover, a dyeing process that requires complicated steps such as adding and dividing fixing agent is neither acceptable nor popular among the dyer groups. Therefore, the ready-made dye sachet is regularly used since it does not require the dyers to add any extra agent because all required chemical substances are in one sachet.

MATERIALS AND METHODS

Materials and Equipment

The main issues regarding materials and equipment can be separated into two parts as follows:

1. Silk Dyeing Process

1.1 Materials

1) Silk yarn in skein form, No.30/32D, 6 ply, 150 tpi (from Jun Mai Thai Company)

2) ‘Lion Playing a Drum’ red dye sachet No.34 of Phua Kiam Seen Company

3) ‘Lion Playing a Drum’ wetting agent sachet of Phua Kiam Seen Company

4) Sodium chloride (NaCl)

5) ‘Lion Playing a Drum’ fixing agent sachet of Phua Kiam Seen Company

1.2 Equipment

1) Prototype dyeing machine I

2) Prototype dyeing machine II

3) LA-650 IR Infra-red dyer

4) KB5 burner (Seng Tai, diameter: 11 centimeters)

5) KB8 burner (Seng Tai, diameter: 16 centimeters)

6) LPG (PTT Public Co., Ltd., Heating value: 11,700-11,900 Kcal/kg)

7) Thermometer

8) Scientific equipment such as beaker and stirring rod

2. Colorfastness to Laundering Test

2.1 Materials

1) 1993 AATCC Standard Reference Detergent WOB (without fluorescent whitening agent and without phosphate)

2) Bleached cotton test fabric 32 x 32 ends x picks/cm construction, 136±10 g/m^2, desized without florescent whitening agent

3) Multi-fiber test fabrics No.1 and FB (8 millimeter (0.33 inch) bands) containing bands of acetate, cotton, nylon, silk, viscose rayon and wool

2.2 Equipment

1) Atlas Launder-Ometer

2) Spectrophotometer Datacolor 650™

3) Stainless steel lever lock canisters Type 1 500 milliliters (1 pt), 75 x 125 millimeters (3.0 x 5.0 inches)

4) Stainless steel balls, 6 millimeters (0.25 inch) in diameter

5) Teflon fluorocarbon gaskets

6) Scientific equipment such as beaker and stirring rod

Methods

For objective 1: To investigate the comparative local dyeing processes and evaluate the quality of dyed silk yarn

1. Selected 3 silk dyeing groups from 10 groups of silk weavers who joined the research collaboration project between Kasetsart University and Bank for Agriculture and Agricultural Cooperatives in Thailand (2005).

2. Interviewed each silk dyeing group to find out their steps of processing in dyeing silk.

3. Ask each group to dye 1 kilogram of degummed silk with 12 ‘Lion Playing a Drum’ red dye sachets No.34 according to their procedure. Three replications of dyeing were performed.

4. Randomly select sample of silk yarn from each replication and test for colorfastness to laundering according to the AATCC Standard Test Method 61-2001 Test No.1A. The test procedures were as follows:

4.1 Prepared 110 meters skeins of each sample. Folded the skein into 50 millimeters (2 inches) wide and 100 millimeters long (4 inches).

4.2 Sewed the prepared skein of sample on a bleached cotton test fabric.

4.3 Attached a 50 millimeters multifiber test fabric only along the upper 50 millimeters edge of the bleached cotton test fabric and on the top of the skein with the wool on the right.

4.4 Washed each prepared specimen at a temperature of 40ºC for 45 minutes by using 0.37% detergent of total volume, total liquor volume 200 milliliters and 10 stainless steel balls.

5. Measured the color value (L*: lightness-darkness, C*: chroma, h*: hue) before and after laundering by using the spectrophotometer Datacolor 650™ of Data Expert Co., Ltd.

6. Evaluated colorfastness to laundering from the dE* values of color change and color staining.

7. Evaluated dyeing reproducibility from the dE* values of each pair of replication in each group.

8. Analyzed data using the Analysis of Variance. Differences among means using Duncan's multiple range test ($P \leq 0.05$).

For objective 2: To develop the prototype dyeing machine for improvement of local silk dyeing and to compare the quality of silk yarn by the selected local groups and techniques

1. Developed a prototype dyeing machine by taking the issue of labor saving into account. The machine continuously turned the silk yarn to make the dyeing solution evenly soak through the fiber and be continuously circulated. The source of energy was gas.

2. Tested the machine to see its functions and deficiencies. Used the collected data to improve the new prototype dyeing machine by taking the issue of labor saving

into account. The new machine must still continuously turned the silk yarn to make the dyeing solution evenly soak through the yarn and continuously circulated. The source of energy was also gas.

3. The dyeing experiment was conducted by using randomized complete block design with 9 treatments and 3 replications. The control process was the dyeing process suggested by Phua Kiam Seen Company using and used in the Infra-red dyeing machine. Sample in each replication was randomly selected and tested for the color values before and after washing. The 9 treatments were as follows:

Treatment 1 Dyeing silk by Local Handicraft Group from Amphur Napho in Buri Rum.

Treatment 2 Dyeing silk by Hangkarok Silk Group from Ban Sanuan Nai in Buri Rum.

Treatment 3 Dyeing silk by Agricultural Housewife Group from Ban Nonmuang in Nong Bua Lam Phu.

Treatment 4 Dyeing silk by the prototype dyeing machine I with 180 (60+120) minutes duration.

Treatment 5 Dyeing silk by the prototype dyeing machine I with 150 (60+90) minutes duration.

Treatment 6 Dyeing silk by the prototype dyeing machine I with 120 (60+60) minutes duration.

Treatment 7 Dyeing silk by the prototype dyeing machine II with 110 (30+80) minutes duration.

Treatment 8 Dyeing silk by the prototype dyeing machine II with 90 (30+60) minutes duration.

Treatment 9 Dyeing silk by the prototype dyeing machine II with 70 (30+40) minutes duration.

4. Dyed the silk yarn by using LA-650 IR Infra-red dyer and used this dyed silk as a standard sample. The dyeing steps were as follows:

4.1 Used water in the ratio of 30:1, 20 sachets of the ‘Lion Playing a Drum’ red dye No. 34 (10% owf.), 2 kilograms of the silk yarn and the 2% owf. ‘Lion Playing a Drum’ powdered wetting agent. First, the degummed silk was soaked in water. Then, the dye and the wetting agent was dissolved in 50°C water and poured into the dyeing solution in prepared water. The silk yarn was wrung and put it in the prepared dyeing solution at 35°C and the temperature gradually increased to 90°C (used 30 minutes duration for raising the temperature). The temperature was maintained at 90°C for 30 minutes by adding salt during the first 15 minutes. The silk yarn was rinsed in plain water 5 times (used water in the ratio of 20:1 for each time) and soaked in water with the ‘Lion Playing a Drum’ powdered fixing agent in the ratio of 30:1 and the fixing agent 2% owf. The process needed to done at 60°C for 20 minutes and the silk yarn then hung dried.

4.2 Evaluated the value of colorfastness to laundering from the randomized piece of skein by using the standard AATCC Test Method 61-2001 Test No.1A.

4.3 Measured the color value both before and after laundering by using the spectrophotometer Datacolor 650™ of Data Expert Co., Ltd. Took the before laundering value as the controlled value to be compared with the color value of the received from the developed machines and that received from the local dyeing groups.

5. Adjusted the dyeing period in the prototype dyeing machine. The steps required were mentioned below:

5.1 The prototype dyeing machine I: The skein hanging wheel in this machine was quite high so only one-third of a skein soaked in the dye solution. The liquor ratio was then adjusted and increased to 50:1. The dyeing period was adjusted to be 90 minutes which was a threefold increase of the normal duration (30 minutes). The 90 minutes was considered to be the average time for this type of machine. Two other time durations, 120 minutes and 60 minutes durations were used since they were the durations which added and deducted one-third of time duration of the average time respectively.

5.2 The prototype dyeing machine II: The skein hanging wheel in this machine allowed half of a skein to soak in the dye solution. The dyeing period was adjusted to be 60 minutes which was a twofold increase of the normal duration. The 1 hour was considered to be the average time for this type of machine. Two other time durations, 80 minutes and 40 minutes durations, were used since they were the durations which added and deducted one-third of time duration of the average time respectively.

6. Dyed the silk yarn by using the prototype dyeing machine with the following steps.

6.1 The steps in dyeing the silk by using the prototype dyeing machine I were as follows:

Used water in the ratio of 50:1, 20 sachets of ‘Lion Playing a Drum’ red dye No. 34 (10% owf.), 2 kilograms of silk yarn and the 2% owf. ‘Lion Playing a Drum’ powdered wetting agent. First, the degummed silk was soaked in water for 30 minutes. Then, the dye and the wetting agent was dissolved in 50°C water and poured into the dyeing solution in prepared water. The silk yarn was wrung and stretched and put into the prepared solution at 35°C and the temperature gradually increased to

70°C (used 60 minutes duration for raising the temperature). The temperature was maintained at 70°C for 120 minutes, 90 minutes and 60 minutes for each treatment. Added salt at 60 minutes, 45 minutes and 30 minutes for each treatment respectively. The silk yarn was rinsed in plain water 5 times (used water in the ratio of 20:1 for each time) and soaked in water with the 'Lion Playing a Drum' powdered fixing agent in the ratio of 30:1 and used the fixing agent 2% owf. The process needed to done at 60°C for 20 minutes and the silk yarn then hung dried.

6.2 The steps in dyeing the silk by using the prototype dyeing machine II were as follows:

Used water in the ratio of 30:1, 20 sachets of 'Lion Playing a drum' red dye No.34 (10% owf.), 2 kilograms of silk fiber and 2% owf. of the 'Lion Playing a Drum' powdered wetting agent. First, the degummed silk was soaked in water for 30 minutes. Then, dye and the wetting agent was dissolved in 50°C water and poured into the dye solution in the prepared water. The silk yarn was wrung and stretched and put into the prepared solution at 35°C and the temperature gradually increased to 90°C (used 30 minutes duration for raising the temperature). The temperature was maintained at 90°C for 80 minutes, 60 minutes and 40 minutes for each treatment. Added salt at 40 minutes, 30 minutes and 20 minutes for each treatment respectively. The silk yarn was rinsed in plain water 5 times (used water in the ratio of 20:1 for each time) and soaked in water with the 'Lion Playing a Drum' powdered fixing agent in the ratio of 30:1 and used the fixing agent 2% owf. The process needed to done at 60°C for 20 minutes and the silk yarn then hung dried.

7. Asked the 3 groups of subjects to dye 2 kilograms of silk yarn taken from the degummed silk of Jun Mai Thai Company by using 'Lion Playing a drum' dye and fixing agent. Three replicated dye processes were required.

8. Randomly selected sample of silk yarn from each replication and tested for colorfastness to laundering according to AATCC Standard Test Method 61-2001 Test No.1A.

9. Measured the color values (L*: lightness-darkness, C*: chroma, h*: hue) using the spectrophotometer Datacolor 650^{TM} of Data Expert Co., Ltd.

10. Evaluated colorfastness to laundering from the dE* values of color change and color staining.

11. Evaluated dyeing reproducibility from the dE* values of each pair of replication in each group.

12. Analyzed data using the Analysis of Variance. Differences among means were analyzed using Duncan's multiple range test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Results and Discussion Related to Objective 1

According to the mentioned two objectives, the results relating to objective 1 can be illustrated as follows:

1. Thai Silk Dyeing Processes from Selected Local Dyeing Groups

As mentioned earlier, this study intentionally selected three silk dyeing groups from the main silk producing region- the Northeastern region. Moreover, samples of silk dyeing groups were derived from participatory groups in the collaborative research project between Bank for Agriculture and Agricultural Cooperatives (BAAC) and Kasetsart University (KU).

From the interview session, steps in dyeing silk of each group were elicited as follows:

1.1 Group 1: Local Handicraft Group, Amphur Napho, Buri Rum Province

Illustration of general figures and pictures of the dyeing process from the first sample dyeing group can be seen below. The dyeing process started with one kilogram of silk and 20 liters of water (LR. = 20:1), 12 sachets of ‘Lion Playing a Drum’ red dye No.34 (12% owf.) , 1 sachet of ‘Lion Playing a Drum’ wetting agent (2% owf.) and 2 sachets of ‘Lion Playing a Drum’ fixing agent (2% owf.) were used. The dyeing steps were as follows:

1) The silk yarn was soaked in water for 30 minutes then wrung and stretched the yarn.

2) Six sachets of dye were dissolved in 10 liters of warm water. Half a kilogram of silk was soaked in the solution. A further 6 sachets of dye were added to

the solution and some warm water added to total around 10 liters. Another half of silk was soaked in the solution until it was evenly soaked. In this process, silk was soaked in the dyeing solution for 60 minutes then, wrung and stretched the silk yarn.

3) The dye solution remaining from the earlier steps was put in the remaining water (10 liters) then, boiled.

4) The dyed silk yarn was put in the dye solution and the heat reduced until the solution did not boil. The yarn was left in the solution for 10-15 minutes.

5) The dissolved wetting agent powder was put in warm water and added to the dyeing solution. The silk yarn was left in the dyeing solution for 30 minutes, constantly being turned to make sure that it was submerged in the solution.

6) The silk yarn was washed in water (5 times: total water use for washing off equal to 125 liters per 1 kilogram of silk).

7) The fixing agent was dissolved in warm water and the silk yarn soaked in the fixing solution for 10 minutes.

8) The silk yarn was wrung and hung dried, constantly being stretched.

1.2 Group 2: Hangkarok Silk Group, Ban Sanuan Nai, Buri Rum Province

In the case of the second sample dyeing group the dyeing process generally used one kilogram of silk, 10 liters of water (LR. = 10:1), 12 sachets of ‘Lion Playing a Drum’ red dye No. 34 (12% owf.) and 1 gram of alum (1% owf.). The dyeing steps were as follows:

1) The silk yarn was soaked in water for 30 minutes, then, wrung and stretched the yarn.

2) Water was boiled.

3) The dye was dissolved in the water.

4) The heat was reduced so the dye solution did not boil and the silk yarn was soaked in the dye solution. The silk yarn was turned 4 times then left in the dye solution for 45 minutes.

5) The silk yarn was washed in water (5 times: total water use for washing off equal to 100 liters per 1 kilogram of silk).

6) Alum was dissolved in warm water and the dyed silk soaked in the solution for 5-10 minutes.

7) The silk yarn was wrung and hung dried, constantly being stretched.

1.3 Group 3: Agricultural Housewife Group, Ban Nonmuang, Nong Bua Lam Phu Province

The dyeing process of the third sample dyeing group used one kilogram of silk, 20 liters of water (LR. = 20:1) and 12 sachets of ‘Lion Playing a Drum’ red dye No. 34 (12% owf.). The dyeing steps were as follows:

1) The silk yarn was soaked in water for 30 minutes then wrung and stretched the yarn.

2) Water was boiled.

3) Six sachets of dye were dissolved in the water and the silk yarn was soaked in the dye solution for 60 minutes. Then, 6 more sachets of dye were added to the dye solution and the silk yarn left in the solution for another 60 minutes.

4) The silk yarn was hung dried.

5) The silk yarn was washed in water and hung dry again. This procedure was repeated 4 times (total water use for washing off was 100 liters per 1 kilogram of silk).

6) Water was squeezed from the silk yarn and the yarn was stretched then hung to be dried.

From the above steps a comparative analysis of the 3 dyeing groups in Thailand could produce the following conclusions.

The liquor ratio used in the dyeing process of each group was different. The liquor ratio used by Local Handicraft Group, Hangkarok Silk Group, and Agricultural Housewife Group was 20:1, 10:1 and 20:1 respectively.

The dyeing period was also different. The dyeing period used by Local Handicraft Group, Hangkarok Silk Group and Agricultural Housewife Group was 100, 45 and 120 minutes respectively.

The last difference among the 3 groups was the use of a fixing agent. Local Handicraft Group, Amphur Napho used a chemical fixing agent from Phua Kiam Seen Company while Hangkarok Silk Group, Ban Sanuan Nai used alum as a fixing agent. Agricultural Housewife Group, Ban Nonmuang did not use any fixing agent in the dyeing process.

The interview also revealed that the dyeing processes were different depending upon knowledge inherited from ancestors. For example, one difference was that the silk yarn was soaked and squeezed in the dye solution before it was boiled. This step was usually practiced in the Napho group but it was not evident in other groups. However, there were some similarities among the 3 groups. For example, wood was the source of heat and no thermometer was used for temperature measurement. Further, all dyeing groups made their measuring judgments from their own experience and the containers used in the dyeing process came from kitchen utensils made of aluminium or iron.

This finding was in fact similar to information mentioned by other researchers. Moeyes (1993) stated that wood was used in the dyeing process at the local level, which made the controlling of temperature relatively more difficult. Containers used in the process were also inappropriate. W. Pansubkul (personal communication, April 9, 2005) suggested that steps in the dyeing process among communities were different because they were based mainly upon knowledge inherited from the ancestors.

Figure 6 The containers used in the local dyeing process

2. Evaluation of Local Dyed Silk Quality

2.1 Color values

The L* values of the silk yarns were quite low and did not differ greatly. This simply meant that the color was rather dark. The group order ranking from the darkest color was Agricultural Housewife Group, Ban Nonmuang, Local Handicraft Group, Amphur Napho and Hangkarok Silk Group, Ban Sanuan Nai respectively, as shown in Table 4.

As far as the dyeing process was concerned, it was found that Agricultural Housewife Group of Ban Nonmuang soaked the silk yarn in dye solution about 120 minutes, which was the longest period of dyeing time among the 3 groups. This could be the main cause of the darkest color being produced by this group.

The results of the analysis of variance of L* values obviously indicated that the L* values were significantly different at .01 level (Appendix Table 1). The L* values of silk yarn dyed by Hangkarok Silk Group of Ban Sanuan Nai were significantly different from those of other groups (Appendix Table 2).

Table 4 L*, C* and h* values of the dyed silk

Sample	L*	C*	h*
Napho silk	35.713	63.130	29.257
Sanuan Nai silk	38.600	62.787	26.173
Nonmuang silk	35.697	62.687	28.397

The C* values of the silk yarns were considered quite high. The group ranking from the highest C* value was Local Handicraft Group of Amphur Napho, Hangkarok Silk Group of Ban Sanuan Nai and Agricultural Housewife Group of Ban Nonmuang respectively.

The results of the analysis of variance of C* values, however, indicated that the C* values were not significantly different at .05 level (Appendix Table 3).

The h* values showed that the color of the silk yarns were in the range of yellow-red. The group ranking from the highest h* value was Local Handicraft Group of Amphur Napho, Agricultural Housewife Group of Ban Nonmuang and Hangkarok Silk Group of Ban Sanuan Nai respectively.

The result of the analysis of variance of h* values indicated that the h* values were significantly different at .05 level (Appendix Table 4). The h* values of silk yarn dyed by Hangkarok Silk Group, Ban Sanuan Nai were significantly different from those of other groups (Appendix Table 5).

2.2 Colorfastness to laundering

A colorfastness to laundering test was carried out using AATCC Test Method 61-2001 Test No. 1 A. Results can be seen in Table 5. It was found that the dE* values of color change were rather low and not different. This meant that color would not change substantially. The group ranking from the least dE* of color change was Agricultural Housewife Group, Local Handicraft Group and Hangkarok Silk Group respectively.

Table 5 dE* values of color change and color staining after laundering

Sample	dE*of color change	dE* of color staining
Napho silk	1.800	21.523
Sanuan Nai silk	1.907	22.070
Nonmuang silk	1.423	24.980

The dE* values of color change of Local Handicraft Group and Hangkarok Silk Group were equal to the level 4 in Grey Scale for Color Change (good colorfastness) while that of Agricultural Housewife Group was slightly improved to level 4-5 in Grey Scale for Color Change (good-excellent colorfastness).

When the dyeing process was thoroughly considered, it was found that the silk yarn of Agricultural Housewife Group was soaked in the dye solution about 120 minutes, which was the longest dyeing time among the 3 groups. This fact, that the longer time allowed more dye solution to diffuse from the surface towards the center of the fibers, led to more colorfastness to laundering.

The result of the analysis of variance of dE* values of color change indicated that the dE* values were not significantly different at .05 level (Appendix Table 6).

The dE* values of color staining were quite high. This meant that there were high color stains on white test cloth. The group ranking from the least color staining was Local Handicraft Group, Hangkarok Silk Group and Agricultural Housewife Group respectively.

The dE* values of color staining of Local Handicraft Group and Hangkarok Silk Group were equal to only level 2 in Grey scale for color staining (poor colorfastness) while that of Agricultural Housewife Group was even worse at level 1-2 in Grey scale for color staining (very poor-poor colorfastness).

When the dyeing process was carefully investigated, it was found that Agricultural Housewife Group was the only group that did not apply any fixing agent in the dyeing process. W. Pansubkul (personal communication, April 9, 2005) confirmed that the use of a fixing agent would have helped increase colorfastness in acid dyeing.

The result of the analysis of variance of dE* values of color staining indicated that the dE* values were not significantly different at .05 level (Appendix Table 7).

2.3 Dyeing reproducibility

According to the dE* values of the three replication pairs in each dyer group presented in Table 6, it was clear that the maximum and minimum dE* values of Local Handicraft Group of Amphur Napho were 2.24 and 0.08: those of Hangkarok Silk Group of Ban Sanuan Nai were 4.54 and 1.27, and those of Agricultural Housewife Group of Ban Nonmuang were 1.54 and 0.76. When compared with the general benchmarking which used the dE* value criteria at lower than 2 only the last group could satisfy such criteria. This meant that Agricultural Housewife Group of Ban Nonmuang had the relatively highest capacity in terms of dyeing reproducibility while Local Handicraft Group of Amphur Napho and Hangkarok Silk Group of Ban Sanuan Nai ranked second and third respectively.

Table 6 dE* values of the three replication pairs

Dyer group	**dE* values of the three replication**		
	1 vs. 2	**1 vs. 3**	**2 vs. 3**
Napho	2.06	0.80	2.24
Sanuan Nai	4.54	3.48	1.27
Nonmuang	1.54	0.91	0.76

Results and Discussion Related to Objective 2

Explanation and analytical result relating to objective 2 can be expressed in detail as follows:

1. Prototype Dyeing Machines Development and Involved Characteristics

The search for a dyeing machine with higher efficiency in terms of dyeing quality, including color value, colorfastness and dyeing reproducibility is now a feature of the dyeing industry everywhere. Improvement of dyed silk quality results from a combination of many factors related to both mechanical and operational aspects. Traditional dyeing methods, despite them producing quality dyed silk, results in doubtful degrees of consistency in long term reproduction. Problems of inconsistent fastness and reproducibility from such traditional dyeing methods occur naturally, mainly due to dyeing methods which have been developed over time with limited scientific research support.

Sources of weaknesses potentially linked to traditional dyeing operations include:

1) Lack of temperature control. This is normally done through visual observation.

2) Insufficient circulation of dyeing solution during the dyeing process.

3) High variations of heat from firewood.

4) Effects from the various materials used as container on quality of dyeing process.

5) Other errors potentially produced from traditional methods including time measurement and quantity of water measurements.

Therefore, an attempt was made to develop the so called ‘prototype dyeing machine (PDM)’ by improving from those mentioned fundamental errors in traditional methods. There were two consequential stages of such dyeing mechanical development.

At the first stage, the prototype dyeing machine I (PDM I) was constructed on the basic foundation of improving the heat variation and circulation of dyeing solution from the traditional dyeing method. The hypothesis was that less variation of heat degree and better circulation of the dyeing solution would yield a higher quality of dyed silk. Installing the container of dyeing solution and using liquid petroleum gas (LPG from PTT Public Co., Ltd., Heating value: 11,700-11,900 Kcal/kg) instead of firewood were thus the key parts of the PDM I in solving the above inconsistency problems.

The second stage of development of a prototype dyeing machine as the PDM II, however, still remained to be improved upon due to mechanical flaws of the PDM I, such as excessive water use (usually called the high liquor ratio) and too low temperature obtained. Not only the quality of dyed silk would be affected, but also dyeing cost was expected to increase. As result of the two main flaws, the introduction of a container cover and flexibility in container size were added to the PDM I. These improvements, in fact, were still based on the same hypothesis of the PDM I.

In general consideration, the main criteria in constructing both PDMs lay upon 3 conceptual foundations: low investment cost, appropriate technology and incubation of local wisdom.

1) Low investment cost.

The PDM is primarily aimed to be applied to small scale dyeing in rural areas as the main target, so a reasonable investment cost is needed. It was, therefore, an important assumption that an individual dyer or any dyeing group in the Thai community was often subject to budget constraints. The total cost of investment in a dyeing machine should be made possible for any community-based enterprise, for an example.

2) Appropriate technology

According to such target group of end users, the PDM must be designed and then operated with simple techniques. It should be a practical machine that can be easily operated by any dyeing group with a limited mechanical knowledge and background. Complexity of modern technology, i.e. that through completely computerized systems, was not considered appropriate in this case due to limited knowledge-base users.

3) Incubation of local wisdom

A significant development aspect of a dyeing machine was that it must not detract from the local wisdom in dyeing which has long been implemented on the rural areas of Thailand. The PDM should thus be developed on the basis of technical incubation to support such local knowledge of rural dyeing groups.

Theoretically, Trotman (1984), suggested that an effective dyeing machine should consist of the following characteristics which could possibly be applied to the case of silk yarn dyeing in this research.

1) Perfect circulation of dye solution as well as silk yarn

2) Systematic and consistent temperature control

3) Appropriate liquor ratio to optimize water, fuel and chemical uses

4) Fast flow-in and out - of the dyeing solution

5) Container made from more durable and smooth materials as well as convenience for cleaning

In comparative main ideas, the design of PDM was in fact the application of Trotman's concept of an effective dyeing machine in the framework of a Thai local context. Especially in terms of appropriate technology, the PDM is designed to be operated by local dyers, so that only the semi-automatic system was installed in this machine instead of a fully automatic system. The principles of PDM in controlling dye solution, consistent temperature, liquor ratio and container characteristics were then applicable to Trotman's concept of an effective dyeing system.

1.1 Physical characteristics and operation of prototype dyeing machine I

Physical characteristics of the prototype dyeing machine I (PDM I) consisted of the followings:

1) Overall figure: size 65 cm x 110 cm x 145 cm

2) Container: rectangle, size 50 cm x 95 cm x 30 cm

3) Skein hanging wheel: diameter 42 cm, length 80 cm

4) Material: stainless steel No.304, 1.5 mm thickness

5) Motor specifications: 1/4 HP, 220 V, 50 Hz, 1.5 A, 1,450 rpm

6) Power Input: 157.2 W/hr (Calculate from: Voltage x Current x Power factor = 220 x 0.84 x 0.85)

See Figure 7 and Figure 8 for more details

Figure 7 The prototype dyeing machine I

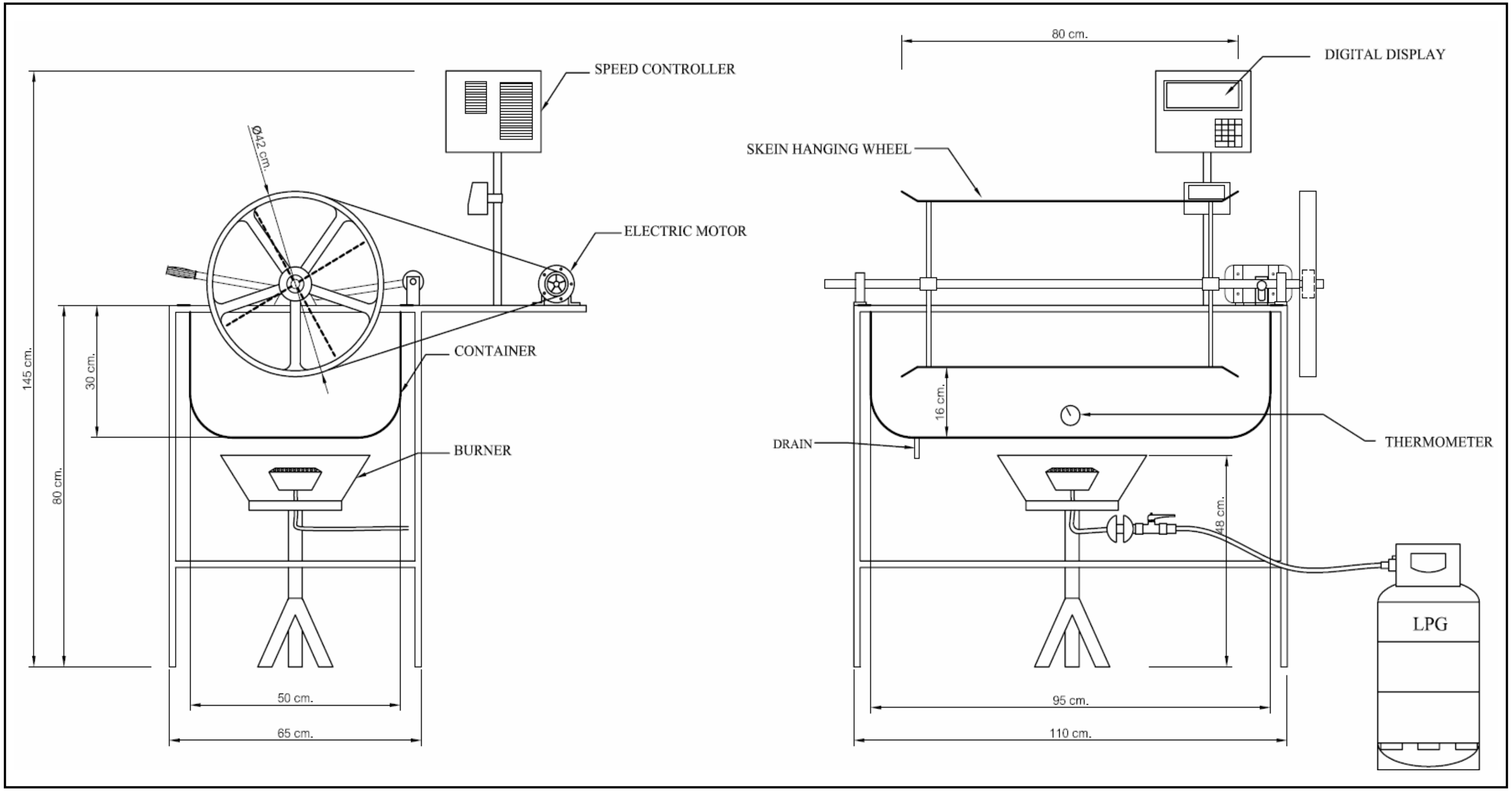


Figure 8 Outline drawing of prototype dyeing machine I

The PDM I was basically a small-scale machine invented to operate the whole dyeing process of silk yarn within an open container with a rotary wheel and temperature measurement. The machine was fully operated through an electrical motor gear system which ran the skein hanging wheel. Speed of such motor gear operation was in fact controlled by the speed control set manually by operator.

Temperature level was measured by the analog system which would reflect directly the heat level from the dye solution in the container. LPG (from PTT Public Co., Ltd., Heating value: 11,700-11,900 Kcal/kg) consumption as fuel for the PDM I was released through the burner of KB5 (Brand: Seng-Tai, Diameter: 11 cm). Temperature control was manually operated by dyers through adjusting the appropriate LPG level to suit the targeted temperature.

However, it was noticed that the wheel system of PDM I was rather set approximately 16 cm from the bottom of the container resulting in relatively higher liquor ratios and poorer soaking of the silk yarn in the dye solution. In other words, use of more water was needed to satisfy this dyeing process despite the quality of dyed silk still remaining rather fluctuated due to the light color found. At the same time, temperature obtained from the PDM I was measured at 60-75°C which was considered a little low in that it should be as high as 90°C, in cases of dyeing silk with acid dyes.

In fact, raising the starting temperature of the PDM I to be as high as 70°C would also take as much as one full hour (60 minutes) which was already a long period of time. After such time was required, an effective dyeing process would take place by consuming another 60, 90 and 120 minutes depending upon the different treatments used. Accordingly, the total time spent for a batch of dyeing process by the PDM I was therefore approximately 120, 150 and 180 minutes. Yet, there was still some evidence to show that the quality of dyed silk yarn needed to be further improved, such as color strength as well as color changing and staining being rather high and uncertain.

1.2 Physical characteristics and operation of prototype dyeing machine II

Physical characteristics of the prototype dyeing machine II (PDM II) consisted of the followings:

1) Overall figure: size 60 cm x 100 cm x 110 cm

2) Container: semicircle, size 50 cm x 90 cm x 30 cm

3) Skein hanging wheel: diameter 42 cm, length 80 cm

4) Material: stainless steel No. 304, 1.5 mm thickness

5) Motor specifications: 1/4 HP, 220 V, 50 Hz, 1.5 A, 1,450 rpm

6) Power Input: 261.8 W/Hr (Calculated from: Voltage x Current x Power factor = 220 x 1.4 x 0.85)

See Figure 9 and Figure 10 for more details

Figure 9 The prototype dyeing machine II

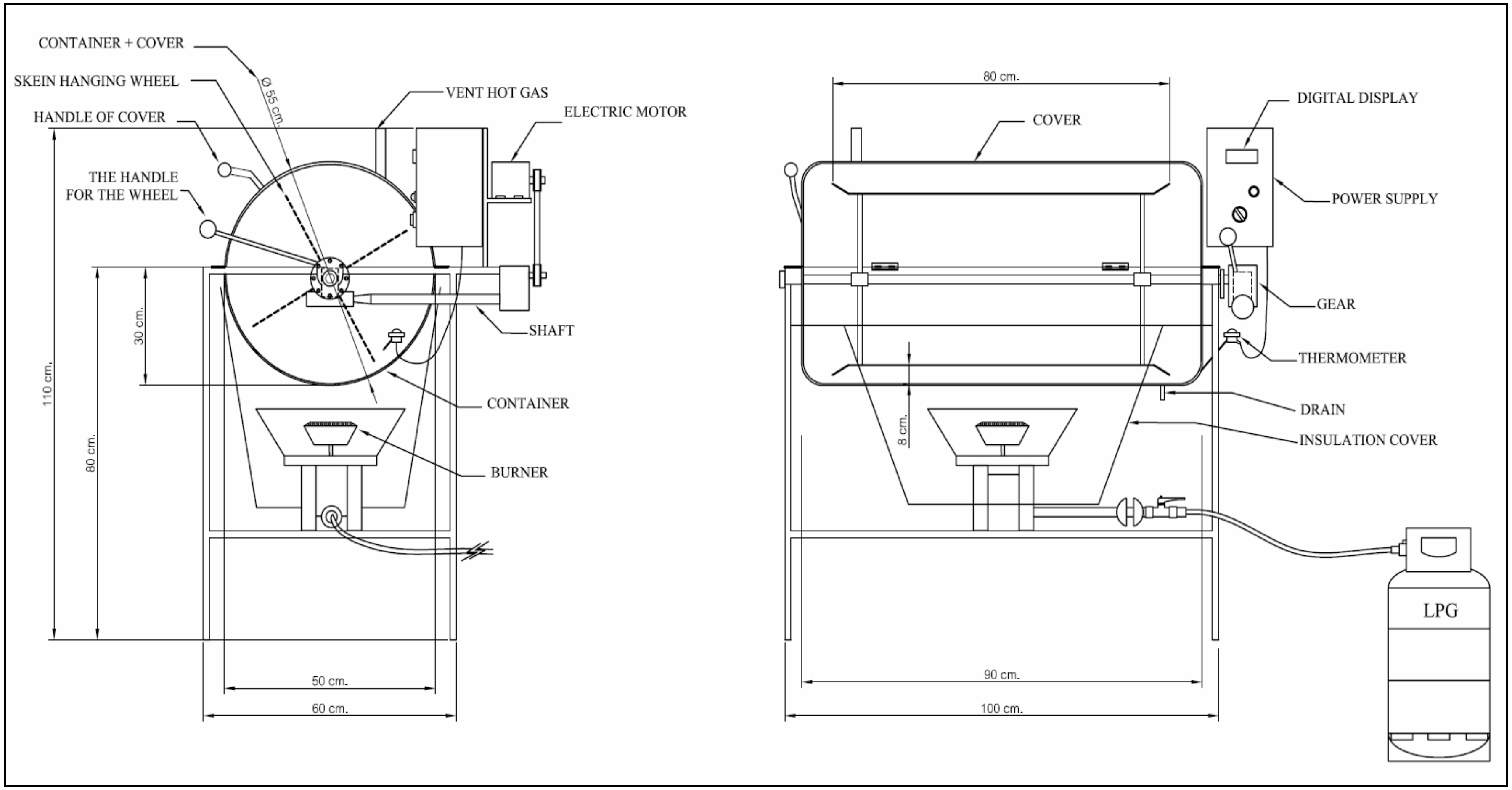


Figure 10 Outline drawing of prototype dyeing machine II

In response to the weaknesses and limitations of the PDM I operation, the improved dyeing machine called the PDM II was invented to seek higher efficiency during the whole dyeing process. The PDM II was still considered a small-scale machine constructed to take care of the dyeing process of silk yarn within a semi-closed container with cover and exhaust stack, a rotary wheel and digital system of temperature measurement.

The PDM II machine was fully operated through an electrical motor shaft system which ran the skein hanging wheel. The speed of such motor shaft operation was set and controlled by the speed gear controller which was set in this study at speed No.3 or at 40 1.5 rpm of skein hanging wheel. According to that set speed the skein would not be easily removed from the wheel.

Temperature level was measured by the digital system which would reflect the temperature directly and accurately from the dyeing solution in the container. LPG (from PTT Public Co., Ltd., Heating value: 11,700-11,900 Kcal/kg) consumption as fuel for the PDM II was released through the burner of KB8 (Brand: Seng-Tai, Diameter: 16 cm) which would result in a higher level of heat obtained. Temperature control was manually operated by dyers through adjusting the appropriate LPG level to suit the targeted temperature.

In correcting the weakness of poor circulation of dye solution and then high liquor ratio of the PDM I, the PDM II then offered an improved mixing system by allowing the wheel system to be positioned closer, approximately 8 cm, to the bottom of the container resulting in relatively lower liquor ratio and better mixing between dyeing solution and silk yarn. In other words, more effective water use could then be expected as less water quantity was needed and then less waste water would be released.

With the semi-closed container with cover, temperature obtained from the PDM II could possibly be measured as high as 100ºC in which the expected standard 90ºC is reached within only 30 minutes. In addition to such starting time required, effective dyeing period for the PDM II would need another 40, 60 and 80 minutes for the complete dyeing process depending on different treatments. Accordingly, the total time consumption for an average batch of dyeing silk yarn in case of the PDM II would be 70, 90 and 110 minutes respectively.

With the better circulation of dye solution and mixing system with silk yarn as well as high consistent temperature control, the quality of dyed silk yarn was obviously seen as higher, especially in terms of lower color change and higher color strength. Color staining, however, also seemed to be somewhat better but not to a considerable level, probably due to an ineffective washing-off process after dyeing completion.

Development of such technical innovation from the PDM I to the PDM II was basically the ‘learning by doing process’ conducted by the researcher in order to seek for the improvement in the dyeing process. Yet this does not imply that the newly developed PDM II would be considered the best dyeing technique which minimized the errors or limitations of the former PDM I. In fact, the final output in terms of quality dyed silk yarn would reveal the effectiveness of such dyeing improvements. Practically speaking, this technical innovation of dyeing machine improvement was what was called the ‘result-based experiment’ which will require more and more experiments in the future. More importantly, not only the technical aspects of the dyeing methods would be taken into consideration, economic and social aspects of the dyeing methods should also be taken into account when considering the best practice of dyeing machine in reality.

Table 7 illustrates the technical innovation from the PDM I to the PDM II in various key characteristics which mainly resulted from this research.

Table 7 Technical innovation of dyeing process from PDM I to PDM II

Characteristics	PDM I	PDM II
Overall figure	65 cm x110 cm x 145 cm	60 cm x 100 cm x 110 cm
Container size	50 cm x 95 cm x 30 cm	50 cm x 90 cm x 30 cm
Container shape	Open rectangle container without cover	Improved into semi-circle container with cover
Container cover	Lack of container cover result in high heat loss and evaporation	Installment of cover to increase heat control and reduce evaporation
Skein hanging wheel	Made from flat and sharp stainless steel resulting in cutting the yarn while packing. Positioned far above the container bottom producing relatively poor mixing between dye solution and yarn	Made from the round stainless steel to prevent cutting problem. Positioned near the bottom to produce better mixing
Water consumption	LR. equal to 50:1 requires considerable amount of water for effective dyeing process	LR. equal to 30:1 consumes less amount of water due to semi-closed system of semi-circle
Amount of silk yarn input	Possibly input up to 2 kg of silk yarn per batch	Possibly input up to 2 kg of silk yarn per batch
Heat capacity	Raising the temperature as high as 60-75°C	Possibly increased up to 100°C
Temperature measurement	Measured relatively less reliably by analog system	Measured relatively more reliably by digital system
Dyed silk yarn obtained	Producing light color and low colorfastness in terms of color change	Producing strength color and high colorfastness in terms of color change

Table 8 illustrates the comparative main characteristics of local dyeing methods and 2 dyeing methods, in terms of investment capital, dyeing container, labor use, fuel, electricity use, liquor ratio use, time consumption and waste water released.

Table 8 Comparative main characteristics of local and 2 prototype dyeing methods

Main Characteristics	LDM	PDM I	PDM II
Investment capital	1,000 baht	15,000 baht	21,000 baht
Dyebath container	kitchen utensils aluminium, iron	rectangle stainless steel	semicircle stainless steel
Labor use	3-4 persons	2 persons	2 persons
Fuel	firewood	2.3 kg LPG (brand: PTT)	2.23 kg LPG (brand: PTT)
Electricity use	none	0.4716 KWh	0.4790 KWh
Liquor ratio use	10:1 - 20:1	50:1	30:1
Time consumption of 3 treatments	45 minutes 100 minutes 120 minutes	120 minutes 150 minutes 180 minutes	70 minutes 90 minutes 110 minutes
Waste water released	20-40 liters	100 liters	60 liters

2. Comparative Quality of Dyed Silk Yarn

In order to compare the quality of silk yarn dyed by the selected local groups and by the prototype dyeing machine, 2 kilograms of silk yarn, and 10% owf. Phua Kiam Seen acid dyes were used in every treatment. The sample of silk yarn from each replication of treatment was tested and the findings were as follows.

2.1 Color values

With respect to the mentioned 3 dyeing methods, key indicators of color values including L*, C* and h* values, revealed many different degrees of dyed silk yarn quality. As the base line experiment, the standardized Infra-red dyeing machine emphasizing dyeing a small sample of silk yarn illustrated the L*, C* and h* values as shown in the Table 9. Such three value indicators were considered the expected average results under the controlled conditions of time consumption and temperature raising. However, the operation and quality of dyed silk from the Infra-red dyeing machine was rather idealistic since it demanded too high operation costs from the limitation of silk yarn input. Anyway, these L*, C* and h* values of the Infra-red dyeing machine would still be used as the benchmark value of dyed silk yarn quality.

When compared in terms of the L* values, the local dyeing methods using Napho silk, Sanuan Nai silk and Nonmuang silk, could produce the lighter color of dyed silk yarn as seen from the higher L* values**.** Time consumption of the local dyeing methods was also found to be longer than that of infra-red dyeing. The dyed silk yarn by PDM I was considered highest L* values implying that the color of silk yarn was relatively lightest among the three alternative methods. Although dyeing time spent for the PDM I was relatively long, soaking between silk yarn and dyeing solution was considered not so complete due mainly to improper position of the skein hanging wheel that allowed dyeing solution to soak only one-third of the silk yarn. On the other hand, the dyed silk yarn by the PDM II machine seemed impressively to produce a similar quality of output to that of the Infra-red dyeing method. Also, the PDM II using only 70 minutes could yield the same quality to that of the local Napho silk dyeing which would consume up to 100 minutes. This better quality of output was simply an example of effectiveness from technical innovation of silk dyeing found only from the PDM II.

The result of the analysis of variance of L* values of nine treatments indicated that L* values were significantly different at 0.001 level (Appendix Table 8). The L* values from nine treatments were categorized into four subsets according to Duncan's grouping. The first subset of L* values included the silk yarn dyed by PDM II (110 minutes), PDM II (90 minutes), Napho group (100 minutes), PDM II (70 minutes) and Nonmuang group (120 minutes). The second subset was composed of L* values of silk yarn dyed by Nonmuang group (120 minutes), Sanuan Nai group (45 minutes). The third subset was L* values of silk yarn dyed by PDM I (180 minutes). The last subset consisted of the L* values of silk yarn dyed by PDM I (150 minutes) and PDM I (120 minutes) (Appendix Table 9).

In terms of the C* values which implied the degree of color purity or degree of chroma. Generally, the C* values of dyed silk yarn from three time treatments under the PDM I was relatively the lowest implying the lowest purity of color produced. As compared with other types of dyeing machines, the PDM I was then the one with weakness in this quality.

The result of the analysis of variance of C* values of nine treatments evidently indicated that C* values were significantly different at 0.001 level (Appendix Table 10). The C* values from nine treatments were categorized into four subsets according to Duncan's grouping. The first subset of C* values included the silk yarn dyed by PDM I (120 minutes) and PDM I (150 minutes). The second subset was C* values of silk yarn dyed by PDM I (180 minutes). The third subset was the C* values of silk yarn dyed by Nonmuang group (120 minutes) The last subset was composed of the C* values of silk yarn dyed by PDM II (90 minutes), PDM II (70 minutes), PDM II (110 minutes), Napho group (100 minutes) and Sanuan Nai group (45 minutes) (Appendix Table 11).

In terms of the h* values implying the quality of color name, quality of dyed silk yarn from the local Napho silk and the PDM II were all similar to that of the standard Infra-red dyeing machine. The hue quality of the dyed silk yarn from Sanuan Nai silk, Nonmuang silk and all outputs from the PDM I, on the other hand, were found lower than the controlled dyeing conditions of the Infra-red dyeing machine. This implied that the genuine color possibly found in the dyed silk yarn from the local dyeing and the PDM I could be varied. At the same time, consistency of genuine color could be found in the dyed silk yarn of the PDM II method.

The result of the analysis of variance of h* values of nine treatments indicated that h* values were significantly different at 0.001 level (Appendix Table 12). The h* values from nine treatments were categorized into four subsets according to Duncan's grouping. The first subset of h* values included the silk yarn dyed by PDM I (120 minutes) and PDM I (150 minutes). The second subset was h* values of silk yarn dyed by PDM I (180 minutes). The third subset was the h* values of silk yarn dyed by Nonmuang group (120 minutes) and Sanuan Nai group (45 minutes). The last subset contained the h* values of silk yarn dyed by Napho group (100 minutes), PDM II (70 minutes), PDM II (90 minutes) and PDM II (110 minutes) (Appendix Table 13).

Considering all three aspects of silk yarn quality in terms of L*, C* and h* values, some comparative quality of dyed silk yarn from different dyeing methods could be discussed as follows:

1) The quality of dyed silk yarn outputs from the PDM II was relatively the most efficient one among three main dyeing methods (local, PDM I and PDM II). In other words, the output quality of dyed silk yarn from the PDM II was comparable with that produced from the controlled Infra-red dyeing machine. Moreover, time consumption by the PDM II was less than most of other dyeing methods if given the same quality of output obtained.

2) Technical innovation from various characteristics of the PDM I to the PDM II could be seen from changes in the L*, C* and h* values in the way that quality of dyed silk yarn was obviously improved. This research contribution from the development of the PDM II though may not be the best suggested technical innovation, yet it was a good foundation for dynamic dyeing improvements in the future.

3) Despite the output quality from the local dyeing generally being considered lower than those of the prototype dyeing machines, the local dyed silk yarn especially produced from Napho silk still showed impressive results of L*, C* and h* values as compared with the output produced from the standard Infra- red dyeing machine. These key color values suggested the high potential of Napho silk dyeing which was comparable to the standard Infra-red dyeing machine. However, it consumed much more time for the whole dyeing process due mainly to uncontrollable conditions of temperature level and human error.

4) In fact, final efficiency evaluation of comparative technical aspects among all dyeing methods, however, still remained doubtful. Top quality of dyed silk yarn from any dyeing method would probably be undesirable if produced from too high cost of operation and unpractical dyeing techniques to realistic conditions. For example, the satisfied values of L*, C* and h* values as well as time consumption by the prototype dyeing machine, despite it being found more efficient than the local dyeing method, may possibly cause a lot higher costs from a more complicated dyeing process. As consequences, application of such efficient dyeing machine would be limited to the realistic dyers.

Table 9 L*, C* and h* values of the silk yarn dyeing by using the prototype dyeing machines, by the local groups and by using the Infra-red dyeing machine.

Sample	L*	C*	h*
Infra-red dyeing (60 minutes)	36.130	60.913	27.776
Napho silk (100 minutes)	37.117	61.420	27.267
Sanuan Nai silk (45 minutes)	38.650	61.933	25.640
Nonmuang silk (120 minutes)	37.730	59.630	25.393
PDM I silk (180 minutes)	42.013	58.047	21.680
PDM I silk (150 minutes)	43.800	56.500	19.473
PDM I silk (120 minutes)	44.473	55.827	18.697
PDM II silk (110 minutes)	36.717	61.367	27.933
PDM II silk (90 minutes)	36.987	61.320	27.863
PDM II silk (70 minutes)	37.270	61.337	27.457

Differences among all L*, C* and h*values from various methods as compared with the standardized Infra-red dyeing method were illustrated in Table 10. Differences in such values, or dL*, dC* and dh* values, simply implied the degree of color differences from aspects of light, chroma and hue. Therefore the lower level of differences would suggest a better quality of dyed silk as compared with the standardized infra red method. The color differences in terms of dL*, dC* and dh* values of the PDM II were generally the best among the three dyeing methods. This indicated the highest effectiveness degree of dyeing method from the PDM II.

However, the quality of dyed silk from local dyeing methods was surprisingly better than the results of PDM I due mainly to poor temperature control and color absorption of the first prototype dyeing machine. These weaknesses equipped with the PDM I were then needed to be taken into consideration if dyeing methods would be improved.

Overall, the value dE* implied the total color differences as combination of the dL*, dC*, dh* values. As expected, the dE* values indicated that silk dyeing from the PDM II was relatively most effective, followed by that of local dyeing methods and the PDM I.

The result of the analysis of variance of dE* values of color difference between sample and standard indicated that dE* values were significantly different at 0.001 level (Appendix Table 14). The dE* values from nine treatments were categorized into four subsets according to Duncan's grouping. The first subset of dE* values of color difference between sample and control group was composed of the silk yarn dyed by PDM II (110 minutes), PDM II (90 minutes), PDM II (70 minutes) and Napho group (100 minutes). The second subset of dE* values of color difference between sample and control group included the silk yarn dyed by Nonmuang group (120 minutes) and Sanuan Nai group (45 minutes). The third subset of dE* values of color difference between sample and control group was the silk yarn dyed by PDM I (180 minutes). The fourth subset of dE* values of color difference between sample and control group consisted of the silk yarn dyed by PDM I (150 minutes) and PDM I (120 minutes) (Appendix Table 15).

Table 10 dL*, dC*, dh* and dE* values of the silk yarn dyeing by using the prototype dyeing machines, by the local groups compared with silk yarn dyeing by using the Infra-red dyeing machine.

Sample	dL*	dC*	dh*	dE*
Napho silk (100 minutes)	0.987	0.510	-0.540	1.517
Sanuan Nai silk (45 minutes)	2.520	1.023	-2.280	3.647
Nonmuang silk (120 minutes)	1.600	-1.280	-2.500	3.290
PDM I silk (180 minutes)	5.883	-2.863	-6.320	9.103
PDM I silk (150 minutes)	7.670	-4.410	-8.490	12.263
PDM I silk (120 minutes)	8.343	-5.083	-9.223	13.443
PDM II silk (110 minutes)	0.587	0.457	0.277	0.767
PDM II silk (90 minutes)	0.857	0.410	0.097	0.987
PDM II silk (70 minutes)	1.140	0.427	-0.340	1.313

2.2 Colorfastness to laundering

Color change from laundering dyed silk yarn as expressed by dE* values indicated inconsistency of dyeing quality among different dyeing methods (Table 11). It was found that the dE* values of color change were rather low and different. This meant that color would change substantially. Setting 2.000 value as standardized dE* values from the CIELAB samples, the PDM II showed the best quality of dyed silk from the lowest dE* values of color change ranging from 1.010-1.713. Ineffective results of color change from the local dyeing method and the PDM I were not much greatly different.

In the same quality group, the dE* values of color change of PDM II (110 minutes), Napho silk (100 minutes), PDM I (180 minutes) and PDM II (90 minutes) were equal to the level 4-5 in Grey Scale for Color Change (good-excellent colorfastness). On the other hand, dyeing methods producing at the level 4 in Grey Scale for Color Change (good colorfastness) included the PDM II (70 minutes), Nonmuang silk (120 minutes), and Sanuan nai (45 minutes). Lastly, the dyeing methods including PDM I (150 minutes) and PDM I (120 minutes) yielded the quality at the level 3-4 in Grey Scale for Color Change (average colorfastness).

When the dyeing process was thoroughly considered, it was found that the colorfastness in terms of color change with the same Grey Scale for Color Change at level 4-5 would consume different times from 90 minutes to 110 minutes of PDM II. Surprisingly, the local dyeing method of Napho Silk could come up with the same quality of dyed silk as that of PDM II. However, this local dyeing method required much more complicated processes especially during the stage of soaking and squeezing in the dye solution when the dyer might have to contact directly with chemicals.

The result of the analysis of variation of dE* values of color change indicated that dE* values were significantly different at .01 level (Appendix Table 16). The dE* values of color change from nine treatments were categorized into three subsets according to Duncan's grouping. The first subset of dE* values of color change consisted of the silk yarn dyed by PDM II (110 minutes), Napho group (100 minutes), PDM I (180 minutes), PDM II (90 minutes) and PDM II (70 minutes). The second subset of dE* values of color change included the silk yarn dyed by PDM I (180 minutes), PDM II (90 minutes), PDM II (70 minutes), Nonmuang group (120 minutes) and Sanuan Nai group (45 minutes). The third subset of dE* values of color change comprised the silk yarn dyed by PDM II (90 minutes), PDM II (70 minutes), Nonmuang group (120 minutes), Sanuan Nai group (45 minutes), PDM I (150 minutes) and PDM I (120 minutes) (Appendix Table 17).

The dE* values of color staining were at the same time found quite in the high level implying that there were high color stains on white test cloth. For example, the dyed silks with level 2 in Grey Scale for Color Staining (poor colorfastness) were Napho silk (100 minutes), PDM II (110 minutes) and PDM I (150 minutes). The dE* values of color staining at level 1-2 in Grey Scale for Color Staining (very poor-poor colorfastness) included the products of local dyeing methods such as the Sanuan Nai silk (45 minutes), Nonmuang silk (120 minutes), PDM I (180 minutes), PDM I (120 minutes), PDM II (90 minutes) and PDM II (70 minutes).

However, the result of the analysis of variation of dE* values of color staining evidently indicated that dE* values were significantly different at .001 level (Appendix Table 18). The dE* values from nine treatments were categorized into four subsets according to Duncan's grouping. The first subset of dE* values of color staining included the silk yarn dyed by Napho group (100 minutes) and PDM II (110 minutes). The second subset of dE* values of color staining was composed of the silk yarn dyed by PDM II (110 minutes) and PDM I (150 minutes). The third subset of dE* values of color staining consisted of the silk yarn dyed by PDM I (150 minutes), PDM I (120 minutes), PDM II (70 minutes), PDM II (90 minutes) and PDM I (180 minutes). The fourth subset of dE* values of color staining contained the silk yarn dyed by Sanuan Nai group (45 minutes) and Nonmuang group (120 minutes) (Appendix Table 19).

It was then interesting to note that the quality of dyed Napho silk was the best among overall local and prototype dyeing methods. Use of a fixing agent in this local method may play an important role in increasing colorfastness in acid dyeing. When the amount of water in the washing step was considered, it was found that Napho group used up to 250 liters of water for 2 kilograms of silk yarn, which was more than the amount used by other groups. The fact of using a large amount of water might be the main factor in making colorfastness to laundering in terms of color change and color staining better.

Table 11 dE* values of color change and color staining of the silk yarn dyeing by using the prototype dyeing machines and by the local groups after laundering

Sample	dE*of color change	dE* of color staining
Napho silk (100 minutes)	1.023	18.613
Sanuan Nai silk (45 minutes)	2.493	28.820
Nonmuang silk (120 minutes)	2.280	29.000
PDM I silk (180 minutes)	1.430	24.997
PDM I silk (150 minutes)	2.603	22.813
PDM I silk (120 minutes)	2.643	24.757
PDM II silk (110 minutes)	1.010	20.317
PDM II silk (90 minutes)	1.547	24.987
PDM II silk (70 minutes)	1.713	24.950

2.3 Dyeing reproducibility

The most effective dyeing method in terms of dyeing reproducibility due to the results expressed in Table 12 was PDM II (110 minutes) followed by PDM II (90). Both respective dyeing methods produced rather low dE* values, less than 1.00, implying a high quality of dyed silk produced. On the other hand, the least effective one in terms of dyeing reproducibility was found at the local dyeing method of Sanuan Nai (45 minutes). According to the result of such local method, the dE* values among some pairs of replication such as the pair between 1 vs. 3 and 2 vs. 3 were even higher than 3.00 or the pair between 1 vs. 2 was lower than 1.00.

Such degrees of inconsistency of dE* values implied that the local dyeing method of Sanuan Nai remained faced with significant limitations of dyeing process from various causes such as variation of water control, temperature

Table 12 dE* values of the three replication pairs of the silk yarn dyeing by using the prototype dyeing machines and by the local groups

Dyer group	dE* values of the three replication		
	1 vs. 2	1 vs. 3	2 vs. 3
Napho (100 minutes)	0.48	1.94	1.93
Sanuan Nai (45 minutes)	0.89	3.37	3.61
Nonmuang (120 minutes)	1.73	1.80	0.25
PDM I (180 minutes)	0.73	1.08	0.49
PDM I (150 minutes)	0.80	1.98	2.44
PDM I (120 minutes)	0.51	1.54	1.03
PDM II (110 minutes)	0.33	0.38	0.18
PDM II (90 minutes)	0.66	0.36	0.71
PDM II (70 minutes)	0.84	0.81	1.37

control or even dyeing period. Inconsistent degree of dyeing reproducibility would therefore suggest that the local dyeing method would still need further improvement while better control of dyeing quality was the main advantage of the improved prototype dyeing machine, especially the PDM II.

Overall evaluation of dyeing methods, therefore, should take into consideration the other aspects of dyeing method especially economic viability, social acceptance and environmental impact in addition to the technical aspect of dyeing method as already analyzed and explained. The combination of evaluation from technical, economic, social and environmental aspects would possibly produce the best conclusion to suggest the most applicable dyeing method that should be made promoted.

Economic Comparison between Local Dyeing Methods and Prototype Dyeing Machines

Economic considerations in this study were here applied in order to illustrate the monetary viability or financial feasibility in terms of cost and return analysis from local and prototype dyeing methods. In other words, technical explanation already mentioned in detail was not sufficient to justify comparative effectiveness among different dyeing methods. For example, the dyeing machine which produced very high dyed silk yarn quality may be too costly and thus not economically feasible to be operated. At the same time, the dyeing machine producing not so high quality of dyed silk yarn can be seen as having a lower cost, higher profit rate and being more practical to operate. With all these possible situations, every dyeing method will need to prove its production cost as compared with the expected yield and then market value of dyed silk. Therefore, recommendation for promotion of any dyeing method in reality should at least be made upon both technical and economic feasibility.

According to various dyeing methods in this study which are rather different and complicated for economic measurement, such economic analysis of cost and return will be on the basis of dyeing per batch or per one cycle of dyeing process. Due to the result of experiments earlier explained, such dyeing per batch are approximately 100, 180, and 110 minutes for local dyeing machine, PDM I and PDM II respectively.

Table 13 Comparative economic cost structure of local and prototype dyeing methods

Unit: Baht per batch

Main Cost Items	LDM	PDM I	PDM II
Fixed Cost			
1. Land	200 m^2	200 m^2	200 m^2
Land rent	6.94	6.94	6.94
2. Investment capital	1,000 baht	15,000 baht	21,000 baht
Depreciation cost	0.55	8.33	11.66
Opportunity cost	0.14	2.08	2.92
Variable Cost			
1. Silk yarn materials	2 kg	2 kg	2 kg
Silk yarn cost	2,720	2,720	2,720
2. Labor required	4 persons	2 persons	2 persons
Labor cost	300	150	150
3. Fuel use	2 kg Charcoal	2.30 kg LPG	2.23 kg LPG
Fuel cost	50.00	41.40	40.14
4. Electricity demand	none	0.4716 KWh	0.4790 KWh
Electricity cost	0	1.33	1.33
5. Water supply	330 liters	360 liters	320 liters
Water cost	4.33	4.67	4.21
6. Dyeing materials	20 sachets	20 sachets	20 sachets
Dye cost	120	120	120
7. Chemical products	2 sachets of wetting agent and 4 sachets of fixing agent	2 sachets of wetting agent and 4 sachets of fixing agent	2 sachests of wetting agent and 4 sachets of fixing agent
Chemical cost	30	30	30
Total Fixed Cost	7.63	17.35	21.52
Total Variable Cost	3,224.33	3,067.40	3,065.68
Total Cost	3,231.96	3,084.75	3,087.20

1. Cost Structure

1.1 Fixed cost

Fixed cost or, in other words, investment cost in the process of dyeing will include mainly cost of dyeing machine and land cost.

Fixed cost of dyeing machines including LDM, PDM I and PDM II will be valued at market price assuming the duration of 5 years life and no salvage value afterwards. In this sense, depreciation cost and opportunity cost, per year and then per batch, of money invested in such fixed cost will be measured to reflect all investment in dyeing machines. The interest rate or opportunity cost of money in this study will employ a 5% rate.

It is assumed in this economic analysis that both the local and prototype dyeing machines will be operated during its lifetime about 6 months per year due to market demand for dyed silk yarn and seasonal labor availability in rural areas. Assuming two batches of dyeing per day, the total number of batches per year will be approximately 360 batches.

On the other hand, land used for operating the dyeing machine as well as for waste water release will be assumed at 200 square meters. Accordingly, land cost per year in terms of land rent is assumed at 2,500 baht per year or 6.94 baht per batch

1.2 Operating cost

Main operation costs or variable costs per batch of dyeing process such as silk yarn, fuel, labor, chemicals, electricity and other materials will be measured from the actual market costs that occurred during such time spent.

Silk yarn cost is estimated from raw silk yarn No.30/32 D, 6 ply, 150 tpi which cost 1,310 baht/kg while the degumming cost is 50 baht/kg. This will result in the total degummed silk yarn at 1,360 baht/kg. (Price is derived from Jun Mai Thai Co., Ltd. in Nov. 2006.)

Labor cost, however, will be justified by assuming that a batch of dyeing requires approximately half a day of labor cost or 50% of daily local market wage rate, 150 baht per day, which is also the minimum wage rate of the Northeastern region (announced by Ministry of Labor, January 2007). Saving labor force by 50% (reducing from 4 to 2 laborers) is also an important assumption of labor usage in the local dyeing methods as compared to the prototype dyeing machines.

Fuel cost is separated into charcoal and LPG. Charcoal market cost 25 baht/kg while LPG (brand- PTT) in a 15 kg cylinder cost 272 baht (including 16.8 baht/kg of LPG announced by Ministry of Energy from May 2004 and transportation cost approximately at 20 baht/cylinder).

Electricity cost is based on energy consumed by PDM I at 0.1572 KWh, 0.4716 KWh/batch or 28.296 KWh/month while those of PDM II at 0.2618 KWh, 0.4790 KWh/batch or 28.745 KWh/month. With all data involved, variable cost of electricity is calculated at 0.6842 baht/unit (1 unit = 1 KWh) and the baseline cost (normal rate) of electricity, service charge and 7% VAT (announced by Provincial Electricity Authority during June-September 2007) are all valued at 1.33 baht/batch for both PDM I and PDM II.

Water cost is derived from the water supply used in the whole dyeing process (water used for dyebath, washing off and fixing) for LDM, PDM I and PDM II at 330, 360 and 320 liters/batch or 19,800, 21,600 and 19,200 liters/month. Price of water supply is estimated at 10.75 baht/unit (1 unit = 1,000 liters) including the monthly service charge and 7% VAT (announced by the Regional Water Authority, issue No. 11 in 2005). Accordingly, the water cost for LDM, PDM I and PDM II are calculated at 4.33, 4.67 and 4.21 baht/batch.

Dye cost and chemical cost at retail prices are respectively 6 and 5 baht/sachet (announced by Phua Kiam Seen Company in 2007)

2. Profitability

Profitability as the economic result from cost and return analysis will be seen from the calculation of net return and net profit. Net return or short term profit will be measured from the difference between total return from dyed silk yarn and total variable cost spent. Moreover, net profit or long term profit will be measured from the difference between total return and both total fixed costs and variable costs. The estimated net return implies economic viability of daily operation or only taking into consideration cash cost items. At the same time, the estimated net profit will suggest economic viability of total investment process taking into consideration all costs, cash or non-cash, which are actually responsible by the producer.

In estimating the profitability from dyeing silk yarn, the most important factor to differentiate level of return and then profit is the price of obtained dyed silk yarn. Practically speaking, price of dyed silk yarn in this study is constructed from the summation of marginal dyeing cost and degummed silk yarn cost all together.

In this case, the local price of dyed silk yarn will be derived from the summation of dyeing cost (500 baht/2 kg), dye and chemical costs (150 baht/2 kg) which results in the total cost of 650 baht/2 kg or 325 baht/kg. Together with the price of degummed silk at 1,360 baht/kg, the starting price of dyed silk yarn will be 1,685 baht/kg.

In case of dyed silk yarn from PDM I, price is derived from only dye and chemical costs (150 baht/2 kg or 75 baht/kg). The starting price is then estimated at 1,435 baht/kg. In the case of PDM II, additional cost of dyed silk yarn at 50 baht/batch or per 2 kg is given for the better reproducibility level resulting in the total dyeing cost at 350 baht/kg. Including the degummed silk yarn at 1,360 baht/kg, the starting price of dyed silk yarn from PDM II is at 1,710 baht/kg.

With all these considerations, the market prices of dyed silk yarn from LDM, PDM I and PDM II are respectively 1,685, 1,435 and 1,710 baht/kg which figures are employed in the calculation process of Table 14.

According to economic figures explained in Table 13 and 14, one can imagine that economic profit or net profit from the PDM II is considered highest among alternative dyeing machines, 332.80 baht per batch, while that of the PDM I is lowest only at -214.75 baht per batch. Such figures simply imply the degree of economic feasibility in operating the prototype dyeing machine. In comparison, net return or cash profit to the dyers is a little higher than net profit, 354.32 baht per batch, due to the deduction of fixed costs.

It should be noted that fixed costs or non-cash costs will be considered only from an academic point of view, while the real dyers will prefer to consider the net return or cash profit. Fortunately, fixed cost per item in this case is only a small portion of the total cost, so it will not significantly affect the level of profitability.

As expected, labor costs to operate the machine and the market price of dyed silk yarn play important roles in differentiating the degree of profitability. High labor costs for LDM is the main cause leading to a relatively low net return and profit. At the same time, high quality dyed silk yarn produced from PDM II is reflected in the highest expected market price, 1,710.00 baht/kg.

Table 14 Comparative economic returns and profits of dyed silk yarn from local and prototype dyeing methods

Unit: Baht per batch

Return and Profit	LDM	PDM I	PDM II
Return			
Dyed silk yarn	2 kg	2 kg	2 kg
Market price	1,685.00	1,435.00	1,710.00
Total return	3,370.00	2,870.00	3,420.00
Profitability			
Net return	145.67	-197.40	354.32
Net profit	138.04	-214.75	332.80

If traditional dyers can operate the PDM II for 360 batches per year as in the previous assumption, they will therefore obtain net profit at approximately 119,808 baht per year. Such estimated economic profit or net profit is assumed reasonable for annual net income of an average dyeing group. With the same manner of estimation, an average dyeing group with LDM will receive approximately 49,694.40 baht per year. These figures simply reveal the brief statement that various dyeing methods can still be an economically feasible occupation in Thailand. Improvement in dyeing technique as seen from the PDM II will result not only in higher quality dyed silk yarn but also will help promote the dyeing business to become more promising.

Details of annual returns, annual costs and annual net profits as well as the break even point from the dyeing process of PDM II are shown in Table 15.

It should be noted here according to the main figures presented that annual fixed and variable costs of dyeing by PDM II are 7,747 and 1,103,645 baht per year or 0.70% and 99.30% respectively. These figures reflect strongly from the highest weight cost of silk yarn which is overwhelmingly 88.10% of total cost or 979,200 baht per year. If such silk yarn cost is deducted from cost structure of PDM II, the total variable costs will be reduced to 124,445 baht per year. In other words, the proportion of fixed and variable costs of ‘actual dyeing process’ which exclude silk yarn as materials will be changed to 5.86% and 94.14% respectively.

Table 15 Annual return, cost and profit of the PDM II

Unit: Baht per year

	Bath/ Year		%	
Fixed cost	7,747		0.70	
Land rent		2,498		0.22
Depreciation cost		4,198		0.38
Opportunity		1,051		0.10
Variable cost	1,103,645		99.30	
Silk yarn cost		979,200		88.10
Labor cost		54,000		4.86
Fuel cost		14,450		1.30
Electricity cost		479		0.04
Water cost		1,516		0.14
Dye cost		43,200		3.89
Chemical cost		10,800		0.97
Total cost	1,111,392		100.00	
Total return	1,231,200		100.00	
Net return	127,555		10.36	
Net profit	119,808		9.73	
Break even point (year)	0.95			

Note: Break even point or pay back period is estimated from the period of time that all investment and land costs will be recovered from annual net return. Accordingly, total fixed or investment cost of PDM II is approximately 21,000 baht while purchased land at 200 meter sq and physical construction which will be sufficient for operating PDM II are assumed 50,000 baht each. On the other hand, annual net return is already estimated at 127,555 baht as estimated from Table 14 (354.32 x 360 batches)

So, the break even point is = (21,000+50,000+50,000)/127,555

= 0.95 year or 11.38 months.

Social Acceptance and Environmental Assessment of Dyeing Development

The development of the dyeing machine has been very successful in terms of technical and economic aspects since it yields better dyeing results and higher profits. Basically, promotion of the prototype dyeing machine II (PDM II) could then be possible to operators in the private sector. This implied that private investment such as a dyeing group in any Thai villages will result in both high quality silk yarn and considerable profitability. Nevertheless, the ultimate goal of appropriate technology is feasibility from the integrated approach under consideration. Not only from the private viewpoint, in terms of techniques and profitability, but from social acceptance and environmental assessment of dyeing technology are all important in justifying the prototype dyeing machine as well. Both social and environmental perspectives, therefore, need to be taken into account in the research project to gain a complete picture of the improved dyeing machine.

1. Social Perspectives

The main social aspect required to be considered here is the harmony of the local dyeing wisdom and culture together with the development of the new prototype dyeing machine. Innovative technology in dyeing from this study should be based in addition to the foundation of local dyeing wisdom that has long been practiced in the country. Modern technology as in the newly improved dyeing machine must not in one way or another detract from the old-age knowledge of Thai dyeing culture.

1.1 Technical improvement from foundation of local wisdom.

At the primary stage, the general principle used in the development of the new dyeing machine was applied from the advantages and disadvantages of dyeing procedures carried out in the community. Various proper dyeing techniques such as temperature control and dyeing solution circulation were then improved so as to obtain better results. Consequently, the dyeing principles of the prototype dyeing machine are considered an improvement from methods used by the local people.

Without the local wisdom as foundation, any improvement in dyeing techniques can hardly be possible and accepted by the local people.

1.2 Innovative dyeing as labor-saving technology.

Another important social aspect, however, in creating the improved dyeing machine is to offer the dyeing operators an easier task. Generally speaking, middle-age women and older are the main labor force in the dyeing activity. The improved dyeing machine is thus created to reduce the use of intensive labor involved in such hard activity, which should consequently result in better quality of life of these women in local Thai communities. This innovative dyeing method is then considered a labor-saving technology which will provide efficiency as well as quality of life to local women at the same time.

1.3 Opportunity for new generations of dyers

Moreover, many new features of the improved dyeing machine generally indicate that any dyer can be an efficient operator and expect convenience from the adoption of new technology. Any new dyers can become professional dyers within a shorter period of time as compared with the local dyeing methods which required much longer experience. It is widely accepted that the increasing scarcity of experienced dyers is one of the serious problems to sustain the local dyeing method into the future. Due to the new improved dyeing machine, inexperienced but trained people such as young people can get involved in the dyeing career. Opportunity widely opens for this younger generation is the key factor leading to sustainability of quality silk yarn and then Thai silk products in the future.

1.4 Dyeing machine as the center of community investment

The new improved dyeing machine is rather a capital-intensive technology and derived from high investment. This high cost of a new machine, such as PDM II, is then in need of co-investment among local people. Participation and sharing among local people in terms of funding for such a high cost dyeing machine will put the dyeing machine as the center of community investment. The shared investment of community will at the same time create a strong sense of belonging to every member of the investment.

Interviews with the local participants in the dyeing business revealed the fact that they have a strong interest in the machine as a good labor-saving device. However, one prominent concern from most of them was the high cost of the machine and needing a search for an appropriate source of funds. Possible funding sources such as village funds, village cooperatives, savings groups, or government bank especially Bank for Agriculture and Agricultural Cooperatives (BAAC) were among the priorities.

When all social aspects mentioned above are considered, it can be said that the new improved dyeing machine is possibly accepted by both old and new dyers. New technical innovation is developed in harmony with the local wisdom. Not only will it not detract from the old-age knowledge but it will enrich the dyeing occupation into the future under the conservation of precious culture and traditions of various Thai localities.

2. Environmental Perspectives

The issues of environmental impacts from technical innovation can be further discussed in addition to the social impacts. Positive and negative impacts can be seen from the environmental perspectives.

2.1 Forest resource conservation from alternative energy usage.

It is widely known that traditional dyeing processes use up a lot of natural resources and create negative impacts on the environment. In the local dyeing procedures, it cannot be denied that intensive use of charcoal and then wood and forest are all involved in traditional dyeing. In other words, continued deforestation as the ultimate problem leading to global warming and climate change is partly caused by dyeing methods of the local people. This is one of the most serious problems in Thailand and impels a search for better alternative energy sources.

The new improved dyeing machine using LPG as an energy source will help solve this problem to a great extent. Using LPG may not be the way of a completely clean energy but its negative environmental impact would still seem to be much lower than using charcoal or wood. Moreover, temperature can be more easily controlled by using LPG energy resulting in the better quality of dyeing process.

2.2 Reduction of the local health impacts

In addition to forest conservation, the new improved dyeing machine is supposed to play an important role in reducing health costs to dyeing operators. Basically, hardship of traditional dyeing process requires a lot of physical effort from middle-age and old-age women, especially during the stages of dyeing and washing the yarn. Technical improvements in dyeing methods will potentially help reduce the excessive physical effort and thus improve health costs of the elderly. At the same time, direct contact and smelling various dyeing chemicals from local dyeing processes will be reduced under the new improved dyeing machine and so further benefit the health of local operators.

2.3 Emerging problem of waste water release

Despite the new and improved dyeing machine creating many positive environmental and health impacts, negative externality in terms of waste water release from such machine is also evidenced. When the water issue is taken into consideration, it is found that the prototype dyeing machine still uses higher liquor ratio (30:1) than that of the local dyeing methods (20:1). This is simply the result from the recommended standard dyeing process from the dye company. The use of more water also implies more waste water release from the dyeing process and affects the environment of the nearby areas. In other words, treatment cost of such water pollution from the machine should be higher than that of the local dyeing methods. This waste water release seems to be an emerging problem from the newly improved dyeing machine.

Again, technical innovation in the stage of washing off needs to be analyzed and improved in order to reduce the quantity of waste water release. This is probably the role of the next generation of newly improved dyeing machines to reduce the water use and so produce less waste water.

Holistic Considerations of a New Improved Dyeing Machine

Given all descriptions above, one can summarize the holistic considerations, including the technical aspects, economic aspects, social aspects and environmental aspects of the local dyeing methods (LDM) and the selected prototype dyeing machine (PDM II) in the Table 16. An holistic approach simply implies the integrated analysis from every main aspect of effectiveness related to both silk dyeing methods. This analytical approach is then more complete, practical and reliable than that from any single analysis, especially from the technical aspect alone. Since development of a dyeing machine, such as the PDM II, is aimed at applying new techniques to rural communities in Thailand, consideration from all aspects in realistic conditions is then necessary.

Table 16 Holistic considerations of a dyeing machine

Aspect of Consideration	LDM	PDM II	Consideration
Technical aspects	- Dyeing equipment by kitchen utensils	- Dyeing equipment by dyeing machine	+
	- Use experience to control dyeing process	- Use digital system of thermeter	+
	- Lower efficiency production in terms of reproducibility	- Higher efficiency production in terms of reproducibility	+
Economic aspects	- Lower fixed cost	- Higher fixed cost	-
	- Lower net return	- Higher net return	+
	- Lower net profit	- Higher net profit	+
Social aspects	- Labor-intensive	- Labor-saving	+
	- Can be individual or group work	- Should be group work for investment	+
	- Declining experienced dyer	- Transfer dyeing knowledge to young generation	+
Environmental aspects	- Intensive use of wood	- Forest resource conservation	+
	- Higher health cost	- Reduced health costs	+
	- Low waste water	- High waste water	-

Note: positive impact (+) or negative impact (-) when comparing various aspects between LDM and PDM

Summary of Comparative Analyses between Traditional and Improved Dyeing Methods

In conclusion, a clearer description between the main aspects of the LDM and PDM II from input use to output obtained as well as important dyeing processes can be again summarized as in Figure 11. Selected main aspects to be taken into consideration here include:

Quality of output (more consistent quality of dyed silk yarn can be expected from the PDM II as compared with that of the LDM)

Quantity of production (limitation of production due to experienced labor scarcity in the LDM can be made more flexible from the technical innovation of the PDM II)

Value of final product (dyed silk yarn of consistent quality from the PDM II will be expected to be of higher value)

Labor used (PDM II is rather a labor-saving technology implying that less labor can yield the same or even more dyed silk yarn)

Capital investment (PDM II is obviously the higher investment technology as compared with the LDM)

Group work (both PDM II and LDM are appropriate for group work participation)

Management (management for the PDM II is performed through division of capital and investment instead of division of labor in the LDM)

Local wisdom (PDM II can apply or even enrich the local wisdom on top of the LDM)

Market competitiveness (output made from the traditional LDM is mostly concentrated on niche market or specific customer groups not competitive in the open market like output from the PDM II.)

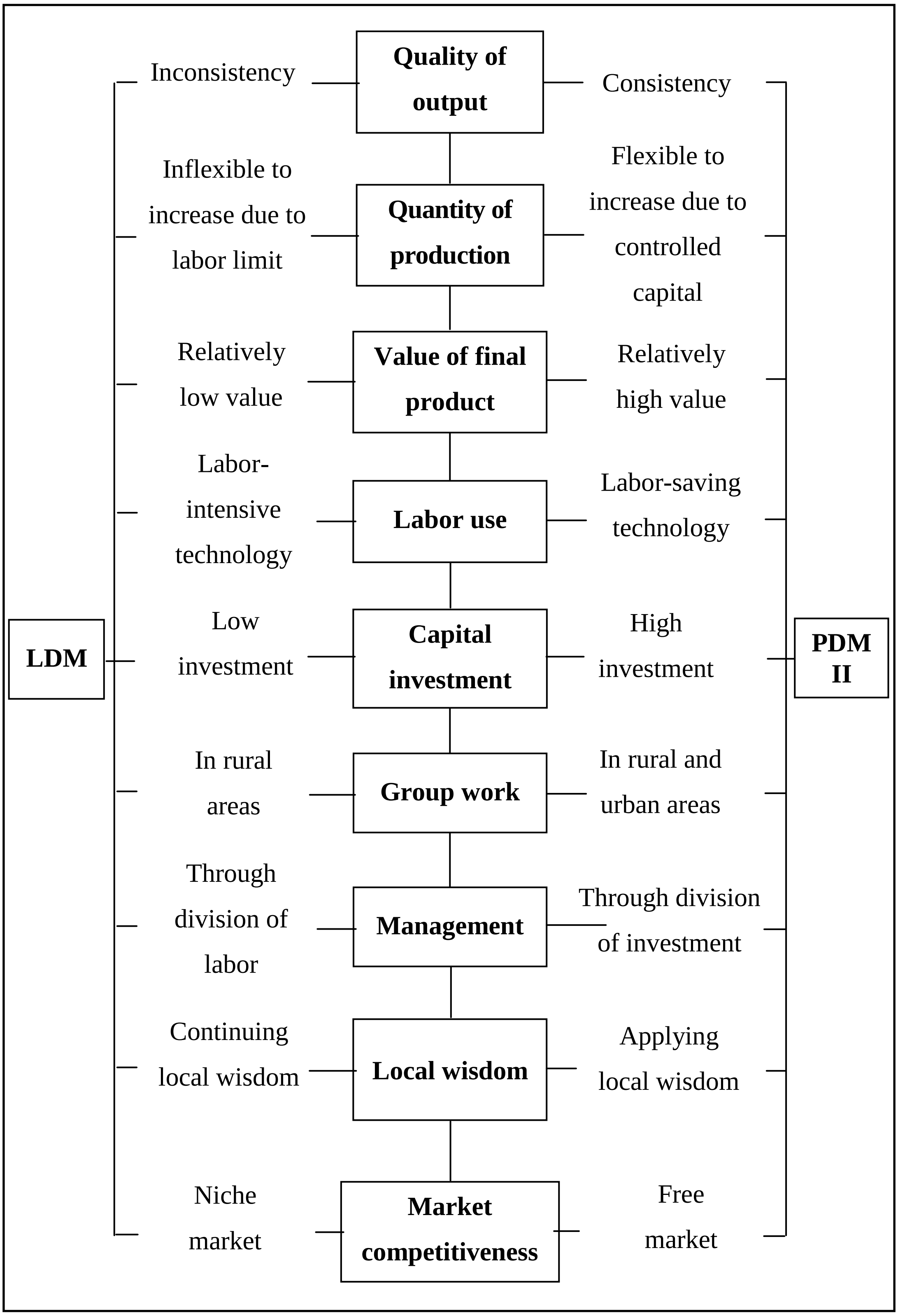


Figure 11 Comparative main figures and aspects between LDM and PDM II

CONCLUSION AND RECOMMENDATIONS

Conclusion

This study primarily aimed at examining the traditional dyeing methods that have long been practiced in Thailand and suggesting new dyeing machines in order to improve the quality of dyed silk yarn. The ultimate goal and also main hypothesis of this research was that better quality of dyed silk yarn as inputs could result in better silk products as outputs. Technical innovation from the prototype dyeing machine as well as economic, social and environmental evaluation of such new improved technology would be an important foundation for the development of Thai silk dyeing and the silk industry at present and in the future.

From intensive interviews of the 3 local dyer groups including Local Handicraft Group, Amphur Napho, Buri Rum Province; Hangkarok Silk Group, Ban Sanuan Nai, Buri Rum Province and Agricultural Housewife Group, Ban Nonmuang, Nong Bua Lam Phu Province, it was found that there were many significant differences in these traditional dyeing processes, especially liquor ratio, dyeing period and use of fixing agents. These different characteristics were partly the result of age-old knowledge and local wisdom inherited from their ancestors in addition to the available technology level in the local areas. However, there were still some similarities among the 3 groups: using wood as the source of heat, using no scales or thermometers for substances and temperature measurement. Containers used in the dyeing process were also modified from kitchen utensils made of aluminum or iron which could not be standardized.

From analytical measurement, the L* values of the dyed silk remained quite low, which implied that the color was rather dark. Sanuan Nai silk had the highest L* value followed by Napho silk. The C* values were considered moderate. Napho silk had the highest C* value followed by Sanuan Nai silk. The h* values were generally found in the yellow-red range. Napho silk had the highest in the h* value followed by Nonmuang silk. The dE* values of color change due to laundering of the dyed silk were less than 2 indicating good colorfastness in terms of color change. Nonmuang silk had the highest colorfastness followed by Napho silk. However, the dE* values of color staining were quite high indicating low colorfastness in terms of color staining.

The analyses of variance of the L*, C*, h* values of silk yarns dyed by all groups indicated that the L* and h*values were significantly different at .01and .05 level respectively while the C* values were not significantly different even at .05 level. The analyses of variance of the dE* values of the dyed silk after laundering indicated that the dE* values of color change and color staining were not significantly different at .05 level.

When the reproducibility of dyeing of each group was evaluated, the results showed that only Nonmuang group could produce good reproducibility since the dE* values of the three replication pairs were confirmed to be lower than 2.

After the dyeing procedures and problems of local dyeing groups were carefully examined, the first prototype dyeing machine (or usually called in this study as the PDM I) was thus created in order to improve dyeing processes from the local dyeing method and to serve as a labor saving machine for the existing condition of labor scarcity in rural areas.

The so called PDM I was simply a small-scale machine which carried an open container with rotary wheel and temperature measurement. The machine functioned through an electrical motor gear system that used a skein hanging wheel. The analog system was attached to evaluate temperature level. Gas as the source of heat was released through the burner of KB5.

After an experiment of PDM I, it was however found that some unsolved problems still existed. The main problem was that color values of the skein from PDM I were dramatically different from those of the standard Infra-red dyeing machine. The cause of such difference was that the skein hanging wheel was set too far from the bottom of the container. Consequently, a large amount of water (LR. = 50:1) was required in the process. Only one third of the skein was submerged in the dyeing solution although a large amount of water was used. Moreover, the temperature of the dyeing solution did not reach the expected 90°C since the machine was an open system and this factor resulted in high heat loss.

The second prototype dyeing machine (hereafter called the PDM II) was then developed to eliminate all flaws existing in PMD I. The PMD II was also a small scale machine using a semi-closed container with cover, exhaust stack, a rotary wheel and digital temperature system. The PDM II machine was fully operated through an electrical motor shaft system that controlled the skein hanging wheel. The burner of KB8 was applied to let out gas which was the source of fuel. The skein hanging wheel was located approximately 8 cm closer to the bottom of the container which resulted in the better mixing of silk yarn and dyeing solution.

In quantitative analysis, the comparative qualities of dyed silk yarn in terms of the L* values of dyed silk were found. The dyed silk from PDM II (dyeing period at the rate of 120 minutes) produced the highest L* value followed by dyed silk from PDM I (150 minutes). In terms of the C* values, it was found that Sanuan Nai silk had the highest C* value followed by Napho silk. Moreover, PDM II silk (110 minutes) had the highest h* value followed by PDM II silk (90 minutes). When the colorfastness was considered, it was found that PDM II silk (110 minutes) had the highest colorfastness in terms of color change followed by Napho silk. However, the dE* values of color staining were still quite high indicating low colorfastness in terms of color staining. The Napho silk had the highest color fastness in terms of color staining followed by PDM II silk (110 minutes).

When silk yarn types from all treatments and that from the standard Infra-red dyeing machine were comparatively examined, it was found that silk containing the L* C* and h* value close to that from the standard Infra-red dyeing machine were those outputs from PDM II (110 minutes), PDM II (90 minutes) and PDM II (70 minutes) respectively.

The analyses of variance (ANOVA) of the color values (including L* values, C* values, h* values) and the colorfastness to laundering (including dE* values of color change and dE* values of color staining) among silk yarn dyed by all 9 groups of treatment indicated that the L*, C*, h*and dE* values of color staining were significantly different at .001 level while the dE* values of color change was significantly different at .01 level.

When the reproducibility of dyeing of each treatment was evaluated, the result showed that only PDM II (110 minutes) and PDM II (90 minutes) could produce very good reproducibility since the dE* value of three replication pairs were confirmed to be lower than 1.

When all factors including color value, colorfastness and reproducibility were carefully examined, it was then clear that PDM II yielded in overall the best results in all factors. Consequently, it could be stated in this study that PDM II was not only an improved labor-saving machine as the primary target but also a recommended innovative machine for better quality of local dyeing process. The PDM II could consistently increase both the quality and quantity of dyed silk yarn for the producers, the markets and the Thai silk businesses under competitive conditions and scarce experienced labor resources.

Considering all results from this research, facts and figures related to silk dyeing process currently practiced in Thailand suggested many implications to be taken into consideration. This research revealed some technical weak points of dyeing efficiency that could be improved so as to better the quality of dyed silk yarn. The higher quality of such dyed yarn was regarded as the fundamental factor for further steps of higher value and price of various Thai silk products in the market. On the other hand, increasing efficiency of silk dyeing techniques would at the same time lead to labor-saving technology especially for dyeing group members who are partly elderly people. Substitution between sources of fuel materials from wood to gas would be another alternative to improve both reducing the unit cost of dyeing and conserving the forest resources of the communities. Social and environmental considerations were both in favor of the development for a new, improved dyeing machine. Between the local dyeing methods and improved dyeing machines, test of better economic feasibility for the new improved silk dyeing machines was then confirmed under the realistic conditions of locality and nationality.

Promotion of integrated knowledge from the age-old local wisdom in dyeing techniques to be applied using modern technology in terms of improved dyeing machines would, therefore, be the key challenge of research on silk dyeing at the moment and in the near future. Development of a new dyeing machine should be made on top of traditional dyeing methods in order that the advantages of local wisdom could be kept and continued while innovative knowledge would still be possible. The appropriate combination of integrated knowledge between local and modern dyeing techniques would be the crucial foundation for further dyeing development. Therefore, continued development of dyeing technology is always needed so as to ensure that the quality of Thai silk will be all times at the heart of the fabric and textile business here in Thailand and be able to compete in any international market. In fact, such expectations would probably be the ultimate goal of further studies in the future.

Suggestions

From the main findings explained in this study, some suggestions can therefore be added to make a more complete conclusion as follows:

1. The best possible dyeing machine is not yet invented.

It is concluded from this study that the development of a new dyeing machine from various local dyeing methods is still possible and needs to continue into the future. The new improved dyeing machine recommended as the PDM II is not yet the best dyeing machine available among the present technologies. As seen from its many existing limitations, many other technical aspects can still be added and improved upon. Technical research in dyeing methods is still needed to complement the characteristics of PDM II.

2. Technical innovation is moving in environmentally friendly directions.

As the whole world is turning into becoming more environmentally friendly in its technology the development of improved dyeing machines should also help serve the function of reducing all environmental impacts released from the dyeing process. Any additional development of a dyeing machine in the future then must involve in decreasing the following aspects: water pollution, waste release, energy consumption and chemical contacts. This is the dynamic trend that global development is moving towards-environmental friendly technology.

3. Development of dyeing technology should go hand in hand with human development.

Application of the new dyeing machine under realistic conditions needs to take into consideration not only technical innovation in dyeing but the socio-economic conditions of people in the local communities. Learning process, training and improvement of the local wisdom of dyers are as important as the technical development itself. One must believe that a dyeing machine, alone, can not improve Thai silk quality but the Thai people themselves.

4. The implication of a dyeing machine is not only to create better quality dyed silk yarn but to benefit the Thai silk industry as a whole.

Overall linkage from the dyed silk yarn to various Thai silk products needs special vision from everyone concerned to realize the challenge. Better quality of dyed silk yarn is the vital foundation to create higher silk value in the market. Investment in technical development of dyeing is then not only the improvement of dyeing methods and then better quality of dyed silk yarn but the way to continually improve the value of Thai silk and create better prosperity in the future. The development of a dyeing machine, therefore, is not about the sole issue of improvement in dyed silk yarn quality but all the accompanying issues about value creation of various Thai silk products, poverty eradication of local dyers, better quality of life for older women and the precious heritage of Thai silk to be continued.

Recommendations

Although this study is mainly involved with the improvement of dyeing techniques, implementation of such innovation will need to take into consideration many aspects and factors in the realistic conditions. The ultimate goal of this study is to promote the new prototype dyeing machine from the experimental stage into the adoption and extension stages. Also, promotion of a dyeing machine into practice will need to be examined from the micro aspects such as technical operation of a local silk dyer to the macro aspects, such as measures of policy assistance in supporting the new, improved dyeing machine in its wider applications.

Recommendations produced from this study can then be separated into three main parts: technical recommendations, recommendations for further study and policy recommendations.

1. Technical Recommendations

Technical recommendations for the further improvement of dyeing machines include:

1.1 Technical improvement of dyeing machines should concentrate on less water consumption.

Less water used in dyeing machine does not imply only an efficient amount of water needed for the dyeing process but also less water pollution released from the dyeing process. Further dyeing machines, such as PDM III or PDM IV, should include at least the design of a new skein hanging wheel, which can lead to more economic use of water. Lower cost of water and better environmental quality can then be expected.

1.2 Development of dyeing machines should be constructed of various sizes to suit different purposes.

It can be expected that economy of scale from dyeing machines will play an important role in the realistic applications of the PDM II. The right size of machine for the right purpose of dyeing, such as a small machine designed for an individual dyer or for the small dyeing group in rural areas must be encouraged to develop. Larger scale dyeing machines for the growing community-based enterprises is also necessary. In other words, too large or too small sized PDM II will lead to the higher average costs or diseconomy of scale.

1.3 Further improvements of dyeing method should incorporate temperature control functions in relation with automatic heat systems.

Temperature control and automatic heat systems will be another innovation of dyeing machines that will be needed in the future. In order to save time, gas energy and labor costs in the dyeing process, further development of dyeing machines should turn into fully automatic machines for regulating temperature target and gas release. The PDM II with heat indicator is only a semi-automatic system in this respect since it still requires manpower to operate the gas release system.

1.4 Dyeing machines should be constructed with insulators in order to prevent heat loss during the dyeing process.

Lack of an insulator is one of the limitations of the PDM II that leads to high heat loss and higher costs of dyeing later on. Dyeing machines with the installation of insulating on the container cover will therefore increase the cost of machine construction while maintaining the expected level of temperature thereby reducing the cost of dyeing.

1.5 Replacement of gas energy with electricity should make the standard dyeing machine better able to control temperature.

As heat control is central for better dyeing quality and lower dyeing cost, using electricity and replacing gas energy is a viable option in need of consideration. Electricity as the source of energy will provide more consistent heat levels to control the quality of dyeing and therefore the quality of dyed silk yarn.

2. Recommendations for the Further Study

Priorities of recommendation that should be employed for trial in further studies, especially in improving the PDM II, include the following:

2.1 reducing LR to test the suitability for the PDM II

2.2 alternative functions, other than dyeing, of the PDM II in degumming, bleaching or washing

2.3 applying other dyes and materials instead of the typical acid dyes and silk.

2.4 differentiating the shades or concentration of the same color in order to confirm the colorfastness, color values and reproducibility.

2.5 dyeing different colors, from the red color in this study, to verify the quality of dyed silk yarn.

3. Policy Recommendations

Policy recommendations for the further improvement of dyeing machines include:

3.1 Feasible investment in the newly improved dyeing machines should be done more effectively through group work.

Since investment in dyeing machines will involve considerable funds spent in fixed costs for local people, dyeing through group work or dyeing groups must be considered instead of an individual investor. Saving groups or cooperative groups in a typical Thai community can also be utilized to serve the collective need for investment in a dyeing machine. Advantages of group work include that it will potentially reduce the average cost per unit of dyeing as compared to an individual person.

3.2 Training local dyers is the heart of successful technical development.

One should accept the fact that success of dyeing techniques does not depend on the machine per se but the people who operate it. Training the dyers regarding the improvement aspects of the new machine is then the required fundamental condition of the whole development process. Technical training, experience sharing and participatory research with local people will require subsidies from public funds or government policies. Adaptation of experiences and adoption of appropriate technologies among villagers in Thailand are important factors behind the success of technical development.

3.3 Economic assistance through various fiscal and monetary measures are still necessary to speed up the growth of dyeing business.

In order to support traditional dyeing groups especially in rural areas, the government should provide either fiscal or policy measures to help speed the growth of dyeing groups. Credit with a low interest rate or soft loans for community-based enterprises including the dyeing business are the basic assistance measure from monetary policy. Community funded systems are possible including various community activities and the promising business investment, like dyeing machines, in appropriate areas. Both monetary and fiscal policies are considered vital factors under government subsidy especially to start dyeing groups in the short term before they become more competitive in the longer term.

3.4 Property rights of PDM is needed to ensure the reward of intellectuality.

In order to standardize the characteristics of PDM II which is proved to be the most effective dyeing machine, the issue of property rights must be considered. Not only the technical aspects of dyeing machines will be guaranteed with property rights, the benefits for inventors of such machine are also ensured. Lack of property rights in the future may result in the inappropriate duplication of dyeing machines and thus deteriorate the development of intellectual inventions like the dyeing machine of this study.

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APPENDIX

Appendix Table 1 Analysis of variance of L* values of the dyed silk

Source of variation	df	SS	MS	F
Treatment	2	16.762	8.381	7.939**
Block	2	4.993	2.497	2.356
Error	4	4.223	1.056	

** Significant at .01 level

Appendix Table 2 Duncan's multiple range tests of L* values of the dyed silk

Sample	Mean	Duncan's Group	
Napho silk	35.713	A	
Sanuan Nai silk	38.600		B
Nonmuang silk	35.697	A	

Appendix Table 3 Analysis of variance of C* values of the dyed silk

Source of variation	df	SS	MS	F
Treatment	2	0.324	0.162	0.492
Block	2	2.509	1.254	3.805
Error	4	1.319	0.330	

Appendix Table 4 Analysis of variance of h* values of the dyed silk

Source of variation	df	SS	MS	F
Treatment	2	15.190	7.595	13.780*
Block	2	0.248	0.124	0.225
Error	4	2.205	0.551	

* Significant at .05 level

Appendix Table 5 Duncan's multiple range tests of h* values of the dyed silk

Sample	Mean	Duncan's Group	
Napho silk	29.257		B
Sanuan Nai silk	26.173	A	
Nonmuang silk	28.397		B

Appendix Table 6 Analysis of variance of dE* values of color change after laundering

Source of variation	df	SS	MS	F
Treatment	2	0.387	0.193	1.650
Block	2	0.200	0.100	0.855
Error	4	0.469	0.117	

Appendix Table 7 Analysis of variance of dE* values of color staining after laundering

Source of variation	df	SS	MS	F
Treatment	2	20.715	10.358	2.991
Block	2	0.085	0.043	0.012
Error	4	13.853	3.463	

Appendix Table 8 Analysis of variance of L* values of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Source of variation	df	SS	MS	F
Treatment	8	234.156	29.269	89.732***
Block	2	1.668	0.834	2.557
Error	16	5.219	0.326	

*** Significant at .001 level

Appendix Table 9 Duncan's multiple range tests of L* values of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Sample	Mean	Duncan's Group			
Napho silk (100 minutes)	37.117	A			
Sanuan Nai silk (45 minutes)	38.650		B		
Nonmuang silk (120 minutes)	37.730	A	B		
PDM I silk (180 minutes)	42.013			C	
PDM I silk (150 minutes)	43.800				D
PDM I silk (120 minutes)	44.473				D
PDM II silk (110 minutes)	36.717	A			
PDM II silk (90 minutes)	36.987	A			
PDM II silk (70 minutes)	37.270	A			

Appendix Table 10 Analysis of variance of C* values of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Source of variation	df	SS	MS	F
Treatment	8	132.022	16.503	71.819***
Block	2	2.132	1.066	4.639
Error	16	3.677	0.230	

*** Significant at .001 level

Appendix Table 11 Duncan's multiple range tests of C* values of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Sample	Mean	Duncan's Group			
Napho silk (100 minutes)	61.420				D
Sanuan Nai silk (45 minutes)	61.933				D
Nonmuang silk (120 minutes)	59.630			C	
PDM I silk (180 minutes)	58.047		B		
PDM I silk (150 minutes)	56.500	A			
PDM I silk (120 minutes)	55.827	A			
PDM II silk (110 minutes)	61.367				D
PDM II silk (90 minutes)	61.320				D
PDM II silk (70 minutes)	61.337				D

Appendix Table 12 Analysis of variance of h* values of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Source of variation	df	SS	MS	F
Treatment	8	325.205	40.651	157.040***
Block	2	2.457	1.228	4.746
Error	16	4.142	0.259	

*** Significant at .001 level

Appendix Table 13 Duncan's multiple range tests of h* values of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Sample	Mean	Duncan's Group			
Napho silk (100 minutes)	27.267				D
Sanuan Nai silk (45 minutes)	25.640			C	
Nonmuang silk (120 minutes)	25.393			C	
PDM I silk (180 minutes)	21.680		B		
PDM I silk (150 minutes)	19.473	A			
PDM I silk (120 minutes)	18.697	A			
PDM II silk (110 minutes)	27.933				D
PDM II silk (90 minutes)	27.863				D
PDM II silk (70 minutes)	27.457				D

Appendix Table 14 Analysis of variance of dE* values of color difference between sample and control

Source of variation	df	SS	MS	F
Treatment	8	615.586	76.948	140.664***
Block	2	4.029	2.015	3.683
Error	16	8.753	0.547	

*** Significant at .001 level

Appendix Table 15 Duncan's multiple range tests of dE* values of color difference between sample and control

Sample	Mean	Duncan's Group			
Napho silk (100 minutes)	1.517	A			
Sanuan Nai silk (45 minutes)	3.647		B		
Nonmuang silk (120 minutes)	3.290		B		
PDM I silk (180 minutes)	9.103			C	
PDM I silk (150 minutes)	12.263				D
PDM I silk (120 minutes)	13.443				D
PDM II silk (110 minutes)	0.767	A			
PDM II silk (90 minutes)	0.987	A			
PDM II silk (70 minutes)	1.313	A			

Appendix Table 16 Analysis of variance of dE* values of color change of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Source of variation	df	SS	MS	F
Treatment	8	10.412	1.302	4.029**
Block	2	1.429	0.714	2.212
Error	16	5.168	0.323	

** Significant at .01 level

Appendix Table 17 Duncan's multiple range tests of dE* values of color change of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Sample	Mean	Duncan's Group		
Napho silk (100 minutes)	1.023	A		
Sanuan Nai silk (45 minutes)	2.493		B	C
Nonmuang silk (120 minutes)	2.280		B	C
PDM I silk (180 minutes)	1.430	A	B	
PDM I silk (150 minutes)	2.603			C
PDM I silk (120 minutes)	2.643			C
PDM II silk (110 minutes)	1.010	A		
PDM II silk (90 minutes)	1.547	A	B	C
PDM II silk (70 minutes)	1.713	A	B	C

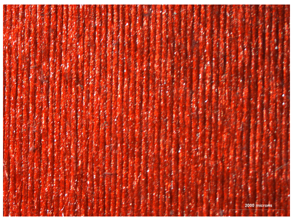
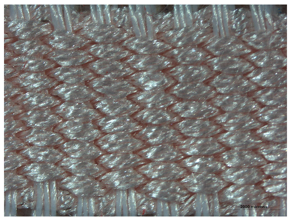
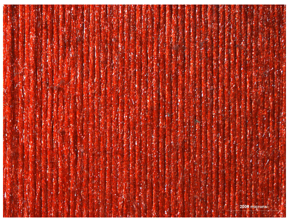
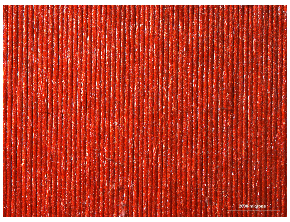
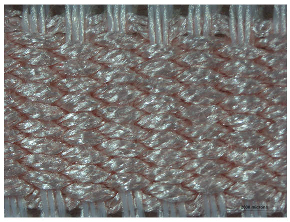
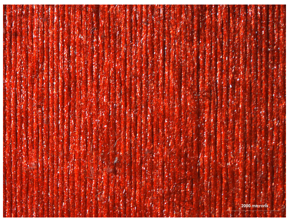
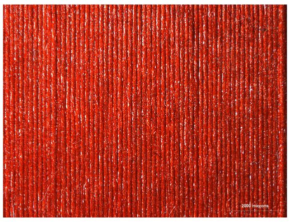
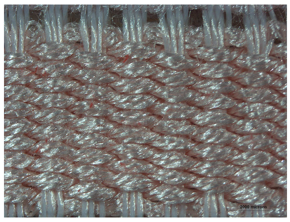
Appendix Table 18 Analysis of variance of dE* values of color staining of silk yarn dyeing by using the prototype dyeing machine and by the local groups

Source of variation	df	SS	MS	F
Treatment	8	49.213	6.152	9.467***
Block	2	2.156	1.078	1.659
Error	16	10.397	0.650	

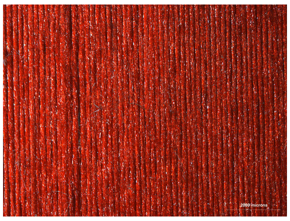
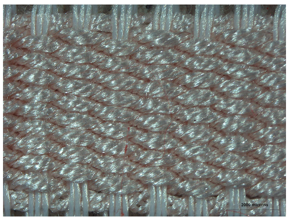
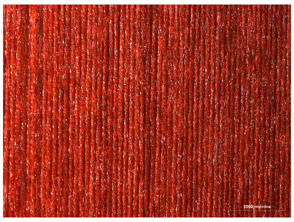
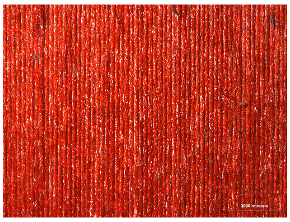
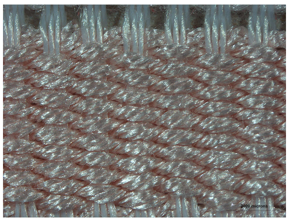
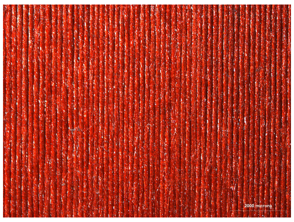
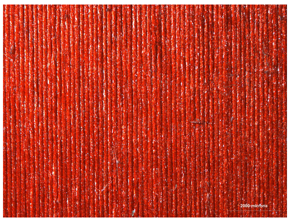
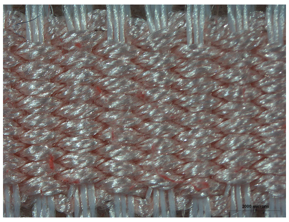
*** Significant at .001 level

Appendix Table 19 Duncan's multiple range tests of dE* values of color staining of silk yarn dyeing by using the prototype dyeing machine and by the local groups

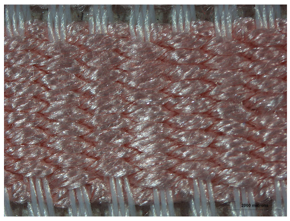
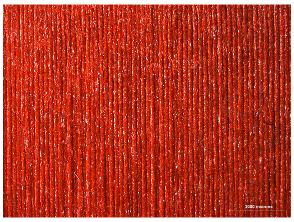
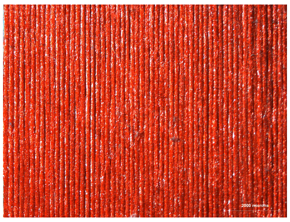
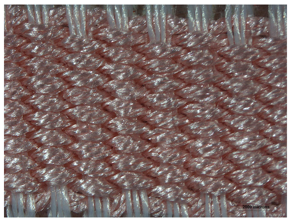
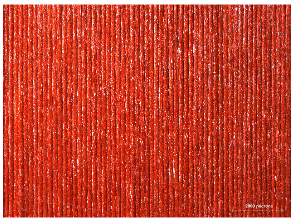
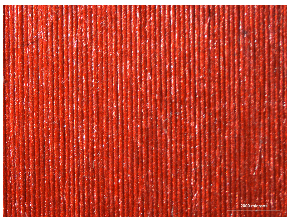
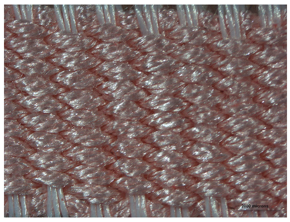
Sample	Mean	Duncan's Group			
Napho silk (100 minutes)	8.683	A			
Sanuan Nai silk (45 minutes)	17.397				D
Nonmuang silk (120 minutes)	17.307				D
PDM I silk (180 minutes)	14.037			C	
PDM I silk (150 minutes)	12.417		B	C	
PDM I silk (120 minutes)	13.840			C	
PDM II silk (110 minutes)	10.053	A	B		
PDM II silk (90 minutes)	13.590			C	
PDM II silk (70 minutes)	13.860			C	

Treatment	Illustrations of dyed silk yarn		
Replication	Before laundering	After laundering	Staining
1			
2			
3			

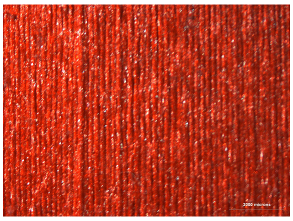
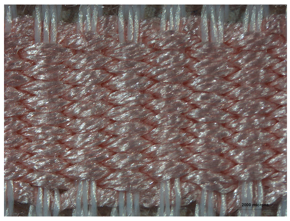
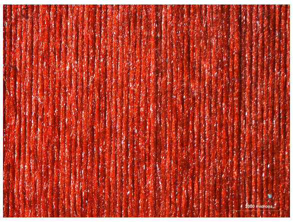
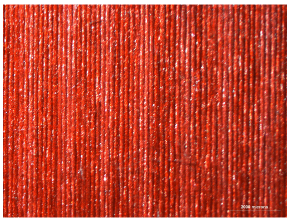
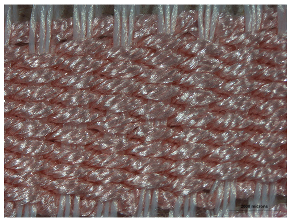
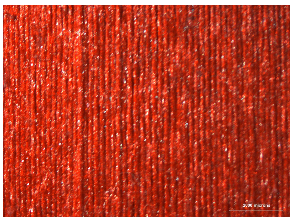
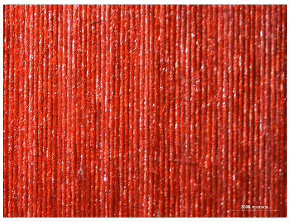
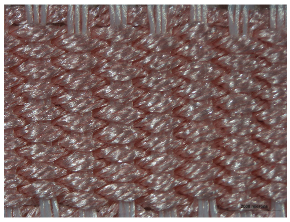
Appendix Figure 1 Illustrations of Infra-red dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	Illustrations of dyed silk yarn		
Replication	Before laundering	After laundering	Staining
1			
2			
3			

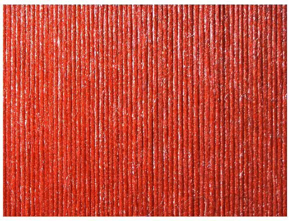
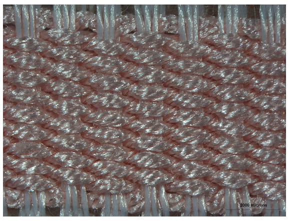
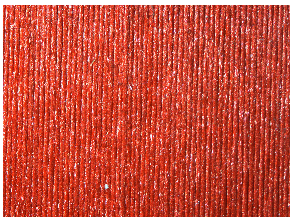
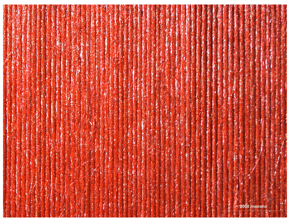
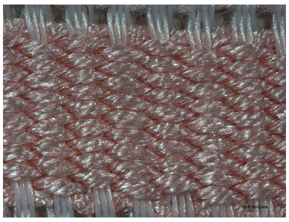
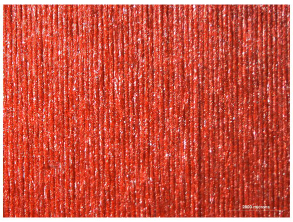
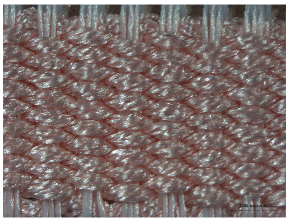
Appendix Figure 2 Illustrations of Napho (100 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	Illustrations of dyed silk yarn		
Replication	Before laundering	After laundering	Staining
1			
2			
3			

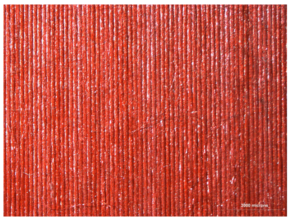
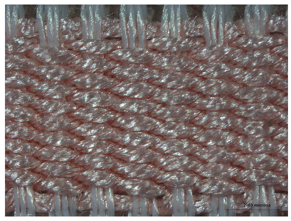
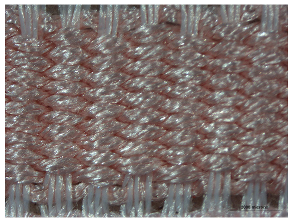
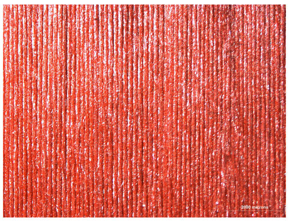
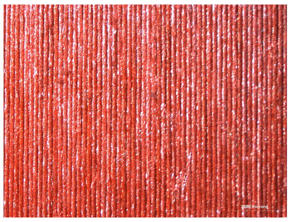
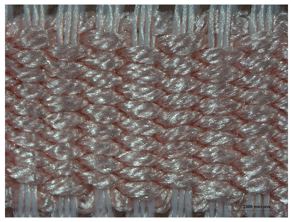
Appendix Figure 3 Illustrations of Sanuan Nai (45 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	Illustrations of dyed silk yarn		
Replication	**Before laundering**	**After laundering**	**Staining**
1			
2			
3			

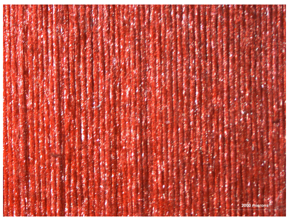
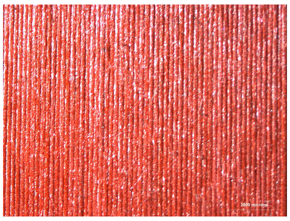
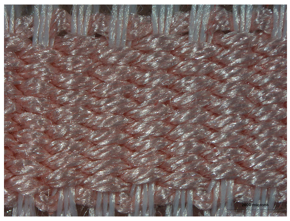
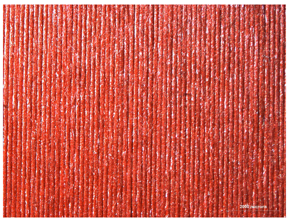
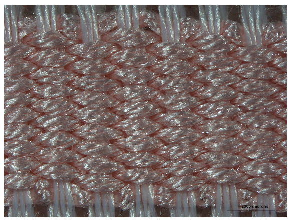
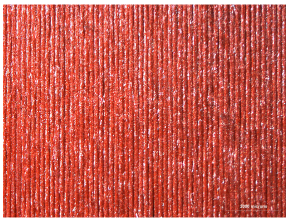
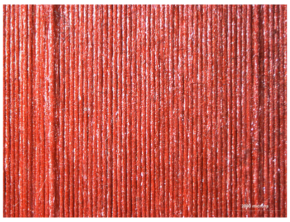
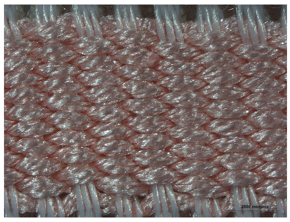
Appendix Figure 4 Illustrations of Nonmuang (120 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	**Illustrations of dyed silk yarn**		
Replication	**Before laundering**	**After laundering**	**Staining**
1			
2			
3			

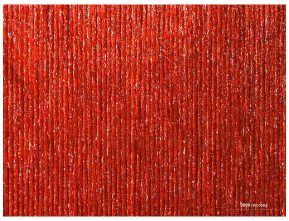
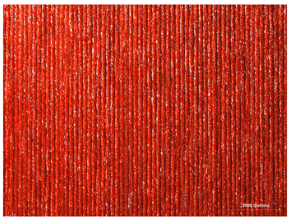
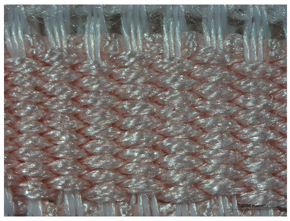
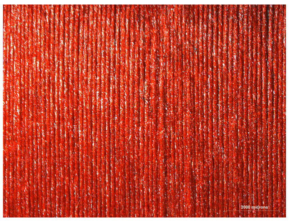
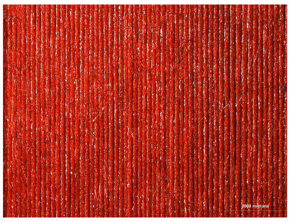
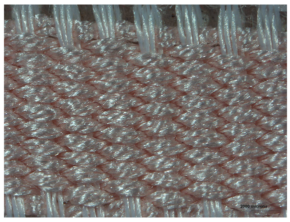
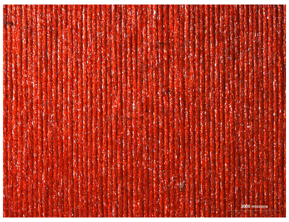
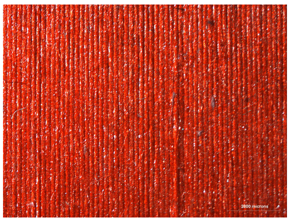
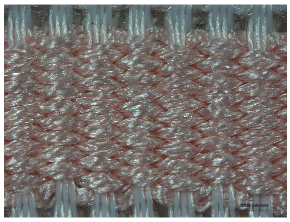
Appendix Figure 5 Illustrations of PDM I (180 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	Illustrations of dyed silk yarn		
Replication	**Before laundering**	**After laundering**	**Staining**
1			
2			
3			

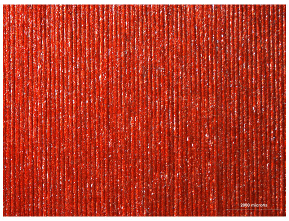
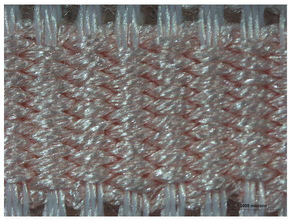
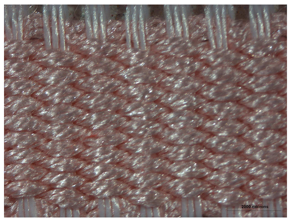
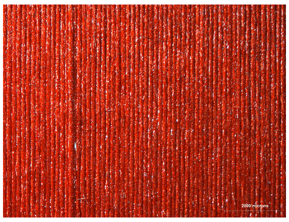
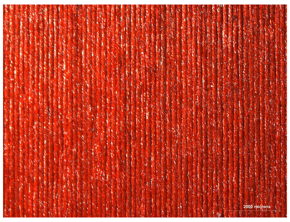
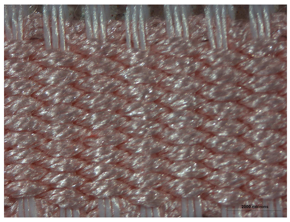
Appendix Figure 6 Illustrations of PDM I (150 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	Illustrations of dyed silk yarn		
Replication	Before laundering	After laundering	Staining
1			
2			
3			

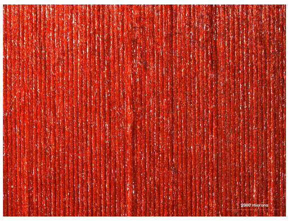
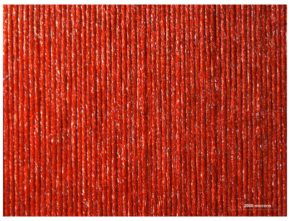
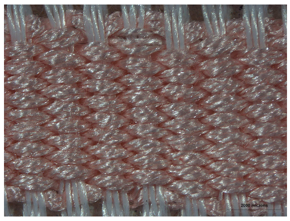
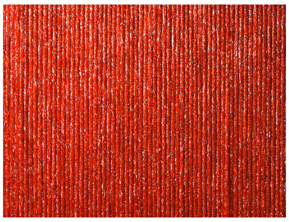
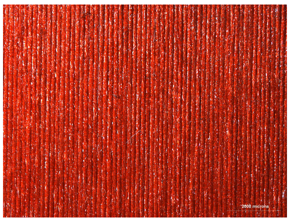
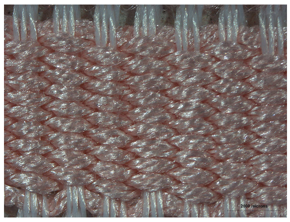
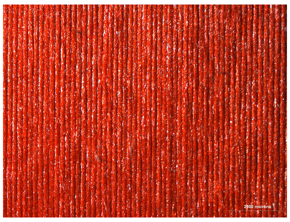
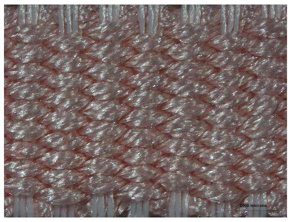
Appendix Figure 7 Illustrations of PDM I (120 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment Replication	Illustrations of dyed silk yarn		
	Before laundering	After laundering	Staining
1			
2			
3			

Appendix Figure 8 Illustrations of PDM II (110 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	Illustrations of dyed silk yarn		
Replication	Before laundering	After laundering	Staining
1			
2			
3			

Appendix Figure 9 Illustrations of PDM II (90 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

Treatment	Illustrations of dyed silk yarn		
Replication	Before laundering	After laundering	Staining
1			
2			
3			

Appendix Figure 10 Illustrations of PDM II (70 minutes) dyed silk yarn before laundering, after laundering and color staining on white test cloth

CURRICULUM VITAE

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WORK PLACE **:** Faculty of Agriculture, Kasetsart University

SCHOLARSHIP/ AWARDS **:** -