Development of Dyeing Machines for Improving the Quality of Local Thai Silk Dyeing

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ABSTRACT

This study intentionally attempted to investigate and analyze the improvement in technical feasibility under two objectives namely development of the prototype dyeing machines from local dyeing method and comparative quality of dyed silk from the prototype dyeing machines with that from the standard infrared dyer. According to disadvantages learned from selected local dyeing groups in the Northeastern region, the first prototype dyeing machine was simply constructed to improve in context of labour and energy saving. With remaining flaws in excessive water use and high heat loss, the second prototype dyeing machine was then developed to eliminate such limitation by improving dyeing container and heat control systems. The study was made at the Department of Home Economics, Faculty of Agriculture, Kasetsart University during 2007 to 2009. And then was found that comparative qualities of obtained dyed silk yarn were much improved in most experimental indicators including colour values, colourfastness to laundering and dyeing reproducibility. The quality of dyed silk yarn was also significantly closer to that dyed from the standard infrared machine and was thus confirmed that development of prototype dyeing machines could possibly lead to improvement of dyed silk yarn quality. The study, however, suggested that further improvement in prototype dyeing machine would still be needed through more effective systems including less water use, diversified container sizes, local labour and energy saving as well as heat loss prevention. Overall technical innovation should also be based upon the environmental friendly direction while providing learning opportunity and utilizing local wisdom of the local Thai dyers at the same time.

Key words : Thai silk, dyeing machine, technical improvement

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INTRODUCTION

Among all textile materials and products available in Thailand, silk stands alone as the most predominant one due mainly to its long time recognition as one symbol of the national prides. With its unique beauty, specific usage and consistent demand in the market, the making of Thai silk products has long been realized, both nationally and internationally. (Payananth, 2004)

Along with the prosper path of Thai silk development for years, a number of disadvantages in silk production and usage itself, however, still remain. One of the weaknesses that can not be denied is that it is rather difficult to wash and care for local Thai silk while its colour can also easily bleed. This major disadvantage of quality results in the relatively low use of Thai silk in daily life. Conversely, Thai silk, which is considerably higher price compared with other textile materials, is generally chosen for special purposes and by the high income people (Anon, 1998). Moreover, another crucial problem of Thai silk is related to the silk yarn dyeing method which yields diversified dyed silk yarn quality and, consequently, inconsistent quality of silk products themselves. Such silk yarn dyeing problem is in fact the root of many other problems related to Thai silk quality, market value and thus profitability of the producers.

As one can simply imagine that traditional method of silk dyeing in Thailand is just the labour-intensive dyeing with inconsistent output quality. Silk yarns are simply suspended on wooden poles or hoops and turned around by hand. Normal temperature, dyeing cycle time and amount of chemical substances are not precisely measured, but on the other hand, approximated by the dyers from their own experiences. This inexact proportion of dyeing substances really affects the quality of dyed silk in terms of colourfastness 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 precisely and correctly. Reproduction of the dyeing cycle time, dyeing temperature, rate of temperature rise, and agitation of the substrate and dye must be specifically controlled during dyeing (Kasembunyakorn *et al.*, 2008).

Due to all disadvantages from

local dyeing methods, the search for newly developed dyeing machines in order to better produce silk quality 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 from producing, less costly, creating higher value silk fabrics and then enjoying stronger competitiveness in all market levels. At the end, continuity of customer satisfaction and worldwide recognition of Thai silk will thus be sustained in the competitive markets of the global economy.

The main objective of this research is therefore to search for the better and more effective dyeing methods for Thai silk yarn. In order to investigate and analyze the technical feasibility of improving Thai dyed silk yarn, this paper will concentrate on two objectives as follows: to develop the prototype dyeing machines as improved from the local dyeing method and to compare the quality of dyed silk obtained from the prototype dyeing machines with that from the standard infrared dyer.

MATERIALS AND METHODS

Methods of experiment consist of 3 main steps: namely development of prototype dyeing machines, test of various dyeing methods and evaluation of dyed silk quality.

1. Development of Prototype Dyeing Machines

1.1 Developed the prototype dyeing machine by improving local dyeing methods in terms of labour saving, heat consistency and application of gas energy. The first prototype dyeing machine (called PDM I) is basically invented as an open container with skein dyeing wheel on the foundation of improving heat variation and circulation of dyeing solution from the traditional dyeing method.

1.2 Improved efficiency of the first dyeing machine in order to obtain the better dyed silk quality. The second prototype dyeing machine (called PDM II) is thus constructed as a semi-closed container with cover and electrical motor shaft to control the skein dyeing wheel and improve the flaws remained from PDM I in terms of high heat loss and excessive water use.

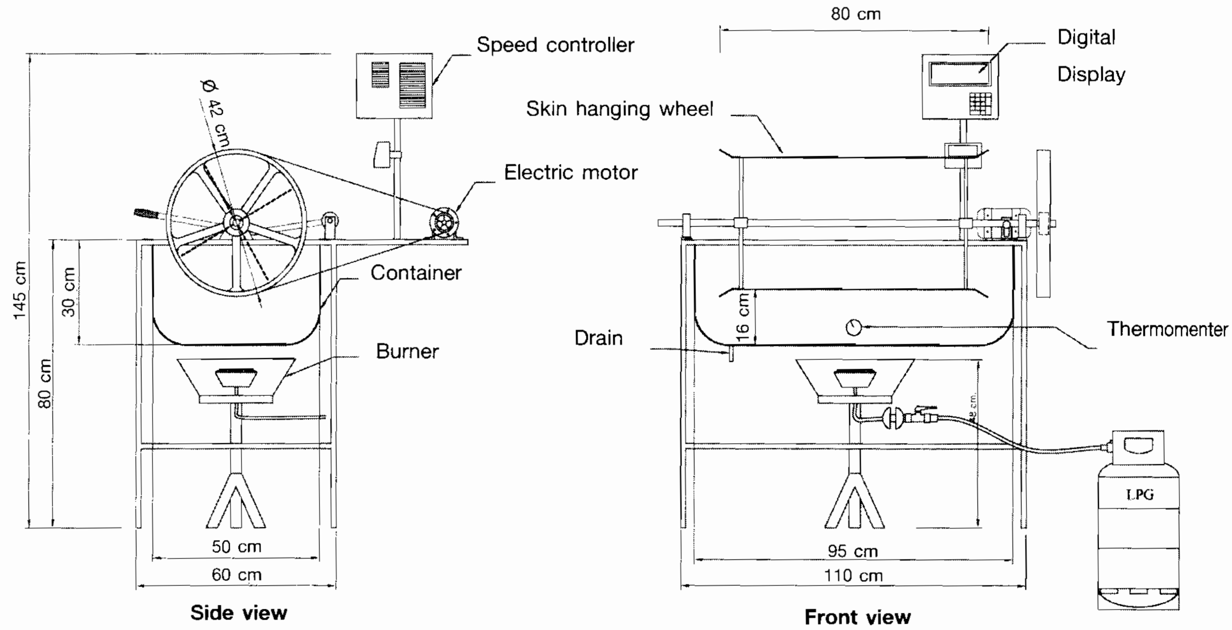

Figure 1. Outline drawing of prototype dyeing machine I

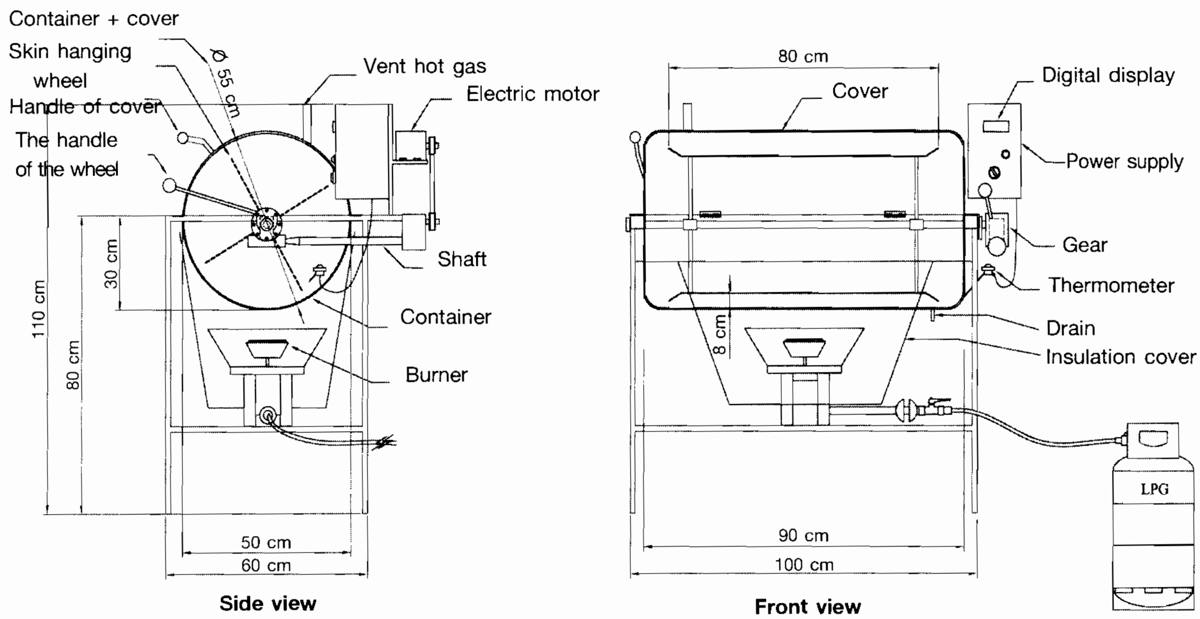

Figure 2. Outline drawing of prototype dyeing machine II

2. Test of Comparative Dyeing Machines

2.1 Consider physical functions and deficiencies tested the prototype dyeing machine especially in turning around the silk yarn to let the dyeing solution evenly soak through the yarn and continuously circulated.

2.2 Conducted dyeing experiment by using RCB design with 3 replications and 6 treatments : PDM I at 120 150 180 minutes and PDM II at 70 90 110 minutes with the infrared dyeing machine at 60 minutes as control dyeing process. Samples in each treatment were randomly selected and tested for the colour values before and after washing.

2.3 Dyeing the silk with IRD: dyed the silk yarn by using LA-650 IR Infrared dyer (IRD) and used this dyed silk as a standard sample.

2.3.1 Used water in the ratio of 30:1, 20 sachets of red dye No 34 of of Phua Kiam Seen Company with 2 kg of silk yarn of Jun Mai Thai Company (skein form, No 30/32D, 6 ply, 150 turns/inch) and 2% owf powdered wetting agent of Phua Kiam Seen Company. The degummed silk was first soaked in water while the dye and the wetting agent was dissolved in 50 °C water and poured into dyeing solution with prepared water. The silk yarn was wrung and put it in the prepared dyeing solution at 35 °C to raise the temperature to 90 °C within 30 minutes. The temperature was then maintained at 90 °C for 30 minutes by adding sodium chloride (NaCl) during the first 15 minutes. The silk yarn was rinsed in plain water 5 times with water in the ratio of 20:1 and soaked in water with powdered fixing agent of Phua Kiam Seen Company in the ratio of 30:1 and fixing agent 2% owf The process needed to maintain at 60 °C for 20 minutes and then hung dry the silk yarn then hung dried.

2.3.2 Evaluated the value of colourfastness to laundering from the randomized piece of skein by using the standard AATCC Test Method 61-2001 Test No 1A (Anon, 2002).

2.3.3 Measured the colour value both before and after laundering by using the spectrophotometer Data Colour 650™ by taking the before-laundering value as the control value to compare with the colour value received from the developed machines.

2.4 Adjusted dyeing period in the prototype dyeing machines as follows:

2.4.1 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 dyeing 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). Such period of 90 minutes was considered the average time for this type of machine. Two other time durations, 120 and 60 minutes, were used since they were the durations which added and deducted one-third of time duration of the average time respectively.

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

2.5 Dyeing the silk with PDM: dyed the silk yarn by using the prototype dyeing machines with the following steps.

2.5.1 Dyeing the silk with the PDM I : the PDM I used water in the ratio of 50:1, 20 sachets of red dye No 34 of of Phua Kiam Seen Company (10% owf on weight of fiber), 2 kg of silk yarn of Jun Mai Thai Company (skein form, No 30/32D, 6 ply, 150 turns/inch) and 2% owf powdered wetting agent of Phua Kiam Seen Company and then soaked the degummed silk in water for 30 minutes. The dye and the wetting agent was dissolved in 50 °C water and poured into dyeing solution with prepared water. The silk yarn was wrung, stretched and put into the prepared solution at 35 °C and increased the temperature gradually to 70 °C within 60 minutes. The temperature was maintained at 70 °C for 120, 90 and 60 minutes for each treatment and then added sodium chloride at 60, 45 and 30 minutes for each treatment respectively. The silk yarn was rinsed in plain water 5 times with water in the ratio of 20:1 for each time and soaked in water with powdered fixing agent of Phua Kiam Seen Company in the ratio of 30:1 and fixing agent 2% owf. The process needed to be done at 60 °C for 20 minutes and the silk yarn then was hung dried.

2.5.2 Dyeing the silk with the PDM I: Improving dyeing techniques from the PDM I to the PDM II, would use water in the ratio of 30:1 with the same in red dye, amount of silk fiber and powdered wetting agent and then soaked the degummed silk in water for 30 minutes.

The dye and the wetting agent was also dissolved in 50 °C water and poured into the prepared dyeing solution. The silk yarn was then wrung, stretched and put into the prepared solution at 35 °C and the increased temperature gradually to 90 °C within 30 minutes. The temperature was maintained at 90 °C for 80, 60 and 40 minutes for each treatment and then added sodium chloride at 40, 30 and 20 minutes for each treatment respectively. The silk yarn was rinsed in plain water 5 times with water in the ratio of 20:1 for each time and soaked in water with powdered fixing agent in the ratio of 30:1 and fixing agent 2% owf. The process also needed to be done at 60 °C for 20 minutes and the silk yarn was then hung dried.

3. Evaluation of Dyed Silk Yarn Quality

3.1 Randomly selected a sample of dyed silk yarn from each replication and tested for colourfastness to laundering according to AATCC Standard Test Method 61-2001 Test No 1A (Anon,2002).

3.2 Measured the colour values including: L* = lightness-darkness, C* = chroma and h* = hue by using the spectrophotometer Data Colour 650™.

3.3 Evaluated colourfastness to laundering from the dE* values of colour change and colour staining : dE* values = total colour difference by using the spectrophotometer Data Colour 650™ and evaluated dyeing reproducibility from the dE* values of each pair of replication in each group.

3.4 Analyzed the collected data to observe significant differences in quality of dyed silk using analysis of variance and Duncan's multiple range tests.

The main hypothesis under the above process of data analysis is that quality of dyed silk yarn should be found better from the improvement in dyeing techniques. In other words, taking into consideration all flaws found from the local dyeing methods, the obtained dyed silk yarn from the innovative dyeing machines should produce some better quality on the output dyed yarn, especially as compared with that of the standard infrared dyer. While the PDM I is firstly developed before improving to be the PDM II, the better dyed silk quality from the two prototype machines is also expected to be seen since various technical disadvantages from the PDM I are already reduced during the construction of the PDM II. These hypotheses will be tested and explained scientifically through key indicators. The remained ineffective aspects of the prototype dyeing machines are possibly discussed in order to comprehend the potential to further develop such dyeing quality in the future.

RESULTS AND DISCUSSION

From all research experiments and steps already mentioned, preparation of materials and equipments in relation to explained methods of experiment has drawn a number of significant results and discussion. The main result of experiment aims to explain the key research issue that whether or not the quality of dyed silk yarn can possibly be improved from development of dyeing machine as compared with standard quality from the infrared dyer. It is then found clearly from overall experimental key indicators that quality of dyed silk yarn from the PDM I is considerably improved by the PDM II. Both prototype dyeing machines are specifically developed in this study to reduce various disadvantages of traditional dyeing methods that have long been practiced in the rural Thailand. Technical innovation in dyeing method for improving dyed silk yarn quality is therefore proved possible. This main result will lead to detailed discussion and further suggestion.

1. Development and Improvement of Prototype Dyeing Machines I and II

Due to problems and limitation of local dyeing methods in Thailand, the search for dyeing machine with higher efficiency in terms of dyeing quality including colour value, colourfastness and dyeing reproducibility is the highlight of dyeing industry anywhere. Improvement of dyed silk quality is resulted from combination of many factors related to both mechanical and operational aspects. Traditional dyeing method despite it may also produce quality dyed silk but the degree of consistency is still in doubt for long term reproduction. Problems of inconsistent fastness and reproducibility from such traditional dyeing method are naturally occurred mainly due to dyeing techniques of local people which has long been developed through time with limited scientific research support.

The main sources of weaknesses potentially linked to traditional dyeing operation included: lack of temperature control, normally done through visual observation, insufficient circulation of dyeing solution during dyeing process, high variation of heat from fire wood use, effect on colour value from various materials made for the dyeing container and other errors potentially produced from traditional method including time and water quantity measurement.

Therefore, an attempt was made to develop the so-called prototype dyeing machine by improving those mentioned fundamental errors of traditional method. There were two consequential stages of such dyeing mechanical development.

At the first stage, the PDM I was constructed on the basic foundation of improving heat variation and circulation of dyeing solution from the traditional dyeing method (Figure 1) and 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 KB 5. The hypothesis was that less variation of heat degree and better circulation of dyeing solution would yield the higher quality of dyed silk. Installing the container of dyeing solution and using gas instead of fire wood were thus the key parts of the PDM I in solving the mentioned inconsistency problem.

The second stage of development the PDM II. still remained to be improved due to mechanical flaw of the PDM I such as too excessive water use, high liquor ratio, and too low temperature obtained (Figure 2). 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 (motor specifications: 1/4 HP, 220 V, 50 Hz, 1.5 A, 1,450 rpm) that controlled the skein hanging wheel. The burner of KB 8 was installed to let out gas which was the source of fuel. The skein hanging wheel was located approximately 8 cm closer to the bottom of container which resulted in better mixing of silk yarn and dyeing solution. Not only the quality of dyed silk would be affected, but dyeing cost was also expectedly increased. As the potential solution, introduction of container cover and flexibility of container size were added to development of the PDM II.

2. Comparative Quality of Dyed Silk Yarn from the Prototype Dyeing Machines

In order to compare the quality of dyed silk yarn which was obtained from two prototype dyeing machines, the same quantity of 2 kg of silk yarn with 10% acid dyes were used in every treatment. The sample of silk yarn from each replication of treatment was tested which produced the findings (Tables 1 and 3). Significant results of all dyeing experiment with discussion can be summarized in terms of colour values, colourfastness to laundering and then dyeing reproducibility as follows.

2.1 Colour values: with respect to the mentioned dyeing methods, key indicators of colour values, including L*, C* and h* values, revealed many different degrees of dyed silk yarn quality. As the base line experiment, the standardized infrared dyer emphasizing on dyeing only a small sample of silk yarn illustrated the L*, C* and h* values (Table 1). Such three value indicators were considered the expected average results under the controlled conditions of time consumption and temperature raise. However, the operation and quality of dyed silk from infrared dyeing machine was rather idealistic since it demanded too high operation cost from the limitation of silk yarn input in each treatment. However, these L*, C* and h* values of the infrared machine would still be used as the benchmark value of dyed silk yarn quality especially when comparing with the result of experiments from the prototype dyeing machine I and II.

A method for dyeing silk with acid dyes recommended by Dystar Comopany of Bayer and Hoechst (2003) pointed out that the exhaustion rate of acid dye of acid dye hightly depends on the temperature. At a temperature lower than 30 °C, the fiber does not adsorb any colour 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 colour by slowly increasing the temperature. The suitable temperature for dyeing silk with acid dyes

Table 1. L*, C* and h* values of the silk yarn dyeing by using the prototype dyeing machines (PDM) and the infrared dyeing machine

Sample	L*	C*	h*
IRD silk (60 mins)	36.13	60.91	27.78
PDM I silk (180 mins)	42.01 b	58.0 b	21.68 b
PDM I silk (150 mins)	43.80 c	56.50 a	19.47 a
PDM I silk (120 mins)	44.47 c	55.83 a	18.69 a
PDM II silk (110 mins)	36.71 a	61.37 d	27.93 c
PDM II silk (90 mins)	36.98 a	61.32 d	27.86 c
PDM II silk (70 mins)	37.27 a	61.34 d	27.46 c

L* = lightness – darkness C* = chroma and h = hue

Means in the same column followed by a common letter are not significantly different at the 5% level by DMRT.

Table 2. dE* values of colour change and colour staining of the silk yarn dyeing by using the prototype dyeing machines after laundering

Sample	dE*of colour change	dE* of colour staining
IRD silk (60 mins)	1.41	18.77
PDM I silk (180 mins)	1.43 ab	24.99 c
PDM I silk (150 mins)	2.60 c	22.81 ab
PDM I silk (120 mins)	2.64 c	24.76 c
PDM II silk (110 mins)	1.01 a	20.32 a
PDM II silk (90 mins)	1.55 abc	24.99 c
PDM II silk (70 mins)	1.71 abc	24.9509 c

dE* = total colour difference

Means in the same column followed by a common letter are not significantly different at the 5% level by DMRT.

is 90°C.

In quantitative analysis, the comparative qualities of dyed silk yarn are measured and found improved. The dyed silk from PDM II (at the rate of 120 mins) produced the highest L* value followed by dyed silk from PDM I (150 mins). Moreover, PDM II silk (110 mins) had the highest h* value followed by PDM II silk (90 mins).

When various silk yarn types from all treatments and that from the standard Infrared dyeing machine were comparatively examined, the results revealed that silk containing the L* C* and h* values close to that from the standard Infrared dyeing machine were those outputs from PDM II (110 mins), PDM II

(90 mins) and PDM II (70 mins) respectively. The analyses of variance (ANOVA) of the colour values (including L* values, C* values, h* values) among silk yarn dyed by all 6 groups of treatment indicated that the L*, C*, h*and dE* values of colour staining were significantly different at .001 level.

2.2 Colourfastness to laundering: colour change from laundering dyed silk yarn as expressed from dE* values (Table 2) rather indicated inconsistency of dyeing quality among different dyeing methods. It was found that the dE* values of colour

Table 3. dE* values of the three replication pairs of the silk yarn dyeing by using the prototype dyeing machines (PDM)

Sample	dE* values of replication pair		
	1 vs 2	1 vs 3	2 vs 3
IRD silk (60 mins)	0.57	0.61	0.97
PDM I (180 mins)	0.73	1.08	0.49
PDM I (150 mins)	0.80	1.98	2.44
PDM I (120 mins)	0.51	1.54	1.03
PDM II (110 mins)	0.33	0.38	0.18
PDM II (90 mins)	0.66	0.36	0.71
PDM II (70 mins)	0.84	0.81	1.37

1 = replication 1 2 = replication 2
3 = replication 3
dE* = total colour difference

change were rather low and different implying that colour 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 colour change ranging from 1.010-1.713. Despite the results were found relatively less effective, values of colour change from the PDM I was not much different anyway.

In quantitative analysis, the comparative colourfastness was considered, it was found that PDMII silk (110 mins) had the highest colourfastness in terms of colour change. However, the dE* values of colour staining were still quite high in dicating low colourfastness in terms of colour staining. The analyses of variance (ANOVA) of the colourfastness to laundering including dE* values of colour change and dE* values of colour staining. Among silk yarn dyed by all 6 groups of treatment indicated that the dE* value of colour change was highly significant different.

2.3 Dyeing reproducibility: the most effective dyeing method in terms of dyeing reproducibility due to the resulted was PDM II (110 mins) followed by PDM

II (90 mins) (Table 3). Both respective dyeing methods produced the rather low dE* values, less than 1.00, implying the high quality of dyed silk produced. On the other hand, the least effective one in terms of dyeing reproducibility was found at the PDM I silk (150 mins).

With all results and discussion obtained, one may see clearly that dyeing silk yarn in Thailand can be much improved from development of newly invented dyeing machines. Even though, some suggestions in relation to further technical improvement of dyeing machine can still be added to make a more complete conclusion of the current and, especially, the future development of dyeing industries.

When the reproducibility of dyeing among all treatments were evaluated, the result showed that only PDM II (110 mins) and PDM II (90 mins) could produce very good reproducibility since the dE* value of three replication pairs were confirmed to be lower than 1.00. In the dyeing industry, the result of total difference, dE* from CIELAB of samples, must be at least 1-2 level.

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

With limitation in academic data and research support, this study will concentrate mostly on the technical feasibility of dyed silk yarn quality from development of dyeing machines. It is the ultimate goal, however, that further development and so extension of dyeing machine would be implemented with holistic consideration and under realistic conditions. With increasing demand for higher quality of Thai silk and more competitive silk business at all market levels, research related to the improvement of dyed silk yarn and silk fabric seemed possibly to be the endless research. Not only technical research aspect, other holistic research approach are also worth being conducted including economic feasibility study of dyeing innovation, assessment of environmental impacts from dyeing mechanization, trade and marketing barriers of Thai silk as well as attitude and social acceptance of local Thai dyers towards the new dyeing techniques are also needed in terms of detailed research.

CONCLUSION

The first prototype dyeing machine (the PDM I) was thus created in order to directly improve dyeing processes from the local dyeing method and to serve as the labour-saving machine under existing condition of labour scarcity in rural areas of the country After an experiment of PDM I, it was however found some unsolved problems still examined in PDM I. The key problem was that colour values of the skein from PDM I were dramatically different from those of the standard Infrared dyeing machine. The cause of such differences was that the skein hanging wheel was set too far from the bottom of the container resulting in excessive use of water at the ratio 50:1. Moreover, the temperature of dyeing solution did not reach the expected 90°C since the machine was an open system simply producing high heat loss during the dyeing process.

References

Anon. 2002. *AATCC Technical Manual.* American Association of Textile Chemists and Colorists, North Carolina. 461 p.

Anon. 2003. *Dystar Your Partner in Dyeing of Silk.* Dystar Company of Bayer and Hoechst, Bangkok. (unpublished)

Kasembunyakorn, S.; Piromthamsiri, K; Saitthite, B. and Kongkachuichay, P. 2008. Local Silk Dyeing in Thailand. *J. of Asian Regional Assoc. for Home Econ.* 15 (2): 74-79.

Anon. 1998. *Patterns on Fabric: Thai Wisdom.* Ministry of University Affairs, Bangkok. 135 p.

Payananth, K. 2004. History of Thai Weaving Fabric. Pages 137-141. *In: Rural Economic Promotion and Environment Development Foundation.* Roy Ros Buppa Pastaporn, Arun Printing, Bangkok. 248 p.