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Experimental study on the drying of natural latex medical gloves

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Abstract. The purpose of this research was to study latex film drying at 70 ºC using a laboratory drying oven. Two different total solid content (TSC) latex compounds, which 45% TSC and 35% TSC were used. The undried latex films were prepared according to the common procedures used in latex gloves manufacturers, that is, by dry coagulant dipping process. The experimental results such as initial moisture content, the amount of moisture and drying time of latex films in each latex compound formula were determined. After that, the results were projected to calculate on the production capacity expand by 1 million piece/day of natural latex medical gloves. Finally, the rate of moisture entering the latex drying oven and the energy consumption of the drying oven were estimated. The results indicated that when the 35% TSC of latex compound was used. The initial moisture content of latex film was higher than 45% TSC of latex compound about 7%. The drying time of 35% TSC was longer than 45% TSC for 2.5 min and consume more energy about 10%. As a result, the 45% TSC latex compound was the better way to saving energy and managing humidity in the production line. Therefore, it was found to very useful to an approximate design length and size of actual of latex drying oven and the rate of moisture entering the oven as well.

1. Introduction

Nowadays, natural latex medical gloves industry are widely used in the clinical and medical setting and for various objectives, which helps to protect the disease infection or contamination. The main reasons of increment for using the medical gloves is due to people are now becoming more hygiene awareness and want to be prevented them from impurity and chemicals substance [1]. In this way, the demand for latex rubber gloves industry is viewed to increase steadily. It is reported that a demand of medical gloves is increasing around 5 - 10% per year [2].

Concentrated natural rubber (NR) latex is the main raw material to produce the dipping products such as medical glove, nipple, hot/cold bag, balloon, sporting goods and so on. Thailand is the world largest producer and exporter of the concentrated latex, accounting for one-third of the total exports volume in the

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Nomenclature

$\dot{P}$	Production rate of latex films (g/s)	$\overline{W}_{m,t}$	Weight of moisture on ceramic plate at time = t (g)
W_t	Weight of undried latex film from each former (g/piece)	$\dot{Q}$	Total heat energy requirement (kW)
W_d	Weight of dry matter from each former (g/piece)	$\dot{Q}_d$	Sensible heat of dry matter (kW)
W_m	Weight of moisture from each former (g/piece)	$\dot{Q}_m$	Sensible heat of moisture (kW)
$\dot{W}_d$	The amount of dry matter entering the oven (g/s)	$\dot{Q}_e$	Latent heat of vaporization of water (kW)
$\dot{W}_m$	The amount of moisture entering the oven (g/s)	T_i	Initial Temperature of latex films (ºC)
n	Number of formers entering the oven (piece/s)	T_f	Final Temperature of latex films (ºC)
$\dot{M}_r$	The amount of moisture to be removed (g/s)	C_{pw}	Specific heat capacity of water (kJ/kg K)
M_i	Initial moisture content of latex films (% wb)	C_{ps}	Specific heat capacity of rubber (kJ/kg K)
M_f	Final moisture content of latex films (% wb)	h_v	Latent heat of vaporization of water (kJ/kg)
$\overline{W}d$	Weight of dry matter on ceramic plate (g)		

world [2]. Although, Thailand is the number one producer and exporter of concentrated NR latex but in term of the products of concentrated NR latex, for examples, medical gloves, Thailand has the proportion only 22 percent of the world market. The main reason of the slow progress in the development of rubber product industry of Thailand is the lack of continuous improvement in research and development.

The methods of making medical gloves via dipping process are consisted of the following steps [2,3]: first, a former is dipped into the latex compound, withdrawing a former, drying and vulcanizing the latex film, respectively [4]. In all actuality, the drying process is involved in the several production lines, for example: drying process was applied to cleaning, dipping coagulant and latex compound, leaching and chlorination section. The hot air was supplied to each drying oven in order to remove moisture and also maintain the temperature of formers and latex films properly. Thus, the drying process not only takes into account the dipping process production line but also consumes amount of heat energy in this process more than 80% of total energy consumption [3].

The objective of this work was to study latex films drying using a laboratory drying oven by measuring amount of moisture of latex film on the ceramic plates. The latex films were prepared according to the common procedures used in latex gloves manufacturers, that is, by dry coagulant dipping process. The experimental data were projected to calculate the rate of moisture entering the actual latex drying oven in the factory, and also determine drying kinetics of the undried latex film to anticipate how long is the undried latex films keep stay in the actual drying oven. Last, the heat energy required for actual oven also calculated when the production capacity expand by 1 million piece/day.

Consequently, by conducting this experiment, we wish to elucidate the energy of drying characteristic of medical rubber gloves, which can be a great advantage for development of the gloves industry in Thailand.

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2. Drying Kinetics of Latex Film

The hot air was supplied by various heat sources such as thermal hot oil and fired burner that transferring heat from a heat exchanger to fresh air. The undried latex film on the formers were entering into the latex drying oven and the moisture content in the latex films were removed to hot air. The most important thing has to concern, which determines the flow rate of hot air supply in the oven that could be maintained the drying kinetics of the latex film firmly. Therefore, mass and heat balance were applied to this study.

2.1. Mass Balance

In order to increase the productive capacity to 1 million piece/day, it means that about 12 pieces of glove must be pass through the latex drying oven per second. Each of undried latex film at initial moisture content and temperature needs to be dried to a final moisture content at a temperature, thus the latex gloves production rate into the latex drying oven can be calculated as follows: [5]

$$\dot{P} = nW_t \tag{1}$$

The weight of undried latex film from each former consists of weight of dry matter and weight of moisture in latex film is calculated as follows:

$$W_t = W_d + W_m \tag{2}$$

The rate of moisture entering the oven is calculated as follows:

$$\dot{W}_m = \frac{M_i \dot{P}}{100} \tag{3}$$

The rate of dry matter that passes through the oven is calculated as follows:

$$\dot{W}_d = \dot{P}\left(1 - \frac{M_i}{100}\right) \tag{4}$$

Hence, the rate of moisture to be removed is calculated as follows:

$$\dot{M}_r = \dot{P}\left(\frac{M_i - M_f}{100}\right) \tag{5}$$

2.2. Heat Balance

In the classical concepts for drying process the total heat requirement comes from 2 types of heat: [6] that is, the combination of sensible heat of moisture and dry matter, in this case stand for dry rubber and latent heat of vaporization of moisture. For this study, the rate of required heat calculation was focused on the rate of moisture and dry matter entering the latex drying oven. Other mechanical parts such as former holder, conveyor chain, drying oven wall were neglected. Therefore, the rate of required heat for drying latex films can be calculated as follows:

$$\text{Heat required} = \begin{bmatrix}\text{Sensible heat of dry} \\ \text{matter to increase} \\ \text{temperature} \\ \text{from } T_i \text{ to } T_f\end{bmatrix} + \begin{bmatrix}\text{Sensible heat of} \\ \text{moistureto increase} \\ \text{temperature from} \\ T_i \text{ to } T_f\end{bmatrix} + \begin{bmatrix}\text{Latent Heat required} \\ \text{to evaporate the} \\ \text{moisture at} \\ \text{temperature } T_f\end{bmatrix} \quad (6)$$

For this model, e.g. 6 can be written as follows:

$$\dot{Q} = \dot{P}\left[C_{pd}\left(1 - \frac{M_i}{100}\right) + C_{pm}\frac{M_i}{100}\right](T_f - T_i) + \dot{P}h_v\left(\frac{M_i - M_f}{100}\right) \quad (7)$$

The final drying temperature of the latex films was assumed to be 70 ºC referring to the manufacturing procedure. A summary of the parameters used in the estimation is shown in table 1.

Table 1. Calculation Parameters used for the drying process. [6, 7]

Parameter	Parameter Value	
M_f	5.00	% wb
T_i	25	ºC
T_f	70	ºC
C_{pm}	4.19	kJ/kg K
C_{pd}	3.20	kJ/kg K
h_v	2333	kJ/kg
n	12	piece/s

3. Materials and Methods

3.1. Material

NR latex was an ammoniacal latex containing 0.7 % NH_4OH with a dry rubber content (DRC) of 60 %, which was purchased from Thai rubber latex public Co., Ltd., Thailand. Potassium hydroxide dispersion, potassium laurate dispersion, sulfur dispersion, zinc dibutyl dithiocarbamate dispersion (ZDBC), wingstay-L dispersion and ZnO dispersion and calcium nitrate were prepared from the commercial grade reagents.

3.2. Latex Compounding Preparation

The NR latex was stirred at room temperature using stirring speed of 300 rpm, then it was firstly mixed with 20% Potassium laurate solution and 10% Potassium hydroxide solution which were functioned as stabilizer. Next, 50% sulfur dispersion, 50% Zinc dibutyl dithio carbamate dispersion, 50% Wingstay–L dispersion, 50% ZnO dispersion were respectively added into the latex mixture. Finally, the DI water

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was added to obtain TSC = 45% and 35% of latex compound, respectively. The amount of the chemicals were listed in table 2. After the mixing was completed, the latex compound was stirred at 30 rpm for 24 hrs maturation time.

Table 2. The amount of chemicals in 45% and 35% TSC latex compound

Chemicals	Undried weight (g)	
	45% TSC	35% TSC
60% Concentrated Latex	167.0	167.0
20% K-laurate solution	1.0	1.0
10% KOH solution	3.0	3.0
50% Sulfur dispersion	1.0	1.0
50% ZDBC dispersion	2.5	2.5
50% Wingstay – L dispersion	1.0	1.0
50% ZnO dispersion	0.5	0.5
DI water	52.2	117.4

3.3. Film Preparation
The undried latex films were prepared according to the common procedures used in latex gloves manufacturers, that is, by dry coagulant dipping process. The ceramic plates that used in this experiment were cut from the palm and the back of the hand area of medical gloves ceramic dipping formers. The sizes were set on a 30 mm x 40 mm. It is important to clean up and dry in an oven before staring the experiment. First, the clean ceramic plates were heated up at 60°C and dipped by using 10% calcium nitrate as the coagulant and dried in an oven at 120°C for 5 min then cooled down in desiccator until the temperature reached 60°C. Next, the ceramic plates were dipped into the latex compound for 8 seconds. After reaching a dwell time, the ceramic plates were slowly withdrawn and instantly weighted by an analytical balance in order to record the initial mass of undried latex film. After that, the undried latex film were dried in the oven with a time step equal to 2.5 minute and weighted the latex film again also repeat the drying process until the mass of latex film was constant to complete the experiment.

Thus, the moisture content of the latex film at each time step is calculated by ratio between amount of moisture and the total weight of undried latex film at each time step as follows:

$$M_t = \frac{\overline{W}_{m,t}}{W_t} \tag{8}$$

4. Results and Discussion

4.1 The Amount of Moisture
In this study, two different total solid content (TSC) latex compounds, which 45% TSC and 35% TSC were used. From table 2, it is shown that DI water in 35% TSC latex compound was larger than 45% TSC latex compound 65.2 g or 125%.

The surface area of ceramic plate was 0.0012 m^2. To find the total surface area of the medium size medical gloves former, the 3D scanner was used for measuring the surface area so that the dipped surface area of the former is about 0.0635 m^2. After calculating the experimental data shown in figure 1. The weight of moisture of 45% TSC and 35% TSC latex compound was about 10.32 and 11.33 g/piece and initial moisture content of latex films is about 50.37% and 56.91%, respectively. As a result, the rate of moisture to be removed which was calculated by using e.g. (5) were about 111.46 and 124.11 g/s for 45% TSC and 35% TSC, respectively.

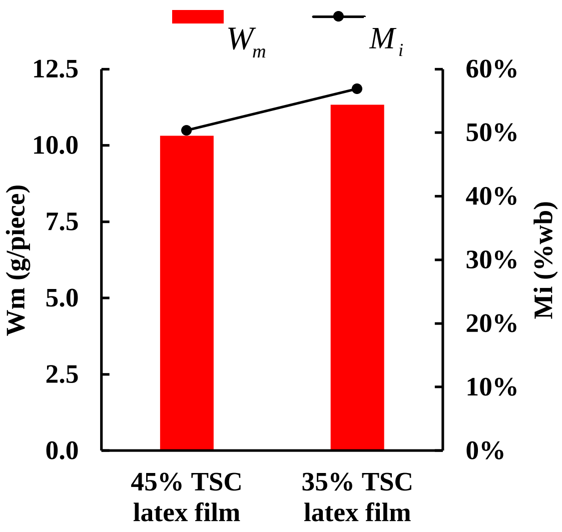

Figure 1. W_m and M_i value of each former dipped by 45% and 35% TSC latex compound

4.2 Film Formation and Drying Time

Some previous research [8–10], They indicated that there are 3 steps of the latex films formation. Step 1, a linear cumulative moisture loss occurs overtime and ends when irreversible contact between latex particles is achieved. During this moment, the evaporation rate is similar to the evaporation of pure water. The mass transfer limitation is localized in the gaseous phase [8, 11]. Step 2, Latex particles deform and come into close contact with so-called honeycomb structure, which is associated with a sharp decrease in the water evaporation rate. The overall rate of evaporation decreases considerably [8]. Step 3, a homogenous film is formed and the evaporation rate strongly decreases and the mass transfer limitation is also clearly within the film. The remaining moisture leaves the film by diffusion through the air/dried latex layer interphase [8, 11]

In this experiment, the weight of undried latex films on the ceramic plates and drying time were recorded. The result of change in moisture content of the latex film dipped by 45% TSC and 35% TSC compound were represented in figure 2. Each of moisture content value was calculated by e.g. (8), whereas the cumulative moisture loss of the latex film dipped by 45% TSC and 35% TSC compound were shown in figure 3. The amount of moisture loss at each time step were recorded and counted to plot the cumulative moisture loss.

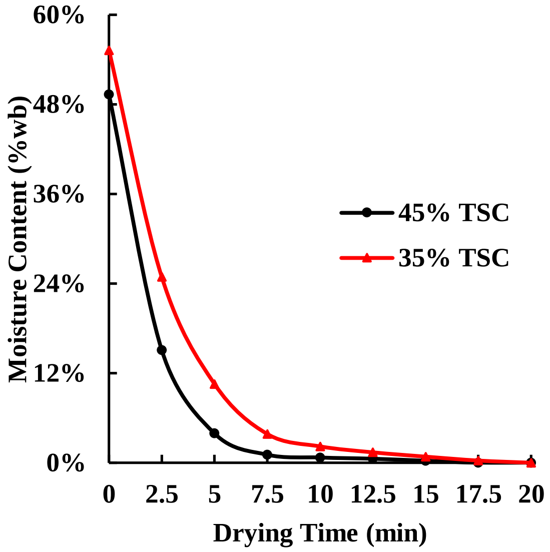

Figure 2. Change in the moisture content of the latex film dipped by 45% TSC and 35% TSC latex compound

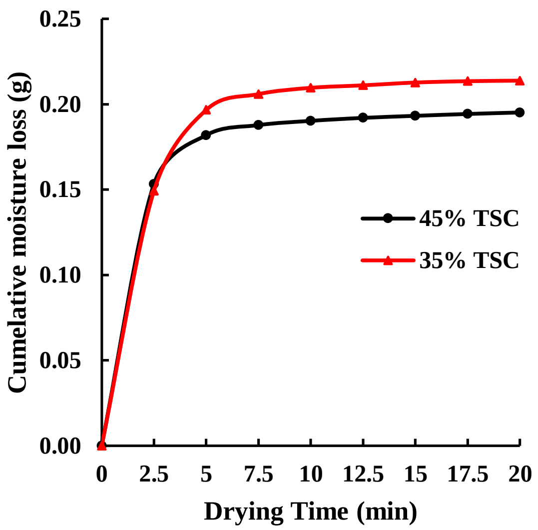

Figure 3. Change in the cumulative moisture loss from latex film dipped by 45% TSC and 35% TSC latex compound

From the experimental data, it was observed that, when the drying time increased from 0 - 2.5 min, the moisture content and cumulative moisture loss are dramatically decreased and increased, respectively. It can be seen that, when drying time is reached 5 min for 45% TSC and 7.5 min for 35% TSC, a constant weight of latex film was detected. These results can be explained that the moisture content of latex film and the humidity ratio of hot air were balanced. In term of the film formation, the honeycomb structure was completely formed and become to a homogenous film. Consequently, the 5 min and 7.5 min drying time from dipped latex film by 45% TSC and 35% TSC latex compound was applied in this study.

4.3 Energy Requirement
As the previous section, the rate of required heat for drying latex films was focused on the latex film. Other mechanical parts were not included. In order to increase the production capacity expand by 1 million piece/day, the big problem that has to deal with the massive of moisture in the undried latex film.

The rate of required heat in e.g. (7) was calculated by using parameters value from various research [6,7,11] about 300.94 kW and 330.03 kW for 45% TSC and 35% TSC, respectively. For more details, the rate of required heat was divided into three parts as follows from e.g. (6), sensible heat of dry matter, sensible heat of moisture and latent heat of moisture to evaporate.

Sensible heat of dry matter was about 17.56 kW for 45% TSC and 14.83 kW for 35% TSC compound. Similarly, sensible heat of moisture was about 23.33 kW for 45% TSC and 25.65 kW for 35% TSC compound. Meanwhile, latent heat of moisture to evaporate was about 260.05 kW for 45% TSC and 289.54 kW for 35% TSC compound. As a result, it should be noted that the latent heat of evaporation takes on an important role about 86% of the rate of required heat as shown in figure 4.

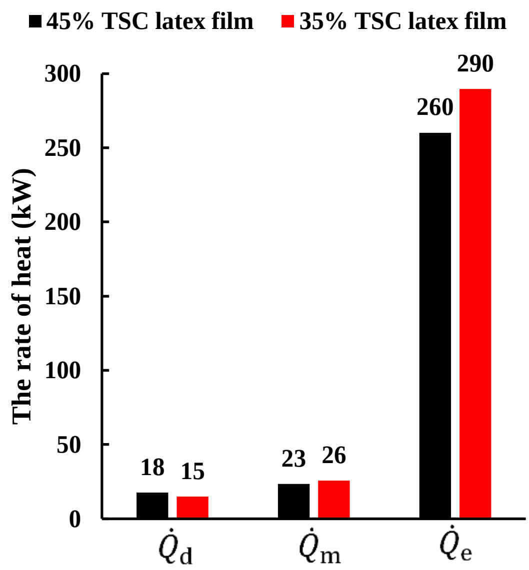

Figure 4 . The rate of required heat for drying latex film dipped by 45% and 35% TSC latex compound

5. Conclusion
For this study, the amount for moisture entering, drying time and total energy usage of latex drying oven were determined. The effect of different TSC of latex compound causes impact to the increase of energy consumption about 10% and drying time for 2.5 min. It also affects to expand the whole length of production line as well. At the present, the most of latex compound formula try to reduce operating cost by reducing TSC of latex compound. The energy supply for drying oven also has to increase inevitably. Therefore, it was found to be very useful to an approximate design length and size of actual of latex drying oven and the amount of moisture entering as well.

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