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Original Article

Correlation between dry rubber content in field latex and viscosity measured with efflux time method

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Abstract

Viscosity of field latex was determined with a horizontal capillary viscometer connected to a vertical reservoir tube. The flow behavior shows that the viscosity of rubber latex increased exponentially with dry rubber content (DRC). The linear relation between viscosity and DRC was obtained when DRC is less than 8 wt%. However, further dilution seems to give more discrepancies because of experimental errors. Therefore, the maximum DRC that is still on the linear relation should be applied in order to minimize the experimental errors while making the effect of dissolved solids in rubber latex negligible. The viscosity of diluted latex was also checked with the rotational viscometer, which gave the confirmation that dilution could shield the effect of dissolved solids. The experiment showed that the efflux time method could predict the DRC well in the range of 9-10 wt%.

Keywords: natural rubber, latex, dry rubber content, viscosity, efflux time

1. Introduction

Thailand ranks among the top countries in exporting natural rubber products to the world market. Natural rubber is the raw material in the production of tires, toys, rubber gloves, and other rubber products. Rubber is usually sold in the market either in the form of dry rubber blocks or concentrated rubber latex. Both are made from field rubber latex, which is traded in the rubber field or at the cooperative organization in the village. The price of the field latex depends on the rubber content in the latex. Therefore, it is necessary to determine the dry rubber content (DRC) before trading. The methods used nowadays are those correlated with the specific gravity of the natural rubber and the standard method of ISO 126-2005. Latex as much as 700 cm^3 is used in the former method, while it takes significant time and needs chemicals in the preparation of the latter method. A new method is proposed here since it needs small amount of latex, takes a short time and needs no chemicals in the measurement.

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The viscosity of the solution or suspension is mainly related to contents in the liquid. This concept was applied very early by Einstein in his hydrodynamic study of the sucrose molecules in the aqueous solution. There are many studies pertinent to the flow of suspensions of colloidal particles. For example, Hernandez *et al.* (2006) proposed an equation to explain the viscosity of a dilute suspension of SiO_2, Al_2O_3 and TiO_2 as a function of pH because pH could change the interactions among colloidal particles. Another example involved the dilute gelatin system. Olivares *et al.* (2006) applied the technique of horizontal capillary to measure the viscosity to study the entanglement of gelatin chains when they were subjected to temperature changes. Viscosity measurement has been widely applied for other hydrocolloids such as mulberry extract to study the effect of the concentration on the solution viscosity. It was found that the relation was non-linear due to the entanglement of polymer chains in water. In addition, viscosity is an indicator for the effect of charged polymers in water (Lin and Lai, 2009) and for the effect of the particle shape, which could change under shear stress. This situation is possible for a system at higher concentration or higher density. Interestingly, for the flow of polyethylene oxide (PEO) together with polystyrene particles in a micro-capillary, the particles get bigger when the PEO is attached to their surfaces so they move faster in water (Amnuaypanich *et al.*, 2007).

Up to present, there has been no work investigating the viscosity of natural rubber latex as to determine the rubber content. Therefore, in this work, we explored the possibility of applying this method to determine the DRC of the field rubber latex. However, there are many methods available to determine liquid viscosity. For example, in rotational flow, the torque is applied and measured. In sedimentation, drag force of the sediment is correlated with liquid viscosity. In this study, the viscosity is easily obtained from capillary flow where pressure drop could be expressed as a function of viscosity, i.e. Hagen-Poiseuille equation. It should be noted that the Hagen-Poiseuille equation is basically derived from the laminar flow of Newtonian fluid. We then assume first that the dilution of rubber latex could oppress the non-Newtonian nature of the suspension.

2. Research Methodology

The apparatus was set up according to the one suggested by Hernandez *et al.* (2006), where the horizontal capillary was applied as shown in Figure 1. The liquid is poured into the vertical tube with a radius (R_0) of 0.65 cm up to a specified point. The flow is then initiated and passing through the horizontal capillary, which is made of a glass tube with a radius (R_c) of 0.5 mm. The time is recorded when the liquid front moves down to any specified level.

The value of H (elevation) is then plotted with the efflux time (t) as expressed by the Equation 1, where L is the length of the capillary tube, which is 30 cm and ρ is the density of the liquid. The equation could be derived based on the assumption that the flow is steady, the mechanical energy is conserved (Bernoulli's equation) and the laminar Newtonian flow can be applied (Hagen Poiseuille equation).

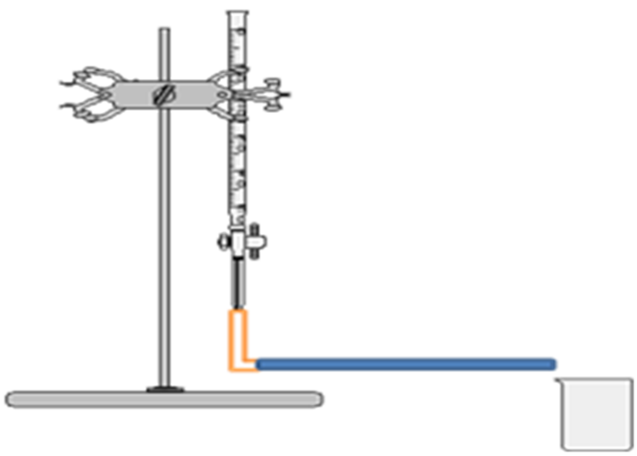

Figure 1. Experimental setup, where a vertical tube is connected with a horizontal capillary.

$$H = H_0 \exp\left(\frac{-t\rho g R_c^{\,4}}{4\eta L R_o^{\,2}}\right) \tag{1}$$

When $ln(H)$ is plotted against the efflux time (t), the linear line is obtained, of which the slope (M) is related with the viscosity as shown in Equation 2.

$$\eta = \frac{\rho g R_c^4}{4 M L R_0^2} \tag{2}$$

The experiments were performed for various dilution ratios, i.e. water volume:latex volume ratio of 100:0, 75:25, 50:50, 40:60, 25:75, 20:80, 12:88, 9:91, 6:94, 3:97, 1:99. In each experiment, the viscosity is obtained from Equation 2. The value of experimental DRC was from the standard method of acid coagulation. Briefly, rubber particles suspending in the latex coagulate upon adding sulfuric acid solution. The coagulum is then dried in the oven and the weight of dried rubber is obtained. The DRC is reported as the ratio of dry rubber weight to total weight of rubber latex.

3. Results and Discussion

3.1 Properties of rubber latex

The field latex from the Thai Rubber Latex Corporation (Thailand) PCL at Rayong has the properties as the following. The total solid content (TSC) is around 34 wt%. The dry rubber content (DRC) is 32.8 wt%. The volatile fatty acid number is 0.07-0.08. The ammonia content is 0.45 wt%, which gives the pH of the latex of around 9.5 and the magnesium content is 200-400 ppm. Upon dilution with water to obtain the half content of rubber in the latex, it was found that both DRC and non–rubber content are approximately reduced in half. Therefore, it would assume throughout the experiment that both the rubber content and non–rubber content will be diluted proportionally according to the specific ratio of dilution.

3.2 Shear rate consideration

The suspension of natural rubber latex could behave as a non-Newtonian fluid. Therefore, it is essential to check first whether the device is suitable. The consideration was made based on the shear rate ($\dot{\gamma}$) which depended on the size of the capillary and the pressure drop, as shown in Equation 3.

$$\dot{\gamma} = \frac{R_c \Delta P}{2L\eta} \tag{3}$$

For the chosen tube size, the shear rate is about 7,540 s^{-1} when the liquid level is at 75 cm and it is about 2,010

s^{-1} when the level is at 20 cm. According to Olivares *et al.* (2006), shear rate should be in the range of 50-2,500 s^{-1} to assure a Newtonian flow. Therefore, in this experiment, the assumption of Newtonian flow could be applied with some acceptable errors.

3.3 Viscosity of rubber latex

The viscosities of field latex and diluted latex were obtained for different values of DRC. This is shown in Figure 2. It can be seen in Figure 2 that when the DRC increases, the viscosity of the rubber latex increases exponentially as probably explained by the Mooney equation (Bird *et al.*, 2002).

$$\frac{\mu_{eff}}{\mu_o} = \exp\left(\frac{\frac{5}{2}\phi}{1-\phi/\phi_o}\right) \tag{4}$$

Here, μ_{eff} and μ_o are viscosities of the suspension and the pure liquid, respectively. It represents the behavior of a liquid suspended with spherical particles at a high concentration, i.e. the volume fraction is greater than 0.05. If we assume that the density of the rubber particle is about the same as that of water, then DRC in this case is greater than 5.0. In this range, there are strong interactions among solid particles, which greatly increase the viscosity of the suspension. When the concentration of solid particles is small, i.e. when DRC is small, there is no interference among particles leading to a linear relation, which is known as Einstein's equation (Bird *et al.*, 2002).

$$\frac{\mu_{eff}}{\mu_o} = 1 + \frac{5}{2}\phi \tag{5}$$

Figure 3 shows the range of small concentrations (small DRC) of the rubber latex. It is clearly seen that the linear relation could be obtained in the range of DRC less than 8 wt%.

It is of interest to note that the effect of size of rubber particles is also important. Since the larger particles could generate more friction when they are moving in the liquid, the suspension with rubber particles of larger sizes should have higher viscosity. The results were qualitatively checked by comparing between the efflux times of concentrated latex and field latex at the same DRC. It is well known that concentrated latex contained a greater fraction of large particles than the original field latex because of the centrifugal separation so it was observed that the concentrated latex yielded longer efflux time than the field latex.

3.4 Effect of dissolved solid on viscosity of the latex

Normally, a high concentration of a solution or a suspension leads to non-linearity in the correlation between viscosity and solid content in the liquid. Since the field rubber latex is composed of dissolved solids in addition to rubber particles, the effect of dissolved solid should also be investigated. The total solid content (TSC) was measured by completely drying the latex sample to obtain the dried solid. It was found that for a latex sample with DRC of 32.8 wt%, TSC is 34 wt% and for a latex sample with DRC of 37.152 wt%, TSC is 38.168 wt%. Therefore, the amount of dissolved solids in the latex is about 1.016-1.2 wt%. To investigate the effect of dissolved solids, the rubber particles were first removed from the latex via coagulation with sulfuric acid solution. The remaining liquid is known as serum and it contains both the dissolved solids and the sulfuric acid.

The viscosity of the serum was then investigated with the method of rotational flow in a Brookfield viscometer along with the viscosity of the sulfuric acid solution. The results are shown in Figure 4. The comparison was made between the cases of DRC of 32.85 wt% and 0.99 wt% latex. It is seen that the dilution with water could shield the effect

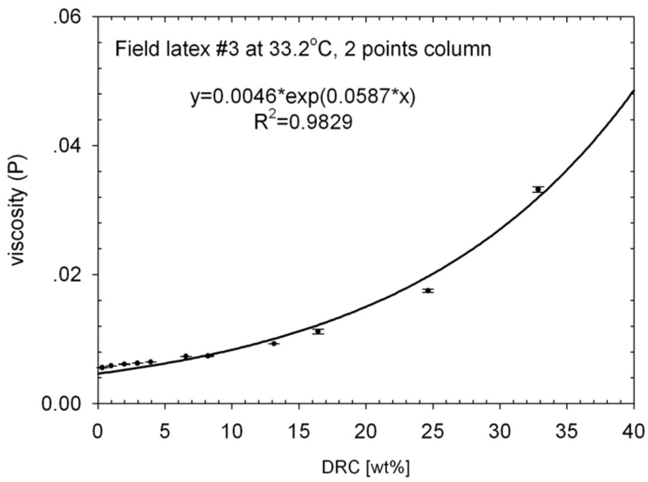

Figure 2. Viscosity of diluted rubber latex changes with DRC (wt%).

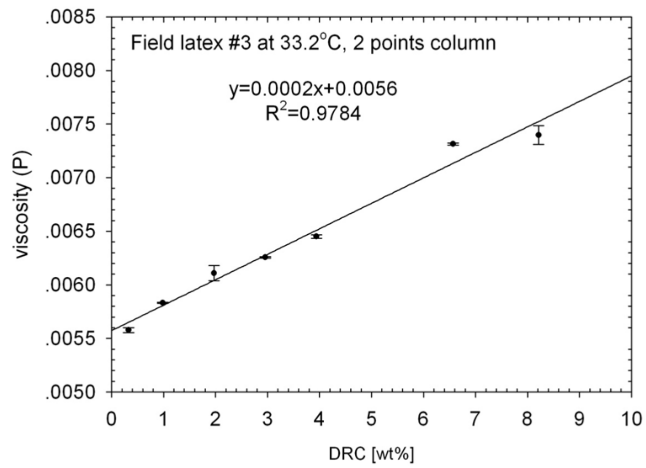

Figure 3. Linear correlation between viscosity and DRC obtained in the low range of DRC (not greater than 9 wt%).

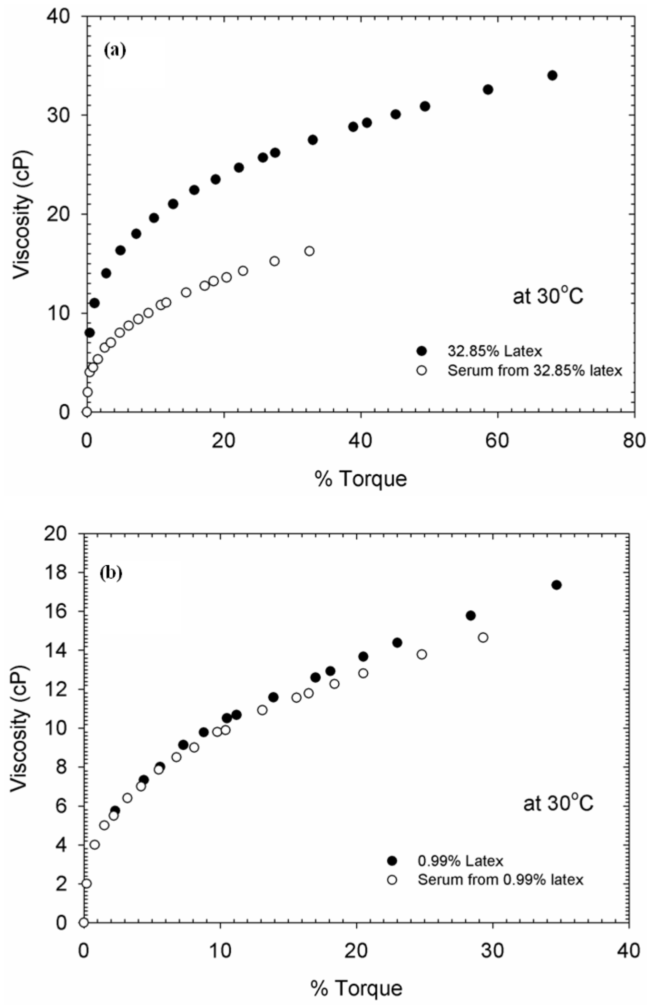

Figure 4. Comparison between viscosity values of latex and its serum is shown for different DRC values: (a) 32.85 wt% (b) 0.99 wt%.

of dissolved solids remaining after the dilution. This was also checked with our set-up apparatus for the serums from latexes with DRC of 6 wt% and 25 wt%. The values are in close proximity and close to the viscosity of the sulfuric acid solution used in coagulation which is 0.014 P. This confirms that dilution with more and more water will finally eliminate the effect of dissolved solid and the viscosity of the serum is mainly affected by the acid itself.

3.5 Correlation between DRC and the efflux time and the use of this correlation

It is easier to make use of the correlation between DRC and the efflux time since the efflux time can be quickly measured at the point of latex trading without any more calculation. An example of this correlation is shown in Figure 5, where the whole range of usual DRC and the linear range of DRC are given. The maximum of DRC in linear range is 8 wt%, at which point the effect of dissolved solid is negligible while the linear relation is still maintained.

The correlation was later used to estimate the DRC of the unknown rubber latex. The experiment was done at 33.8 °C, which is close to the temperature at which the correlation was obtained. The field rubber latex was diluted to yield 5-10 wt% DRC and the DRC for each sample was estimated from the correlation and compared with the known value from preparation. The results are shown in Table 1.

In Table 1, the predicted values of DRC via efflux time method are close to the true values for only three samples whose DRC ranges from 9 to 10 wt%, where the differences are observed to be less than 5%. These predicted values were the average results from three repeated measurements for a specific value of DRC. The deviation of the results for each DRC was due to the difference in measuring the efflux time which was more difficult at higher DRC, at which point the level of the suspension in the vertical tube could not be obviously seen. The deviation of the maximum DRC (DRC of 32.8 wt%) in three measurements was found to be 3 wt%

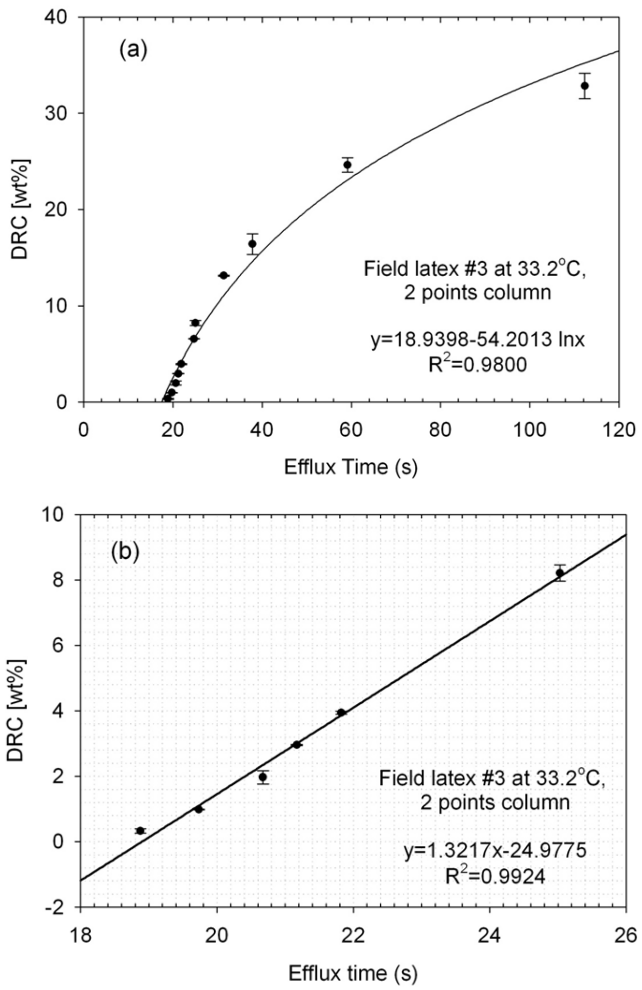

Figure 5. Correlation between DRC and the efflux time: (a) whole range, (b) linear range

Table 1. Comparison between predicted and prepared DRC.

Predicted DRC (wt%)	Prepared DRC (wt%)	% Difference
10.078	10.000	-0.78
9.127	9.500	3.93
8.999	9.000	0.01
7.461	8.500	12.22
7.426	8.000	7.17
5.651	7.500	24.66
4.664	7.000	33.37
4.087	6.500	37.13
4.069	6.000	32.18
3.800	5.500	30.90
2.351	5.000	52.98

above or below the average. The predictions of other samples at lower DRCs were affected increasingly with further dilution. This can be attributed to the accumulative experimental errors upon dilution several times. Therefore, the dilution should be applied until the suspension has DRC near 9 wt%.

4. Conclusions

The method of measuring the efflux time of diluted field rubber latex was proved to be beneficial in predicting the DRC of the latex sample. The dilution with water was done to eliminate the effect of dissolved solid in the rubber latex so it changed the correlation from non-linearity to linearity. However, there was an acceptable limit of dilution. Increasingly diluted suspension will yield more experimental errors. Therefore, dilution should be done with care. The recommended dilution is that the field latex could be diluted to the DRC of 9 wt% before checking the efflux time. However, more samples of rubber latex with various non-rubber contents should be experimented thoroughly in the future.

It should also be noted that there are many factors influencing the viscosity of the latex. Those include the temperature during the measurement, the age of the latex, and seasonal and clonal variations. It is possible to construct the correlation incorporating the effect of temperature by performing the experiments at various appropriate temperatures. The age of the latex may not be important if the measurement will be done not too long after collecting the latex. Seasonal and clonal variations may bring about the difference in rubber particle size and the compositions in natural rubber latex. These factors should be concerned for good practice and should be investigated in detail in the future.

Even without the confirmation of other factors, this research study asserts the possibility of using the efflux time to determine the DRC of the field rubber latex. In addition, the cost of equipment used in this study is slightly less than the equipment cost in the specific gravity method and it is a one-time investment. Unlike the case of using acid coagulation in which the acid cost is much less and it takes some time for the measurement, the method of efflux time measurement should be more worthwhile in the long run.

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