# Viscosity of Linseed Oil as a Function of Mineral Spirits and Temperature

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### ABSTRACT AND SUMMARY

The viscosities of raw linseed oil, boiled linseed oil, and combinations of raw or boiled linseed oil with mineral spirits were measured as a function of temperature. In general, the viscosity data for these solutions were found to follow the equation $n = Be^{E/RT}$, where n is viscosity, B is a constant, E is the activation energy of flow, and T is absolute temperature. The viscosity values interpolated from the regression equations at 25 C, 40 C, and 60 C were analyzed as a function of percent mineral spirits for raw and boiled linseed oils. The results suggest that linseed oil-mineral spirits mixtures behave as ideal solutions.

### INTRODUCTION

Linseed oil contains the mixed triglycerides of oleic (19.0%), linoleic (24.1%), and linolenic (47.4%) acids (1). Under certain conditions these unsaturated acids can react to form an insoluble cross-linked polymer. The most common and probably the most important polymerization reaction occurs upon exposure of the oil to oxygen from the atmosphere. When exposed to the atmosphere, linseed oil reacts with molecular oxygen, through a series of reactions known as autoxidation, and the final product is a film on the surface of the oil. The exact mechanism of this polymerization process is not entirely understood, but it is believed to involve the double bonds of the acid groups and to depend upon the relationship of these double bonds to each other (2).

Because of autoxidation, linseed oil has long been used as a surface coating material, both alone and in oil based paints. More recently, however, considerable interest has been focused on boiled linseed oil for use as surface coating material for protecting concrete (3-5). Boiled linseed oil is prepared from raw linseed oil by blowing oxygen through the oil at elevated temperatures. The primary effect of this blowing process is to inactivate the natural antioxidants found in raw linseed oil (6).

Normally in linseed oil autoxidation, only the portions exposed to oxygen polymerize; however, methods have been studied in this laboratory and elsewhere (7) that are effective in polymerizing the oil in situ. This allows the use of linseed oil for impregnation of materials like concrete or wood. In the impregnation of porous materials, knowledge of the viscosity behavior of the impregnant is important in the prediction of impregnation time. This dependence can be described quantitatively by Washburn's equation (V =

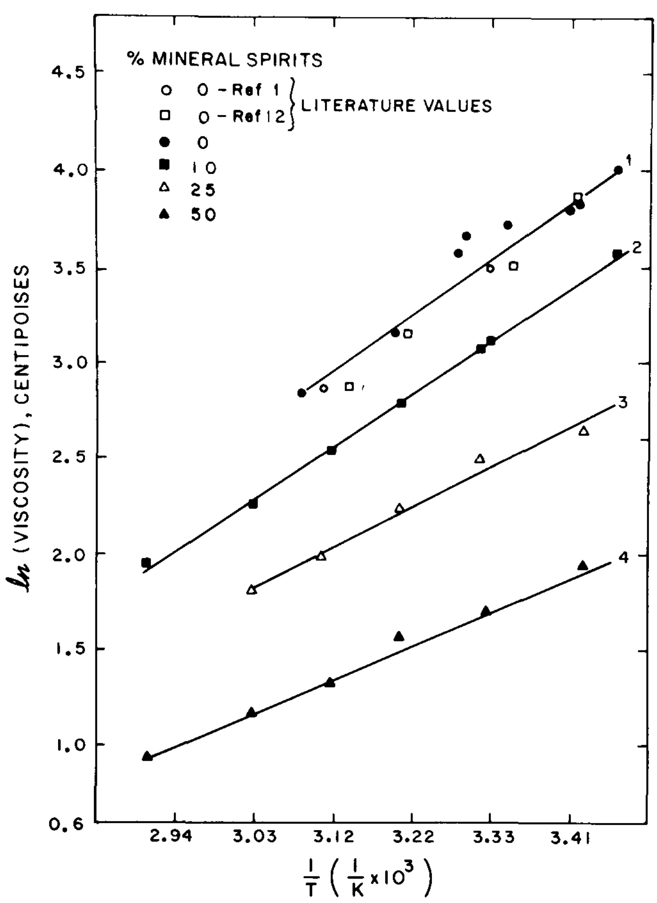


FIG. 1. Viscosity of raw linseed oil vs temperature for different percentages of mineral spirits by volume.

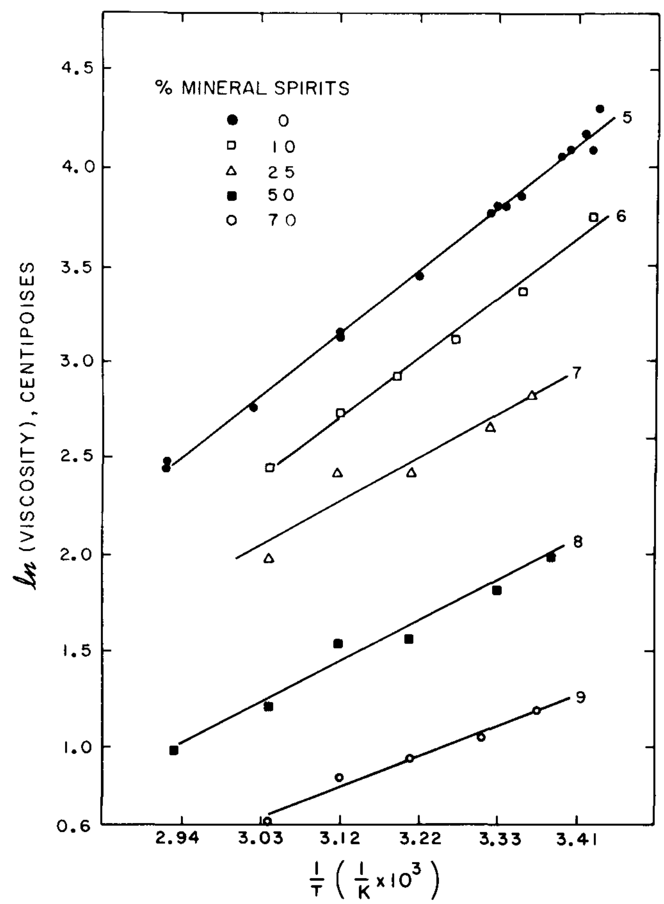


FIG. 2. Viscosity of boiled linseed oil vs temperature for different percentages of mineral spirits by volume.

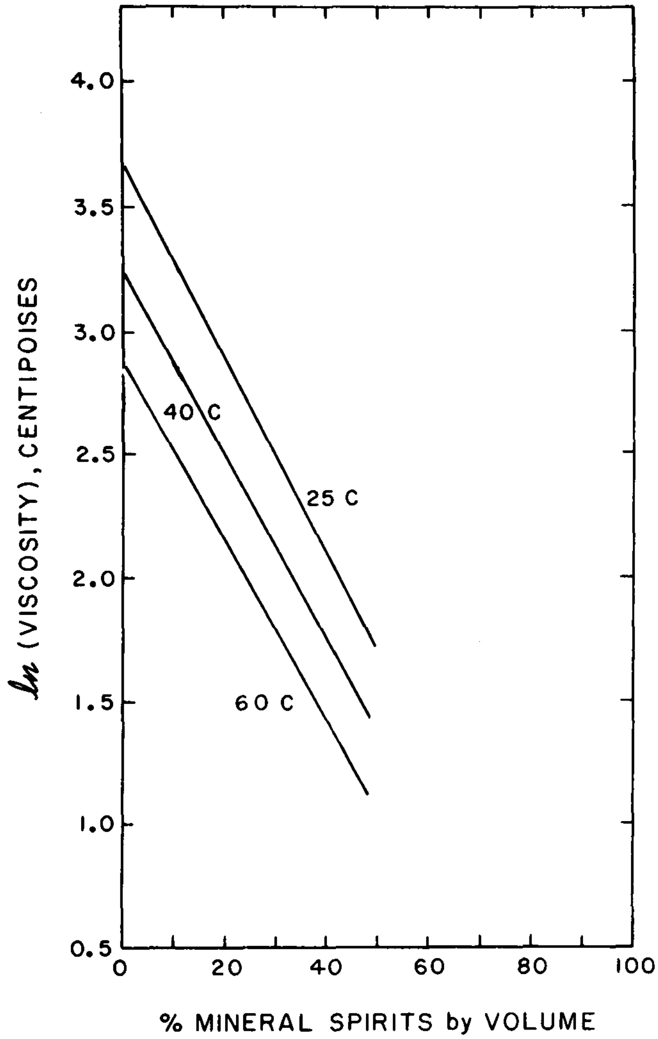


FIG. 3. Viscosity of raw linseed oil vs percent mineral spirits by volume.

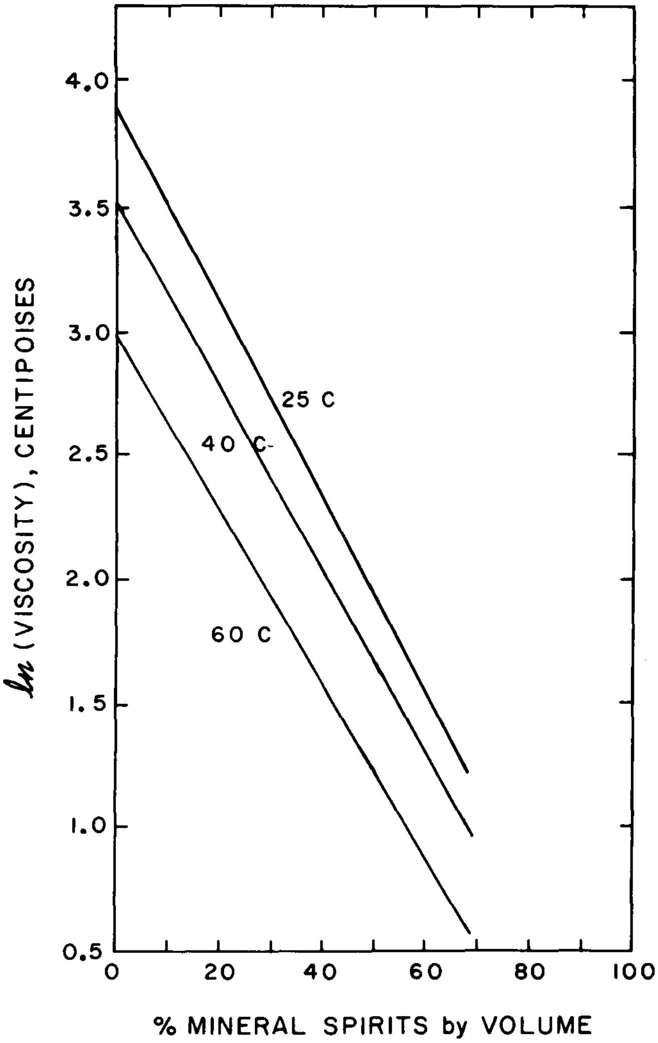


FIG. 4. Viscosity of boiled linseed oil vs percent mineral spirits by volume.

$k(\frac{rt}{n})^{1/2}$, where r is the radius of the capillary, n is the viscosity of the liquid and V is the volume of flow that penetrates the given medium in time t. This relationship has found practical application in the impregnation of concrete with methyl methacrylate, where the rate of impregnation was found to vary with the square root of time (8).

It has been previously reported that a large number of triglycerides (linseed oil was not included) behaved as Newtonian liquids (9). Because of the similarity in structure and molecular weight between linseed oil and the above triglycerides, linseed oil may also be considered a Newtonian liquid (10). Many viscosity-temperature relationships have been proposed to adequately describe different Newtonian liquids. For instance, the viscosities of the methyl esters of certain saturated fatty acids ($C_2$ to $C_{19}$) were found to behave according to the equation $H = A + S\theta$ where $H = \log(1.200 + \log n)$ with n being the dynamic viscosity in centipoises, A = constant, S = slope index, and $\theta = \log(1 + T1.35)$, with T being temperature in K (11).

It is the purpose of this paper to present and discuss viscosity results for raw linseed oil, boiled linseed oil, and combinations of raw or boiled linseed oil with mineral spirits (because of its widespread use as a solvent for linseed oil) as a function of temperature and percent of mineral spirits.

## EXPERIMENTAL PROCEDURES

All viscosity measurements were performed with either the Cannon-Manning vacuum viscometers 5V11 or 4V42 or the Cannon-Ubbelhode dilution Viscometer 75E209, using commercial raw and boiled linseed oils and commercial mineral spirits. Since vacuum viscometers measure absolute viscosity, and dilution viscometers measure kinematic viscosity, the values obtained from the dilution viscometer in centistokes were multiplied by the average density of linseed oil (0.938 g/cc) so that all the values would be in centipoises. The viscosity data are presented in Figures 1-4.

## DISCUSSION OF RESULTS

The equation applying to Newtonian liquids without significant secondary bonding ($n = Be^{E/RT}$) adequately describes the temperature dependence of the viscosities of raw and boiled linseed oil and the various linseed oil-mineral spirits mixtures (10). In this equation, n is the viscosity, B is a constant, E is the activation energy of flow, and T is the temperature in K. A plot of the natural logarithm of the viscosities vs the reciprocal of the absolute temperatures yielded a straight line in all cases. These lines are plotted in Figures 1 and 2 and the regression equations along with their $R^2$ (coefficient of determination) values are listed in Table I.

The intercepts and slopes of the equations presented in Table I are slightly different for the different percentages of mineral spirits by volume, and these differences are probably due to experimental error. In combining all of the

TABLE I

Linear Regression Equations and Adjusted $R^2$ Values[a]

| Line number | % Mineral spirits by volume | Linear regression equation[b] | Adjusted $R^2$ values |
|---|---|---|---|
| 1 (Fig. 1) | 0 | $\ln(N) = -5.73 + 2820 (1/T)$ | 93.8 |
| 2 (Fig. 1) | 10 | $\ln(N) = -6.05 + 2780 (1/T)$ | 99.9 |
| 3 (Fig. 1) | 25 | $\ln(N) = -4.54 + 2120 (1/T)$ | 97.7 |
| 4 (Fig. 1) | 50 | $\ln(N) = -4.21 + 1790 (1/T)$ | 97.3 |
| 5 (Fig. 2) | 0 | $\ln(N) = -6.81 + 3210 (1/T)$ | 99.5 |
| 6 (Fig. 2) | 10 | $\ln(N) = -6.76 + 3060 (1/T)$ | 99.2 |
| 7 (Fig. 2) | 25 | $\ln(N) = -4.77 + 2270 (1/T)$ | 88.3 |
| 8 (Fig. 2) | 50 | $\ln(N) = -4.96 + 2070 (1/T)$ | 97.5 |
| 9 (Fig. 2) | 70 | $\ln(N) = -4.06 + 1570 (1/T)$ | 97.3 |

[a]$R^2$ is the coefficient of determination and indicates the proportional reduction in the variability of dependent variable attained by the use of the independent variable. All equations are significant at the 0.01 level.

[b]Viscosity (N) is in centipoises and temperature (T) is K.

TABLE II

Multiple Regression Equations for Viscosity Concentration and Temperature[a]

| | | |
|---|---|---|
| (1) | Raw Linseed Oil $\ln(N) = -4.72 + 2492 (1/T) - 0.0353 (c)$ | $R^2 = 97.9$[b] |
| (2) | Boiled Linseed Oil $\ln(N) = -5.48 + 2789 (1/T) - 0.03546 (c)$ | $R^2 = 98.9$ |

[a]Viscosity (N) is in centipoises, temperature (T) is in K, and concentration (c) is % mineral spirits by volume.

[b]$R^2$ is coefficient of determination. All regression equations are significant at the 0.005 level.

concentration (percent of mineral spirits by volume) and temperature data for both the raw and boiled linseed oil the multiple regression equations presented in Table II are obtained. The multiple regression equations present a single slope for both concentration and temperature. The single slope for all concentrations and temperatures (Table II) vs the individual slopes in Table I will give slightly different regression lines and either the equations in Tables I or II can be used to give an estimation of the viscosity in the data range presented in Figures 1-4. All regression lines in Tables I and II are highly significant.

The literature values for raw linseed oil also followed equation 1, Table I as well as the equation in Table II, and corresponded to the experimental values (Fig. 1) (1,12). Although there were no literature values found for the raw linseed oil-mineral spirits mixtures to verify the experimental values, it would appear that one can easily justify the similarity of behavior between these solutions and pure raw linseed oil since linseed oil and mineral spirits combine to form a single phase system, and both are nonpolar liquids. In the case of the boiled linseed oil used in these experiments, the blowing process did not appear to drastically alter the chemical composition or the molecular weight of the oil (T.F. Gallagher, P.R. Blankenhorn, and D.E. Kline, in preparation). Therefore, it is assumed to be quite probable that it would follow the same pattern of behavior as raw linseed oil.

Since it was difficult to measure the viscosities for different concentrations at the exact temperatures desired, it was necessary to calculate viscosity data from the regression equations in Table II (presented in Figures 3 and 4) in order to do a viscosity vs percent mineral spirits by volume study. Using this interpolated data for 25 C, 40 C, and 60 C, the viscosity vs percent mineral spirits relationship was analyzed for both raw and boiled linseed oils. These solvent-solute systems behaved as ideal solutions at every temperature over the range of concentrations studied (Figs. 3 and 4). In this context, an ideal solution is one in which a plot of natural logarithm of viscosities vs percent solute yields a straight line.

In the physical sense this indicates that there is no significant reordering of the linseed oil molecules when solvated by the mineral spirits and that linseed oil molecules and the molecules comprising the mineral spirits do not appear to interact with each other (13).

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