Thermochimica Acta, 21 (1977) 225–231

WEAK TRANSVERSE MAGNETIC FIELD EFFECT ON THE VISCOSITY OF WATER AT SEVERAL TEMPERATURES

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(Received 28 December 1976)

ABSTRACT

Experiments performed at 10, 20, 25, 30, 35, 40 and 50°C show that a transversally applied magnetic field H (H ranges from 0 to 12 kG) weakly increases the viscosity of distilled water. The largest value of this increase occurs at the applied magnetic field strength of 12 kg at the vicinity of a temperature of 25°C.

INTRODUCTION

The purpose of this work is to describe the observed effect of an applied transverse magnetic field H ($H = 0$, 5, 8, 10 and 12 kG) on the viscosity of distilled water at 10, 20, 25, 30, 35, 40 and 50°C (Table 1; Figs. 2–4).

The present study performed under carefully controlled experimental conditions confirms the recent findings by Lielmezs et al.[1] and Lielmezs and Aleman[2, 3] that an externally applied magnetic field causes small distilled water viscosity increase at 25°C.

In addition to the results of the previous work, it was found that while on one hand the observed water viscosity changes increased with the applied magnetic field strength H; the observed viscosity increases for each of the applied magnetic field H strength values (H = 0, 5, 8, 12 kG) showed the largest viscosity increase at 25°C isotherm (Table 1, Fig. 2–4).

EXPERIMENTAL

The recent paper by Lielmezs et al.[1] describes in detail the apparatus and methods used for the measurement and evaluation of the transverse applied magnetic field effect on the viscosity of distilled water. The same manipulation, techniques and calculation methods were used in this work. The measuring apparatus consists of two parts; the electromagnet system and the viscometer–temperature bath assembly. To recapture[1–3] the overall design of the measuring system, Fig. 1 shows the flow diagram of the apparatus.

As previously[1–3] doubly distilled water was used for water samples for viscosity measurements. The same[1–3] Cannon-Fenske opaque (calibrated, reverse flow, No. 50,

TABLE 1

SUMMARY OF RESULTS[a]

Temp, (°C)	*$H = 5$ kG*			*$H = 8$ kG*			*$H = 10$ kG*			*$H = 12$ kG*		
	$\nu^* = [(\nu^{H}-\nu^{0})/\nu^{0}] \times 100$	*Standard deviation*[b], σ_H	*Null hypothesis*[c], $\mu_H = \mu_0$ $\sigma \neq \sigma_0$	$\nu^* = [(\nu^{H}-\nu^{0})/\nu^{0}] \times 100$	*Standard deviation*[b], σ	*Null hypothesis*[c], $\mu_H = \mu_0$ $\sigma_H \neq \sigma_0$	$\nu^* = [(\nu^{H}-\nu^{0})/\nu^{0}] \times 100$	*Standard deviation*[b], σ	*Null hypothesis*[c], $\mu_H = \mu_0$ $\sigma_H \neq \sigma_0$	$\nu^* = [(\nu^{H}-\nu^{0})/\nu^{0}] \times 100$	*Standard deviation*[b], σ	*Null hypothesis*[c] $\mu_H = \mu_0$ $\sigma_H \neq \sigma_0$
10	0.0000	—	—	0.0457	2.59056×10^{-4}	rejects at 95% confidence level	0.0989	12.88212×10^{-4}	rejects at 95% confidence level	0.1758	7.15542×10^{-4}	rejects at 95% confidence level
20	0.0453	2.48334×10^{-3}	rejects at 95% confidence level	0.0794	1.81659×10^{-4}	rejects at 95% confidence level	0.1135	3.77862×10^{-4}	rejects at 95% confidence level	0.2048	5.58570×10^{-4}	rejects at 95% confidence level
25	0.0560	7.50110×10^{-4}	rejects at 80% confidence level	0.1570	12.40900×10^{-4}	rejects at 90% confidence level	0.2273	3.43028×10^{-4}	rejects at 95% confidence level	0.3246	3.93700×10^{-4}	rejects at 95% confidence level
30	0.0399	3.04959×10^{-4}	rejects at 90% confidence level	0.1240	7.65696×10^{-4}	rejects at 95% confidence level	0.2015	8.85172×10^{-4}	rejects at 95% confidence level	0.2261	6.77160×10^{-4}	rejects at 95% confidence level
35	—	—	—	0.0666	0.89443×10^{-4}	rejects at 95% confidence level	0.1058	0.70711×10^{-4}	rejects at 95% confidence level	0.2462	3.20936×10^{-4}	rejects at 95% confidence level
40	0.0349	2.84605×10^{-4}	rejects at 90% confidence level	0.0879	2.63133×10^{-4}	rejects at 95% confidence level	0.1411	3.43350×10^{-4}	rejects at 95% confidence level	0.2697	8.36660×10^{-4}	rejects at 95% confidence level
50	0.025	3.36155×10^{-4}	rejects at 80% confidence level	0.0917	1.77637×10^{-4}	rejects at 95% confidence level	0.1674	1.51658×10^{-4}	rejects at 95% confidence level	0.2297	1.30384×10^{-4}	rejects at 95% confidence level

[a] For detailed discussion regarding the use of statistical analysis methods, see any appropriate standard textbook. [b] Standard deviation, σ_x is defined as:

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n-1}}$$

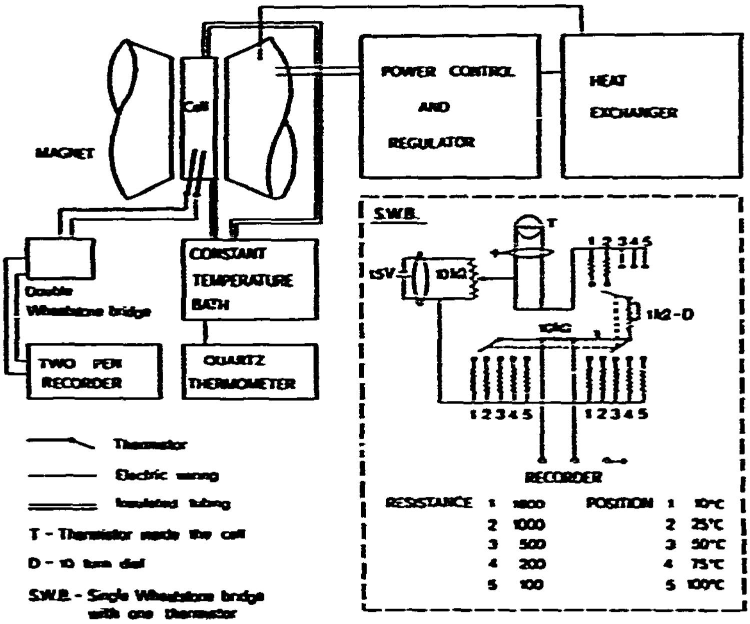

Fig. 1. Apparatus.

V561) viscometer and the same viscometer cleaning and measurement procedures were used in this work. As a result of this, the measurements of this work were performed at the same accuracy level as discussed in our previous work[1—3].

RESULTS AND DISCUSSION

Following the calculation method of our previous work[1—3], the viscosity of distilled water for both, the applied and the no applied field conditions, was calculated from the simplified expression:

$$\nu = Ct \tag{1}$$

where ν is the viscosity in stokes, C is a constant (determined by calibration) and t is the efflux time in seconds. The results of this study are summarized in Table 1 and Figs. 2–4. Table 1 presents for all given temperatures and the applied magnetic field H strengths, the fractional viscosity coefficient, given as $\nu^* = [(\nu^H - \nu^\circ)/\nu^\circ] \times 100$; such that ν° is the arithmetic mean average viscosity at the ambient earth field (or the so-called no-field condition) while ν^H is the corresponding viscosity value at the given applied magnetic field strength H.

Table 1 also presents statistical analysis data, standard deviation, σ_H, calculated at the given applied magnetic field strength H; and the t-distribution null-hypothesis results considering that the true mean $\mu_H = \mu_0$, while the variances for the applied field and no-field conditions are not equal, i.e., $\sigma_H \neq \sigma_0$. The obtained results (Table 1, Figs. 2–4) show that for each given temperature (T = 10, 20, 25, 30, 35, 40 and 50°C)

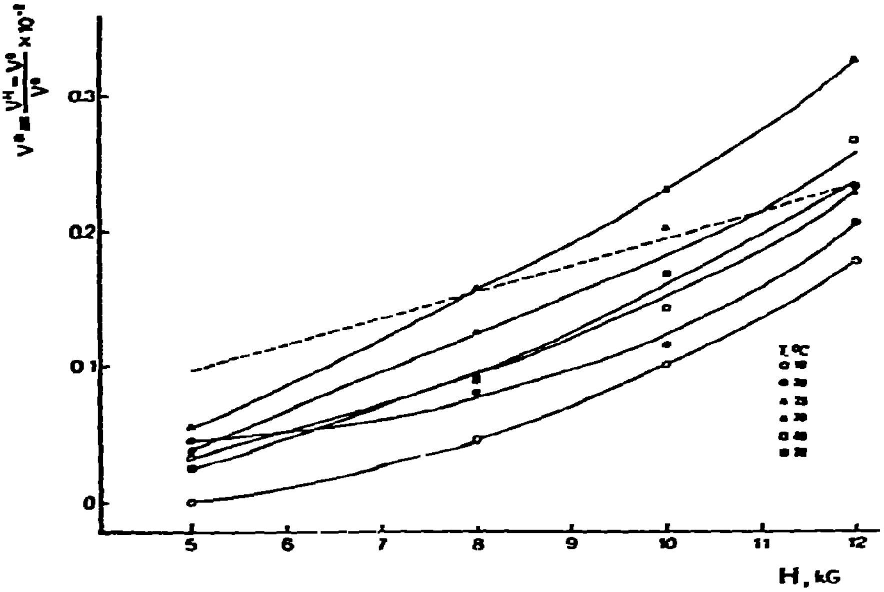

Fig. 2. Relation between the fractional average viscosity $\nu^* = [(\nu^H - \nu^0)/\nu^0] \times 10^2$ and the applied external magnetic field strength *H* in kG at various temperatures. Dashed line represents calculated values for ν^* using the linear approximation given by Lielmezs et al.[1].

the viscosity of the distilled water increases as the applied magnetic field strength *H* is increased. This observed viscosity increase although small, confirms* our previously reported findings.

The obtained data reveal (Table 1, Figs. 2–4) that when the observed fractional viscosity ν^* values are plotted against the applied magnetic strength, *H*, the temperature, *T*; and the inverse temperature, 1000/*T*; the measured magnetic field effect on the water viscosity increases up to the 25°C temperature where it reaches apparently the maximum value; then decreases to a minimum value in the vicinity of 35°C; with the subsequent increase approaching the 40°C isotherm.

In this connection, it is of interest to recall that in 1956 Lavergue and Drost-Hansen[4] suggested the existence of discontinuities in the temperature curve of the density of water near 15 and 30°C; while in 1955 Drost-Hansen and Neill[5] associated discontinuities in the temperature dependence with vapour pressure, index of refraction, specific heat, second derivative of viscosity near temperatures of 15, 30, 45 and 60°C. Also several other investigators[6–8] have indicated that there may be kinks in the activation energy curve for viscous flow of water. However, the interpretation of these results must be considered to be somewhat uncertain since the available data have

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* This is shown on Fig. 2 where we have plotted for 25°C isotherm the ν^* values obtained from the previously established linear approximation[1]: $\nu^* = 1.9324 \times 10^{-4}$ H. As seen from Fig. 2 (dashed line), this approximation yields higher ν^*-values at lower applied magnetic field strengths but smaller fractional viscosity ν^* increases at higher magnetic field *H* strengths.

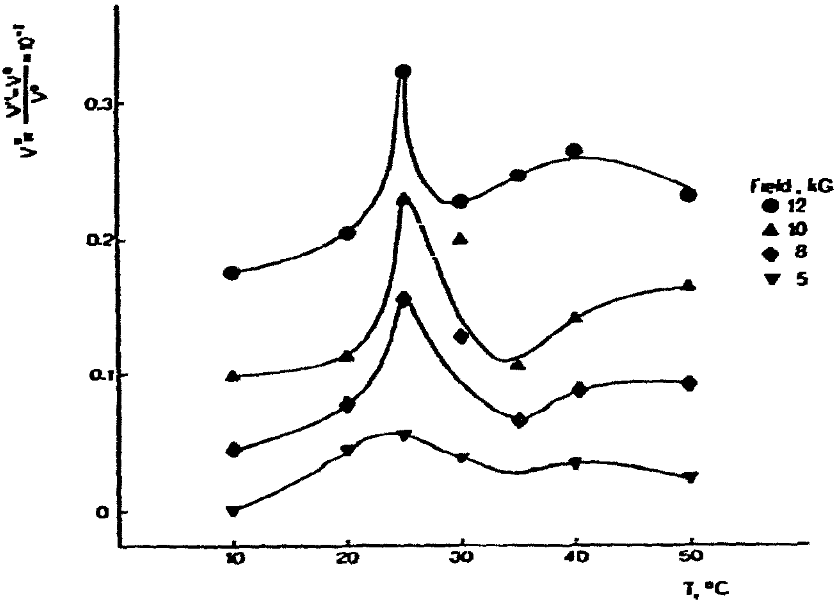

Fig. 3. Relation between the fractional mean average viscosity $\nu^* = [(\nu'' - \nu^\circ)/\nu^\circ] \times 10^2$ and temperature, in °C; at various applied external magnetic field strengths.

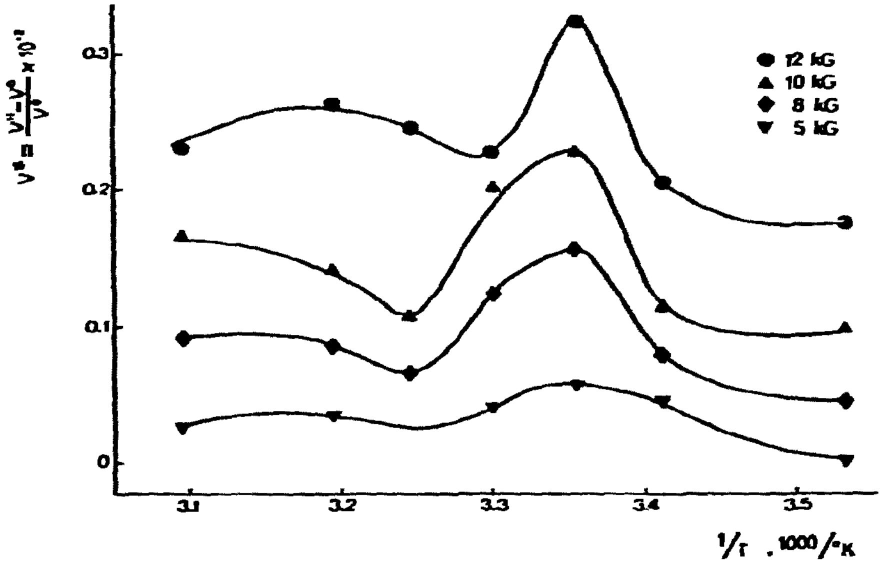

Fig. 4. Relation between the fractional mean average viscosity $\nu^* = [(\nu'' - \nu^\circ)/\nu^\circ] \times 10^2$ and inverse temperature, in 1000/K; at various applied external magnetic field strengths, H in kG.

been measured over large temperature intervals. Drost-Hansen[9] statistically analyzing the dielectric constant data of Devoto[10] found what he, at that time, interpreted to be a break in the dielectric constant-temperature curve at 15°C.

However, subsequent work by Rusche and Good[11] in measuring the dielectric constant of pure water from $-5°C$ to nearly 25°C did not confirm Drost-Hansens[9] analysis of Devoto[10] data. The following water viscosity measurements of water by Korson, Drost-Hansen and Millero[12] in the range from 8 to 70°C, at 1°C intervals, again did not present evidence for the previously observed[4–9] anomalies in the water structure. As a matter of fact, the obtained results[12] prompted Korson et al.[12] to state that although these anomalies may be real they owe their existence to the interfacial effects thus supporting the so-called three layer model of water near interfaces as proposed by Drost-Hansen[13].

Independent of these observations, Hasted[14] reports that further work to study the discontinuities in the temperature-dependent functions of physical properties of water, is in progress. As a matter of fact, Hasted[14] states that using small diameter capillary tube diameters (to possibly eliminate interfacial water structure layer effects) the obtained static dielectric constant measurements of water in the temperature region of 23.3°C indicate that at this temperature there might exist water structure in dependence of the temperature function of the relaxation time.

Recalling at the same time that water shear viscosity is a parameter which is determined by the rates of molecular reorientation and translation; then in this connection it is of particular interest to note Fig. 5. In this figure, we have plotted fractional viscosity ν^*-difference ($\Delta\nu^*$) and the corresponding temperature T-difference (ΔT) ratio versus temperature, T in °C; using difference values as obtained from Fig. 3. Within the accuracy of our measurements, Fig. 5 indicates that the fractional viscosity ν^*-temperature coefficient may suddenly change its sign in the

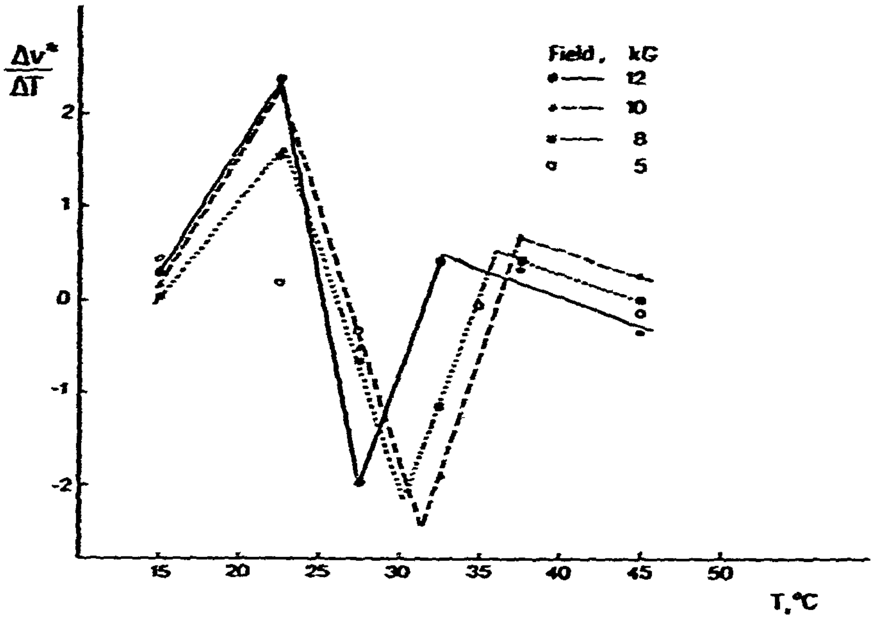

Fig. 5. Relation between the fractional viscosity ν^*–temperature coefficient ($\Delta\nu^*/\Delta T$) and temperature, in °C. Note that due to the overall larger uncertainty in 5-kG data (Table 1), the ν^*–temperature coefficient has not been included at this field strength of 5 kG in the presented comparison of this Figure.

temperature range of 22.5–27.5°C. However, closer inspection of Figs. 2–4 and Fig. 5 reveal that if indeed there exists a discontinuity in v^*–T relation then this discontinuity should be found within the 25–26°C range.

Therefore, it is apparent that smaller intervals of temperature are necessary to be used (measured from 15–35°C temperature, at least in 0.5°C intervals) to confirm the existence of such discontinuity in the observed v^*–T relation (Figs. 2–4). Whether this possible discontinuity in v^*–T curve accentuates the possibly indicated structural changes of water by static dielectric constant measurements[14], is subject matter of further study. Such study might also yield information regarding the suspected discontinuities[4—12] in functions and the associated existence of higher order water structural transitions as well as give additional insight into the presently held view[12—14] that such discontinuity effects are most likely attributable to experimentally caused interfacial phenomena.

ACKNOWLEDGEMENT

We gratefully acknowledge the financial assistance of National Research Council of Canada.

REFERENCES

1 J. Lielmezs, H. Aleman and L. Fish, *Z. Phys. Chem. Neue Folge*, 99 (1967) 117.
2 J. Lielmezs and H. Aleman, *Thermochim. Acta*, In Press (1977).
3 J. Lielmezs and H. Aleman, unpublished data (1976).
4 M. Laverque and W. Drost-Hansen, *Naturwissenschaften*, 22 (1956) 511.
5 W. Drost-Hansen and H. W. Neill, *Phys. Rev.*, 100 (1955) 1800.
6 M. Magat, *J. Phys. (Paris)*, 6 (1935) 179.
7 M. M. Qurashi and A. K. M. Ahsanallah, *Br. J. Appl. Phys.*, 12 (1961) 65.
8 D. F. Othmer and J. W. Conwell, *Ind. Eng. Chem.*, 37 (1945) 1112.
9 W. Drost-Hansen, *Ann. N.Y. Acad. Sci.*, 125 (1965) 471.
10 G. Devoto, *Gazz. Chim. Ital.*, 60 (1930) 208.
11 E. W. Rusche and W. B. Good, *J. Chem. Phys.*, 45 (1966) 4667.
12 L. Korson, W. Drost-Hansen and F. J. Millero, *J. Phys. Chem.*, 73 (1969) 34.
13 W. Drost-Hansen, *Ind. Eng. Chem.*, 60 (1968) 8.
14 J. B. Hasted, in F. Franks (Ed.), *Water, Comprehensive Treatise*, Vol. I, Plenum Press, New York, 1972.