

THERMAL CONDUCTIVITY MEASUREMENTS OF NON-NEWTONIAN FLUIDS

W.Y. Lee, Y.I. Cho and J.P. Hartnett
Energy Resources Center
University of Illinois at Chicago Circle
P.O. Box 4348, Chicago, Illinois 60680

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ABSTRACT

Thermal conductivity measurements of five non-Newtonian aqueous solutions (Polyethylene Oxide, Polyacrylamide, Carboxymethyl Cellulose, Carbopol-960 and Attagel-40) are in good agreement with the corresponding values for water up to concentrations of 10,000 wppm.

Introduction

The thermal conductivity is an important transport property required for the analysis of any heat transfer problem. It has been common practice to assume that the value of the thermal conductivity of aqueous solutions of high molecular weight polymers is equal to that of water. To check this assumption, thermal conductivity measurements were conducted with several different non-Newtonian aqueous solutions, including Polyethylene Oxide (WSR-301), Polyacrylamide (Separan AP-273), Carboxymethyl Cellulose (CMC), Carbopol-960 and Attagel-40 with the concentration ranging from 100 to 10,000 parts per million by weight.

Test Facilities

The principle of the thermal conductivity measurement is Fourier's law of heat conduction (1), which can be expressed as

$$k = \frac{q \Delta x}{S \Delta T}$$

Hence, the thermal conductivity can be determined by measuring the heat flux into the surface, q ; the gap width, Δx ; the surface area, S ; and the temperature difference between two surfaces, ΔT . It is assumed that the heat flux, q , is one-dimensional.

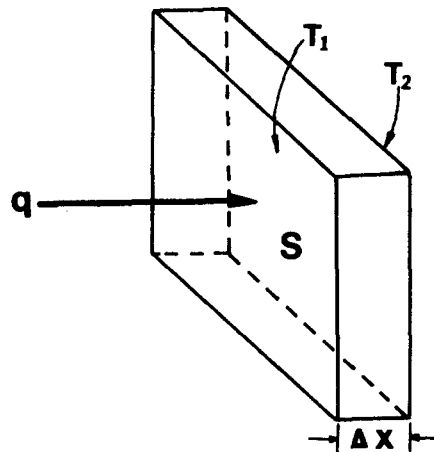


FIG. 1
Simple Thermal Conductivity Measurement

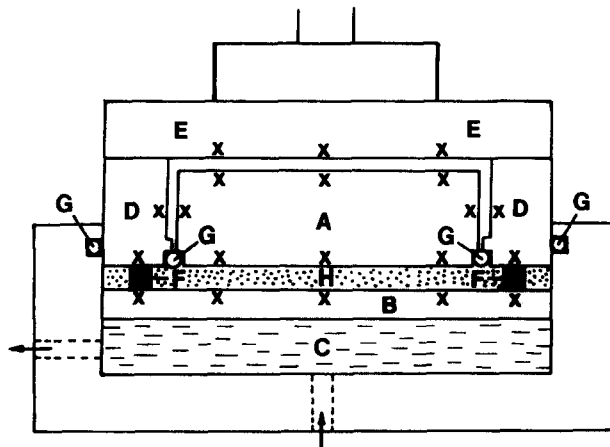


FIG. 2
Thermal Conductivity Cell Diagram: A - Hot Plate (Main Heater),
B - Cold Plate, C - Cooling Water Chamber, D - Side Guard Heater,
E - Upper Guard Heater, F - Spacer, G - Gasket, H - Test Fluid,
X - Position of Thermocouple

A schematic diagram of the thermal conductivity cell which is designed to simulate conditions shown in Fig. 1 is presented in Fig. 2. A detailed description of the apparatus can be found in Tyrrell (2) and Yoo (3).

The apparatus consists of two circular parallel plates, a main heater, side and upper heaters, cooling jacket and three plexiglass spacers which are used to establish the desired gap between the hot and cold plates. As shown in Fig. 2, the main heater, A, provides the heat flow which results in a temperature difference (usually 2° to 6°C) between the two circular plates. A 12 volt battery supplies the necessary D.C. power to the main heater. By measuring the voltage drop across the standard resistance (0.1 Ω) and the main heater, the total heat flux from the hot to the cold plate was calculated. The side and upper guard heaters designated as D and E respectively were installed to minimize heat losses, ensuring that the preponderance of the heat generated from the main heater goes to the cold plate (4). Thermal equilibrium was confirmed by measuring temperature using 38 thermocouples mounted at various locations.

The constant temperature bath and circulator by Brinkman Instrument Inc. supplied the temperature-controlled water to the cooling jacket located under the cold plate to ensure that the temperature of the cold plate was maintained at a prescribed temperature during the entire experiment.

Experimental Results and Discussion

In conducting the experiments, special care was taken to get rid of air bubbles in the gap between the hot and cold plates. It was observed that a relatively few air bubbles trapped in the gap caused a considerable decrease in the measured thermal conductivity. Approximately two hours were required to reach thermal equilibrium in the thermal conductivity cell.

As a calibration run, distilled water was used. The resulting thermal conductivity measurements are in excellent agreement with previously reported values (5,6) with the differences always being less than two percent.

The thermal conductivities of aqueous solutions of five different additives (Polyox, Separan, CMC, Carbopol and Attagel) with the concentration ranging from 100 to 10,000 parts per million by weight in distilled water were measured at four different temperatures (20°, 30°, 40° and 50°C). The results are presented in Table 1. An error analysis of the experimental measurements yielded a probable error of approximately three percent. All of these non-Newtonian aqueous solutions exhibit thermal conductivity values which differ less than five percent from the values of water at corresponding temperature.

TABLE 1
Data of Thermal Conductivities

Liquid	$\begin{matrix} k \\ \text{temp} \\ c(\text{wppm}) \end{matrix}$	$k(\text{w/m}^\circ\text{C})$			
		20°C	30°C	40°C	50°C
Water (current data)	—	0.593	0.612	0.627	0.645
Water (Ref. 5-6)	—	0.600	0.615	0.629	0.640
Polyethylene Oxide (WSR-301)	100	0.599	0.619	0.630	0.651
	1,000	0.597	0.619	0.638	0.646
	10,000	0.604	0.624	0.634	0.656
Polyacrylamide (Separan AP-273)	100	0.590	0.602	0.611	0.648
	1,000	0.590	0.609	0.616	0.646
	10,000	0.592	0.610	0.632	0.648
Carboxymethyl Cellulose (CMC)	1,000	0.576	0.603	0.632	0.648
	10,000	0.582	0.611	0.637	0.665
Carbopol-960	100	0.585	0.614	0.634	0.648
	1,000	0.595	0.606	0.629	0.651
	10,000	0.616	0.644	0.650	0.679
Attagel-40	1,000	0.594	0.605	0.625	0.650
	10,000	0.604	0.614	0.636	0.645
Polyacrylamide (with 4% NaCl)	1,000	0.588	0.604	0.637	0.643

The current thermal conductivity results show excellent agreement with results obtained by Bellet et al. (7) for aqueous solutions of CMC and Carbopol-960 at room temperature in the concentration range less than 10,000 wppm. However, Bellet et al. observed substantial deviations in the thermal conductivity measurements for much higher concentration solutions of CMC and Carbopol-960, providing a note of caution that the current conclusions not be extended beyond the range of the measurement program.

Table 1 also shows the thermal conductivity results of 1,000 wppm aqueous

solution of Polyacrylamide (Separan AP-273) in the presence of four percent NaCl. The effect of four percent NaCl is found negligible in the thermal conductivity measurement.

It is concluded that the thermal conductivity of water can be used to represent the thermal conductivity of the five aqueous non-Newtonian solutions (Polyethylene Oxide, Polyacrylamide, Carboxymethyl Cellulose, Carbopol-960 and Attagel-40), provided that the concentration of these non-Newtonian solutions is less than 10,000 parts per million by weight.

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