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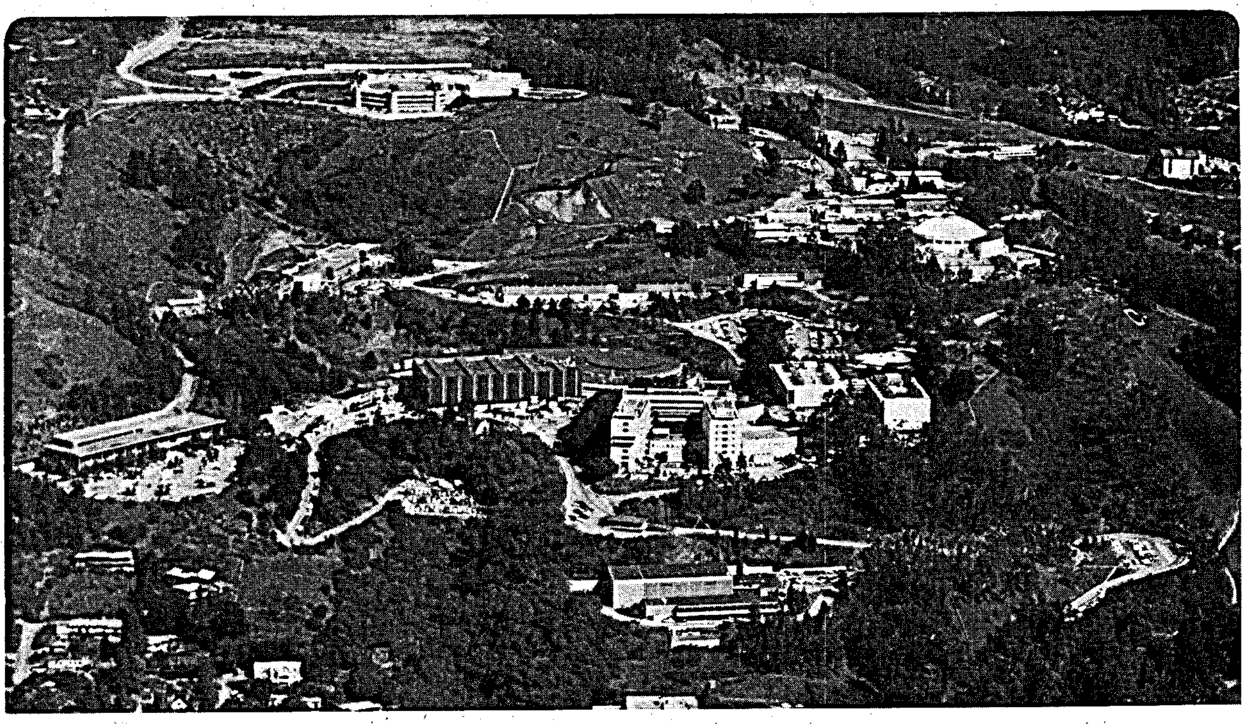

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Abstract

Experimental values for the viscosity of sodium chloride solutions are critically reviewed for application to geothermal energy. Data published recently by Kestin, Los, Pepinov, and Semenyuk as well as earlier data are included. A theoretically based equation for calculating relative viscosity was developed and used to generate tables of smoothed values over the ranges 20^{o}C-350^{o}C, 0 - 5 m and pressures up to 50 MPa. The equation reproduces selected data to an average of better than 2 percent over the entire range of temperatures and pressures. Selected tables of data are included for KCl up to 150^{o}C, $CaCl_2$ solutions up to 100^{o}C, and for mixtures of NaCl with KCl and $CaCl_2$. Recommendations are given for additional data needs.

Prologue

The Lawrence Berkeley Laboratory is funded by the U.S. Department of Energy, Division of Engineering, Mathematical and Geosciences for an aqueous solutions database. The objective of this work is to provide critically evaluated data relevant to the utilization of geothermal energy for both power production and direct utilization. The larger work covers solids, liquids and gases to include the following: rocks, minerals and deposited scales; methane, isobutane, hydrogen sulfide, steam and carbon dioxide; sodium chloride, potassium chloride and calcium chloride solutions; and, water. However, this work is limited to aqueous solutions of the materials and properties shown in Table 1.

Tables of smoothed values generated from correlation equations are provided to cover a range of conditions up to 350°C, 50 MPa pressures and concentrations generally to 5 molal. The properties are those thermodynamic, transport and physical parameters shown in Table 1, e.g., heat of solution, viscosity and solubility. Chemical analyses show that site-specific geothermal brines are comprised mainly of dissolved sodium chloride, with significant concentrations of potassium and calcium chlorides. See Table 2. Thus, this aqueous solutions database centers on these three materials as the major electrolytes which determine such properties as viscosity, density and enthalpy.

The data for aqueous solutions are used to model and predict the flow of heat from a production well, through a power plant and heat exchanger, and back to the reservoir via injection wells. Engineering and economic decisions up to and including the construction of geothermal plants are based on both the availability and quality of basic data. While this report is intended to be both comprehensive and in-depth, it is recognized that there may be important omissions. The reader is urged to forward important publications and comments to our aqueous solutions database for inclusion in a subsequent updating of this report.

Sidney L. Phillips

Table 1. Selected materials and properties included in the aqueous solutions database.

Material	*Property										
	ΔH_s	ΔH_d	C_p	V	λ	d	s	Λ	η	K_f	γ±
NaCl	✓	✓	✓	✓	✓	✓	✓	✓	✓	│	✓
KCl	✓	✓	✓	✓	✓	✓	✓	✓	✓	│	✓
$CaCl_2$	✓	✓	✓	✓	✓	✓	✓	✓	✓	│	✓
$FeCl_3$	✓	✓	✓	│	│	│	│	│		│	│
$FeCl_2$	✓	✓	✓	│	│	│	│	│		│	│
Na_2SO_4	✓	✓	✓	│	│	│	│	│		│	│
$CaHCO_3^+$	│	│	│	│	│	│	│	│		✓	│
HSO_4^-	│	│	│	│	│	│	│	│		✓	│
HCO_3^-	│	│	│	│	│	│	│	│		✓	│
$CaOH^+$	│	│	│	│	│	│	│	│		✓	│
$FeCl_2^{+2}$	│	│	│	│	│	│	│	│		✓	│
$FeCl_2^+$	│	│	│	│	│	│	│	│		✓	│
$FeCl_4^-$	│	│	│	│	│	│	│	│		✓	│
$Fe(OH)^{++}$	│	│	│	│	│	│	│	│		✓	│
$Fe(OH)_2^+$	│	│	│	│	│	│	│	│		✓	│
HS^-	│	│	│	│	│	│	│	│		✓	│
FeS	│	│	│	│	│	│	✓	│		│	│
H_2S, NH_3, CO_2	│	│	│	│	│	│	✓	│		│	│
$CaCO_3$	│	│	│	│	│	│	✓	│		│	│
SiO_2	│	│	│	│	│	│	✓	│		│	│

*Key:

ΔH_s = heat of solution
ΔH_d = heat of dilution
C_p = heat capacity
V = vapor pressure
λ = thermal conductivity
d = density
S = solubility
Λ = electrical conductivity
η = viscosity
K_f = formation constant
γ± = activity coefficient

Table 2. Sodium, potassium, calcium and chloride content of selected geothermal reservoir water. Concentrations in ppm (12).

Area	Na	K	Ca	Cl
Baca, NM	2010	541	36	3770
Beowawe, NV	214	9	-	50
Brawley, CA	13900	2400	2560	31000
Cerro Prieto, Mexico	4175	575	212	7470
East Mesa, CA	798 9002	49 1047	47 896	825 15868
Heber, CA	4720	231	1062	8242
Mono-Long Valley, CA	236	62	2	266
Raft River, ID	433	36	48	804
Salton Sea, CA	54800 10600	18400 1250	27600 1130	160000 19700

How happy is the man who finds wisdom,
The man who gains understanding!
...
She is more precious than corals,
and none of your heart's desires can compare with her.
...
Her ways are ways of pleasantness
And all her paths are peace.
She is a tree of life to those who grasp her,
And happy is every one who holds her fast.

Proverbs

Rigidity threatens all realization: what lives and glows today may be crusted over tomorrow and, becoming all-powerful, suppress the strivings of the day after.

Martin Buber

Contents

A. Introduction

The utilization of geothermal energy resources requires calculations and modeling of the flow of heat from production wells, through power plants and heat exchangers, and back to the earth via injection wells (1,2). The flow of heat is by water, aqueous electrolyte solution, steam or hydrocarbon. Important properties which determine both the flow and transfer of heat include enthalpy and heat capacity (3,4), density (5), thermal conductivity (6), solubility (7), electrical conductivity (8), vapor pressure (9), and viscosity (10,11). This paper reports the results of a review of the available data on the viscosity of sodium chloride solutions covering the following ranges of geothermal conditions: temperatures up to 350^{o}C, pressures up to 50 MPa, and concentrations to 5 m (27 percent weight). The interest in sodium chloride solutions stems partly from the fact that NaCl is the major dissolved electrolyte in geothermal brines. For example, wells in Baca Location No. 1 in New Mexico, contain over 2000 ppm Na and over 3000 ppm Cl; wells in East Mesa in California have over 700 ppm Na and over 800 ppm Cl; and wells in the Salton Sea area of California 10,000 to 50,000 ppm Na and 20,000 to 160,000 ppm Cl (12).

The lack of reliable data on the basic properties of geothermal brines is a reflection of the difficulty, or even impossibility, of obtaining brine samples which have not lost dissolved gases and solids, or have not undergone chemical reactions after the sampling step (13). It is likely that measurements of the basic properties of site-specific brines only approximates values for the in situ, unreacted brines. In any case, data obtained at one site cannot be used with confidence for calculating the flow of heat at other sites. On the other hand, data obtained from laboratory measurements on solutions of distilled water and purified salts e.g., NaCl, KCl are reliable, and can be used to model the heat flow for any geothermal brine. Data on the effects of other constituents (e.g., CH_4,$CaCl_2$, CO_2) as well as mixtures of these dissolved salts and gases permit estimating the properties of brines at all temperatures, pressures and concentrations in the ranges of geothermal interest.

Viscosity of a liquid is a measure of the resistance of the liquid to flow; the reciprocal of viscosity is the fluidity (14). The addition of electrolytes to water either increases or decreases the viscosity of the resulting solution. For example, addition of NaCl, $BaCl_2$, $LaCl_3$, KCl or $CaCl_2$ increases the viscosity, while $CsNO_3$ can decrease the viscosity of aqueous solutions (14). The magnitude of the change in viscosity differs for each electrolyte.

Data on the change in viscosity of NaCl solutions with temperature, concentration, pressure and with other dissolved constituents are used for example to calculate fluid volumes when injecting brines (15). A 139^{o}C (282^{o}F) change in temperature for a 1.11 specific gravity brine will cause an estimated 88.5 percent decrease in viscosity for a geothermal fluid (15). This change may be compensated by a decrease in pumping capacity. A note of caution: the temperature change will also cause a decrease in density and thereby increase the fluid volume; this could necessitate an increase in pumping capacity. Thus, on relating the effects of changes in viscosity for predictive modeling, other properties such as density changes need to be considered.

Viscosity data are also used to calculate other properties of solutions, such as kinematic viscosity, and to interpret the structure of electrolyte solutions (14). In this case, the data are interpreted in terms of ion-water interactions, for example the degree of hydration of a dissolved electrolyte such as $LaCl_3$ when solution concentrations exceed about 1 m (16), and for more dilute solutions of other electrolytes e.g., NaCl (17,18).

The available experimental data on the viscosity of NaCl solutions up to 350°C temperatures and 50 MPa pressures is not large. Within the past five years three sets of data above 100°C have been published: the work by Kestin et al (11) to 150°C and 35 MPa, that reported by Pepinov, Yusufova and Lobkova covering temperatures up to 350°C and pressures to 30 MPa (19), and the results by Semenyuk, Zarembo and Fedorov up to 356°C and 150 MPa (20). Over the past decade these three sets of data together with the earlier and widely referenced measurements by Korosi and Fabuss (21) constitute most of the available data for temperatures exceeding 100°C. At high pressures and temperatures, only the work by Kestin et al (11), Pepinov et al (19), and Semenyuk et al, have been published.

Unless noted otherwise, all numerical values were obtained from the original publications. These experimental data were converted where necessary to units of °C, molal concentrations, centipoise viscosity units, and to megapascal pressures. The density values needed to convert molar to molal quantities were obtained from our database (22). Data on the viscosity of water were calculated using the recent correlation published by Kestin for temperatures up to 150°C and saturated vapor pressures (23), or calculated from the equation recommended by the Eighth International Association for the Properties of Steam (24).

Detailed studies of the viscosity of electrolyte solutions such as those of NaCl were begun by Poiseuille in 1847. The derivation of equations directed toward predicting electrolyte viscosities for dilute solutions at temperatures near 25°C began about 100 years ago with publications by Arrhenius, and 75 years ago by Gruneisen. However, the commonly accepted equation is that published by Jones and Dole in 1929 which is based in part on the Debye-Huckel theory (14); this equation was further developed on a theoretical basis by Falkenhagen and Vernon in 1932 (25); and, more recently by others including Out and Los (26), Krumgalz for nonaqueous solutions (27) and Leyendekkers (28). For solutions exceeding about 1 m concentrations, the theoretical approach developed by Vand in 1948 (29) and analyzed by Thomas (30) for colloids and nonelectrolyte solutions (e.g., sucrose) has been applied to electrolyte solutions, for example by Spedding and Pikal (16) and Breslau and Miller (31). Alternate approaches for concentrated solutions utilizing transport equations were used by Angell and Bressel (32), Slama and Kodejs (33), and by Leyendekkers (28). However, the viscosity of NaCl or other electrolyte solutions cannot yet be calculated from theoretically based equations for temperatures exceeding about 95°C, concentrations above about 1 m, and pressures higher than saturated vapor pressures.

Information on the theory of viscosity of NaCl solutions is found in the paper "The Viscosity of Aqueous Solutions of Strong Electrolytes with Special Reference to Barium Chloride" by Jones and Dole (14); on experimental measurements by Kestin and Khalifa (34), Pepinov, Yusufova and Lobkova (35), Semenyuk, Zarembo and Federov (20), and Touloukian, Saxena and Hestermans (36); and treatment of data from Dynamic Viscosity of Water Substance (23,24), Thermophysical Properties of Matter, Vol. II, Viscosity (36), "Tables of the Dynamic and Kinematic Viscosity of Aqueous NaCl Solutions in the Temperature Range 20-150°C and the Pressure Range 0.1-35 MPa" (37), and "Viscosity of NaCl Solutions" (10). Out and Los give a comprehensive discussion on the A, B and D coefficients in the Jones and Dole equation (26); new values for the A, B coefficients at 25°C were measured by Dordick, Korson and Drost-Hansen (38). An additional source of data on the viscosity of aqueous NaCl solutions at elevated temperatures is contained in the publication Pressure Buildups and Flow Tests in Wells (39). The data are presented as a family of curves covering the temperatures 4°C to 204°C, and NaCl concentrations from zero molal to about 6 molal. However, the data used to construct these plots are not available. The Saline Water Conversion Engineering Data Book contains plots of viscosity up to 100°C (40).

Of special interest are the following three widely referenced books: Viscosity of Electrolytes and Related Properties (41), Ionic Processes in Solutions (42), and Electrolyte Solutions (43). The International Joint Conference on Thermophysical Properties which includes liquids will be held in Gaithersburg, MD., in June 1981.

B. Scope

The time span covered is mainly from 1929 to July 1980; earlier data are found in the International Critical Tables (44). Besides basic data on the viscosity of NaCl solutions for geothermal applications this review also includes selected portions from the literature on viscosity for KCl and $CaCl_2$ solutions, sea water and petroleum brines that meet one or more of the following criteria: (1) theory, and methods for calculating viscosity, (2)instrumentation for measuring viscosity up to 350°C; (3) the effects of viscosity on geothermal fluids; and, (4) effect of mixtures of other electrolytes such as KCl on the viscosity of NaCl solutions. Selected tabulated values consisting of extensive data for the viscosity of KCl, and $CaCl_2$ are given in this report, and the reader is referred to the original publications for details.

The paper published by Jones and Dole contains an excellent background summary of viscosity measurements and theory for dilute aqueous solutions beginning with the work of Poiseuille in 1847, and on up to 1929 (14). The papers by Spedding and Pikal (16) and by Thomas (30) provide a good discussion of Vand's theory both for nonelectrolytes (29) and as modified for application to concentrated solutions of electrolytes.

C. Viscosity of Sodium Chloride Solutions

Selected theoretically based and empirical equations which have been used to describe the change in viscosity of aqueous NaCl solutions as a function of temperature, concentration and pressure are reviewed in this section. The theoretical approaches include those based on Jones and Dole for 0.005-1 m solutions, the application of Vand's equation to electrolytes, and the semi-empirical approach developed by Leyendekkers and Angell for concentrated solutions (28, 32). More emphasis is placed on the first two.

1. Dilute Solutions

Based on the Debye-Huckel theory, Jones and Dole introduced a square root term for concentration into the equation for the fluidity, f, of an electrolyte to obtain

$$f = 1 + Ac^{1/2} + Bc \qquad (1)$$

Eq 1 represented the available data for $BaCl_2$ at 25°C to a maximum deviation of 0.032 percent, over the range 0.005 - 1 molal (14). The equation is valid for other electrolytes (e.g., KI, $LiNO_3$); however, for solutions of non-electrolytes such as methyl acetate, the value of A was found to be zero. Eq 1 is generally written with the fluidity replaced by the relative viscosity, $\eta_r = \eta/\eta_w$ (25); the concentration, c, is in either molar or molal units. An additional term, Dc^2, is sometimes added to eq 1 to give the extended Jones-Dole equation.

The A term of eq 1, the limiting slope, was originally derived by Falkenhagen and Vernon. For binary 1 - 1 electrolytes (46)

$$A = \frac{\beta}{320} \frac{\Lambda^o}{\lambda_1^o \lambda_2^o} \left[1 - 0.6863 \left(\frac{\lambda_1^o - \lambda_2^o}{\Lambda^o} \right)^2 \right] \quad (2)$$

where

Λ^o is the limiting conductivity of the electrolyte
λ_1^o and λ_2^o are the limiting conductivities of the ions.

and

$$\beta = \frac{29.16 \times 2\sqrt{2}}{\eta_o (DT)^{1/2}}$$

where

η_o is the viscosity of the solvent
D is the dielectric constant
T is the temperature, ^{o}K.

As shown by eq 2 the A parameter is a function of both temperature and conductance. The B coefficient is an empirical quantity whose value depends strongly on the temperature; the B coefficient has been related to the size and shape of the ions, and to electrolyte - water interactions. The Dc^2 term accounts for solute-solute interactions (26,38). The B and D coefficients are discussed with clarity in the publications by Spedding and

Pikal (16), and by Out and Los (26). Table 3 lists A, B and D values for NaCl, KCl and $CaCl_2$ up to 95°C and 1 m. Much work has been done to theoretically calculate the B coefficient; see, for example, the literature review by Mandal, Seal and Basu (46), and by Out and Los (26).

2. Moderate to High Concentrations

In three widely referenced publications Vand derived an equation for the relative viscosity of both a suspension of rigid spheres, and dissolved nonelectrolytes in the absence of either Brownian motion or mutual attraction:

$$\ln \eta_r = \frac{k_1 \phi + r_2 (k_2 - k_1) \phi + \cdots}{1 - Q'\phi} \quad (3)$$

Eq 3 may be written as a power series

$$\eta_r = 1 + 2.5 \phi + 7.349 \phi^2 + \cdots \quad (4)$$

$$\ln \eta_r = \frac{A_3}{1 - Q'} \quad (5)$$

Eq 5 has been used by Stokes and co-workers for highly hydrated electrolytes at moderate to high concentration levels, and by Spedding and Likal for rare earth chlorides up to saturation concentrations. For solutions of electrolytes, the particle volume is replaced by the term cV, where c = molar concentration, and V = molar volume of the electrolyte (16,26). Eq 4 was applied to NaCl and other solutions up to 95°C and 1.2 m concentrations by Breslau and Miller (31) and by Out and Los (26) using the results of Thomas where the D coefficient was calculated to be 10.05 (30).

Another approach to developing an equation for the viscosity of electrolytes to high concentration involves exponential expressions. These include the models discussed in the recent publications by Leyendekkers (28), Slama and Kodejs (33), and earlier work by Thomas (30) and Angell and Bressel (32).

Leyendekkers applied the Tamman-Tait-Gibson (TTG) model to calculate the viscosity of 20 electrolytes including NaCl solutions, over the range 0-6 m at $20^{o}C$. The central idea of the TTG model is any change in the volume of the water solvent is due to pressure applied by the dissolved electrolyte. For viscosity the appropriate equation is of the form

$$\ln \frac{\eta_s}{\eta_{wis}} = a_1 m + a_2 m^2 + \cdots \qquad (6)$$

The calculated values based on Eq (6) fit experimental data for NaCl solutions to better than 1-2 percent up to 6 m concentration at $20^{o}C$ (28).

In summary, the theoretically based equations available can be applied only to a limited range of temperatures, concentrations and pressures. The Jones-Dole equation is mainly for dilute solutions and temperatures up to $95^{o}C$, the Vand equations for concentrated solutions and temperatures around $25^{o}C$. Spedding and Pikal developed an equation for rare earth chlorides based on the Vand model, but containing a term for the square root of concentration. The experimental data are reproduced within the limits of experimental error at $25^{o}C$, and for concentrations between 0.01 - 3.9 m (16). However, there is currently neither a theoretically based equation nor a model that can be used to calculate the viscosity of NaCl or other solutions up to $350^{o}C$ and 50 MPa pressures.

D. Interpolating Equations

There are two interpolating equations which have been developed for generating tables of smoothed values for NaCl and other solutions up to high temperatures and pressures. These include those based on the Othmer Rule used by Korosi and Fabuss, and Kestin et al in logarithmic form, and the expressions developed by Fabuss and Korosi and by Pepinov, Yusufova and Lobkova, based on the Jones-Dole equation.

1. Othmer Rule

The Othmer rule relates the viscosity of an aqueous solution to changes in the viscosity of water according to the logarithmic equation

$$\log \eta_r = A + B \log \eta_w \qquad (7)$$

where A and B coefficients are functions of concentration (11,21). Eq 7 reproduces experimental data from seven laboratories for NaCl solutions to a maximum difference of less than ±2 percent up to 150°C, 35 MPa and 6 m concentrations; Kestin and Khalifa have used the following form for eq 7 (zero pressure)

$$\log [\ \mu^o(t,c)/\mu^o_w(t)] = A\ (c) + B\ (c) \log [\ \mu_w{}^o(t)/\mu_w{}^o(20^oC)\ ]$$

Eq 7 has also been used to correlate data on the viscosity of KCl and other solutions. See references 37, 48 and 55.

2. Jones - Dole Equation

Fabuss and Korosi (45) and more recently Pepinov, Yusufova and Lobkova used the extended Jones and Dole equation to develope empirical correlations for their measurements of viscosity

$$\eta_r = 1 + Am^{1/2} + Bm + Dm^2 \qquad (8)$$

Pepinov et al retained up to six terms for the constants A, B, D, their correlation includes a pressure term for interpolating data up to 30 MPa and 350°C, with a stated accuracy of 1 percent:

$$A = A_0 + \sum_{n=1}^{n=3} A_n t^n + p \sum_{n=4}^{n=5} A_n t^{(n-4)},$$

$$B = B_0 + \sum_{n=1}^{n=3} B_n t^n + p \sum_{n=4}^{n=6} B_n t^{(n-4)},$$

$$D = D_0 + \sum_{n=1}^{n=3} D_n t^n + p \sum_{n=4}^{n=6} D_n t^{(n-4)},$$

where the coefficients A_n, B_n and D_n are given by:

A_0	$= 0.5649011\times10^{-2}$	B_0	$= 0.5112900\times10^{-1}$	D_0	$= 0.2061946\times10^{-1}$
A_1	$= 0.2011989\times10^{-4}$	B_1	$= 0.9948465\times10^{-3}$	D_1	$= -0.1717302\times10^{-3}$
A_2	$= -0.1200112\times10^{-6}$	B_2	$= -0.3451046\times10^{-5}$	D_2	$= 0.8796201\times10^{-6}$
A_3	$= 0.4514873\times10^{-9}$	B_3	$= 0.6835311\times10^{-8}$	D_3	$= -0.1740261\times10^{-8}$
A_4	$= 0.1999090\times10^{-6}$	B_4	$= 0.6105840\times10^{-4}$	D_4	$= -0.1362641\times10^{-4}$
A_5	$= -0.7889921\times10^{-8}$	B_5	$= -0.6531548\times10^{-7}$	D_5	$= -0.1650395\times10^{-7}$
		B_6	$= -0.1447941\times10^{-8}$	D_6	$= 0.3002503\times10^{-9}$

In summary, empirical correlation equations are available for the viscosity of NaCl and other solutions (e.g., KCl) up to 350°C, 35 MPa and 6 m. An alternate approach to the Jones-Dole equation is the Othmer rule: correlations are available up to 150°C, 35 MPa and 6 m. Kestin and coworkers have used this approach for NaCl, and KCl solutions and for mixtures of NaCl + KCl solutions up to 150° and 35 MPa (23,47, 48). However, these statistically developed empirical equations are valid only for interpolation and machine computation in the concentration and temperature range covered by the experimental data.

E. <u>Laboratory Measurements of Viscosity</u>

This section summarizes laboratory instrumentation used to measure the viscosity of aqueous NaCl and other electrolyte solutions. The discussion includes instrumentation used at 25°C, but emphasis is on those methods which have been applied to elevated temperatures and pressures. A good discussion on viscosity measurements is given in the Encyclopedia of Chemical Technology (49), and by Kestin and Khalifa (34).

The four viscometers commonly used to measure the viscosity of NaCl aqueous solutions are the following: capillary, rotational, falling sphere, and oscillating disk. For temperatures above about 50°C, the most widely used is the capillary-type, for example, the Ostwald, Cannon and Ubbelohde viscometers.

Goncalves and Kestin used both the Ostwald and Ubbelohde viscometers in measuring the viscosity of NaCl and KCl solutions over the range 25°C to 50°C. Calibration was performed with respect to water at 20, 25, 30, 40, and 60°C, with temperatures controlled to ±0.1°C. The solutions were prepared by weighing the desired amount of reagent grade NaCl in double-distilled water. The accuracy of the viscosity measurements was taken to be ±0.1 percent (50).

Korosi and Fabuss measured the viscosity over the temperature range 25°C to 150°C using a specially built Cannon glass capillary viscometer with 470 mm overall length secured to a metal support frame by means of two screw clamps. The ends of the 3/8 in. O.D. receiving tube and a 1/4 in. O.D. capillary side tube of the viscometer were connected to the manifold and valve system with two Cajon O ring fittings. The capillary side of the viscometer joined a stainless steel holder enclosing a palladium silver membrane, which was connected to a normally open, air pressure-operated Nupro bellows valve. The line rejoined the receiving side of the viscosity in a T fitting. From here connection was made to the source of pressurized hydrogen, through an air pressure operated, and normally closed, Whitey valve, and through the panel terminal located on top of the assembly. The whole assembly was submerged in a thermostat filled with oil for temperature control (45).

Ostwald-type viscometers were also used by Ezrokhi in measuring NaCl viscosity at 25, 40, and 60°C (51), by Postnikov for temperatures to 80°C (52), by Suryanarayana and Venkatesan for temperatures to 55°C (53), and by Jones and Christian at 25°C (54).

Recent viscosity measurements at pressures up to 30 MPa reported by Kestin and coworkers (11,55) were made using a modified oscillating disk viscometer. The instrument consisted of a high-pressure bomb of type 347, 18-8 stainless steel, sealed with the aid of tie-bolts made from Inconel X, and provided with a synthetic sapphire, Bridgman-type window. The oscillating system was enclosed in the bomb, and carried a reflecting mirror on a stem. The bomb was mounted on a titanium-carbide ball bearing, and enclosed in an automatically controlled heater surrounded by a radiation shield. Oscillation was initiated by rotation of the bomb on its bearing, and observed by a telescope which was trained on a precision scale. For brines such as NaCl solutions, the following parameters were used: natural period of $\approx$ 16 sec., stainless steel disk with $R \approx 33.9725$ mm radius and $d \approx 3.2131$ mm thickness between two fixed plates of spacing $b \approx 2.9782$ mm. Pressure measurements were made using high-precision Bourdon gauges, each accurate to 0.2 percent of its maximum range. Temperatures were measured with calibrated thermocouples. In other work, Pepinov, Yusufova and Lobkova used a modified capillary method to measure NaCl viscosities. The amount of liquid flowing through the capillary was varied with a pump; the capillary was made from corrosion-resistant nickel-rhenium alloy, and had an inside diameter of 0.349 mm, with a length of 553.07 mm (35). Semenyuk, Zarembo and Federov used a capillary type titanium apparatus for temperatures to 400°C and pressures to 200 MPa. Out and Los used a Ubbelohde (ASTM) type viscometer to measure viscosities up to 95°C with 0.02 percent precision.

In summary, the oscillating disk, Ostwald, Cannon and Ubbelohde-type capillary viscometers are the instruments mainly used for measuring the viscosity of NaCl solutions for temperatures to 150°C, and a modified capillary used for temperatures up to 350°C and pressures to 150 MPa.

F. Density of Water and Sodium Chloride Solutions

Density values for NaCl solutions and water are needed to convert kinematic viscosity to absolute viscosity, to calculate molar concentrations from molal concentrations and to calculate the viscosity of water (24). We have taken density date for NaCl solutions from our correlation (22), and density values for water from the 1968 IFC formulation (24).

G. Correlation Equation for Sodium Chloride Solutions

Over 1500 selected data points were used to develop our correlation; all were initially given equal weight. See Table 4. The form developed is similar to that derived by Vand with an added exponential term

$$\frac{\eta}{\eta_w} = 1 + am + bm^2 + cm^3 + dT\,(1-e^{km}) \qquad (9)$$

where
a = 0.0816
b = 0.0122
c = 0.000 128
d = 0.000 629
k = -0.7
T = temperature, ^{o}C
m = molal concentration, g-moles NaCl/Kg H_2O

η = absolute viscosity of NaCl solutions, centipoise
η_W = viscosity of water, centipoise

In eq 9, the viscosity of water is calculated from (24):

$$\eta_w = \eta_0 \exp\left[\frac{d}{d^*}\sum_{i=0}^{5}\sum_{j=0}^{4} b_{ij}\left(\frac{T^*}{T}-1\right)^i\left(\frac{d}{d^*}-1\right)^j\right]$$

with

$$\eta_0 = \left(\frac{T}{T^*}\right)^{1/2}\left[\sum_{k=0}^{3} a_k\left(\frac{T^*}{T}\right)^k\right]^{-1} \quad \text{(in Pa-sec, or } 10^3 \text{ cP)} \qquad (10)$$

where $T^* = 647.27°K$ and $d^* = 317.763$ kg-m^{-3}

As seen, eq 9 reduces to that of water when m=0, and reduces to polynomial form with a temperature correction term for large values of molality.

Eq 9 reproduces the experimental data to an average of better than 2 percent over the ranges 10-350^{o}C, 1-50 MPa and 0-5 m. See Figure 1, where the values calculated from eq 9 are compared with the smoothed values of Kestin et al up to 150^{o}C and 35 MPa, and selected experimental data including that of Korosi and Fabuss, Out and Los, Pepinov et al, Semenyuk et al and Suryanarayana. The largest difference of -5 percent is that for the data by Semenyuk, Zarembo and Federov for the 19.12 percent NaCl solution.

Table 5 consists of η/η_W values up to 350^{o}C and 5 m concentrations; Figure 2 shows the change in relative viscosity of NaCl solutions up to 350^{o}C. Figures 3 and 4 are plots of eq 9 versus concentration and temperature, respectively.

1. Effect of Pressure

The change in viscosity has been studied for pressures up to 150 MPa, and temperatures to 356°C. Over these ranges the viscosity increases by 1-2 percent; see Figure 5. Details on the instrumentation used, as well as experimental procedures are contained in the publications by Kestin and coworkers (11,37,50,55) up to 150°C and 35 MPa, Pepinov et al up to 350°C and 35 MPa (19,35), and by Semenyuk et al up to 356°C and 150 MPa (20).

H. Viscosity of Other Solutions

Besides NaCl, geothermal brines contain significant concentrations of both KCl and $CaCl_2$, as shown by the selected data in Table 2. Data on the effect of these electrolytes on the viscosity of NaCl solutions is therefore important for modeling the viscosity of a geothermal hot brine reservoir. Experimental work on the effect of these other important electrolytes takes two forms: (1) a study of the viscosity change of the pure electrolyte, and (2) a study of the viscosity change of mixtures of NaCl with the other electrolyte, e.g., KCl.

1. Potassium Chloride

Data on the viscosity of KCl solutions published by Grimes, Kestin, Khalifa up to 150°C and 35 MPa (48) are given in Table 8 and shown in Figure 6; data have also been published by Korosi and Fabuss up to 150°C and saturated vapor pressures (21). The relative viscosity of KCl solutions is lower than that of NaCl solutions at equivalent molal concentrations and temperatures as shown in Figure 6. Furthermore, the addition of NaCl in the molal ratio 3:1 gives a solution with a relative viscosity higher than that for 4 m KCl, but less than that of 4 m NaCl. This 3:1 ratio is roughly the ratio of NaCl to KCl in the Baca and Salton Sea areas, as shown in Table 2.

Note also the nonlinear shape of the relative viscosity curves for both pure KCl, as well as the NaCl-KCl mixtures.

2. Calcium Chloride

Data on the viscosity of $CaCl_2$ solutions up to 90°C were published recently by Gruzdev, Genrikh and Shestova (56), and by Goncalves and Kestin (68). See Table 10.

Ref. 56 contains plots of the relative viscosity of $CaCl_2$ solutions up to 90°C for concentrations between 0.474 - 4.4 m. The plots show a flat region over which there is no change in viscosity; at 4.4 m, the relative viscosity decreases over the temperature range 50-90°C. Additionally, the relative viscosity values are higher than those of comparable NaCl solutions by a factor of 1-2. We have correlated the experimental data contained in the International Critical Tables, as well as that published in References 56 and 68 for concentrations up to 4 m (30 percent w), and 70°C. See Table 12; Fig. 7.

3. Mixtures

The viscosity of mixtures of NaCl with KCl obtained from publications by Correia, Kestin and Khalifa (47) and Korosi and Fabuss (57) are given in Table 9; values for the viscosity of $CaCl_2$ with NaCl are in the publication by Verba et al (67). See Table 9. Measurements of the viscosity of mixtures of NaCl with $CaCl_2$ over the range 20-90°C and up to 35 percent show that the viscosity is higher than that of NaCl, even at equal molal concentrations. See Table 11. For NaCl/$CaCl_2$ ratios of about 2:1, the viscosity is about 10 percent higher than for equivalent NaCl solutions; the viscosity is about 25 percent higher when the molal ratio is 1.

The data for Na, K and Ca concentrations in geothermal brines in Table 2 show that Na is always the major constituent. Because dissolved KCl lowers viscosity while $CaCl_2$ causes an increase, it may be that the two contributions sufficiently offset each other so that viscosity data for pure NaCl solutions are a good approximation to the viscosity of a site-specific geothermal brine.

4. Sea Water

The following empirical equation was developed by Mashovets and coworkers for calculating the viscosity of sea water of composition 3.56w percent at a specified temperature (65):

$$\log \eta_{sw} = 0.913 \log \eta_w - 0.00597 \quad (11)$$

Equation 11 which is similar to the Othmer rule was used to calculate values up to 350^{o}C (65). Isdale, Spence and Tudhope have published an extensive table consisting of values for the viscosity of sea water up to 180^{o}C, and for salinities between 32, 33 and 148.38 g/Kg based on the correlation (66):

$$\log_{10}(\eta_{20}/\eta) = [(t+20)/(t+109)]\ [A(1+a,\ St_2S^2\ B(1+b_1S + b_2S^2)\ (t-20)] \quad (12)$$

Experimental data are reproduced by eq 12 to ± 1 percent.

I. Summary and Conclusions

The change in relative viscosity with concentrations differs markedly for $CaCl_2$ solutions as compared with NaCl and KCl solutions. See Figure 8. In this figure data for $LaCl_3$ obtained from Spedding's paper are plotted for comparative purposes. As seen, $CaCl_2$ has a shape similar to that of $LaCl_3$. The shape in the curve for $LaCl_3$ has been attributed to the highly hydrated La^{+3} ion (16); it is likely that the rapid increase in viscosity for Ca^{+2} is related also to hydration. Application of the Vand equation might assist in verifying that the large increase in viscosity at concentrations exceeding about 3 m is due an obstruction of the steam lines in the water solvent by hydrated Ca^{+2} ions. By contrast, KCl is not considered to be highly hydrated in aqueous solutions (14). Additional information to this approach is found in the publications by Vand (29), Spedding and Pikal (16), and Out and Los (26).

The A coefficient of the Jones-Dole equation is determined by ion-water interactions to form ion-bound water complexes, and by ionic mobilities; A coefficients are calculated from theory for NaCl, KCl and many other electrolytes. The B coefficient of ions in water shows a strong temperature dependence; the magnitude of B depends on the dissolved salt and resulting ion-water interactions. The dependence of B on temperature has been studied for NaCl, KCl and other electrolytes (e.g., LiCl) by Out and Los up to 95°C, by Kaminsky for temperatures between 12.5 and 42.5°C, and by Kay et al for tetraalkylammonium halides between 0 and 65°C. Systematic studies of the D coefficient are mainly those by Out and Los, and at 25°C, by Desnoyers and Perron. See Reference 26 for more details.

The a, b and c coefficients in the Vand equation have not been as well studied for aqueous electrolytes such as NaCl. If the first term only is retained, then the Vand equation, eq 5, gives an "excellent representation of the viscosities of many 'strongly hydrated' electrolytes in the region of moderate to high concentrations". The rapidly increasing viscosity with increased concentration is attributed to an "obstruction" effect, owing to interference of large hydrated ions with the stream lines in the solvent. See Spedding and Pikal (16).

J. Recommendations

After reviewing the available experimental data in light of that required for geothermal energy utilization, some specific recommendations are appropriate. Mainly, additional data are needed at pressures from 2 MPa to 50 MPa, and for temperatures between 100°C and 350°C for mixtures of NaCl with $CaCl_2$ and KCl. Future work might include the following:

1. Development of an equation for predicting the viscosity of NaCl and other solutions up to high temperatures, concentrations and pressures. The equation would permit estimation of viscosity where data do not exist. Currently, the best available approach is that of Jones and Dole (14) for temperatures below 100°C, concentrations up to 1 m (26), and at saturated vapor pressures.

2. Data are needed on the viscosity of selected mixtures of NaCl, KCl and $CaCl_2$, to determine the effect of these salts on viscosity so that geothermal brines can be more closely modeled. Some work has been done on binary mixtures of NaCl with KCl and $CaCl_2$; data are needed on the viscosity of mixtures of these three salts up to high temperatures.

3. Investigation of the effect of pressure up to 50 MPa. Currently, only three sets of data have been published for pressures different from saturation values at temperatures exceeding 100°C.

4. Laboratory measurements of the viscosity of site-specific geothermal brines. The data will provide information on the variation in viscosity for each site, and can be used to test the applicability of NaCl solutions for modeling.

5. Experimental data for the viscosity of $CaCl_2$ solutions, especially at temperatures exceeding 100°C. These data will permit better modeling of a geothermal brine at high temperatures.

6. Development of theoretical or empirical equations which permit calculating the viscosity of mixtures of NaCl, KCl and $CaCl_2$ at high temperatures. These mixture equations will substantially reduce the number of experimental measurements which otherwise must be made. Young's rule has been applied to mixtures of NaCl + KCl (47), and the additivity of kinematic fluidity has been applied to NaCl + KCl, and NaCl + $CaCl_2$ (69).

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K. Symbols and Units

Units:

$MPa = 10^6\ N/m^2 = 10\ bar = 145.04\ psi = 0.1\ atm$

$10^{6} \mu P = 1$ poise $= 1\ P = 1 g/cm\ s = 1\ dyn\ s/cm^2$

$= 10^{-1} kg/m\ s = 10^{-1} N\ s/m^2 = 10^{-1}\ Pa\ s$

dm^3 = cubic decimeter = 1 liter = 1000 cm^3

$g/cm^3 = Kg/m^3 \times 10^{-3}$

Absolute viscosity = kinematic viscosity x density

Symbols:

η_r	=	relative viscosity = η/η_w
η	=	viscosity of NaCl solutions, cp
η_w	=	viscosity of water, cp
m	=	molal (except, under Units, m = meter)
t	=	temperature, ^oC
P	=	pressure, MPa
cp	=	centipoise
η_{sw}	=	viscosity of sea water, cp
η_{20}	=	viscosity at 20^{o}C, cp
S	=	salinity
μ	=	viscosity, 10^{-6} Pa s
d, D	=	density, g/cm^3 or Kg/m^3
c	=	concentration, molar
Φ	=	volume fraction of solids
K_1	=	shape factor of single spheres

K. Symbols and Units (cont.)

K_2 = shape factor of collision doublets

Q = hydrodynamic interaction constant

A_3 = adjustable parameter

η_{wis} = viscosity of water in solution

W = weight percent

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Tables

1. Selected materials and properties included in the aqueous solutions database. See Page iii of the Introduction.

2. Sodium, potassium, calcium and chloride content of selected geothermal reservoir brines. Concentrations are in ppm. See Page iv of the Introduction.

3. Values of the Jones - Dole A, B and D coefficients for NaCl, KCl and $CaCl_2$ solutions up to 95°C.

4. Summary of experimental data used to develop the correlation equation for NaCl solutions.

5. Relative viscosity of NaCl solutions up to 350°C and 5 m concentrations.

6. Viscosity of NaCl solutions up to 150°C and 5 m concentrations.

7. Viscosity of NaCl solutions up to 350°C and 50 MPa pressures.

8. Viscosity of KCl solutions up to 150°C and 35 MPa pressures.

9. Viscosity of selected mixtures of NaCl + KCl up to 150°C and 35 MPa.

10. Relative viscosity of $CaCl_2$ solutions up to 90°C.

11. Viscosity of selected NaCl + $CaCl_2$ solution mixtures up to 90°C.

12. Interpolated values for the relative viscosity of $CaCl_2$ solutions, 0.25 - 3 m; 20 - 70°C. Calculated from the correlation equation:

$$\frac{DW}{\ln \eta_r} = 45.91 - 0.2000\,t - (0.4201 - 0.00570\,t)\,W$$

Table 3. Values of the Jones-Dole A, B and D parameters in eq 1 and eq 2 for NaCl, KCl and $CaCl_2$ solutions (28,36).

Temp.	A $(liter/mole)^{1/2}$			B (liter/mole)			D $(liter/mole)^2$		
°C	NaCl	KCl	$CaCl_2$	NaCl	KCl	$CaCl_2$	NaCl	KCl	$CaCl_2$
5	0.0057	0.0047		0.034	-0.0821	0.23	0.024	0.022	
15	.0059	.0049		.062	-0.0421		.016	.012	
25	.0061	.0051		.078	-0.0141	.271	.013	.007	
35	.0062	.0052		.087	.0083		.013	.002	
45	.0064	.0054		.094	.0250		.015	.000	
55	.0065	.0056		.101	.0394		.014	.000	
65	.0066	.0057		.108	.0509		.013	.000	
75	.0068	.0059		.115	.0599		.011	.001	
85	.0069	.0060		.121	.0714		.011	-0.002	
95	.0071	.0062		.126	.0788		.011	-0.001	

Table 4. Summary of experimental data on the viscosity of NaCl solutions used in developing eq 9.

Temperature °C	Concentration molal	*Pressure MPa	Viscometer	Reference	Percent Difference
0-25	0.002-2	vs	Ostwald	54	
10-40	0.1-5.8	vs	Ostwald	58	
12-42	0.001-0.5	vs	Ubbelohde	59	
18-154	0.4-4	1-30	Oscillating disk	37	0.3-0.7
20-80	6	vs	Ostwald	52	
23	0.3-2.5	vs	Electro-magnetic	60	
25-50	0.007-5.8	vs	Ostwald and Ubbelohde	50	
25	0.09-1.2	vs	Unspecified	61	
25-150	0.1-3.6	vs, 10-20	Cannon	21	0.7
25	0.1-5.6	vs	Ostwald	62	
25	1.0-5.6	vs	Fenske Cannon	63	
25-60	1.1-6.1	vs	Ostwald	51	
30-55	1.0-5.0	vs	Ostwald	53	0.8
35	0.01-0.07	vs	Unspecified	64	
20-350	0.17-4.28	2-30	Capillary	19	1.0
5-95	0.1-1.2	vs	Ubbelohde	26	0.2
100-350	0.9-4	10-150		20	1.9

*vs = vapor saturated pressure

TABLE 5. RELATIVE VISCOSITY,
VIS. NACL / VIS. WATER ,

TEMP. DEG.C	.1	.5	1	2	3	4	5
	CONCENTRATION, M NACL						
10	1.0087	1.0457	1.0971	1.2178	1.3636	1.5357	1.7351
15	1.0089	1.0467	1.0987	1.2201	1.3663	1.5387	1.7382
20	1.0091	1.0476	1.1003	1.2225	1.3691	1.5416	1.7412
25	1.0093	1.0485	1.1018	1.2249	1.3719	1.5446	1.7443
30	1.0096	1.0494	1.1034	1.2272	1.3746	1.5475	1.7473
35	1.0098	1.0504	1.1050	1.2296	1.3774	1.5505	1.7504
40	1.0100	1.0513	1.1066	1.2320	1.3801	1.5534	1.7534
45	1.0102	1.0522	1.1082	1.2343	1.3829	1.5564	1.7565
50	1.0104	1.0532	1.1098	1.2367	1.3857	1.5593	1.7595
55	1.0106	1.0541	1.1113	1.2391	1.3884	1.5623	1.7626
60	1.0108	1.0550	1.1129	1.2415	1.3912	1.5652	1.7656
65	1.0110	1.0559	1.1145	1.2438	1.3939	1.5682	1.7687
70	1.0113	1.0569	1.1161	1.2462	1.3967	1.5711	1.7717
75	1.0115	1.0578	1.1177	1.2486	1.3995	1.5741	1.7748
80	1.0117	1.0587	1.1193	1.2509	1.4022	1.5771	1.7778
85	1.0119	1.0597	1.1208	1.2533	1.4050	1.5800	1.7809
90	1.0121	1.0606	1.1224	1.2557	1.4077	1.5830	1.7839
95	1.0123	1.0615	1.1240	1.2580	1.4105	1.5859	1.7870
100	1.0125	1.0624	1.1256	1.2604	1.4133	1.5889	1.7900
105	1.0127	1.0634	1.1272	1.2628	1.4160	1.5918	1.7931
110	1.0130	1.0643	1.1288	1.2652	1.4188	1.5948	1.7961
115	1.0132	1.0652	1.1303	1.2675	1.4215	1.5977	1.7992
120	1.0134	1.0662	1.1319	1.2699	1.4243	1.6007	1.8022
125	1.0136	1.0671	1.1335	1.2723	1.4271	1.6036	1.8053
130	1.0138	1.0680	1.1351	1.2746	1.4298	1.6066	1.8083
135	1.0140	1.0689	1.1367	1.2770	1.4326	1.6095	1.8114
140	1.0142	1.0699	1.1383	1.2794	1.4353	1.6125	1.8144
145	1.0144	1.0708	1.1398	1.2817	1.4381	1.6155	1.8175
150	1.0147	1.0717	1.1414	1.2841	1.4409	1.6184	1.8205
155	1.0149	1.0727	1.1430	1.2865	1.4436	1.6214	1.8236
160	1.0151	1.0736	1.1446	1.2888	1.4464	1.6243	1.8266
165	1.0153	1.0745	1.1462	1.2912	1.4491	1.6273	1.8297
170	1.0155	1.0754	1.1478	1.2936	1.4519	1.6302	1.8327
175	1.0157	1.0764	1.1493	1.2960	1.4547	1.6332	1.8358
180	1.0159	1.0773	1.1509	1.2983	1.4574	1.6361	1.8388

TABLE 5. RELATIVE VISCOSITY,
VIS. NACL / VIS. WATER ,

TEMP. DEG.C	CONCENTRATION, M NACL .1	.5	1	2	3	4	5
185	1.0161	1.0782	1.1525	1.3007	1.4602	1.6391	1.8419
190	1.0164	1.0792	1.1541	1.3031	1.4629	1.6420	1.8449
195	1.0166	1.0801	1.1557	1.3054	1.4657	1.6450	1.8480
200	1.0168	1.0810	1.1573	1.3078	1.4685	1.6479	1.8510
205	1.0170	1.0819	1.1588	1.3102	1.4712	1.6509	1.8541
210	1.0172	1.0829	1.1604	1.3125	1.4740	1.6538	1.8571
215	1.0174	1.0838	1.1620	1.3149	1.4767	1.6568	1.8602
220	1.0176	1.0847	1.1636	1.3173	1.4795	1.6598	1.8632
225	1.0179	1.0857	1.1652	1.3196	1.4823	1.6627	1.8663
230	1.0181	1.0866	1.1668	1.3220	1.4850	1.6657	1.8693
235	1.0183	1.0875	1.1683	1.3244	1.4878	1.6686	1.8724
240	1.0185	1.0884	1.1699	1.3268	1.4905	1.6716	1.8754
245	1.0187	1.0894	1.1715	1.3291	1.4933	1.6745	1.8785
250	1.0189	1.0903	1.1731	1.3315	1.4960	1.6775	1.8815
255	1.0191	1.0912	1.1747	1.3339	1.4988	1.6804	1.8846
260	1.0193	1.0922	1.1763	1.3362	1.5016	1.6834	1.8876
265	1.0196	1.0931	1.1778	1.3386	1.5043	1.6863	1.8907
270	1.0198	1.0940	1.1794	1.3410	1.5071	1.6893	1.8937
275	1.0200	1.0949	1.1810	1.3433	1.5098	1.6922	1.8968
280	1.0202	1.0959	1.1826	1.3457	1.5126	1.6952	1.8998
285	1.0204	1.0968	1.1842	1.3481	1.5154	1.6982	1.9029
290	1.0206	1.0977	1.1858	1.3505	1.5181	1.7011	1.9059
295	1.0208	1.0987	1.1873	1.3528	1.5209	1.7041	1.9090
300	1.0210	1.0996	1.1889	1.3552	1.5236	1.7070	1.9120
305	1.0213	1.1005	1.1905	1.3576	1.5264	1.7100	1.9151
310	1.0215	1.1014	1.1921	1.3599	1.5292	1.7129	1.9181
315	1.0217	1.1024	1.1937	1.3623	1.5319	1.7159	1.9212
320	1.0219	1.1033	1.1953	1.3647	1.5347	1.7188	1.9242
325	1.0221	1.1042	1.1968	1.3670	1.5374	1.7218	1.9273
330	1.0223	1.1052	1.1984	1.3694	1.5402	1.7247	1.9303
335	1.0225	1.1061	1.2000	1.3718	1.5430	1.7277	1.9334
340	1.0227	1.1070	1.2016	1.3741	1.5457	1.7306	1.9364
345	1.0230	1.1080	1.2032	1.3765	1.5485	1.7336	1.9395
350	1.0232	1.1089	1.2048	1.3789	1.5512	1.7366	1.9425

TABLE 6. ABSOLUTE VISCOSITY OF NACL SOLUTIONS, CP

PRESSURE = SATURATED VAPOR PRESSURE, OR 5MPA

TEMP. DEG.C	CONCENTRATION, M NACL 0	.5	1	2	3	4	5
20	1.0020	1.0497	1.1025	1.2249	1.3718	1.5447	1.7447
25	.8901	.9333	.9808	1.0903	1.2211	1.3748	1.5526
30	.7972	.8366	.8797	.9784	1.0958	1.2337	1.3929
35	.7192	.7554	.7947	.8843	.9906	1.1151	1.2589
40	.6529	.6864	.7225	.8044	.9011	1.0142	1.1448
45	.5962	.6273	.6607	.7359	.8245	.9279	1.0472
50	.5471	.5762	.6071	.6766	.7581	.8531	.9626
55	.5044	.5317	.5606	.6250	.7003	.7880	.8890
60	.4670	.4927	.5197	.5798	.6497	.7310	.8245
65	.4340	.4583	.4837	.5398	.6050	.6806	.7676
70	.4047	.4277	.4517	.5043	.5652	.6358	.7170
75	.3785	.4004	.4230	.4726	.5297	.5958	.6717
80	.3551	.3760	.3974	.4442	.4979	.5600	.6313
85	.3341	.3540	.3745	.4187	.4694	.5279	.5950
90	.3151	.3342	.3537	.3957	.4436	.4988	.5621
95	.2978	.3161	.3347	.3746	.4200	.4723	.5322
100	.2821	.2997	.3175	.3556	.3987	.4482	.5050
105	.2679	.2849	.3020	.3383	.3793	.4264	.4804
110	.2548	.2712	.2876	.3224	.3615	.4063	.4576
115	.2428	.2586	.2744	.3078	.3451	.3879	.4368
120	.2318	.2471	.2624	.2944	.3302	.3710	.4178
125	.2217	.2366	.2513	.2821	.3164	.3555	.4002
130	.2124	.2268	.2411	.2707	.3037	.3412	.3841
135	.2038	.2179	.2317	.2603	.2920	.3280	.3692
140	.1959	.2096	.2230	.2506	.2812	.3159	.3554
145	.1886	.2020	.2150	.2417	.2712	.3047	.3428
150	.1818	.1948	.2075	.2335	.2619	.2942	.3310

In Table 7 which follows, all concentrations are in units of molal concentrations; viscosity values are in units of centipoise (cp)

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = .1M-PASCAL

TEMP DEG.C	* DENSITY KG/M3	CONCENTRATION, M NACL 0	1	2	3	4	5
0	999.557	1.7937	1.9622	2.1758	2.4360	2.7440	3.1013
5	999.676	1.5209	1.6661	1.8485	2.0696	2.3311	2.6343
10	999.428	1.3082	1.4352	1.5931	1.7838	2.0090	2.2698
15	998.850	1.1391	1.2515	1.3899	1.5564	1.7527	1.9799
20	997.976	1.0024	1.1029	1.2255	1.3724	1.5454	1.7454
25	996.833	.8903	.9810	1.0905	1.2214	1.3752	1.5529
30	995.446	.7972	.8796	.9783	1.0958	1.2336	1.3929
35	993.838	.7189	.7944	.8840	.9902	1.1146	1.2583
40	992.025	.6525	.7220	.8038	.9005	1.0135	1.1440
45	990.025	.5955	.6600	.7351	.8236	.9269	1.0460
50	987.851	.5464	.6064	.6757	.7571	.8520	.9614
55	985.512	.5036	.5597	.6240	.6992	.7868	.8877
60	983.021	.4662	.5188	.5787	.6485	.7296	.8230
65	980.383	.4331	.4827	.5387	.6038	.6792	.7661
70	977.605	.4039	.4507	.5033	.5641	.6345	.7155
75	974.694	.3778	.4222	.4717	.5287	.5947	.6705
80	971.653	.3544	.3967	.4434	.4970	.5590	.6301
85	968.487	.3335	.3738	.4179	.4685	.5269	.5939
90	965.197	.3145	.3530	.3950	.4428	.4979	.5611
95	961.786	.2974	.3343	.3741	.4195	.4716	.5314
100	958.257	.2818	.3172	.3552	.3983	.4477	.5044
105	954.610	.2676	.3016	.3379	.3789	.4260	.4798
110	950.847	.2546	.2874	.3221	.3612	.4060	.4573
115	946.968	.2427	.2743	.3076	.3450	.3878	.4366
120	942.974	.2317	.2623	.2943	.3301	.3710	.4177
125	938.866	.2217	.2513	.2820	.3163	.3555	.4002
130	934.644	.2124	.2411	.2707	.3036	.3412	.3840
135	930.309	.2038	.2316	.2602	.2919	.3280	.3691
140	925.861	.1958	.2229	.2505	.2810	.3157	.3552
145	921.301	.1884	.2147	.2415	.2709	.3043	.3424
150	916.629	.1815	.2072	.2331	.2615	.2937	.3304
155	911.846	.1751	.2001	.2253	.2528	.2839	.3193
160	906.953	.1691	.1936	.2180	.2446	.2747	.3089
165	901.950	.1635	.1875	.2112	.2370	.2661	.2992
170	896.839	.1583	.1817	.2048	.2299	.2581	.2902

*Density of water.

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

TEMP DEG.C	DENSITY KG/M3	CONCENTRATION, M NACL					
		0	1	2	3	4	5
175	891.622	.1534	.1764	.1989	.2232	.2506	.2817
180	886.298	.1489	.1713	.1933	.2169	.2436	.2737
185	880.871	.1446	.1666	.1880	.2111	.2369	.2663
190	875.341	.1405	.1622	.1831	.2056	.2307	.2592
195	869.711	.1367	.1580	.1785	.2004	.2249	.2526
200	863.982	.1331	.1541	.1741	.1955	.2194	.2464
205	858.158	.1297	.1504	.1700	.1909	.2142	.2406
210	852.239	.1266	.1469	.1661	.1865	.2093	.2350
215	846.230	.1235	.1435	.1624	.1824	.2047	.2298
220	840.132	.1207	.1404	.1590	.1785	.2003	.2248
225	833.948	.1180	.1374	.1557	.1749	.1961	.2202
230	827.682	.1154	.1346	.1526	.1714	.1922	.2157
235	821.336	.1130	.1320	.1496	.1680	.1885	.2115
240	814.915	.1106	.1294	.1468	.1649	.1849	.2075
245	808.420	.1084	.1270	.1441	.1619	.1815	.2037
250	801.857	.1063	.1247	.1415	.1590	.1783	.2000
255	795.227	.1043	.1225	.1391	.1563	.1753	.1965
260	788.536	.1024	.1204	.1368	.1537	.1723	.1932
265	781.786	.1005	.1184	.1346	.1512	.1695	.1901
270	774.981	.0988	.1165	.1324	.1489	.1668	.1870
275	768.126	.0971	.1147	.1304	.1466	.1643	.1841
280	761.225	.0955	.1129	.1285	.1444	.1618	.1813
285	754.280	.0939	.1112	.1266	.1423	.1595	.1787
290	747.296	.0924	.1096	.1248	.1403	.1572	.1761
295	740.278	.0910	.1080	.1230	.1383	.1550	.1736
300	733.228	.0896	.1065	.1214	.1365	.1529	.1712
305	726.151	.0882	.1050	.1198	.1347	.1509	.1690
310	719.051	.0869	.1036	.1182	.1329	.1489	.1667
315	711.931	.0857	.1023	.1167	.1313	.1470	.1646
320	704.796	.0845	.1010	.1153	.1296	.1452	.1625
325	697.650	.0833	.0997	.1139	.1281	.1434	.1605
330	690.495	.0822	.0985	.1125	.1266	.1417	.1586
335	683.336	.0811	.0973	.1112	.1251	.1401	.1567
340	676.176	.0800	.0961	.1100	.1237	.1385	.1549
345	669.019	.0790	.0950	.1087	.1223	.1369	.1532
350	661.868	.0780	.0940	.1075	.1210	.1354	.1515

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 10.0M-PASCAL

TEMP DEG.C	* DENSITY KG/M3	CONCENTRATION, M NACL					
		0	1	2	3	4	5
0	1004.455	1.7713	1.9377	2.1487	2.4056	2.7098	3.0627
5	1004.439	1.5063	1.6502	1.8307	2.0498	2.3088	2.6090
10	1004.079	1.2987	1.4248	1.5815	1.7709	1.9944	2.2534
15	1003.409	1.1331	1.2449	1.3825	1.5482	1.7434	1.9695
20	1002.459	.9988	1.0989	1.2210	1.3674	1.5397	1.7391
25	1001.257	.8884	.9788	1.0881	1.2187	1.3721	1.5495
30	999.824	.7964	.8788	.9774	1.0948	1.2325	1.3916
35	998.181	.7190	.7945	.8841	.9903	1.1148	1.2585
40	996.345	.6532	.7228	.8047	.9015	1.0147	1.1453
45	994.330	.5968	.6613	.7366	.8253	.9288	1.0482
50	992.148	.5480	.6081	.6777	.7593	.8545	.9642
55	989.811	.5055	.5618	.6263	.7018	.7897	.8909
60	987.326	.4682	.5211	.5813	.6514	.7329	.8267
65	984.701	.4354	.4852	.5415	.6069	.6827	.7700
70	981.943	.4062	.4534	.5062	.5673	.6382	.7197
75	979.056	.3802	.4250	.4747	.5321	.5985	.6748
80	976.046	.3569	.3995	.4465	.5005	.5629	.6346
85	972.915	.3360	.3766	.4211	.4721	.5309	.5984
90	969.665	.3171	.3559	.3982	.4464	.5020	.5657
95	966.301	.3000	.3372	.3774	.4231	.4757	.5360
100	962.823	.2844	.3201	.3585	.4019	.4519	.5091
105	959.232	.2702	.3045	.3412	.3826	.4301	.4844
110	955.530	.2572	.2903	.3254	.3649	.4102	.4619
115	951.719	.2453	.2772	.3109	.3487	.3919	.4413
120	947.798	.2343	.2652	.2975	.3337	.3750	.4223
125	943.768	.2242	.2541	.2853	.3200	.3595	.4048
130	939.630	.2149	.2439	.2739	.3072	.3452	.3886
135	935.385	.2063	.2345	.2634	.2955	.3320	.3736
140	931.033	.1983	.2257	.2537	.2846	.3197	.3597
145	926.575	.1908	.2175	.2446	.2745	.3083	.3469
150	922.011	.1839	.2100	.2362	.2650	.2977	.3349
155	917.341	.1775	.2029	.2284	.2563	.2878	.3237
160	912.568	.1715	.1963	.2211	.2481	.2786	.3133
165	907.692	.1659	.1902	.2142	.2404	.2700	.3036
170	902.713	.1607	.1844	.2079	.2333	.2619	.2945

*Density of water.

TABLE 7. ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 10.0M-PASCAL

TEMP DEG.C	DENSITY KG/M3	CONCENTRATION, M NACL					
		0	1	2	3	4	5
175	897.633	.1558	.1790	.2019	.2266	.2544	.2860
180	892.454	.1512	.1740	.1963	.2203	.2473	.2780
185	887.176	.1469	.1693	.1910	.2144	.2407	.2705
190	881.802	.1428	.1648	.1861	.2089	.2345	.2635
195	876.333	.1390	.1606	.1814	.2037	.2286	.2568
200	870.771	.1354	.1567	.1771	.1988	.2231	.2506
205	865.118	.1320	.1530	.1729	.1942	.2179	.2447
210	859.377	.1288	.1494	.1690	.1898	.2130	.2392
215	853.549	.1258	.1461	.1654	.1857	.2083	.2339
220	847.637	.1229	.1430	.1619	.1818	.2040	.2290
225	841.644	.1202	.1400	.1586	.1781	.1998	.2243
230	835.572	.1176	.1372	.1554	.1746	.1959	.2198
235	829.424	.1151	.1345	.1525	.1713	.1921	.2156
240	823.204	.1128	.1320	.1497	.1681	.1886	.2115
245	816.914	.1106	.1295	.1470	.1651	.1852	.2077
250	810.558	.1085	.1272	.1444	.1623	.1819	.2041
255	804.138	.1064	.1250	.1420	.1595	.1789	.2006
260	797.658	.1045	.1229	.1397	.1569	.1759	.1973
265	791.122	.1027	.1209	.1374	.1544	.1731	.1941
270	784.532	.1009	.1190	.1353	.1521	.1705	.1911
275	777.893	.0992	.1172	.1333	.1498	.1679	.1882
280	771.208	.0976	.1154	.1313	.1476	.1654	.1854
285	764.480	.0960	.1137	.1294	.1455	.1630	.1827
290	757.713	.0945	.1121	.1276	.1435	.1608	.1801
295	750.911	.0931	.1105	.1259	.1415	.1586	.1777
300	744.077	.0917	.1090	.1242	.1397	.1565	.1753
305	737.215	.0903	.1075	.1226	.1379	.1544	.1730
310	730.328	.0890	.1061	.1211	.1361	.1525	.1707
315	723.420	.0878	.1048	.1196	.1344	.1506	.1686
320	716.494	.0865	.1034	.1181	.1328	.1488	.1665
325	709.554	.0854	.1022	.1167	.1313	.1470	.1645
330	702.604	.0842	.1009	.1153	.1297	.1453	.1626
335	695.646	.0831	.0998	.1140	.1283	.1436	.1607
340	688.685	.0821	.0986	.1128	.1268	.1420	.1589
345	681.723	.0810	.0975	.1115	.1255	.1405	.1571
350	674.763	.0800	.0964	.1103	.1241	.1390	.1554

TABLE 7. ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 20.0M-PASCAL

TEMP DEG.C	*DENSITY KG/M3	CONCENTRATION, M NACL 0	1	2	3	4	5
0	1009.321	1.7509	1.9153	2.1238	2.3778	2.6785	3.0272
5	1009.159	1.4931	1.6357	1.8147	2.0318	2.2885	2.5861
10	1008.676	1.2903	1.4155	1.5712	1.7594	1.9815	2.2387
15	1007.905	1.1278	1.2391	1.3761	1.5410	1.7353	1.9603
20	1006.872	.9957	1.0956	1.2173	1.3632	1.5350	1.7338
25	1005.602	.8868	.9771	1.0863	1.2166	1.3698	1.5469
30	1004.116	.7960	.8783	.9769	1.0942	1.2318	1.3908
35	1002.432	.7194	.7949	.8846	.9908	1.1154	1.2592
40	1000.564	.6542	.7239	.8059	.9028	1.0162	1.1470
45	998.528	.5982	.6629	.7383	.8272	.9310	1.0506
50	996.333	.5497	.6100	.6798	.7617	.8571	.9672
55	993.990	.5074	.5639	.6288	.7045	.7928	.8944
60	991.507	.4704	.5235	.5839	.6543	.7362	.8305
65	988.890	.4376	.4877	.5443	.6100	.6863	.7740
70	986.147	.4086	.4560	.5092	.5707	.6419	.7239
75	983.280	.3827	.4277	.4778	.5355	.6024	.6791
80	980.296	.3594	.4023	.4496	.5040	.5669	.6390
85	977.196	.3385	.3795	.4243	.4756	.5349	.6029
90	973.984	.3197	.3588	.4014	.4500	.5060	.5702
95	970.662	.3025	.3401	.3806	.4267	.4798	.5406
100	967.232	.2870	.3230	.3617	.4056	.4559	.5137
105	963.695	.2728	.3074	.3444	.3862	.4342	.4891
110	960.053	.2597	.2932	.3286	.3685	.4142	.4665
115	956.306	.2478	.2801	.3141	.3523	.3959	.4459
120	952.456	.2368	.2681	.3008	.3373	.3791	.4268
125	948.504	.2267	.2570	.2885	.3236	.3636	.4093
130	944.449	.2174	.2468	.2771	.3108	.3493	.3931
135	940.293	.2087	.2373	.2666	.2990	.3360	.3781
140	936.037	.2007	.2285	.2568	.2881	.3237	.3642
145	931.681	.1933	.2203	.2477	.2780	.3122	.3513
150	927.225	.1864	.2127	.2393	.2685	.3016	.3393
155	922.671	.1799	.2057	.2315	.2597	.2917	.3281
160	918.020	.1739	.1991	.2241	.2515	.2825	.3177
165	913.272	.1683	.1929	.2173	.2439	.2739	.3079
170	908.428	.1630	.1871	.2109	.2367	.2658	.2988

*Density of water.

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 20.0M-PASCAL

TEMP DEG.C	DENSITY KG/M3	CONCENTRATION, M NACL					
		0	1	2	3	4	5
175	903.490	.1581	.1817	.2049	.2300	.2582	.2903
180	898.458	.1535	.1767	.1993	.2237	.2511	.2823
185	893.335	.1492	.1719	.1940	.2178	.2445	.2747
190	888.121	.1451	.1675	.1891	.2123	.2383	.2677
195	882.819	.1413	.1633	.1844	.2071	.2324	.2611
200	877.429	.1377	.1593	.1800	.2021	.2269	.2548
205	871.955	.1343	.1556	.1759	.1975	.2216	.2489
210	866.398	.1310	.1521	.1720	.1931	.2167	.2434
215	860.759	.1280	.1487	.1683	.1890	.2121	.2381
220	855.042	.1251	.1456	.1648	.1851	.2077	.2331
225	849.249	.1224	.1426	.1615	.1814	.2035	.2284
230	843.381	.1198	.1398	.1584	.1779	.1996	.2240
235	837.443	.1174	.1371	.1554	.1746	.1958	.2197
240	831.435	.1150	.1346	.1526	.1714	.1923	.2157
245	825.362	.1128	.1321	.1499	.1684	.1889	.2119
250	819.226	.1107	.1298	.1474	.1656	.1857	.2082
255	813.029	.1087	.1276	.1449	.1629	.1826	.2048
260	806.776	.1067	.1255	.1426	.1603	.1797	.2015
265	800.468	.1049	.1235	.1404	.1578	.1769	.1983
270	794.109	.1031	.1216	.1383	.1554	.1742	.1953
275	787.702	.1014	.1198	.1362	.1531	.1716	.1923
280	781.250	.0998	.1180	.1343	.1509	.1691	.1896
285	774.757	.0982	.1163	.1324	.1488	.1668	.1869
290	768.226	.0967	.1147	.1306	.1468	.1645	.1843
295	761.659	.0953	.1131	.1289	.1449	.1623	.1818
300	755.060	.0939	.1116	.1272	.1430	.1602	.1795
305	748.433	.0925	.1101	.1256	.1412	.1582	.1772
310	741.780	.0912	.1087	.1240	.1395	.1562	.1749
315	735.105	.0899	.1074	.1225	.1378	.1543	.1728
320	728.411	.0887	.1061	.1211	.1362	.1525	.1707
325	721.701	.0875	.1048	.1197	.1346	.1507	.1687
330	714.979	.0864	.1036	.1183	.1331	.1490	.1668
335	708.247	.0853	.1024	.1170	.1316	.1474	.1649
340	701.508	.0842	.1012	.1157	.1302	.1458	.1631
345	694.765	.0832	.1001	.1145	.1288	.1442	.1613
350	688.022	.0822	.0990	.1133	.1275	.1427	.1596

TABLE 7. ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 30.0M-PASCAL

TEMP DEG.C	* DENSITY KG/M3	CONCENTRATION, M NACL					
		0	1	2	3	4	5
0	1014.103	1.7324	1.8951	2.1015	2.3527	2.6502	2.9953
5	1013.785	1.4813	1.6228	1.8004	2.0158	2.2705	2.5657
10	1013.171	1.2829	1.4074	1.5622	1.7493	1.9701	2.2259
15	1012.289	1.1234	1.2342	1.3707	1.5349	1.7285	1.9526
20	1011.165	.9933	1.0928	1.2143	1.3599	1.5312	1.7295
25	1009.820	.8857	.9760	1.0849	1.2151	1.3681	1.5450
30	1008.273	.7959	.8782	.9767	1.0940	1.2316	1.3906
35	1006.540	.7200	.7956	.8853	.9917	1.1163	1.2602
40	1004.635	.6553	.7251	.8073	.9044	1.0179	1.1490
45	1002.570	.5997	.6645	.7402	.8293	.9333	1.0533
50	1000.357	.5515	.6120	.6820	.7642	.8599	.9703
55	998.002	.5094	.5662	.6312	.7073	.7959	.8979
60	995.515	.4725	.5259	.5866	.6573	.7396	.8343
65	992.901	.4399	.4903	.5472	.6132	.6898	.7780
70	990.167	.4109	.4586	.5121	.5740	.6456	.7281
75	987.316	.3851	.4304	.4808	.5389	.6062	.6834
80	984.352	.3619	.4051	.4527	.5075	.5707	.6434
85	981.280	.3410	.3822	.4274	.4791	.5388	.6073
90	978.100	.3222	.3616	.4045	.4535	.5100	.5747
95	974.817	.3051	.3429	.3838	.4303	.4838	.5451
100	971.431	.2895	.3258	.3649	.4091	.4599	.5182
105	967.944	.2753	.3103	.3476	.3898	.4382	.4936
110	964.358	.2622	.2960	.3318	.3721	.4182	.4710
115	960.674	.2503	.2829	.3173	.3558	.3999	.4503
120	956.892	.2393	.2709	.3039	.3409	.3831	.4313
125	953.015	.2292	.2598	.2916	.3271	.3675	.4137
130	949.041	.2198	.2495	.2802	.3143	.3532	.3975
135	944.973	.2112	.2400	.2697	.3025	.3399	.3825
140	940.811	.2031	.2312	.2599	.2916	.3276	.3686
145	936.556	.1957	.2230	.2508	.2814	.3161	.3556
150	932.209	.1887	.2154	.2424	.2720	.3055	.3436
155	927.770	.1823	.2083	.2345	.2631	.2955	.3324
160	923.240	.1763	.2017	.2272	.2549	.2863	.3219
165	918.621	.1706	.1956	.2203	.2473	.2776	.3122
170	913.913	.1654	.1898	.2139	.2401	.2696	.3030

*Density of water.

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 30.0M-PASCAL

TEMP DEG.C	DENSITY KG/M3	CONCENTRATION, M NACL 0	1	2	3	4	5
175	909.118	.1604	.1844	.2079	.2334	.2620	.2945
180	904.237	.1558	.1793	.2023	.2271	.2549	.2865
185	899.270	.1515	.1746	.1970	.2212	.2482	.2790
190	894.220	.1474	.1701	.1920	.2156	.2420	.2719
195	889.088	.1435	.1659	.1874	.2104	.2361	.2652
200	883.875	.1399	.1619	.1830	.2055	.2306	.2590
205	878.584	.1365	.1582	.1789	.2008	.2254	.2531
210	873.217	.1333	.1547	.1750	.1965	.2204	.2475
215	867.774	.1303	.1514	.1713	.1923	.2158	.2423
220	862.258	.1274	.1482	.1678	.1884	.2114	.2373
225	856.672	.1246	.1452	.1645	.1848	.2072	.2326
230	851.017	.1221	.1424	.1614	.1813	.2033	.2282
235	845.295	.1196	.1397	.1584	.1779	.1996	.2239
240	839.510	.1173	.1372	.1556	.1748	.1960	.2199
245	833.664	.1150	.1348	.1529	.1718	.1926	.2161
250	827.758	.1129	.1325	.1504	.1689	.1894	.2125
255	821.797	.1109	.1303	.1479	.1662	.1864	.2090
260	815.781	.1090	.1282	.1456	.1636	.1834	.2057
265	809.715	.1071	.1262	.1434	.1612	.1807	.2025
270	803.600	.1054	.1243	.1413	.1588	.1780	.1995
275	797.440	.1037	.1224	.1393	.1565	.1754	.1966
280	791.237	.1020	.1207	.1373	.1543	.1730	.1939
285	784.994	.1005	.1190	.1355	.1523	.1706	.1912
290	778.714	.0990	.1174	.1337	.1503	.1684	.1886
295	772.401	.0975	.1158	.1319	.1483	.1662	.1862
300	766.056	.0961	.1143	.1303	.1465	.1641	.1838
305	759.682	.0948	.1128	.1287	.1447	.1621	.1815
310	753.283	.0935	.1114	.1271	.1429	.1601	.1793
315	746.862	.0922	.1101	.1256	.1413	.1582	.1772
320	740.420	.0910	.1088	.1242	.1397	.1564	.1751
325	733.962	.0898	.1075	.1228	.1381	.1547	.1731
330	727.490	.0887	.1063	.1214	.1366	.1529	.1712
335	721.006	.0876	.1051	.1201	.1351	.1513	.1693
340	714.514	.0865	.1039	.1189	.1337	.1497	.1675
345	708.015	.0854	.1028	.1176	.1323	.1481	.1657
350	701.514	.0844	.1017	.1164	.1310	.1466	.1640

TABLE 7. ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 40.0M-PASCAL

TEMP DEG.C	* DENSITY KG/M3	CONCENTRATION, M NACL 0	1	2	3	4	5
0	1018.798	1.7159	1.8771	2.0814	2.3303	2.6250	2.9668
5	1018.314	1.4710	1.6115	1.7878	2.0017	2.2546	2.5478
10	1017.559	1.2765	1.4004	1.5545	1.7406	1.9603	2.2149
15	1016.558	1.1196	1.2301	1.3661	1.5298	1.7228	1.9461
20	1015.334	.9913	1.0907	1.2119	1.3572	1.5283	1.7261
25	1013.906	.8851	.9752	1.0841	1.2142	1.3671	1.5438
30	1012.291	.7961	.8784	.9770	1.0943	1.2320	1.3910
35	1010.502	.7208	.7965	.8863	.9928	1.1176	1.2617
40	1008.553	.6566	.7266	.8089	.9062	1.0199	1.1512
45	1006.453	.6013	.6663	.7422	.8315	.9358	1.0561
50	1004.214	.5533	.6141	.6843	.7667	.8628	.9736
55	1001.842	.5115	.5684	.6338	.7101	.7991	.9015
60	999.345	.4747	.5283	.5893	.6604	.7430	.8381
65	996.729	.4422	.4928	.5500	.6164	.6934	.7820
70	993.998	.4133	.4612	.5150	.5772	.6493	.7322
75	991.157	.3875	.4331	.4838	.5422	.6099	.6877
80	988.210	.3643	.4078	.4557	.5109	.5746	.6477
85	985.160	.3435	.3850	.4305	.4826	.5427	.6117
90	982.009	.3246	.3644	.4076	.4570	.5138	.5791
95	978.760	.3075	.3456	.3869	.4337	.4877	.5495
100	975.414	.2919	.3286	.3679	.4126	.4638	.5225
105	971.974	.2777	.3130	.3507	.3932	.4420	.4979
110	968.441	.2647	.2988	.3349	.3755	.4221	.4754
115	964.815	.2527	.2857	.3203	.3592	.4038	.4547
120	961.100	.2417	.2736	.3070	.3443	.3869	.4356
125	957.294	.2316	.2625	.2946	.3305	.3714	.4180
130	953.400	.2222	.2522	.2832	.3177	.3570	.4018
135	949.418	.2135	.2427	.2727	.3059	.3437	.3868
140	945.349	.2055	.2339	.2629	.2949	.3313	.3728
145	941.193	.1980	.2257	.2538	.2848	.3199	.3599
150	936.953	.1911	.2181	.2453	.2753	.3092	.3478
155	932.629	.1846	.2110	.2375	.2665	.2993	.3366
160	928.221	.1785	.2044	.2301	.2582	.2900	.3261
165	923.731	.1729	.1982	.2233	.2506	.2814	.3163
170	919.160	.1676	.1924	.2168	.2434	.2733	.3072
175	914.509	.1627	.1870	.2108	.2366	.2657	.2986
180	909.779	.1581	.1819	.2052	.2303	.2586	.2906
185	904.972	.1537	.1771	.1999	.2244	.2519	.2831
190	900.088	.1496	.1727	.1950	.2189	.2457	.2760
195	895.130	.1458	.1685	.1903	.2137	.2398	.2694

*Density of water.

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 40.0M-PASCAL

TEMP DEG.C	DENSITY KG/M3	CONCENTRATION, M NACL 0	1	2	3	4	5
200	890.098	.1422	.1645	.1859	.2088	.2343	.2631
205	884.995	.1388	.1608	.1818	.2041	.2291	.2573
210	879.821	.1355	.1573	.1779	.1998	.2242	.2517
215	874.580	.1325	.1540	.1742	.1957	.2195	.2465
220	869.272	.1296	.1508	.1707	.1918	.2151	.2415
225	863.899	.1269	.1479	.1675	.1881	.2110	.2368
230	858.464	.1243	.1450	.1643	.1846	.2071	.2324
235	852.969	.1219	.1424	.1614	.1813	.2033	.2282
240	847.415	.1195	.1398	.1586	.1782	.1998	.2242
245	841.805	.1173	.1374	.1559	.1752	.1964	.2204
250	836.141	.1152	.1351	.1534	.1723	.1932	.2168
255	830.425	.1132	.1330	.1510	.1696	.1902	.2133
260	824.660	.1113	.1309	.1487	.1671	.1873	.2100
265	818.848	.1094	.1289	.1465	.1646	.1845	.2069
270	812.991	.1077	.1270	.1444	.1623	.1819	.2039
275	807.092	.1060	.1252	.1424	.1600	.1793	.2010
280	801.153	.1044	.1234	.1404	.1579	.1769	.1983
285	795.177	.1028	.1217	.1386	.1558	.1746	.1956
290	789.166	.1013	.1201	.1368	.1538	.1723	.1931
295	783.123	.0999	.1186	.1351	.1519	.1702	.1906
300	777.050	.0985	.1171	.1334	.1500	.1681	.1883
305	770.950	.0971	.1156	.1319	.1483	.1661	.1860
310	764.825	.0958	.1142	.1303	.1465	.1642	.1838
315	758.678	.0946	.1129	.1288	.1449	.1623	.1817
320	752.511	.0934	.1116	.1274	.1433	.1605	.1797
325	746.327	.0922	.1103	.1260	.1417	.1587	.1777
330	740.128	.0911	.1091	.1247	.1402	.1570	.1758
335	733.917	.0899	.1079	.1234	.1388	.1554	.1739
340	727.696	.0889	.1068	.1221	.1374	.1538	.1721
345	721.467	.0878	.1057	.1209	.1360	.1523	.1703
350	715.234	.0868	.1046	.1197	.1347	.1508	.1686

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 50.0M-PASCAL

TEMP DEG.C	*DENSITY KG/M3	CONCENTRATION, M NACL					
		0	1	2	3	4	5
0	1023.402	1.7012	1.8610	2.0637	2.3104	2.6026	2.9415
5	1022.742	1.4619	1.6016	1.7768	1.9894	2.2408	2.5321
10	1021.836	1.2711	1.3945	1.5479	1.7332	1.9520	2.2055
15	1020.708	1.1166	1.2268	1.3625	1.5257	1.7181	1.9409
20	1019.377	.9899	1.0892	1.2102	1.3553	1.5261	1.7237
25	1017.857	.8848	.9749	1.0838	1.2138	1.3666	1.5433
30	1016.166	.7966	.8790	.9776	1.0950	1.2327	1.3919
35	1014.314	.7219	.7977	.8876	.9943	1.1192	1.2635
40	1012.313	.6580	.7281	.8106	.9081	1.0221	1.1537
45	1010.173	.6030	.6682	.7443	.8339	.9385	1.0591
50	1007.902	.5552	.6162	.6867	.7694	.8658	.9770
55	1005.506	.5135	.5707	.6363	.7130	.8023	.9051
60	1002.994	.4768	.5307	.5920	.6634	.7464	.8419
65	1000.369	.4444	.4953	.5528	.6195	.6969	.7860
70	997.636	.4156	.4638	.5179	.5804	.6529	.7363
75	994.800	.3898	.4357	.4867	.5455	.6136	.6918
80	991.864	.3667	.4104	.4587	.5142	.5783	.6519
85	988.831	.3458	.3876	.4334	.4859	.5464	.6159
90	985.704	.3270	.3670	.4106	.4603	.5176	.5833
95	982.485	.3099	.3483	.3898	.4371	.4914	.5537
100	979.176	.2943	.3312	.3709	.4159	.4676	.5268
105	975.778	.2801	.3157	.3536	.3966	.4458	.5022
110	972.294	.2670	.3014	.3378	.3788	.4258	.4796
115	968.725	.2550	.2883	.3233	.3626	.4075	.4589
120	965.071	.2440	.2762	.3099	.3476	.3906	.4398
125	961.335	.2339	.2651	.2975	.3338	.3751	.4222
130	957.517	.2245	.2548	.2861	.3210	.3607	.4059
135	953.619	.2158	.2453	.2756	.3091	.3473	.3909
140	949.641	.2077	.2365	.2658	.2982	.3350	.3769
145	945.584	.2003	.2283	.2567	.2880	.3235	.3640
150	941.450	.1933	.2206	.2482	.2785	.3128	.3519
155	937.239	.1868	.2135	.2403	.2697	.3029	.3407
160	932.953	.1808	.2069	.2330	.2615	.2936	.3302
165	928.593	.1751	.2007	.2261	.2538	.2850	.3204
170	924.159	.1698	.1949	.2197	.2466	.2769	.3113
175	919.653	.1649	.1895	.2137	.2399	.2693	.3027
180	915.076	.1603	.1845	.2081	.2336	.2622	.2947

*Density of water.

TABLE 7.ABSOLUTE VISCOSITY OF NACL SOLUTIONS

PRESSURE = 50.0M-PASCAL

TEMP DEG.C	DENSITY KG/M3	CONCENTRATION, M NACL 0	1	2	3	4	5
185	910.430	.1559	.1797	.2028	.2277	.2556	.2872
190	905.715	.1518	.1752	.1978	.2221	.2493	.2801
195	900.933	.1480	.1710	.1932	.2169	.2434	.2735
200	896.085	.1444	.1671	.1888	.2120	.2379	.2672
205	891.174	.1410	.1634	.1847	.2074	.2327	.2614
210	886.200	.1378	.1599	.1808	.2031	.2278	.2558
215	881.165	.1347	.1566	.1772	.1990	.2232	.2506
220	876.070	.1319	.1534	.1737	.1951	.2189	.2457
225	870.919	.1291	.1505	.1704	.1914	.2147	.2410
230	865.711	.1266	.1477	.1673	.1880	.2108	.2366
235	860.449	.1241	.1450	.1644	.1847	.2071	.2324
240	855.135	.1218	.1425	.1616	.1816	.2036	.2284
245	849.771	.1196	.1401	.1590	.1786	.2003	.2247
250	844.359	.1175	.1378	.1565	.1758	.1971	.2211
255	838.900	.1155	.1357	.1541	.1731	.1941	.2177
260	833.397	.1136	.1336	.1518	.1706	.1912	.2144
265	827.852	.1118	.1316	.1496	.1681	.1885	.2113
270	822.267	.1100	.1298	.1475	.1658	.1858	.2083
275	816.643	.1083	.1279	.1455	.1636	.1833	.2055
280	810.984	.1067	.1262	.1436	.1614	.1809	.2028
285	805.290	.1052	.1246	.1418	.1594	.1786	.2002
290	799.565	.1037	.1230	.1400	.1574	.1764	.1976
295	793.811	.1023	.1214	.1384	.1555	.1743	.1952
300	788.029	.1009	.1200	.1367	.1537	.1722	.1929
305	782.222	.0996	.1185	.1352	.1520	.1703	.1907
310	776.392	.0983	.1172	.1337	.1503	.1683	.1885
315	770.541	.0970	.1158	.1322	.1487	.1665	.1864
320	764.671	.0958	.1145	.1308	.1471	.1647	.1844
325	758.784	.0947	.1133	.1294	.1455	.1630	.1824
330	752.883	.0935	.1121	.1281	.1441	.1613	.1806
335	746.970	.0924	.1109	.1268	.1426	.1597	.1787
340	741.047	.0914	.1098	.1256	.1412	.1581	.1769
345	735.115	.0903	.1087	.1243	.1399	.1566	.1752
350	729.177	.0893	.1076	.1232	.1386	.1551	.1735

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

A. PRESSURE IS EQUAL TO 0.1 MPA OR THE VAPOR PRESSURE WHICHEVER IS HIGHER.

	CONCENTRATION, MOLAL KCL						
TEMP. DEG.C	0	.5	1	2	3	4	5
25	.8901	.8989	.9041	.9107	.9234	.9559	1.0217
30	.7972	.8066	.8133	.8243	.8407	.8732	.9321
35	.7192	.7289	.7368	.7512	.7704	.8026	.8558
40	.6529	.6630	.6718	.6888	.7100	.7418	.7902
45	.5962	.6064	.6159	.6349	.6576	.6889	.7331
50	.5471	.5575	.5675	.5880	.6118	.6425	.6832
55	.5044	.5149	.5253	.5468	.5715	.6014	.6391
60	.4670	.4775	.4882	.5106	.5357	.5650	.6000
65	.4340	.4445	.4553	.4783	.5037	.5323	.5649
70	.4047	.4152	.4262	.4495	.4750	.5029	.5335
75	.3785	.3890	.4001	.4237	.4491	.4763	.5050
80	.3551	.3656	.3766	.4003	.4257	.4521	.4792
85	.3341	.3445	.3555	.3792	.4043	.4301	.4557
90	.3151	.3254	.3364	.3600	.3848	.4099	.4342
95	.2976	.3081	.3190	.3424	.3669	.3913	.4144
100	.2821	.2923	.3032	.3264	.3504	.3741	.3962
105	.2679	.2780	.2887	.3116	.3353	.3583	.3794
110	.2548	.2648	.2755	.2981	.3212	.3436	.3638
115	.2428	.2528	.2633	.2856	.3082	.3300	.3494
120	.2318	.2417	.2521	.2740	.2962	.3173	.3360
125	.2217	.2315	.2418	.2633	.2849	.3054	.3235
130	.2124	.2221	.2323	.2533	.2745	.2944	.3118
135	.2038	.2134	.2234	.2441	.2647	.2840	.3010
140	.1959	.2054	.2153	.2356	.2556	.2744	.2908
145	.1886	.1980	.2078	.2276	.2471	.2653	.2813
150	.1818	.1912	.2008	.2202	.2391	.2568	.2724

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

B. PRESSURE IS EQUAL TO 5.0 MPA

CONCENTRATION, MOLAL KCL

TEMP. DEG.C	0	.5	1	2	3	4	5
25	.8891	.8987	.9045	.9119	.9250	.9576	1.0235
30	.7969	.8067	.8139	.8255	.8422	.8748	.9339
35	.7193	.7294	.7377	.7525	.7719	.8042	.8575
40	.6534	.6637	.6727	.6900	.7115	.7433	.7918
45	.5969	.6073	.6169	.6361	.6591	.6904	.7348
50	.5480	.5585	.5686	.5892	.6132	.6440	.6848
55	.5054	.5160	.5264	.5481	.5728	.6029	.6407
60	.4681	.4786	.4893	.5118	.5370	.5664	.6015
65	.4351	.4457	.4565	.4796	.5051	.5337	.5665
70	.4058	.4164	.4274	.4508	.4764	.5043	.5350
75	.3797	.3902	.4013	.4249	.4505	.4777	.5065
80	.3563	.3668	.3779	.4016	.4270	.4535	.4807
85	.3353	.3457	.3568	.3805	.4056	.4314	.4571
90	.3163	.3266	.3376	.3612	.3861	.4112	.4356
95	.2990	.3093	.3203	.3437	.3682	.3926	.4158
100	.2834	.2936	.3044	.3276	.3517	.3755	.3976
105	.2691	.2792	.2900	.3129	.3365	.3596	.3808
110	.2560	.2660	.2767	.2993	.3225	.3449	.3652
115	.2441	.2540	.2645	.2868	.3095	.3313	.3508
120	.2331	.2429	.2533	.2752	.2974	.3186	.3373
125	.2230	.2327	.2430	.2645	.2862	.3067	.3248
130	.2137	.2233	.2335	.2546	.2757	.2957	.3132
135	.2051	.2147	.2247	.2454	.2660	.2853	.3023
140	.1972	.2067	.2165	.2368	.2569	.2757	.2921
145	.1898	.1993	.2090	.2288	.2483	.2666	.2826
150	.1830	.1924	.2020	.2214	.2404	.2581	.2737

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

C. PRESSURE IS EQUAL TO 10.0 MPA

TEMP. DEG.C	CONCENTRATION, MOLAL KCL 0	.5	1	2	3	4	5
25	.8881	.8984	.9049	.9131	.9266	.9593	1.0253
30	.7965	.8069	.8146	.8268	.8438	.8765	.9357
35	.7194	.7299	.7385	.7537	.7734	.8058	.8593
40	.6538	.6644	.6737	.6913	.7129	.7449	.7936
45	.5976	.6082	.6180	.6374	.6605	.6920	.7364
50	.5489	.5595	.5697	.5905	.6147	.6455	.6864
55	.5064	.5171	.5276	.5494	.5743	.6044	.6423
60	.4691	.4798	.4905	.5131	.5384	.5679	.6031
65	.4362	.4469	.4578	.4809	.5064	.5352	.5680
70	.4070	.4176	.4286	.4521	.4777	.5058	.5365
75	.3809	.3915	.4025	.4262	.4518	.4791	.5080
80	.3576	.3680	.3791	.4029	.4283	.4549	.4822
85	.3365	.3469	.3580	.3817	.4070	.4328	.4586
90	.3175	.3279	.3389	.3625	.3874	.4126	.4371
95	.3003	.3106	.3215	.3450	.3695	.3940	.4173
100	.2846	.2948	.3057	.3289	.3530	.3768	.3990
105	.2704	.2804	.2912	.3142	.3379	.3610	.3822
110	.2573	.2673	.2780	.3006	.3238	.3463	.3666
115	.2453	.2553	.2658	.2881	.3108	.3326	.3522
120	.2344	.2442	.2546	.2765	.2987	.3199	.3387
125	.2243	.2340	.2443	.2658	.2875	.3081	.3262
130	.2150	.2246	.2348	.2559	.2770	.2970	.3145
135	.2064	.2160	.2260	.2466	.2673	.2867	.3037
140	.1984	.2079	.2178	.2381	.2582	.2770	.2935
145	.1911	.2005	.2103	.2301	.2496	.2679	.2839
150	.1843	.1937	.2033	.2227	.2417	.2594	.2750

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

D. PRESSURE IS EQUAL TO 15.0 MPA

TEMP. DEG.C	CONCENTRATION, MOLAL KCL 0	.5	1	2	3	4	5
25	.8870	.8982	.9053	.9143	.9281	.9610	1.0272
30	.7961	.8071	.8152	.8280	.8453	.8782	.9375
35	.7195	.7304	.7393	.7550	.7749	.8075	.8610
40	.6543	.6652	.6746	.6926	.7144	.7465	.7953
45	.5983	.6091	.6191	.6387	.6620	.6935	.7381
50	.5498	.5605	.5709	.5918	.6161	.6470	.6881
55	.5074	.5182	.5288	.5507	.5757	.6059	.6439
60	.4702	.4809	.4918	.5144	.5398	.5694	.6047
65	.4374	.4480	.4590	.4822	.5078	.5367	.5696
70	.4082	.4188	.4299	.4534	.4791	.5072	.5380
75	.3822	.3927	.4038	.4275	.4532	.4806	.5095
80	.3588	.3693	.3804	.4042	.4297	.4564	.4837
85	.3378	.3482	.3593	.3830	.4083	.4343	.4601
90	.3188	.3291	.3401	.3638	.3888	.4140	.4385
95	.3016	.3118	.3228	.3462	.3708	.3954	.4187
100	.2859	.2961	.3069	.3302	.3544	.3782	.4005
105	.2716	.2817	.2925	.3154	.3392	.3623	.3836
110	.2586	.2686	.2792	.3019	.3251	.3476	.3680
115	.2466	.2565	.2671	.2893	.3121	.3340	.3536
120	.2356	.2455	.2559	.2778	.3000	.3213	.3401
125	.2255	.2353	.2456	.2671	.2888	.3094	.3276
130	.2162	.2259	.2360	.2571	.2783	.2983	.3159
135	.2077	.2172	.2272	.2479	.2686	.2880	.3050
140	.1997	.2092	.2191	.2394	.2595	.2783	.2948
145	.1924	.2018	.2115	.2314	.2509	.2692	.2853
150	.1856	.1950	.2045	.2240	.2430	.2607	.2764

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

E. PRESSURE IS EQUAL TO 20.0 MPA

TEMP. DEG.C	CONCENTRATION, MOLAL KCL 0	.5	1	2	3	4	5
25	.8860	.8979	.9057	.9155	.9297	.9628	1.0290
30	.7958	.8073	.8159	.8292	.8469	.8798	.9393
35	.7197	.7310	.7401	.7562	.7764	.8091	.8628
40	.6548	.6659	.6756	.6938	.7159	.7481	.7970
45	.5990	.6100	.6201	.6400	.6634	.6951	.7398
50	.5506	.5616	.5720	.5931	.6175	.6486	.6897
55	.5084	.5193	.5299	.5520	.5771	.6075	.6455
60	.4713	.4821	.4930	.5158	.5412	.5709	.6063
65	.4385	.4492	.4602	.4835	.5092	.5381	.5711
70	.4094	.4200	.4311	.4547	.4805	.5087	.5396
75	.3834	.3939	.4050	.4288	.4545	.4820	.5111
80	.3600	.3705	.3816	.4055	.4310	.4578	.4852
85	.3390	.3494	.3605	.3843	.4096	.4357	.4616
90	.3200	.3304	.3414	.3651	.3901	.4154	.4400
95	.3028	.3131	.3240	.3475	.3722	.3968	.4202
100	.2872	.2973	.3082	.3315	.3557	.3796	.4019
105	.2729	.2830	.2937	.3167	.3405	.3637	.3850
110	.2598	.2698	.2805	.3031	.3264	.3490	.3694
115	.2479	.2578	.2683	.2906	.3134	.3353	.3550
120	.2369	.2467	.2571	.2791	.3013	.3226	.3415
125	.2268	.2365	.2468	.2683	.2901	.3107	.3290
130	.2175	.2272	.2373	.2584	.2796	.2997	.3173
135	.2089	.2185	.2285	.2492	.2699	.2893	.3064
140	.2010	.2105	.2204	.2406	.2607	.2796	.2962
145	.1937	.2031	.2128	.2327	.2522	.2706	.2866
150	.1869	.1962	.2058	.2252	.2443	.2620	.2777

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

F. PRESSURE IS EQUAL TO 25.0 MPA

CONCENTRATION, MOLAL KCL

TEMP. DEG.C	0	.5	1	2	3	4	5
25	.8850	.8977	.9061	.9167	.9313	.9645	1.0309
30	.7954	.8075	.8165	.8305	.8484	.8815	.9410
35	.7198	.7315	.7409	.7575	.7779	.8107	.8645
40	.6552	.6666	.6766	.6951	.7174	.7497	.7987
45	.5997	.6109	.6212	.6413	.6649	.6967	.7415
50	.5515	.5626	.5731	.5944	.6189	.6501	.6914
55	.5094	.5204	.5311	.5533	.5785	.6090	.6471
60	.4724	.4832	.4942	.5171	.5426	.5724	.6078
65	.4397	.4504	.4614	.4848	.5106	.5396	.5727
70	.4106	.4212	.4323	.4560	.4818	.5101	.5411
75	.3846	.3952	.4063	.4301	.4559	.4834	.5126
80	.3613	.3718	.3829	.4068	.4324	.4592	.4867
85	.3403	.3507	.3618	.3856	.4110	.4371	.4631
90	.3213	.3316	.3426	.3664	.3914	.4168	.4414
95	.3041	.3143	.3253	.3488	.3735	.3981	.4216
100	.2884	.2986	.3094	.3327	.3570	.3810	.4033
105	.2741	.2842	.2950	.3180	.3418	.3651	.3865
110	.2611	.2711	.2817	.3044	.3277	.3503	.3708
115	.2492	.2590	.2696	.2919	.3147	.3367	.3564
120	.2382	.2480	.2584	.2803	.3026	.3239	.3429
125	.2281	.2378	.2481	.2696	.2914	.3121	.3303
130	.2188	.2284	.2386	.2597	.2809	.3010	.3187
135	.2102	.2198	.2298	.2505	.2712	.2906	.3077
140	.2023	.2118	.2216	.2419	.2620	.2809	.2975
145	.1949	.2044	.2141	.2339	.2535	.2719	.2880
150	.1881	.1975	.2071	.2265	.2455	.2634	.2791

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

G. PRESSURE IS EQUAL TO 30.0 MPA

TEMP. DEG.C	CONCENTRATION, MOLAL KCL 0	.5	1	2	3	4	5
25	.8839	.8975	.9064	.9179	.9329	.9662	1.0327
30	.7951	.8077	.8171	.8317	.8499	.8832	.9428
35	.7199	.7320	.7418	.7588	.7794	.8124	.8663
40	.6557	.6674	.6775	.6964	.7188	.7513	.8004
45	.6004	.6118	.6222	.6426	.6663	.6982	.7431
50	.5524	.5636	.5742	.5957	.6204	.6516	.6930
55	.5104	.5214	.5323	.5546	.5799	.6105	.6487
60	.4735	.4844	.4954	.5184	.5440	.5739	.6094
65	.4408	.4516	.4627	.4861	.5120	.5411	.5743
70	.4118	.4224	.4336	.4573	.4832	.5116	.5427
75	.3858	.3964	.4075	.4314	.4573	.4849	.5141
80	.3625	.3730	.3841	.4081	.4337	.4606	.4882
85	.3415	.3519	.3630	.3869	.4123	.4385	.4645
90	.3225	.3329	.3439	.3676	.3927	.4182	.4429
95	.3053	.3156	.3265	.3501	.3748	.3995	.4230
100	.2897	.2998	.3107	.3340	.3583	.3823	.4048
105	.2754	.2855	.2962	.3193	.3431	.3664	.3879
110	.2624	.2723	.2830	.3057	.3290	.3517	.3722
115	.2504	.2603	.2708	.2932	.3160	.3380	.3577
120	.2395	.2493	.2597	.2816	.3039	.3253	.3443
125	.2294	.2391	.2494	.2709	.2927	.3134	.3317
130	.2201	.2297	.2398	.2610	.2822	.3023	.3200
135	.2115	.2211	.2310	.2518	.2725	.2920	.3091
140	.2036	.2130	.2229	.2432	.2633	.2823	.2989
145	.1962	.2056	.2154	.2352	.2548	.2732	.2894
150	.1894	.1988	.2083	.2278	.2468	.2647	.2804

TABLE 8. VISCOSITY OF AQUEOUS KCL SOLUTIONS UP TO 150 DEG.C, 35 MPA AND 5 MOLAL. SEE REFERENCE 48.

H. PRESSURE IS EQUAL TO 35.0 MPA

TEMP. DEG.C	CONCENTRATION, MOLAL KCL 0	.5	1	2	3	4	5
25	.8829	.8972	.9068	.9191	.9345	.9679	1.0346
30	.7947	.8079	.8178	.8329	.8515	.8849	.9446
35	.7200	.7325	.7426	.7600	.7809	.8140	.8680
40	.6562	.6681	.6785	.6977	.7203	.7529	.8021
45	.6011	.6127	.6233	.6439	.6678	.6998	.7448
50	.5533	.5646	.5754	.5970	.6218	.6532	.6946
55	.5114	.5225	.5335	.5560	.5813	.6120	.6504
60	.4746	.4855	.4966	.5197	.5454	.5753	.6110
65	.4420	.4528	.4639	.4874	.5134	.5425	.5758
70	.4130	.4237	.4348	.4586	.4846	.5130	.5442
75	.3870	.3976	.4088	.4327	.4586	.4863	.5156
80	.3637	.3742	.3854	.4093	.4351	.4620	.4897
85	.3427	.3532	.3643	.3882	.4136	.4399	.4660
90	.3238	.3341	.3452	.3689	.3941	.4196	.4444
95	.3066	.3168	.3278	.3514	.3761	.4009	.4245
100	.2909	.3011	.3120	.3353	.3596	.3837	.4062
105	.2767	.2867	.2975	.3205	.3444	.3678	.3893
110	.2636	.2736	.2843	.3070	.3303	.3530	.3737
115	.2517	.2616	.2721	.2944	.3173	.3394	.3591
120	.2407	.2505	.2609	.2829	.3052	.3266	.3457
125	.2307	.2404	.2506	.2722	.2940	.3147	.3331
130	.2214	.2310	.2411	.2622	.2835	.3037	.3214
135	.2128	.2223	.2323	.2530	.2738	.2933	.3105
140	.2049	.2143	.2242	.2445	.2646	.2836	.3003
145	.1975	.2069	.2166	.2365	.2561	.2745	.2907
150	.1907	.2000	.2096	.2290	.2481	.2660	.2818

Table 9. Viscosity of selected NaCl - KCl mixtures at temperature and molality shown. Pressures are vapor saturated (vs) values unless otherwise indicated. Data were obtained from References 47 and 57.

Temp. °C	Press. MPa	Molality, NaCl	KCl	Density, g/cm³	Viscosity, cp
25	vs	0.4807	0.2262	1.0262	0.9275
	vs	0.5655	.1414	1.0259	0.9346
	vs	0.6362	.0707	1.0257	0.9408
	vs	0.9614	.4524	1.0538	0.9702
	0.10	1.0044	1.0052	-	1.001
	17.34	1.0044	1.0052	-	1.003
	29.40	1.0044	1.0052	-	1.004
	vs	1.1310	0.2828	1.0529	0.9853
	vs	1.2724	0.1414	1.0521	0.9987
	vs	2.4034	1.1311	1.1274	1.1447
	vs	2.8275	0.7070	1.1255	1.1909
	vs	3.1810	0.3535	1.1243	1.2328
26	0.24	1.9993	1.9958	-	1.130
	18.17	1.9993	1.9958	-	1.136
	31.20	1.9993	1.9958	-	1.141
28	0.10	1.0297	3.0221	-	0.991
	17.89	1.0297	3.0221	-	1.000
	30.99	1.0297	3.0221	-	1.003
40	vs	0.4807	0.2262	1.0207	0.689
	vs	0.5655	0.1414	1.0204	0.693
	vs	0.6362	0.0707	1.0202	0.698
	vs	0.9614	0.4524	1.0477	0.727
	vs	1.1310	0.2828	1.0468	0.737
	vs	1.2724	0.1414	1.0460	0.746
	vs	2.4034	1.1311	1.1202	0.868
	vs	3.1810	0.3535	1.1171	0.925
60	vs	0.4807	0.2262	1.0114	0.499
	vs	0.5655	0.1414	1.0111	0.501
	vs	0.6362	0.0707	1.0108	0.504
	vs	0.9614	0.4524	1.0380	0.531
	vs	1.1310	0.2828	1.0372	0.537
	vs	1.2724	0.1414	1.0363	0.542
	vs	2.4034	1.1311	1.1097	0.642
	vs	2.8275	0.7070	1.1078	0.659
	vs	3.1810	0.3535	1.1064	0.676

Table 9. Continued

Temp. °C	Press. MPa	Molality, NaCl	KCl	Density, g/cm^3	Viscosity, cp
75	vs	0.4816	0.2267	1.0033	0.407
	vs	0.5666	0.1417	1.0028	0.409
	vs	0.6375	0.0708	1.0024	0.411
	vs	0.9632	0.4533	1.0298	0.435
	vs	1.1333	0.2833	1.0291	0.439
	vs	1.2749	0.1417	1.0285	0.444
	vs	2.4078	1.1332	1.1014	0.531
	vs	2.8329	0.7083	1.0998	0.543
	vs	3.1869	0.3541	1.0983	0.556
78	0.72	1.0297	3.0221	-	0.493
	17.41	1.0297	3.0221	-	0.499
	31.26	1.0297	3.0221	-	0.503
79.5	0.93	1.9993	1.9958	-	0.512
	1.65	1.9993	1.9958	-	0.511
	17.27	1.9993	1.9958	-	0.519
	31.26	1.9993	1.9958	-	0.523
80	0.79	1.0044	1.0052	-	0.423
	1.07	1.0044	1.0052	-	0.424
	17.34	1.0044	1.0052	-	0.428
	31.13	1.0044	1.0052	-	0.432
	0.72	3.0029	1.0008	-	0.536
	0.79	3.0029	1.0008	-	0.537
	1.14	3.0029	1.0008	-	0.539
	1.34	3.0029	1.0008	-	0.536
	10.38	3.0029	1.0008	-	0.540
	16.51	3.0029	1.0008	-	0.540
	23.34	3.0029	1.0008	-	0.545
	23.96	3.0029	1.0008	-	0.544
	30.44	3.0029	1.0008	-	0.549
	31.13	3.0029	1.0008	-	0.549
100	vs	0.4830	0.2273	0.9873	0.306
	vs	0.5683	0.1421	0.9867	0.307
	vs	0.6393	0.0710	0.9865	0.309
	vs	0.9660	0.4546	1.0139	0.330
	vs	1.1366	0.2842	1.0132	0.333
	vs	1.2787	0.1421	1.0126	0.335
	vs	2.4144	1.1363	1.0859	0.407
	vs	2.8408	0.7102	1.0843	0.415
	vs	3.1957	0.3551	1.0827	0.423

Table 9. Continued

Temp. °C	Press. MPa	Molality, NaCl	KCl	Density, g/cm^3	Viscosity, cp
125	vs	0.4858	0.2286	0.9690	0.243
	vs	0.5715	0.1429	0.9684	0.243
	vs	0.6429	0.0714	0.9682	0.245
	vs	0.9714	0.4572	0.9962	0.263
	vs	1.1431	0.2858	0.9954	0.264
	vs	1.2862	0.1429	0.9947	0.266
	vs	2.4274	1.1424	1.0692	0.261
	vs	2.8563	0.7141	1.0677	0.333
	vs	3.2130	0.3570	1.0661	0.338
132	0.93	1.0297	3.0221	-	0.305
	1.96	1.0297	3.0221	-	0.305
	17.48	1.0297	3.0221	-	0.309
	31.54	1.0297	3.0221	-	0.313
139	0.72	1.0297	3.0221	-	0.288
	17 50	1.0297	3.0221	-	0.291
150	vs	0.4909	0.231	0.9484	0.201
	vs	0.5774	0.1444	0.9480	0.201
	vs	0.6495	0.0722	0.9477	0.203
	vs	0.9813	0.4618	0.9766	0.218
	vs	1.1549	0.2888	0.9757	0.219
	vs	1.2996	0.1444	0.975	0.221
	vs	2.4512	1.1536	1.0517	0.275
	vs	2.8848	0.7212	1.0502	0.279
	vs	3.2448	0.3606	1.0485	0.282
	0.79	1.9993	1.9958	-	0.278
	0.86	1.9993	1.9958	-	0.278
	16.51	1.9993	1.9958	-	0.283
	31.26	1.9993	1.9958	-	0.289
151	0.79	1.0044	1.0052	-	0.228
	1.14	1.0044	1.0052	-	0.227
	1.34	1.0044	1.0052	-	0.228
	14.72	1.0044	1.0052	-	0.232
	15.68	1.0044	1.0052	-	0.232
152	0.80	3.0029	1.0008	-	0.283
	1.07	3.0029	1.0008	-	0.285
	17.34	3.0029	1.0008	-	0.288
	31.13	3.0029	1.0008	-	0.292

Table 10. Relative viscosity of $CaCl_2$ solutions (56).

Temp. °C	Concentration, molal					
	0.474	1.018	1.672	2.266	3.003	4.457
10	1.129	1.318	1.540	1.871	-	-
20	1.140	1.337	1.583	1.936	2.406	4.32
30	1.150	1.356	1.604	1.978	2,447	4.322
40	1.154	1.353	1.637	1.989	2.485	4.335
50	1.162	1.369	1.649	2.013	2.497	4.277
60	1.164	1.389	1.663	2.035	2.524	4.209
70	1.170	1.390	1.675	-	2.538	4.205
80	1.151	1.376	1.655	2.020	2.499	4.145
90	1.129	1.341	1.608	1.932	2.437	4.106

Table 10. Continued (68)

Molality	Relative Viscosity 20°C	25°C	30°C	40°C	50°C
0	1.002	0.8903	0.7972	0.6525	0.5464
0.266	1.0806	1.0835	1.0860	1.0907	1.0937
0.520	1.1579	1.1634	1.1686	1.1765	1.1827
0.837	1.2631	1.2720	1.2801	1.2938	1.3033
1.532	1.5421	1.5575	1.5716	1.5939	1.6120
1.740	1.6414	1.6583	1.6745	1.6998	1.7199
2.194	1.8883	1.9092	1.9284	1.9600	1.9841
2.680	2.2129	2.2368	2.2589	2.2945	2.3221
3.160	2.6117	2.6355	2.6580	2.6984	2.7269
3.662	3.1494	3.1727	3.1937	3.2276	3.2487
3.704	3.1990	3.2215	3.2416	3.2746	3.2968
4.425	4.2893	4.2964	4.3002	4.3016	4.2939
4.575	4.5723	4.5718	4.5694	4.5606	4.5388
5.097	5.7717	4.7337	5.6991	5.6280	5.5564

Table 11. Viscosity of selected NaCl - $CaCl_2$ mixtures at temperature and molality shown; pressure is saturated vapor pressure (11,43,58).

Temp. °C	Molality, NaCl	Molality, $CaCl_2$	Density, g/cm^3	Viscosity, cp
20	0.9006	-	-	1.076
	0.9006	0.474	1.078	1.248
	0.9006	1.00	1.125	1.494
	0.9006	2.252	1.221	2.46
	0.8063	3.003	1.267	3.08
	0.1728	4.438	1.325	4.79
30	0.9006	-	-	0.8641
	0.9006	0.474	1.072	1.009
	0.9006	1.00	1.119	1.214
	0.9006	2.252	1.216	1.93
	0.8063	3.003	1.262	2.46
	0.1728	4.438	1.319	3.79
40	0.9006	-	-	0.7093
	0.9006	0.474	1.068	0.833
	0.9006	1.00	1.114	1.002
	0.9006	2.252	1.210	1.58
	0.8063	3.003	1.256	2.02
	0.1728	4.438	1.313	3.08
50	0.9006	-	-	0.5972
	0.9006	0.474	1.063	0.701
	0.9006	1.00	1.109	0.840
	0.9006	2.252	1.205	1.32
	0.8063	3.003	1.251	1.68
	0.1728	4.438	1.307	2.53
60	0.9006	-	-	0.5119
	0.9006	0.474	1.058	0.601
	0.9006	1.00	1.104	0.713
	0.9006	2.252	1.200	1.12
	0.8063	3.003	1.245	1.42
	0.1728	4.438	1.302	2.12
70	0.9006	-	-	0.4453
	0.9006	0.474	1.054	0.528
	0.9006	1.00	1.099	0.629
	0.9006	2.252	1.195	0.974
	0.8063	3.003	1.240	1.24
	0.1728	4.438	1.296	1.81

Table 11. Continued

Temp. °C	Molality, NaCl	CaCl$_2$	Density, g/cm^3	Viscosity, cp
80	0.9006	-	-	0.3922
	0.9006	0.474	1.050	0.453
	0.9006	1.00	1.094	0.546
	0.9006	2.252	1.190	0.852
	0.8063	3.003	1.234	1.08
	0.1728	4.438	1.290	1.58
90	0.9006	-	-	0.349
	0.9006	0.474	1.044	0.392
	0.9006	1.00	1.088	0.472
	0.9006	2.252	1.185	0.758
	0.8063	3.003	-	-
	0.1728	4.438	1.284	1.38

Table 12. Interpolated values for the relative viscosity of $CaCl_2$ solutions.

TEMP.	CONCENTRATION, MOLAL $CaCl_2$				
DEG.C	0.25	0.5	1	2	3
20	1.069	1.146	1.321	1.785	2.488
25	1.071	1.149	1.328	1.797	2.463
30	1.073	1.152	1.334	1.809	2.477
35	1.074	1.155	1.341	1.823	2.492
40	1.075	1.159	1.348	1.836	2.507
45	1.078	1.163	1.355	1.849	2.523
50	1.079	1.166	1.363	1.860	2.537
55	1.082	1.170	1.371	1.877	2.555
60	1.084	1.175	1.379	1.892	2.570
65	1.086	1.179	1.388	1.907	2.586
70	1.088	1.184	1.397	1.923	2.604

Figures

1. Difference between viscosity values calculated from eq 9, and data from References 19, 20, 21, 26, 37 and 53.

2. Relative viscosity of NaCl solutions up to 350°C, at concentrations shown.

3. Effect of concentration on viscosity of NaCl solutions up to 5 m, at temperatures shown.

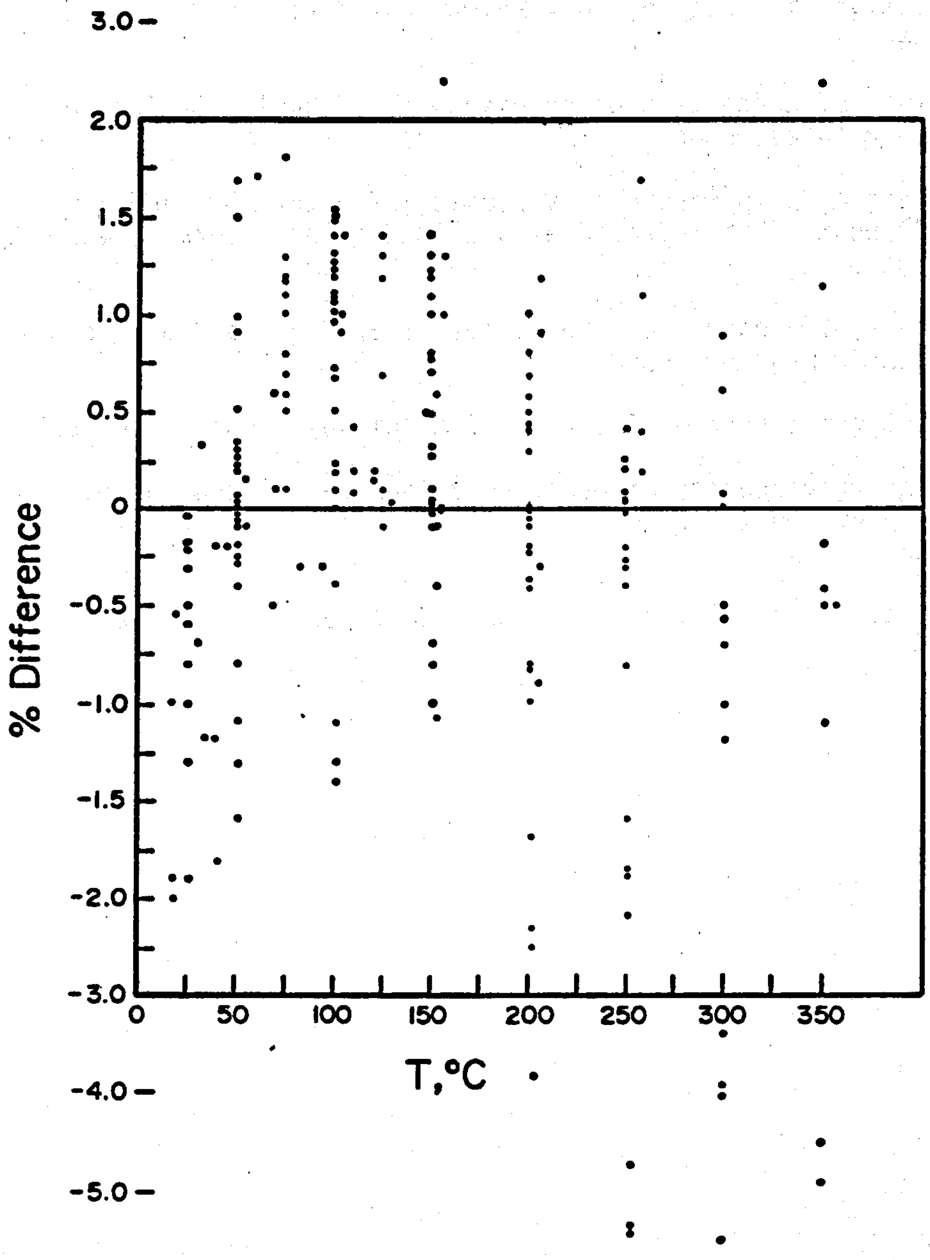
4. Effect of temperature on viscosity of water, 3 m and 5 m solutions of NaCl up to 350°C; pressures are 30 MPa and saturated vapor pressure values.

5. Effect of pressure on the viscosity of 0.2 m and 5 m solutions of NaCl up to 50 MPa and 350°C.

6. Relative viscosity of 0.5 m - 5 m KCl solutions up to 150°C.

7. Relative viscosity of $CaCl_2$ solutions calculated on basis of the Vand equation, 0.25 m - 4 m, 20 - 70°C: _____ calculated; O Ref. 44; ● Ref. 56.

8. Relative viscosity of KCl, NaCl, $CaCl_2$ and $LaCl_3$ at 20°C.



3.0
2.0
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
-2.0
-3.0
-4.0
-5.0
% Difference
0
50
100
150
200
250
300
350
T,°C

Figure 1

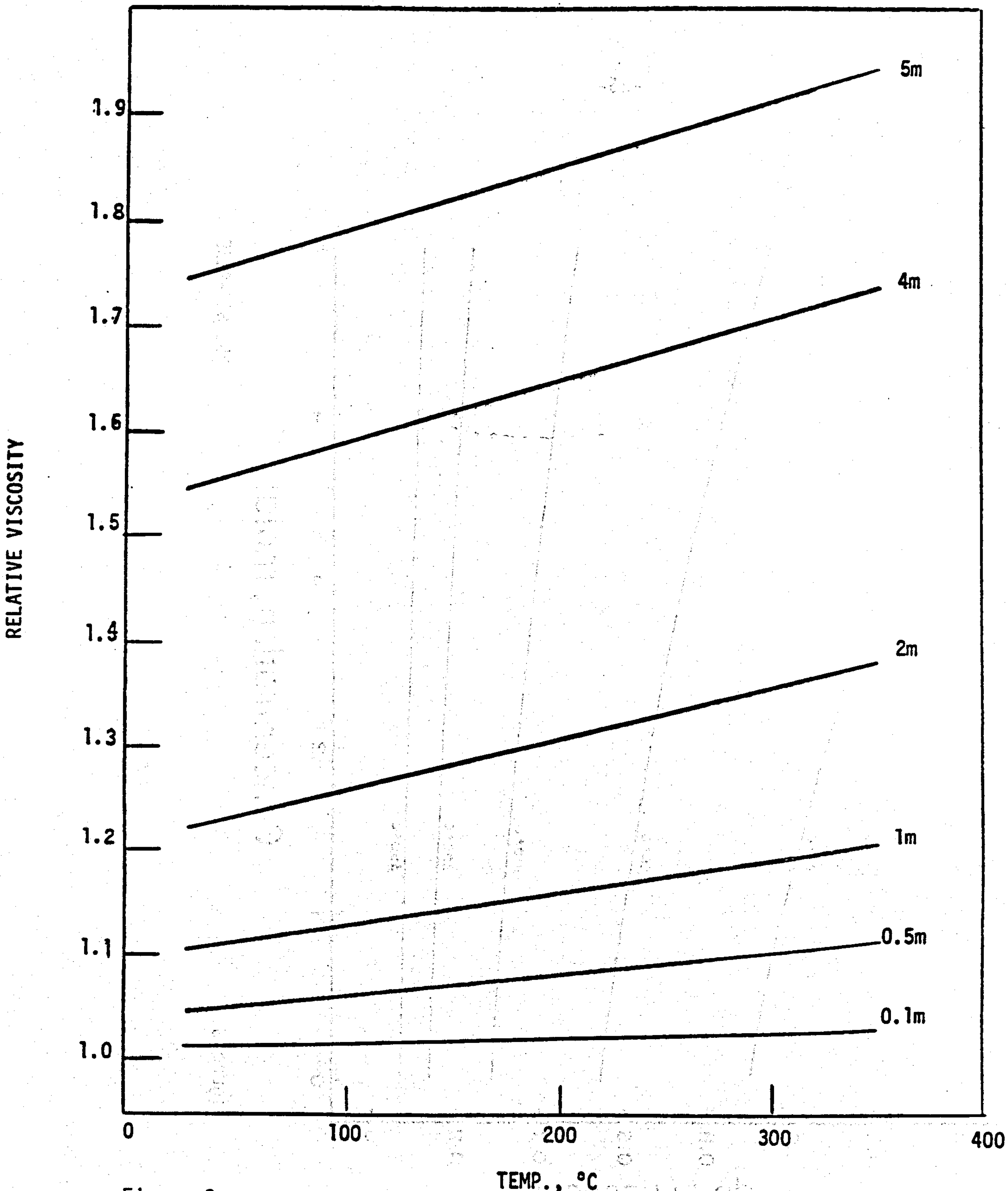

5m
4m
2m
1m
0.5m
0.1m
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
RELATIVE VISCOSITY
0
100
200
300
400
TEMP., °C

Figure 2

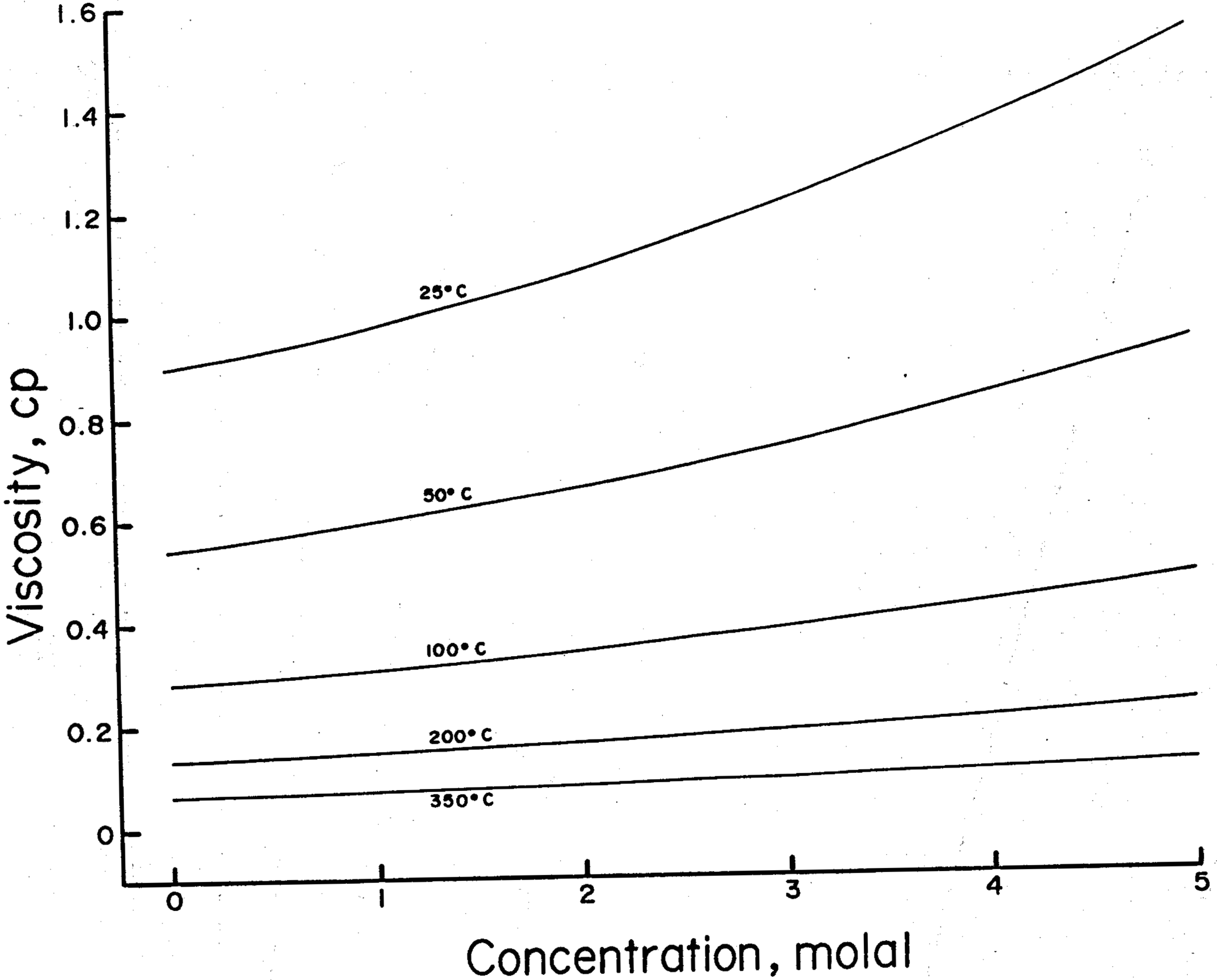


Figure 3

XBL 804-9165

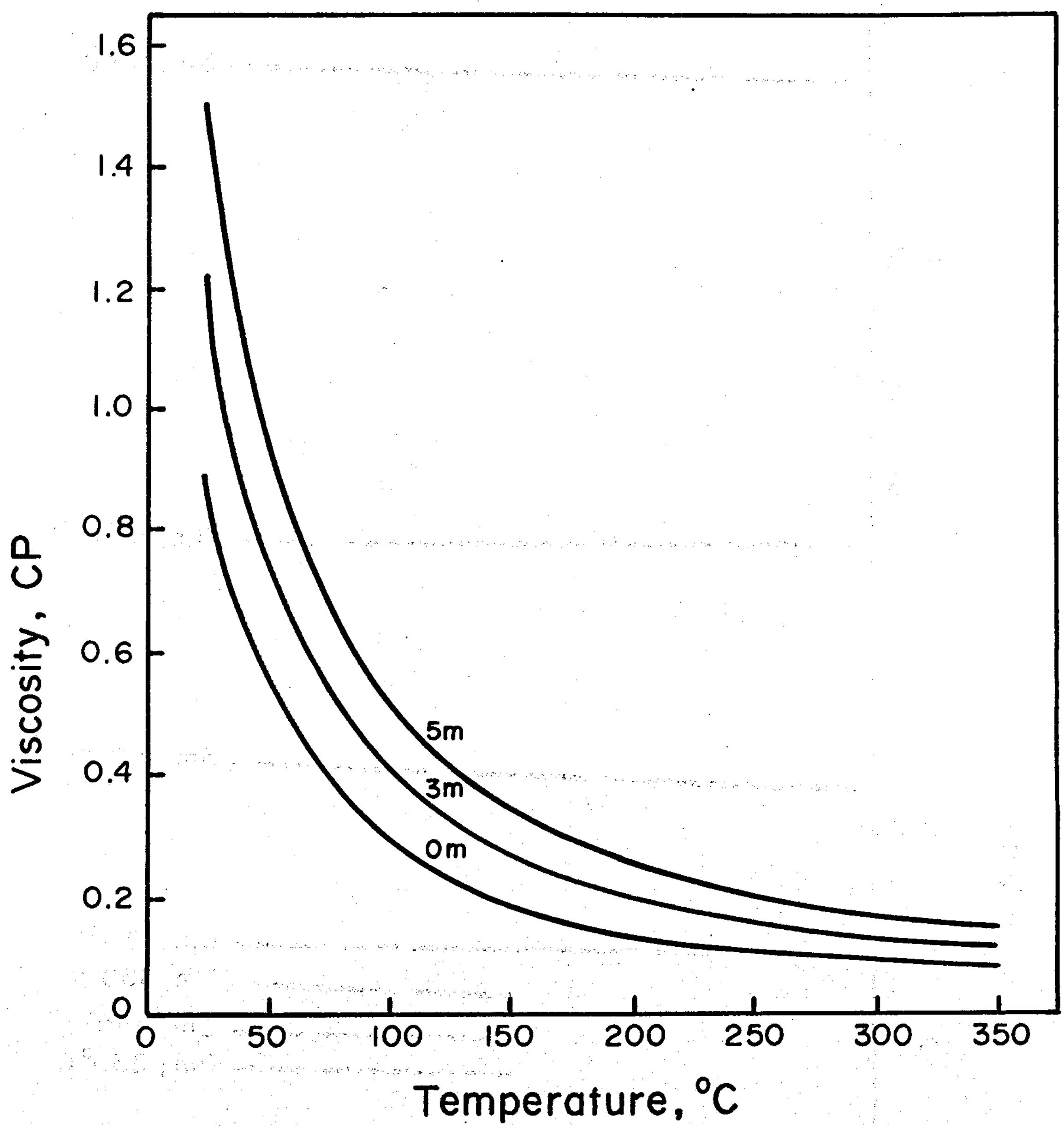


Figure 4 XBL 8010-12297

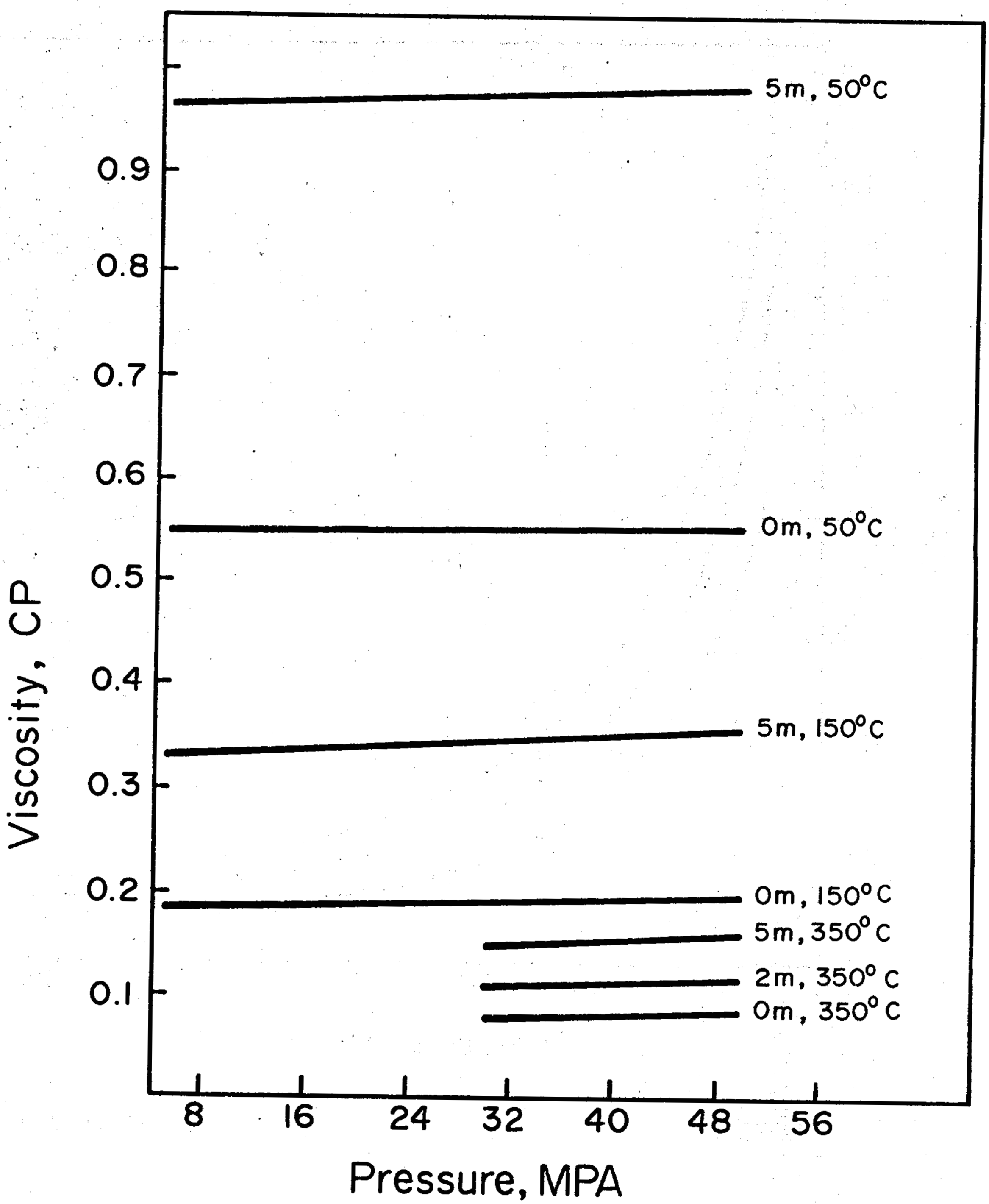
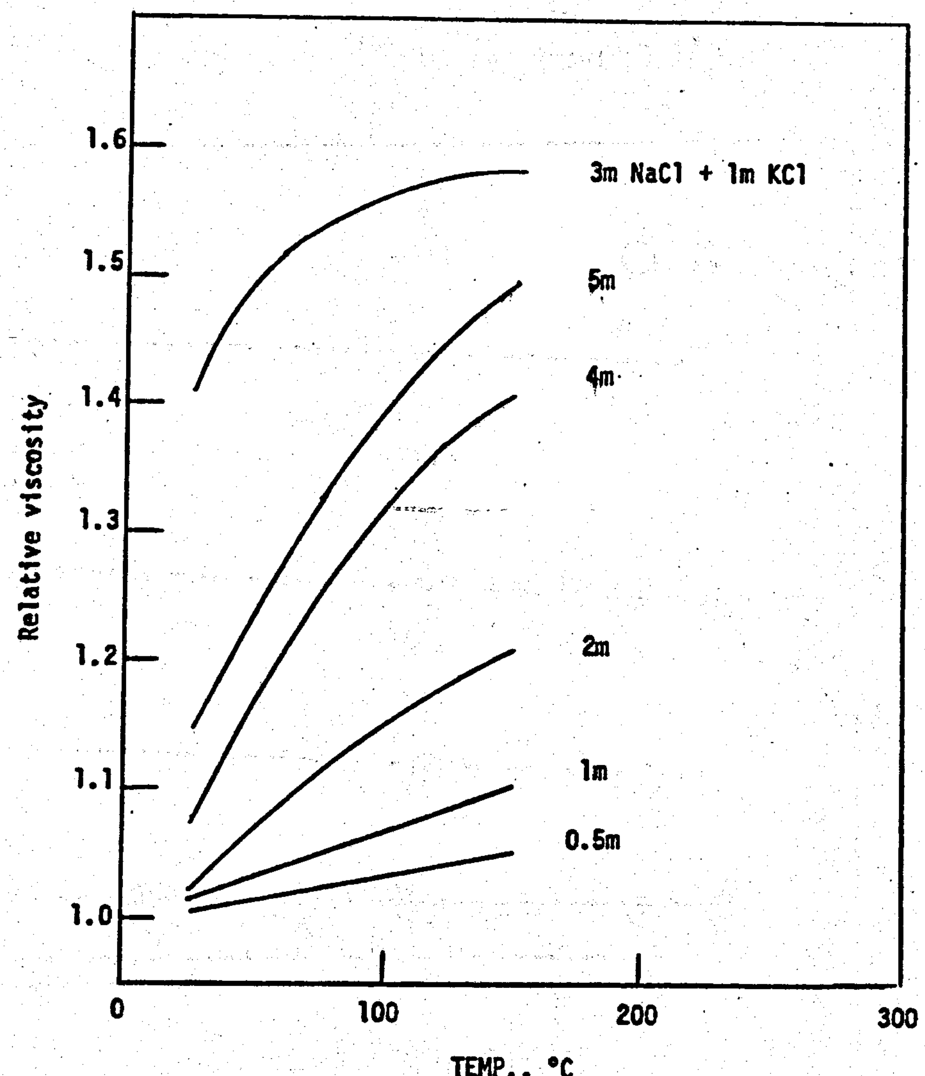


Figure 5

XBL 8010-12298



Relative viscosity of potassium chloride solutions; data obtained from Kestin, Khalifa and Correia (1978)

Figure 6 XBL 808-11240

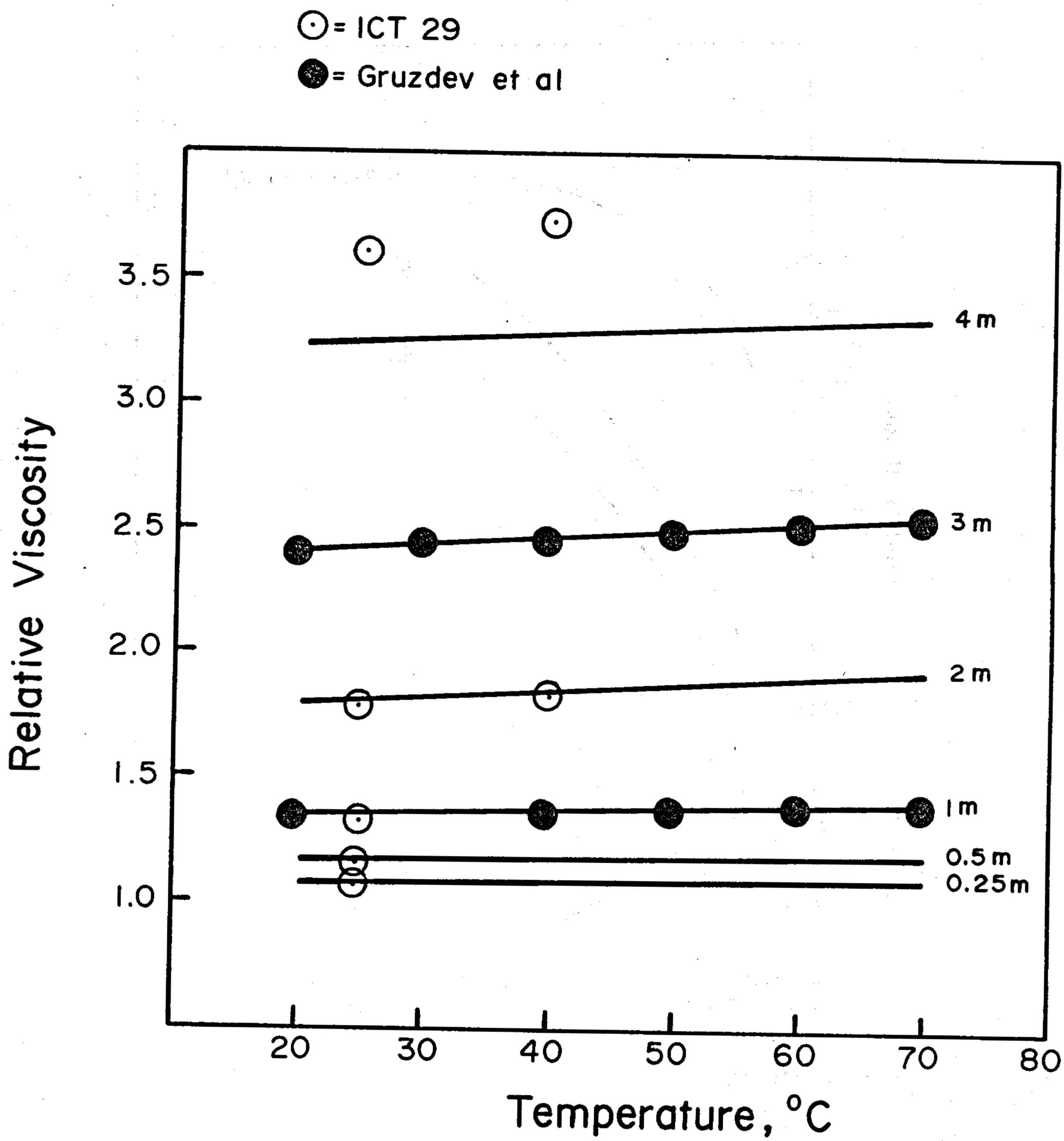


Figure 7

XBL 8010-12296

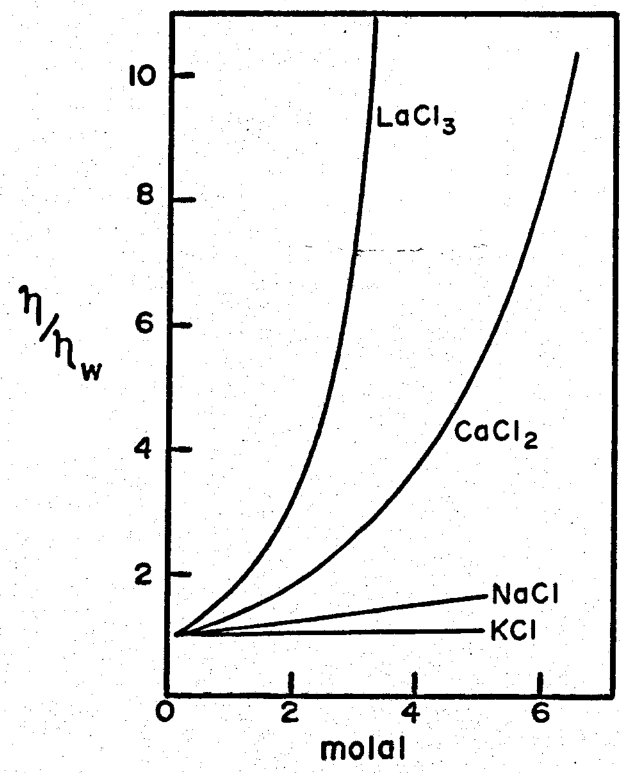


Figure 8 XBL 808-11239