**Title**

THERMAL CONDUCTIVITY OF AQUEOUS NaCl SOLUTIONS FROM 20oC TO 330oC



**Authors**

Ozbek, H.
Phillips, S.L.

**Publication Date**

1979-05-01

LBL- 9086

# THERMAL CONDUCTIVITY OF AQUEOUS NaCl SOLUTIONS FROM 20°C TO 330°C

By

Huseyin Ozbek and
Sidney L. Phillips

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720



Supported by the U.S. Department of Energy, Office of Basic Energy Science, Division of Engineering, Mathematical and Geosciences

## DISCLAIMER

# TABLE OF CONTENTS

Abstract

An evaluation of published data on the thermal conductivity of aqueous NaCl solutions is presented. The literature was screened from 1929 through 1979, and the evaluated data were tabulated. The data were converted where necessary to a set of internally consistent units of °C, watts/m-°C and molal concentrations. An empirical correlation equation with an average deviation of ±2% is given for the thermal conductivity of aqueous NaCl solutions from 20°C to 330°C at saturation pressures. A table of smoothed values generated using this correlation equation is provided for NaCl concentrations between 0 and 5 molal over this temperature range.

## A. Introduction

Thermal conductivity data on aqueous electrolyte solutions are required in the development and utilization of geothermal energy, petroleum recovery, desalination of sea water, and other energy systems involving water containing dissolved salts. Both sea water and geothermal brines contain a large variety of dissolved electrolytes with NaCl the main salt constituent. Consequently, modeling and other studies which require the thermal conductivity of naturally occurring aqueous solutions, such as geothermal fluids, are often based on NaCl solutions (Ref. 1, 2).

This report covers a critical evaluation of the available literature on the thermal conductivity of aqueous NaCl solutions for regions of geothermal interest: temperatures to 350°C, pressures to 500 bars (50 MPa), and concentrations up to saturation. The literature screened in compiling the numerical values covers the time period from 1929 to 1979; earlier data are contained in the International Critical Tables (Ref. 3). The results of this literature survey showed that published numerical data are at atmospheric or vapor saturation pressure, with the highest temperature being 150°C. By far, the most extensive data are contained in graphical form in the report by Yusufova, et al., with over 50 data points between 100°C and 330°C (Ref. 4).

---

Units

1 MPa = 10 bars = 145.04 psi
1 watts/m-°C = 0.578175 Btu/hr-ft-°F = 0.860422 Kcal/hr-m-°C

Density data needed to convert molar to molal concentrations are obtained from the report "Density of NaCl Solutions to 800°C, 200 MPa and Saturation Concentrations" (Ref. 5). Data on the thermal conductivity of water and the corresponding correlation equation are contained in the reports from International Conference on the Properties of Steam (Ref. 6, 7). For a detailed discussion on thermal conductivity and methods for measuring this property, the reader is referred to Touloukian, et al., (Ref. 8).

## B. Analytical Expressions and Correlations

This section covers selected analytical expressions and empirical correlations which have been used to describe the variation in thermal conductivity for NaCl solutions as a function of concentration and temperature.

Based on theoretical considerations, Predvoditelev (Ref. 9) developed the following equation for predicting the thermal conductivity of aqueous solutions:

$$\frac{\lambda}{\lambda_w} = \frac{C_p}{C_{pw}} \left(\frac{\rho}{\rho_w}\right)^{4/3} \left(\frac{M_w}{M}\right)^{1/3} \qquad (1)$$

where

- $\lambda$ : thermal conductivity of aqueous solution
- $\lambda_w$ : thermal conductivity of water
- $C_p$ : heat capacity of aqueous solution
- $C_{pw}$: heat capacity of water
- $\rho$ : density of aqueous solution
- $\rho_w$ : density of water
- $M$ : molecular weight for aqueous solution, determined by additivity rule
- $M_w$ : molecular weight of water

Vargaftik and Os'minin (Ref.10) measured the thermal conductivity of various aqueous solutions including aqueous NaCl solutions at 30°C and found that the deviation between the measured and the predicted values by Equation 1 were no more than 5%. The only exception was aqueous $HNO_3$ solutions, deviation for which showed an increase as the acid concentration increased, reaching a maximum deviation of 12%.

Riedel (Ref. 11) developed an equation which has been widely used to describe the variation in thermal conductivity with temperature and concentration of salt solutions such as NaCl:

$$\lambda = \lambda_w + \sum_i a_i C_i \qquad (2)$$

$a_i$ = experimentally determined coefficient characteristic for each ion, (-0.0047 for $Cl^-$, referred to $Na^+$ as 0)

$C_i$ = concentration of each electrolyte

Korosi and Fabuss (Ref. 12) measured the thermal conductivity for 0.7069m NaCl and 3.5345m NaCl, over the temperature range 25°C-150°C. The authors obtained 12 data points and developed the following polynomial fits for these two concentrations:

$$\begin{aligned} &0.7069\text{m NaCl:} \quad \lambda = 0.540 + 0.001567T - 0.00001397T^2 \\ &3.5345\text{m NaCl:} \quad \lambda = 0.553 + 0.000821T - 0.00000986T^2 \end{aligned} \qquad (3)$$

where

$\lambda$: thermal conductivity, watts/m-°C

T: temperature, °C

The six values for each concentration were reproduced with better than 1% deviation by Equation (3).

Yusufova, et al., (Ref. 4) measured the thermal conductivity of aqueous sodium chloride solutions for temperatures ranging from 20°C to 330°C and concentrations of 5, 10, 15, 20 and 25 weight percent NaCl and developed the following correlation equation which reproduces their experimental data for over 50 values with a deviation of 2%:

$$\frac{\lambda}{\lambda_w} = 1.0 - (2.3434 \times 10^{-3} - 7.924 \times 10^{-6}\, T + 3.924 \times 10^{-8}\, T^2)\, S + (1.06 \times 10^{-5} - 2 \times 10^{-8}\, T + 1.2 \times 10^{-10}\, T^2)\, S^2 \qquad (4)$$

where

$$S = \frac{5844.3 \times m}{1000 + 58.443 \times m}$$

$\lambda$ : thermal conductivity of aqueous NaCl solution

$\lambda_w$: thermal conductivity of water

m : concentration, molality

T : temperature, °C

Numerical data are not available for measurements by Yusufova, et al., and accurate values cannot be obtained from the figures in the publication. For this reason, data by Yusufova, et al., could not be included in Table 1.

Unterberg developed a family of curves which depict the change in thermal conductivity of NaCl solution with temperatures to 149°C for zero to saturation concentrations (Ref. 13). Unterberg assumed that the variation of thermal conductivity with temperature followed the same trend for different concentrations as for pure water.

In summary, correlations are available which reproduce data on the thermal conductivity of NaCl solution in the temperature and concentration regions of interest for the utilization of geothermal energy. However, most of the numerical values are not available, and accurate values cannot be obtained from published graphs.

C. Methods for Measuring Thermal Conductivity

The methods commonly used for measurements of thermal conductivity of aqueous solutions include the following: coaxial cylinders, flat plate, and continuous line source. The first two are steady state methods; the third is a transient method.

Chernen'kaya and Vernigora measured the thermal conductivity of NaCl and other solutions at 25°C and 50°C using a cell comprised of two coaxial thin-walled glass cylinders (Ref. 14). The NaCl solution was placed between the cylinders, and the inner cell was thermostated to 25°C or 50°C for 30 minutes. The difference in temperature across the NaCl solution was measured by a differential thermocouple. The instrument was calibrated with doubly distilled gas-free water, methyl alcohol and benzene. Tufeu, et al., (Ref. 15) also used coaxial cylinder method in their measurements.

Yusufova, et al., used a flat plate method for measuring the thermal conductivity of NaCl from 25°C to 330°C (Ref. 3). The solution was placed between an upper and a lower circular metal plate; the upper plate was maintained at a high temperature to provide downward heat flow to prevent natural convection. A guard heater was located on the periphery both to assure linear heat flow, and to minimize convection. The main difficulties with this method center on maintaining linear heat flow and eliminating convection around the edges of the heated plates.

The non-steady state method such as the continuous line source method has been widely used. In this case, heat is generated at a constant rate in a long, thin wire which is inserted in a large volume of test liquid. The system is initially at a constant temperature; heat is then applied, and the thermal conductivity of NaCl is determined from the measurements of temperature vs. time at a fixed distance from the wire. Vargaftik and Os'minin (Ref.10), Chiquillo (Ref. 16) and Korosi and Fabuss (Ref. 12) used this method in their thermal conductivity measurements.

D. Evaluation and Correlation

The literature scanned for this work covered the time span from 1929 to 1979. The data were converted where necessary to the $^{12}C$ scale of atomic weights, to units of $g/cm^3$ for density, to watts/m-°C for thermal conductivity, from molar to molal concentrations, and from relative values of thermal conductivity to absolute values for NaCl solutions. The required data and interpolating equation for the thermal conductivity of water were taken from the report on the results of the Sixth International Conference on the Properties of Steam (Ref. 6).

The correlation given by Yusufova, et al., (Ref. 4) is the only data available which represents a large number of data points in the temperature and pressure range of geothermal interest. As seen, Equation (5) is the ratio of the thermal conductivity of NaCl solutions to that of pure water. Yusufova used the following equation for liquid water which was contained in the 1968 IFC Formulation, Sixth International Conference on the Properties of Steam (Ref. 6).

$$\lambda_w = -0.92247 + 2.8395 \left(\frac{T + 273.15}{273.15}\right) - 1.8007 \left(\frac{T + 273.15}{273.15}\right)^2 + 0.52577 \left(\frac{T + 273.15}{273.15}\right)^3 - 0.07344 \left(\frac{T + 273.15}{273.15}\right)^4 \quad (5)$$

where

$T$ : temperature, °C

$\lambda_w$: thermal conductivity of water, watts/m-°C

Equation (5) is valid for temperatures ranging from 0°C to 350°C at saturation pressures.

Equations (4) and (5) were used in this work to reproduce and interpolate data on the thermal conductivity of NaCl solutions. Figure 1 shows the variation in thermal conductivity for concentrations from 0 to 5m NaCl and temperatures between 50°C and 300°C. As shown, thermal conductivity decreases almost linearly at each temperature as the concentration increases. Figure 2 is a plot of thermal conductivity versus temperature with concentration as a parameter. Thermal conductivity increases with increasing temperatures up to a broad maximum near 140°C, then decreases as the temperature increases further to 300°C. The thermal conductivity decreases with concentration, by a maximum of 7% for 5m NaCl as compared with pure water. Table 3 contains smoothed values of the thermal conductivity of aqueous NaCl solutions from 20°C to 330°C over the concentration range 0 to 5 molal. Table 2 shows the comparison of the available experimental data with that calculated from Equation (4) and (5). The correlation equation developed by Yusufova, et al., (Ref. 4) reproduces the data by Vargaftik, et al., (Ref.10), Chernen'kaya, et al., (Ref. 14), Chiquillo (Ref. 16), Riedel (Ref. 11), and Kapustinski (Ref. 17) with smaller deviations than the average deviation (2%) of Equation (4) and (5), with one exception, i.e., the thermal conductivity at 30°C and 3.43m measured by Chiquillo (Ref. 16) deviates 2.8% from that predicted by Equation (4) and (5). The data reported by Korosi and Fabuss (Ref. 12), however, have increasing deviation as temperature increases, reaching 32% at 150°C and 3.53m.

## E. Summary and Conclusions

Few experimental data points have been published on the thermal conductivity of NaCl solutions; from 100°C to 150°C there are only the six measurements reported by Korosi and Fabuss (Ref. 12). Data to 330°C reported by Yusufova, et al., (Ref. 4) are not tabulated, but must be calculated from the published correlation. No data are available on the effects of elevated pressures on the thermal conductivity of NaCl solutions. The equation developed by Yusufova, et al., (Ref. 4) was selected for interpolation and used to establish a table of smoothed values for the range 20°C to 330°C and 0 to 5 molal concentration. The available experimental values were compared with these calculated values and the results are shown in Table 2. At a given temperature, thermal conductivity of aqueous NaCl solutions is less than that of pure water, and the maximum difference is about 7% for 5m NaCl concentrations. As the temperature increases, the thermal conductivity initially increases to a broad maximum at about 140°C, then decreases by more than 0.2 watts/m-°C as the temperature is further increased to 330°C.

## F. Recommendations

Additional experimental data should be obtained above 50°C to augment those of Korosi and Fabuss (Ref. 12) and Yusufova, et al., (Ref. 4), and to assist in reconciling the difference in their reported values. Dependence of thermal conductivity on pressure should be investigated.

## G. Acknowledgment

Thanks are given to Y.S. Touloukian, CINDAS, Purdue University, West Lafayette, IN; R.C. Feber, Los Alamos Scientific Laboratory, Los Alamos, NM; Oleh Weres, Lawrence Berkeley Laboratory, Berkeley, CA; and Ken Trompeter, Bureau of Reclamation, Boulder City, NV for their review.

Table 1. Experimental data for thermal conductivity of aqueous NaCl solutions.

| Temperature °C | Concentration molal | Thermal Conductivity watts/m-°C | Reference |
|---|---|---|---|
| 20 | 0.901 | 0.594 | Riedel (Ref. 11) |
| 20 | 1.901 | 0.589 | Riedel (Ref. 11) |
| 20 | 2.700 | 0.590 | Tufeu, et al. (Ref. 15) |
| 20 | 3.020 | 0.583 | Riedel (Ref. 11) |
| 20 | 4.278 | 0.578 | Riedel (Ref. 11) |
| 20 | 4.180 | 0.583 | Tufeu, et al. (Ref. 15) |
| 20 | 5.704 | 0.573 | Riedel (Ref. 11) |
| 20 | 5.770 | 0.574 | Tufeu, et al. (Ref. 15) |
| 25 | 0.707 | 0.574 | Korosi and Fabuss (Ref. 12) |
| 25 | 0.741 | 0.605 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 0.872 | 0.606 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 0.901 | 0.605 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 1.573 | 0.600 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 1.802 | 0.600 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 1.849 | 0.600 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 1.944 | 0.599 | Chernen'kaya and Vernigora (Ref. 14) |
| 25 | 2.534 | 0.595 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 2.716 | 0.595 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 2.878 | 0.596 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 3.535 | 0.567 | Korosi and Fabuss (Ref. 12) |
| 25 | 3.655 | 0.589 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 3.781 | 0.591 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 4.494 | 0.583 | Chernen'kaya and Vernigora (Ref. 14) |
| 25 | 4.521 | 0.587 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 4.883 | 0.587 | Kapustinski and Ruzavin (Ref. 17) |
| 25 | 5.523 | 0.582 | Kapustinski and Ruzavin (Ref. 17) |
| 20-40 | 1.061 | 0.608 | Chiquillo (Ref. 16) |
| 30 | 1.901 | 0.603 | Vargaftik and Os'minin (Ref.10) |
| 20-40 | 1.936 | 0.604 | Chiquillo (Ref. 16) |
| 20-40 | 2.857 | 0.592 | Chiquillo (Ref. 16) |
| 20-40 | 3.434 | 0.581 | Chiquillo (Ref. 16) |
| 30 | 4.278 | 0.589 | Vargaftik and Os'minin (Ref.10) |
| 40 | 2.730 | 0.615 | Tufeu, et al. (Ref. 15) |
| 40 | 4.220 | 0.605 | Tufeu, et al. (Ref. 15) |
| 40 | 5.820 | 0.594 | Tufeu, et al. (Ref. 15) |
| 50 | 0.707 | 0.577 | Korosi and Fabuss (Ref. 12) |
| 50 | 1.944 | 0.635 | Chernen'kaya and Vernigora (Ref. 14) |
| 50 | 3.535 | 0.571 | Korosi and Fabuss (Ref. 12) |
| 50 | 4.494 | 0.617 | Chernen'kaya and Vernigora (Ref. 14) |
| 60 | 2.760 | 0.634 | Tufeu, et al. (Ref. 15) |
| 60 | 4.270 | 0.623 | Tufeu, et al. (Ref. 15) |
| 60 | 5.890 | 0.611 | Tufeu, et al. (Ref. 15) |
| 75 | 0.707 | 0.581 | Korosi and Fabuss (Ref. 12) |
| 75 | 3.535 | 0.557 | Korosi and Fabuss (Ref. 12) |
| 80 | 2.790 | 0.647 | Tufeu, et al. (Ref. 15) |
| 80 | 4.320 | 0.635 | Tufeu, et al. (Ref. 15) |
| 80 | 5.960 | 0.622 | Tufeu, et al. (Ref. 15) |
| 100 | 0.707 | 0.560 | Korosi and Fabuss (Ref. 12) |
| 100 | 3.535 | 0.539 | Korosi and Fabuss (Ref. 12) |
| 125 | 0.707 | 0.518 | Korosi and Fabuss (Ref. 12) |
| 125 | 3.535 | 0.500 | Korosi and Fabuss (Ref. 12) |
| 150 | 0.707 | 0.460 | Korosi and Fabuss (Ref. 12) |
| 150 | 3.535 | 0.455 | Korosi and Fabuss (Ref. 12) |

Table 2. Comparison of experimental data with those calculated from Equation (4) and (5).

| Temperature, Deg. Celsius (°C) | Concentration, Molality (m) | Thermal Conductivity Calculated From Equation (4) and (5), watts/m-°C (λ) | Reference | Measured Thermal Conductivity watts/m-°C ($\lambda_m$) | % Deviation $\frac{\lambda-\lambda_m}{\lambda} \times 100$ |
|---|---|---|---|---|---|
| 30 | 1.901 | 0.606 | Vargaftik and Os'minin (Ref. 10) | 0.603 | 0.5 |
| 30 | 4.278 | 0.594 | Vargaftik and Os'minin (Ref. 10) | 0.589 | 0.8 |
| 25 | 1.944 | 0.598 | Chernen'kaya and Vernigora (Ref. 14) | 0.599 | -0.2 |
| 25 | 4.494 | 0.586 | Chernen'kaya and Vernigora (Ref. 14) | 0.583 | 0.5 |
| 50 | 1.944 | 0.631 | Chernen'kaya and Vernigora (Ref. 14) | 0.635 | -0.6 |
| 50 | 4.494 | 0.619 | Chernen'kaya and Vernigora (Ref. 14) | 0.617 | 0.3 |
| 30 | 1.061 | 0.611 | Chiquillo (Ref. 16) | 0.608 | 0.5 |
| 30 | 1.944 | 0.605 | Chiquillo (Ref. 16) | 0.604 | 0.2 |
| 30 | 2.857 | 0.601 | Chiquillo (Ref. 16) | 0.592 | 1.5 |
| 30 | 3.434 | 0.598 | Chiquillo (Ref. 16) | 0.581 | 2.8 |
| 20 | 0.901 | 0.597 | Riedel (Ref. 11) | 0.594 | 0.5 |
| 20 | 1.901 | 0.591 | Riedel (Ref. 11) | 0.589 | 0.3 |
| 20 | 3.020 | 0.585 | Riedel (Ref. 11) | 0.583 | 0.3 |
| 20 | 4.278 | 0.579 | Riedel (Ref. 11) | 0.578 | 0.2 |
| 20 | 5.704 | 0.574 | Riedel (Ref. 11) | 0.573 | 0.2 |
| 25 | 0.741 | 0.606 | Kapustinski and Ruzavin (Ref. 17) | 0.605 | 0.2 |
| 25 | 0.872 | 0.605 | Kapustinski and Ruzavin (Ref. 17) | 0.606 | -0.2 |
| 25 | 0.901 | 0.605 | Kapustinski and Ruzavin (Ref. 17) | 0.605 | 0.0 |
| 25 | 1.573 | 0.600 | Kapustinski and Ruzavin (Ref. 17) | 0.600 | 0.0 |
| 25 | 1.802 | 0.599 | Kapustinski and Ruzavin (Ref. 17) | 0.600 | -0.2 |
| 25 | 1.849 | 0.599 | Kapustinski and Ruzavin (Ref. 17) | 0.600 | -0.2 |
| 25 | 2.534 | 0.595 | Kapustinski and Ruzavin (Ref. 17) | 0.595 | 0.0 |
| 25 | 2.716 | 0.594 | Kapustinski and Ruzavin (Ref. 17) | 0.595 | -0.2 |
| 25 | 2.878 | 0.593 | Kapustinski and Ruzavin (Ref. 17) | 0.596 | -0.5 |
| 25 | 3.655 | 0.590 | Kapustinski and Ruzavin (Ref. 17) | 0.589 | 0.2 |
| 25 | 3.781 | 0.589 | Kapustinski and Ruzavin (Ref. 17) | 0.591 | -0.3 |
| 25 | 4.521 | 0.586 | Kapustinski and Ruzavin (Ref. 17) | 0.587 | -0.2 |
| 25 | 4.883 | 0.585 | Kapustinski and Ruzavin (Ref. 17) | 0.587 | -0.3 |
| 25 | 5.523 | 0.582 | Kapustinski and Ruzavin (Ref. 17) | 0.582 | 0.0 |
| 20 | 2.700 | 0.590 | Tufeu, et al. (Ref. 15) | 0.586 | 0.7 |
| 20 | 4.180 | 0.583 | Tufeu, et al. (Ref. 15) | 0.580 | 0.5 |
| 20 | 5.770 | 0.574 | Tufeu, et al. (Ref. 15) | 0.574 | 0.0 |
| 40 | 2.730 | 0.615 | Tufeu, et al. (Ref. 15) | 0.615 | 0.0 |
| 40 | 4.220 | 0.605 | Tufeu, et al. (Ref. 15) | 0.608 | -0.5 |
| 40 | 5.820 | 0.594 | Tufeu, et al. (Ref. 15) | 0.602 | -1.3 |
| 60 | 2.760 | 0.634 | Tufeu, et al. (Ref. 15) | 0.637 | -0.5 |
| 60 | 4.270 | 0.623 | Tufeu, et al. (Ref. 15) | 0.630 | -1.1 |
| 60 | 5.890 | 0.611 | Tufeu, et al. (Ref. 15) | 0.624 | -2.1 |
| 80 | 2.790 | 0.647 | Tufeu, et al. (Ref. 15) | 0.653 | -0.9 |
| 80 | 4.320 | 0.635 | Tufeu, et al. (Ref. 15) | 0.646 | -1.7 |
| 80 | 5.960 | 0.622 | Tufeu, et al. (Ref. 15) | 0.640 | -2.9 |

Table 2. Comparison of experimental data with those calculated from Equation (4) and (5). (continued)

| Temperature, Deg. Celsius (°C) | Concentration, Molality (m) | Thermal Conductivity Calculated From Equation (4) and (5), watts/m-°C ($\lambda$) | Reference | Measured Thermal Conductivity watts/m-°C ($\lambda_m$) | % Deviation $\frac{\lambda-\lambda_m}{\lambda} \times 100$ |
|---|---|---|---|---|---|
| 25 | 0.707 | 0.606 | Korosi and Fabuss (Ref. 12) | 0.574 | 5.3 |
| 25 | 3.535 | 0.590 | Korosi and Fabuss (Ref. 12) | 0.567 | 3.9 |
| 50 | 0.707 | 0.638 | Korosi and Fabuss (Ref. 12) | 0.577 | 9.6 |
| 50 | 3.535 | 0.623 | Korosi and Fabuss (Ref. 12) | 0.571 | 8.3 |
| 75 | 0.707 | 0.661 | Korosi and Fabuss (Ref. 12) | 0.581 | 12.1 |
| 75 | 3.535 | 0.646 | Korosi and Fabuss (Ref. 12) | 0.557 | 13.8 |
| 100 | 0.707 | 0.676 | Korosi and Fabuss (Ref. 12) | 0.560 | 17.2 |
| 100 | 3.535 | 0.660 | Korosi and Fabuss (Ref. 12) | 0.539 | 18.3 |
| 125 | 0.707 | 0.682 | Korosi and Fabuss (Ref. 12) | 0.518 | 24.0 |
| 125 | 3.535 | 0.666 | Korosi and Fabuss (Ref. 12) | 0.500 | 24.9 |
| 150 | 0.707 | 0.681 | Korosi and Fabuss (Ref. 12) | 0.460 | 32.5 |
| 150 | 3.535 | 0.665 | Korosi and Fabuss (Ref. 12) | 0.455 | 31.6 |

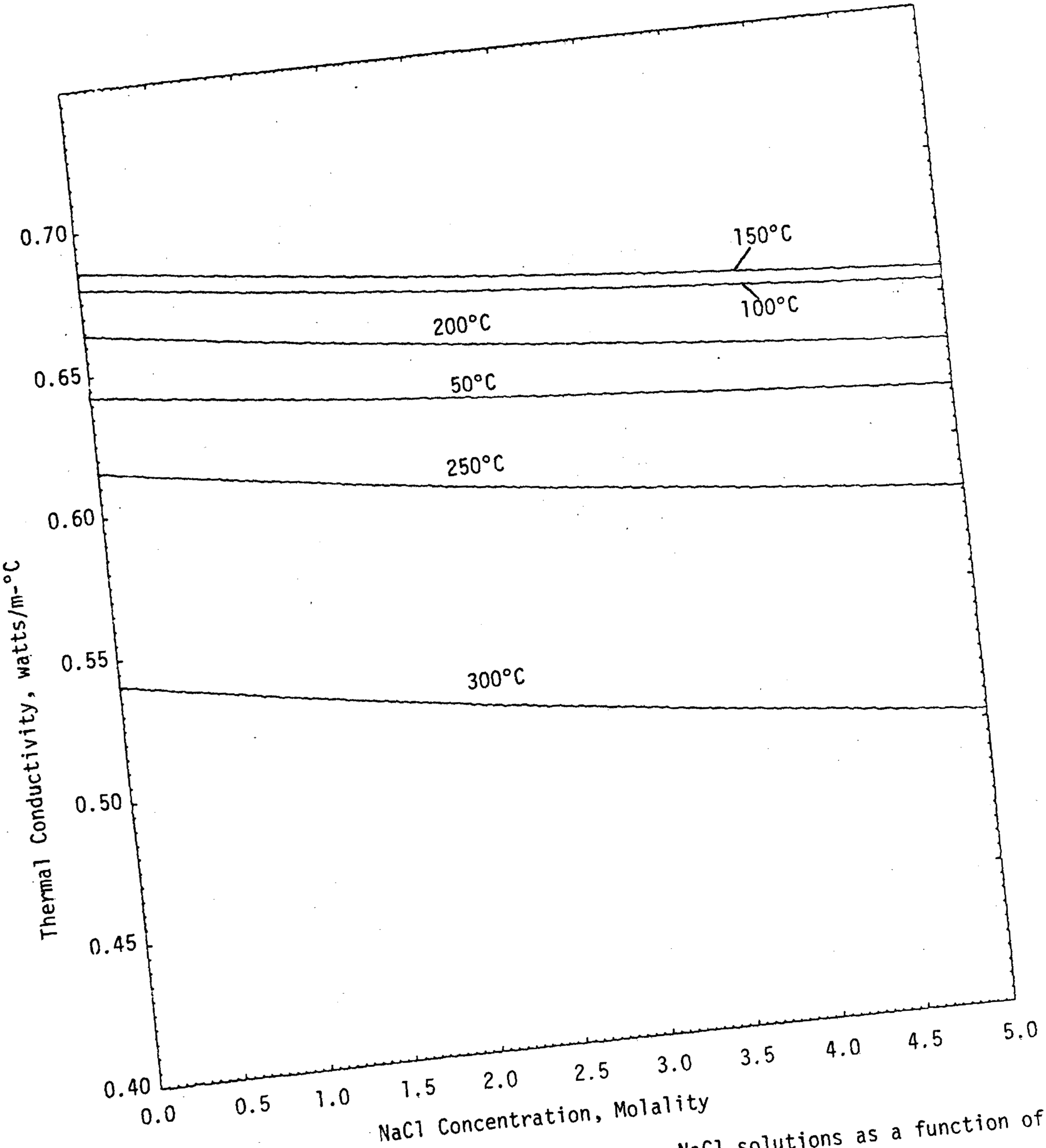


Figure 1. Thermal conductivity of aqueous NaCl solutions as a function of NaCl concentration.

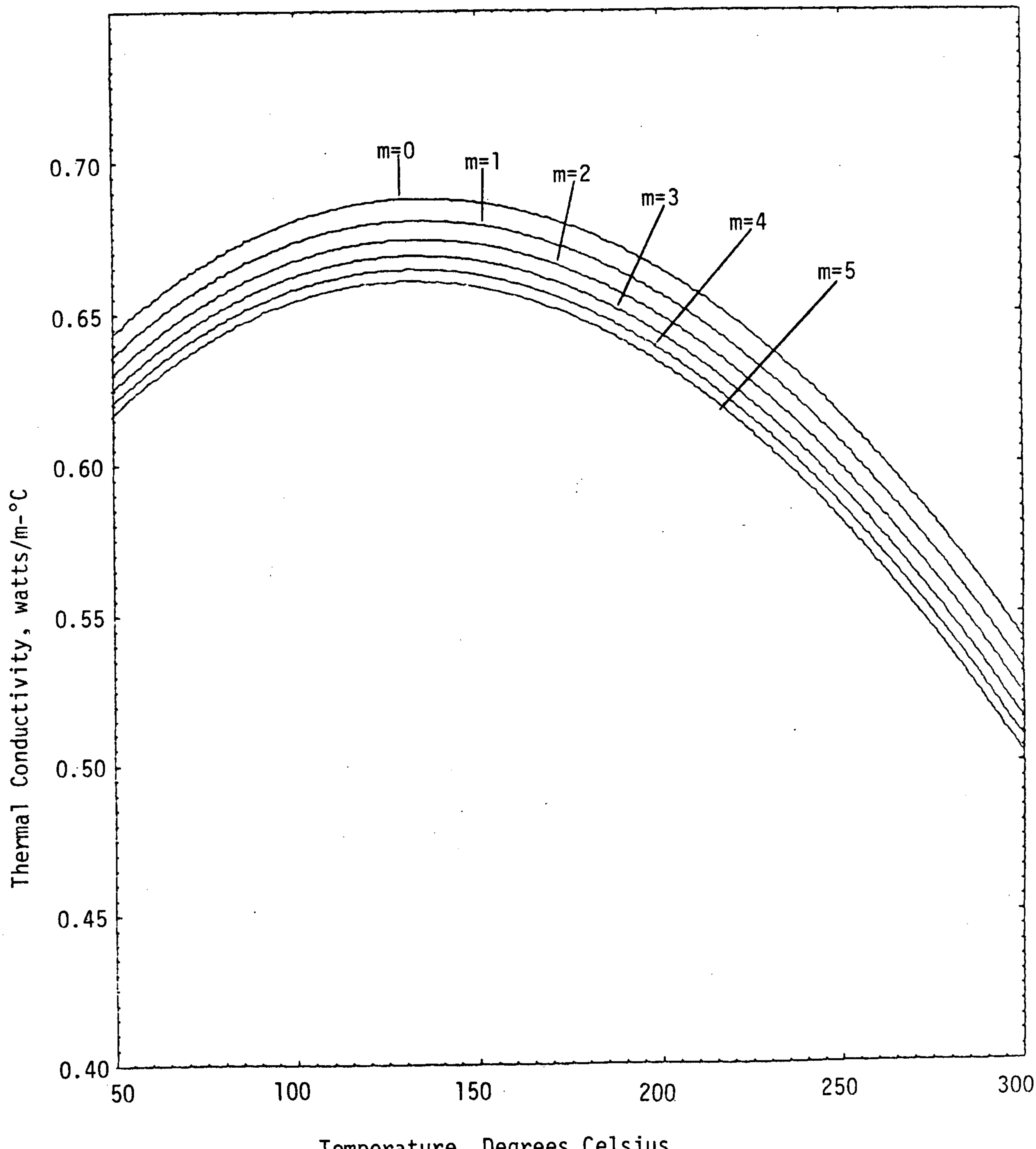


Figure 2. Thermal conductivity of aqueous NaCl solutions as a function of temperature.

Table 3. Recommended values for the thermal conductivity of aqueous NaCl solutions, calculated from Equation (4) and (5), watts/m-°C (λ).

| Temperature, Deg. Celsius (°C) \ Concentration, Molality (m) | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 20 | 0.603 | 0.596 | 0.590 | 0.585 | 0.580 | 0.577 |
| 30 | 0.618 | 0.611 | 0.605 | 0.600 | 0.595 | 0.592 |
| 40 | 0.632 | 0.624 | 0.618 | 0.613 | 0.609 | 0.605 |
| 50 | 0.643 | 0.636 | 0.630 | 0.625 | 0.621 | 0.617 |
| 60 | 0.653 | 0.646 | 0.640 | 0.635 | 0.631 | 0.627 |
| 70 | 0.662 | 0.655 | 0.649 | 0.644 | 0.640 | 0.636 |
| 80 | 0.670 | 0.663 | 0.657 | 0.652 | 0.647 | 0.643 |
| 90 | 0.676 | 0.669 | 0.663 | 0.658 | 0.653 | 0.649 |
| 100 | 0.681 | 0.674 | 0.668 | 0.662 | 0.658 | 0.654 |
| 110 | 0.684 | 0.677 | 0.671 | 0.666 | 0.661 | 0.658 |
| 120 | 0.687 | 0.679 | 0.673 | 0.668 | 0.664 | 0.660 |
| 130 | 0.688 | 0.680 | 0.674 | 0.669 | 0.664 | 0.661 |
| 140 | 0.688 | 0.680 | 0.674 | 0.669 | 0.664 | 0.660 |
| 150 | 0.687 | 0.679 | 0.673 | 0.667 | 0.663 | 0.659 |
| 160 | 0.684 | 0.677 | 0.670 | 0.665 | 0.660 | 0.656 |
| 170 | 0.681 | 0.673 | 0.667 | 0.661 | 0.656 | 0.652 |
| 180 | 0.677 | 0.669 | 0.662 | 0.656 | 0.651 | 0.647 |
| 190 | 0.671 | 0.663 | 0.656 | 0.650 | 0.645 | 0.641 |
| 200 | 0.665 | 0.656 | 0.649 | 0.643 | 0.638 | 0.633 |
| 210 | 0.657 | 0.648 | 0.641 | 0.635 | 0.630 | 0.625 |
| 220 | 0.648 | 0.640 | 0.632 | 0.626 | 0.620 | 0.616 |
| 230 | 0.639 | 0.630 | 0.622 | 0.616 | 0.610 | 0.605 |
| 240 | 0.628 | 0.619 | 0.611 | 0.604 | 0.599 | 0.594 |
| 250 | 0.616 | 0.607 | 0.599 | 0.592 | 0.586 | 0.581 |
| 260 | 0.603 | 0.594 | 0.586 | 0.579 | 0.573 | 0.567 |
| 270 | 0.589 | 0.580 | 0.571 | 0.564 | 0.558 | 0.553 |
| 280 | 0.574 | 0.565 | 0.556 | 0.549 | 0.543 | 0.537 |
| 290 | 0.558 | 0.548 | 0.540 | 0.532 | 0.526 | 0.520 |
| 300 | 0.541 | 0.531 | 0.522 | 0.515 | 0.508 | 0.503 |
| 310 | 0.523 | 0.512 | 0.504 | 0.496 | 0.489 | 0.484 |
| 320 | 0.503 | 0.493 | 0.484 | 0.476 | 0.470 | 0.464 |
| 330 | 0.482 | 0.472 | 0.463 | 0.455 | 0.449 | 0.443 |

H. References

1. A Recommended Research Program in Geothermal Chemistry, Lyon, R.N. and Kolstad, G.A., eds., Department of Energy, WASH-1344, October 1974

2. Symposium on Geothermal Scaling and Corrosion, Congress, American Chemical Society/Chemical Society of Japan, Honolulu, HI, April 1-6, 1979, Chem. Eng. News, 57 (3), P.72 (1979)

3. International Critical Tables, Washburn, E.W., ed., McGraw-Hill Book Co., Inc., NY 10036, Vol. V (1929)

4. Yusufova, V.D., Pepinov, R.I., Nikolaev, V.A., Guseinov, G.M., "Thermal Conductivity of Aqueous NaCl Solutions", Inzh. Fiz. Zh., 29 (4), P.600-605 (1975)

5. Ozbek, H., Otto, R.J., Phillips, S.L., "Density of NaCl Solutions to 800°C, 2000 Bars and Saturation Concentrations", in preparation

6. Haywood, R.W., "Sixth International Conference on the Properties of Steam - Supplement on Transport Properties", J. Eng. Power, 88 (1), P.63-66 (1966)

7. Kestin, J., Whitelaw, J.H., "Sixth International Conference on the Properties of Steam - Transport Properties of Water Substance", J. Eng. Power, P.82-104, January 1966

8. Touloukian, Y.S., Liley, P.E., Saxena, S.C., Thermal Conductivity, Vol. 3, CINDAS, Purdue University, Lafayette, IN., IFI/Plenum Data Corporation, 227 West 17th St., New York, NY 10011 (1970)

9. Predvoditelev, A.S., "Some Invariant Quantities in the Theories of Heat Conductance and of Viscosity of Liquids", J. Phys. Chem. (USSR), 22 (3), P.339-348 (1948)

10. Vargaftik, N.B., Os'minin, Yu.P., "Thermal Conductivity of Aqueous Solutions of Salts, Acids and Alkalies", Teploenergetika, 3 (7), P.11-16 (1956)

11. Riedel, L., "Thermal Conductivities of Aqueous Solutions of Strong Electrolytes", Chem.-Ing.-Technik., 23 (3), P.59-64 (1951); AEC-TR-2501, 23 pages (1962)

12. Korosi, A., Fabuss, B.M., "Thermophysical Properties of Saline Water", U.S. Office Saline Water, Res. Develop. Prog. Rep. 363 (1968)

13. Unterberg, W., Thermophysical Properties of Aqueous Sodium Chloride Solutions, Report No. 64-21, May 1964, Department of Engineering, University of California, Los Angeles, Los Angeles, CA

14. Chernen'kaya, E.I., Vernigora, G.A., "Experimental Determination of Thermal Conductivities of ~~A~~queous Solutions of Salts and Ammonia at 25° and 50°C", Zh. Prikl. Khim., 45 (8), P.1704-1707 (1972)

15. Tufeu, R., LeNeindre, B., Johannin, P., "Notes des Membres et Correspondants et Notes Presentees ou Transmises pour Leurs Soins", C.R. Acad. Sc. Paris, t. 262, Serie B, P.229-231 (1966)

16. Chiquillo, A., "A Measurement of the Relative Thermal Conductivities of Aqueous Salt Solutions by a Non-Steady State Hot-Wire Method", Thesis No. 3955, Eidg. Technische Hochschule, Zurich, Switzerland (1967)

17. Kapustinski, A.F., Ruzavin, I.I., Zh. Fiz. Khim., 29 (12), P.2222-2229 (1955)