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THE THERMOPHYSICAL AND TRANSPORT PROPERTIES OF EUTECTIC NaK NEAR ROOM TEMPERATURE

by

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and Claude B. Reed

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NOMENCLATURE

Symbol (units)	Property
α (m^2/s)	Thermal Diffusivity
c_p [J/(kg·K)]	Specific Heat
k [W/(m·K)]	Thermal Conductivity
L ($W\Omega/K^2$)	Lorentz Number
μ (Pa·s)	Absolute Viscosity
ν (m^2/s)	Kinematic Viscosity
ρ (kg/m^3)	Density
ρ_e ($\mu\Omega$·cm)	Electrical Resistivity
σ (S/m)	Electrical Conductivity
T (^oC, ^oK)	Temperature

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ABSTRACT

The purpose of this report is to compile recommended room temperature thermophysical properties of NaK_{78}. The report was prepared to provide a single unified collection of property values for the eutectic sodium-potassium alloy. These properties include density, kinematic and absolute viscosities, thermal conductivity, specific heat, electrical resistivity, electrical conductivity, Prandtl number, and thermal diffusivity. Each section of the report contains a completely referenced property that focuses on the 0-80°C temperature range. All available data for each property have been taken from original publications. The individual sections are organized following a specific outline, considering:

- discussion of experimental methods,
- discussion of sources of error,
- discussion of each reference,
- tabular presentation of all available data,
- graphical presentation of the data,
- recommendations,
- tabular presentation of recommended values,
- an equation to calculate recommended values, and
- a graphical presentation of the recommended curve (0-80°C) (generated from the above equation.

Also included are experimental methods, whether the references included equations to fit the data, and whether or not these references were primary sources.

1. INTRODUCTION

Recent blanket studies have demonstrated that MHD presents a critical feasibility issue for liquid-metal, self-cooled blankets for tokamaks [1]. Although successful designs have been developed using available theory and data on liquid metal MHD, a number of uncertainties related to MHD effects remain unresolved [1,2]. The main sources of the uncertainties are (a) lack of data needed to validate analytical techniques at parameter values approaching those which exist in the reactor blanket, and (b) lack of analytical techniques capable of treating flows in conduits of complex geometry, such as bends, manifolds, etc. To improve the level of understanding of the details of MHD flows as they apply to magnetically confined fusion blankets, an experimental program is being carried out at Argonne National Laboratory (ANL).

The experimental facility [Argonne's Liquid-Metal Experiment (ALEX)] is capable of attaining maximum Hartmann numbers (M)* and interaction parameters (N)† in the range of 10^3-10^5. Such a capability is close to the range of 10^4-10^5 that these parameters attain in the reactor blanket. ALEX has been designed so that the experimental program will represent much more than a mere extension of the N and M ranges. The program is aimed towards measurement of detailed flow structure characteristics, which are of fundamental importance because existing theories predict unconventional velocity profiles with high velocity wall jets and low velocity core regions, in the cases where 3-D effects become dominant. Since 3-D effects are virtually unavoidable in the blanket, and because the flow profiles have a strong influence on heat transfer and corrosion rates, data validating existing theories are indispensable to design efforts seeking to either minimize or take advantage of such effects.

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*The Hartmann number, $M = aB\sqrt{\sigma/\mu}$, is a dimensionless quantity whose square expresses the ratio of the electromagnetic body forces to the viscous body forces acting on the fluid, where a = duct half-width parallel to B, B = magnetic flux intensity, σ = fluid electrical conductivity, and μ = fluid dynamic viscosity.

†The interaction parameter, $N = \sigma B^2 a/\rho u$, is a dimensionless number expressing the ratio of the electromagnetic body forces to the inertia body forces acting on the fluid, where ρ = fluid density, and u = fluid velocity.

Table 1.1 lists various liquid metals considered as working fluids for ALEX, ranked in order of decreasing electromagnetic interaction properties, as characterized by the ratio of fluid electrical conductivity to fluid density (σ/ρ). In Table 1.1, the electromagnetic interaction properties of the fluids have been normalized by those of lithium. The melting points are also listed in Table 1.1.

Table 1.1. Possible Working Fluids

Fluid	$(\sigma/\rho)/(\sigma_{Li}/\rho_{Li})$	Melting Point, °C
Li	1.0	179
Na	0.81	99
K	0.75	63
22Na78K*	0.45	-13
Ga	0.06	29
Sn	0.046	232
Hg	0.013	4

*Throughout this report, alloy compositions are given in wt %, i.e., 22Na78K is 22 wt % Na.

An ideal LMMHD working fluid for ALEX experiments would have high electromagnetic interaction properties, would be a liquid at room temperature, would be non-toxic, would be chemically stable, and inexpensive. The one requirement of the above group of requirements which is virtually mandatory in making local velocity measurements using presently available instrumentation is that of being a liquid at or near room temperature. The feature of most local velocity instruments which has a bearing on the fluid temperature is their use of organic materials for electrical insulation. Most organic materials will limit applications to 100-125 C. Most problems encountered in the past in collecting room-temperature hot film anemometer velocity data in liquid metals seem insignificant in comparison to those likely to be encountered at elevated temperatures.

Sodium-potassium eutectic alloys, gallium, and mercury are the only room temperature liquid metals in Table 1.1. Gallium is roughly 7.5 times less electromagnetically interactive than NaK. It is also quite expensive.

Mercury is roughly 35 times less electromagnetically interactive, and an order of magnitude more expensive, than NaK. Mercury has been used in many past LMMHD experiments at universities and other R&D institutions because it is chemically stable (thus easy to handle) and its toxicity is generally considered to be a more manageable problem than is NaK's reactivity. One of the major reasons for the low values of M and N thus far achieved experimentally is that the working fluid of choice has been mercury. Had NaK been used in previous experiments instead of mercury, all else being the same, an increase in M by a factor of 2.5 and an increase in N by a factor of 34 would have been gained.

Probably the main reason that mercury was used in previous work was the relatively straightforward operational requirements of mercury loops. As opposed to alkali metal loops, mercury loops do not usually require inert cover gases, leak detection systems, fire suppression and scrubbing systems, and elaborate loop disassembly and liquid metal transfer procedures. The toxicity of mercury is apparently not considered a serious problem, although mercury poisoning of MHD researchers has occurred. In the past, the reduced electromagnetic interaction and Hartmann number achievable with mercury was considered to be a secondary disadvantage compared to the ease of operation of mercury loops.

We are now faced with a different set of circumstances. The charter of liquid-metal-cooled blanket work for fusion is not to develop theories and collect data at low values of M and N for later extrapolation to the (higher) values of interest for fusion. It is, rather, to collect meaningful data at the highest values of M and N that can be achieved, i.e., by using the largest ducts, the highest B fields, and the most electromagnetically favorable working fluid available, within the limitations of current funding and reasonable near-term advances in instrumentation technology. These arguments, coupled with the increased cost and complexity of operation of high temperature loops, eliminated Li, Na, and K from further consideration and thus NaK was selected as the working fluid for ALEX.

The purpose of this report is to compile recommendations on the room temperature, thermophysical properties of NaK_{78}. The report was prepared for use by ALEX personnel to provide a single unified collection of property values for the eutectic sodium-potassium alloy. These properties include density,

kinematic and absolute viscosities, thermal conductivity, specific heat, electrical resistivity, electrical conductivity, Prandtl number, and thermal diffusivity. Each section of this report contains a completely referenced property that focuses on the 0-80°C temperature range. All available data for each property have been taken from original publications. The individual sections are organized following a specific outline, considering:

(1) discussion of experimental methods
(2) discussion of sources of error
(3) discussion of each reference
(4) tabular presentation of all available data
(5) graphical presentation of the data
(6) recommendations
(7) tabular presentation of recommended values
(8) an equation to calculate recommended values
(9) a graphical presentation of the recommended curve (0-80°C) (generated from the above equation).

Table 1.2 is a listing of all the properties and their respective sources. Also included are experimental methods, and whether the references included equations to fit the data, and whether or not these references were primary sources.

Table 1.2. Properties and their Sources

Property	Source	Primary	Equation	Method or Apparatus
Density	Ewing et al. [3,4,5]	yes	yes	Quartz Dilatometer
	Kutateladze et al. [7]	yes	no	Pycnometer
	Nikol'skii et al. [21]	no	yes	Pycnometer
Kinematic Viscosity	Ewing et al. [8]	yes	yes	Modified Ostwald Viscometer
	Macur et al. [10]	yes	yes	Modified Ostwald Viscometer
	Novikov et al. [11]	yes	no	Dampened Torsional Oscillations
	Kitajima et al. [9]	yes	no	Modified Ostwald Viscometer
Absolute Viscosity	None	-	-	------
Thermal Conductivity	Ewing et al [14]	yes	no	Uniaxial Measuring Unit
	Kutateladze et al. [7]	yes	no	Successive Stationary States
	Nikol'skii et al. [21]	no	yes	Successive Stationary States
	Krainova et al. [15,16]	yes	yes	Relative Axial Heat Flux Apparatus with Compensating Guard Heating
Electrical Resistivity, Elec. Conductivity	Tepper et al. [17]	yes	yes	Parallel Resistors
	Hennephof et al. [24]	yes	no	Parallel Resistors
	Drugas et al. [23]	yes	no	Parallel Resistors
Specific Heat	Douglas et al. [25]	yes	yes	Method of Mixing
	Shpil'rain et al. [26]	yes	no	Method of Mixing
	Kutateladze et al. [7]	yes	no	Direct Heating Method
	Nikol'skii et al. [21]	no	yes	Direct Heating Method
Thermal Diffusivity	Novikov et al. [11]	yes	no	Angstrom's Dynamic Method

2. DENSITY

The low temperature density of several NaK alloys have been measured by Ewing [3,4,5] using a dilatometer. A dilatometer measures volume changes as the temperature is varied. Thus, density changes were determined from the experimental measurements of mass and volume, a process very similar to a pycnometer experiment. A high precision potentiometer was used in conjunction with a heated liquid bath capable of temperature control to ±0.5°C. Experimental error was minimized by cleaning the quartz surfaces of the dilatometer. Then, to make a volume measurement, it was necessary to allow the bath to reach equilibrium at the desired temperature and to note with a cathetometer the height of the metal meniscus in the calibrated stem of the dilatometer. The net weight of the metal was determined to eliminate the potential error resulting from the metal adhering to the walls of the capillary. The weight measurements were performed on a beam balance which was accurate to ±0.05 mg.

Using a dilatometer below 200°C and a buoyancy method above 200°C, Ewing [3] constructed a universally accepted plot of NaK density isotherms. Foust [6] reported that Ewing's isotherms are in good agreement with the data from a number of investigators, including Kutateladze's et al. [7] data on NaK_{75}, the worst deviations being 1.0%. The data obtained by Ewing [4,5] for NaK_{78} below 200°C are tabulated in Table 2.1 and plotted in Figure 2.1.

Table 2.1. Available Density Data from Ewing [3,5]

T (°C)	ρ (kg/m^3)
112.3	844.2
122.0	842.1
127.5	840.4
135.2	838.5
142.3	836.6
149.0	834.9
157.0	832.8
164.5	830.9
171.1	829.3
178.2	827.4
184.8	825.9
196.7	822.5
204.0	820.6

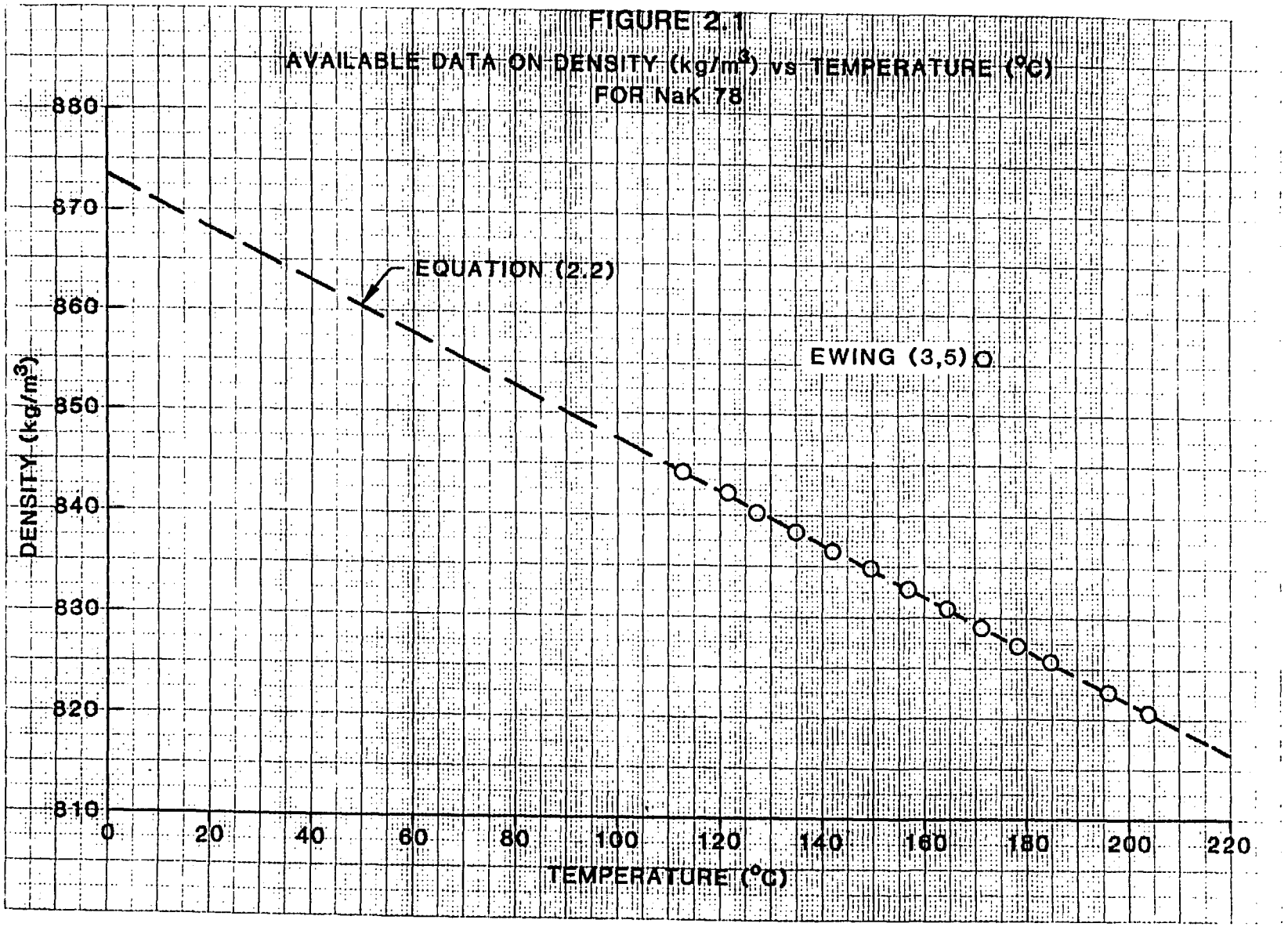


FIGURE 2.1
AVAILABLE DATA ON DENSITY (kg/m³) vs TEMPERATURE (°C)
FOR NaK 78
DENSITY (kg/m³)
880
870
860
850
840
830
820
810
EQUATION (2.2)
EWING (3,5)
0
20
40
60
80
100
120
140
160
180
200
220
TEMPERATURE (°C)

Ewing found the following equation useful for calculating the density of NaK based on the densities of its constituents, Na and K.

$$\frac{1}{\rho_{NaK}} = 1.003 \left[\frac{N_{Na}}{\rho_{Na}} + \frac{N_K}{\rho_K} \right] \tag{2.1}$$

where N_i is the atom fraction of the ith constituent.

The data in Table 2.1 were fit to a linear equation using the method of least squares to yield the following expression for the density of NaK_{78} as a function of temperature:

$$\rho(kg/m^3) = 873.35 - 0.258\ T \tag{2.2}$$
$$T\ (°C)$$

Equation 2.2 is plotted on Figs. 2.1 and 2.2 and is recommended for calculating NaK_{78} densities. Values generated from Eq. 2.2 are tabulated in Table 2.2. Density data for NaK_{78} are not available below 112.3°C; hence, two data points each for NaK_{64} and NaK_{84} are plotted in Fig. 2.2 for comparison purposes.

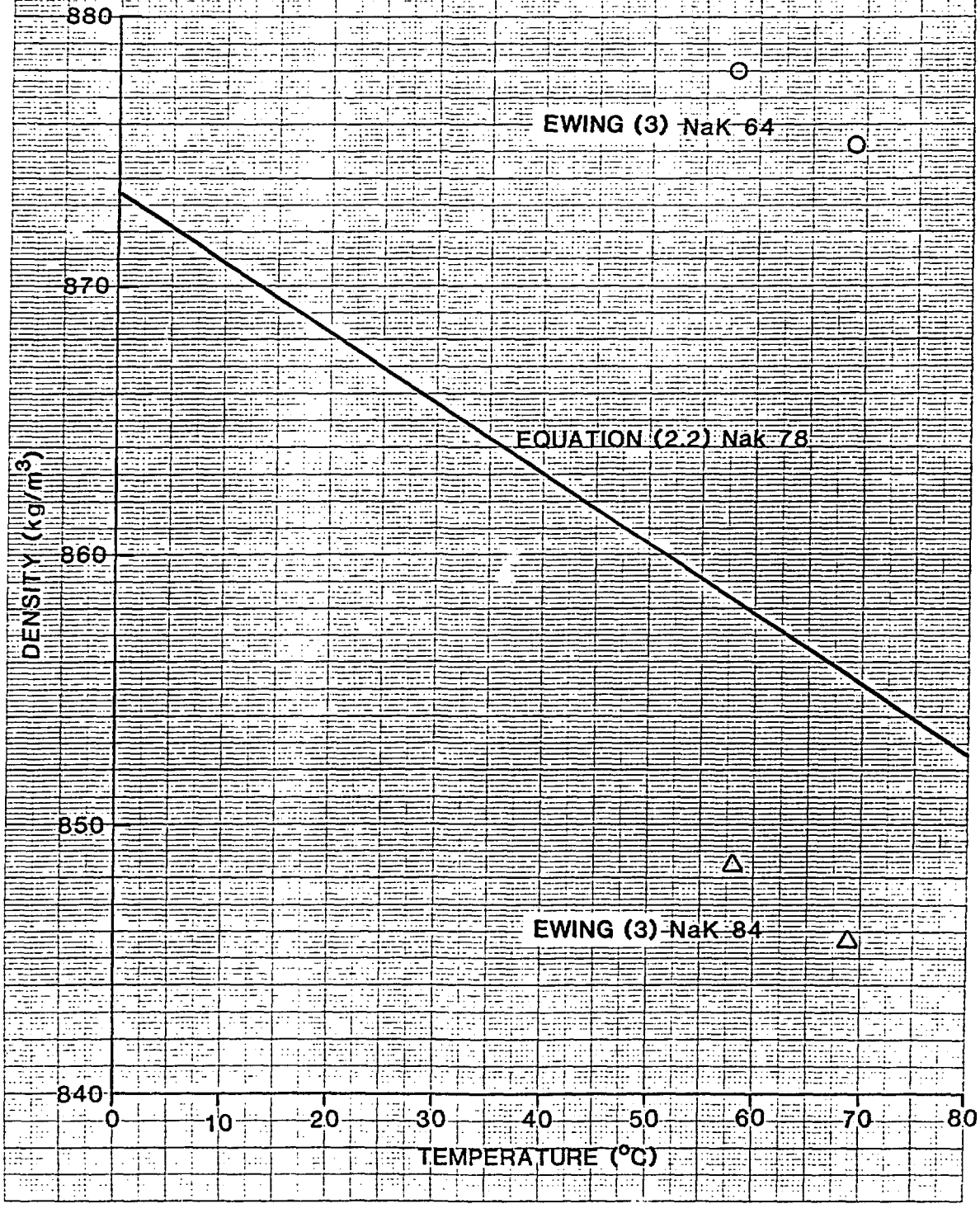
Table 2.2. Recommended Density (kg/m^3) vs Temperature (°C)

T (°C)	ρ (kg/m^3)
0	873.4
10	870.8
20	868.2
30	865.6
40	863.0
50	860.5
60	857.9
70	853.3
80	852.7

FIGURE 2.2

RECOMMENDED CURVE FOR

DENSITY (kg/m^3) vs TEMPERATURE ($^{\circ}C$) FOR NaK 78



The data in Table 2.2 were generated from the following recommended equation

$$\rho(kg/m^3) = 873.35 - 0.258\ T \qquad (2.2)$$

$$T\ (°C);\quad T < 204°C$$

Based on the fact that the data base for Eq. (2.2) extends only to 204°C, Refs. 3, 4, and 5 should be consulted for a density correlation above 204°C.

3. KINEMATIC VISCOSITY

The kinematic viscosity of NaK has been measured using two different methods. The first and most common method is with the Ostwald viscometer. This apparatus consists of a U-tube, one end of which is a capillary tube connected to a reservoir containing the NaK. A known quantity of fluid is placed in the reservoir and allowed to flow under the action of gravity. The time necessary for the free surface of the liquid to fall between two marks on the tube is then correlated to the kinematic viscosity. Calibration constants take into account the variation of the tube's bore, entrance effects, and the unsteadiness due to a falling pressure head.

Difficulties that occur with this method are non-wetting and contact angle problems associated with the high surface tension of NaK. Other problems involve measuring the time it takes for the free surface to fall. At high temperatures, glass is not compatible with NaK and so a metal capillary tube must be used.

Of the collected sources, Ewing et al. [8], Kitajima et al. [9], and Macur et al. [10] used Ostwald viscometers. Kitajima's results are given at 50.9 and 77.1 at. % potassium. We are interested in 67.3 at. % potassium. Kitajima's results at 50.9 at. % K ($NaK_{63.8}$) and at 77.1 at. % K ($NaK_{85.1}$) were used for comparison purposes. Kitajima's temperature range was 83°C to 207°C. He did not give an estimate of the error in his results.

Ewing measured the kinematic viscosity of NaK in the temperature range 58.3-192.7°C. He used a pyrex capillary tube and estimated his overall accuracy at ±0.8%.

Macur measured the viscosity of NaK at -6.1, 0, 25, and 148°C. He also included a chemical analysis of the NaK he used and showed that oxygen content may have some effect on the kinematic viscosity. Macur indicated that his most accurate data were the room temperature ones (±1%) because the visibility of the NaK meniscus was not impaired by a crushed ice bath or other fluid bath necessary to maintain the temperature. He stated that the -6.1°C data were of the lowest accuracy, but he did not estimate the error in that case. Also, Macur did not include a kinetic energy correction term in his viscometer

calibration equation; neither did he discuss whether it was considered necessary or not.

The other method for determining kinematic viscosities, damped torsional oscillations, was used by Novikov et al. [11]. In this device, a cylinder was filled with the liquid metal and suspended by a filament. The cylinder was put in torsional oscillations electromagnetically and filmed with an ordinary camera. The damping of the torsional oscillations was then correlated to the kinematic viscosity of the fluid using the equations of E. G. Shvidkovsky [12]. The primary systematic error in this method was the possibility of transverse oscillations. These were kept to a minimum by using a short filament and suspension rod and by carefully centering the cylinder.

Novikov presented data from roughly 20°C to 725°C, but not in tabular form. His stated experimental accuracy was ~1.5%. Novikov used NaK_{75}. The data points from 20-205°C were read from Novikov's graph and are presented in Table 3.1. Data from Ewing, Macur, and Kitajima are also tabulated in Table 3.1. All data in Table 3.1 are plotted in Fig. 3.1.

The method of least squares was used to fit all the data in Table 3.1 to an equation of the form suggested by Andrade [11], i.e.,

$$\nu(m^2/sec) = A\rho^{-2/3}\, e^{B\rho/T} \qquad (3.1)$$

$$\rho\ (kg/m^3)$$

$$T\ (°K);\quad T < 480\ K$$

The constants A and B determined in this way are $A = 7.681 \times 10^{-6}$ and $B = 0.851$.

Equation 3.1 is shown in Figures 3.1 and 3.2; it was also used to generate the recommended viscosity values tabulated in Table 3.2. Equation 3.1 is recommended for calculating kinematic viscosity as a function of temperature.

Because the temperatures in the data base used to generate Eq. 3.1 were less than or equal to 207°C, Ref. 6 should be consulted for a kinematic viscosity correlation for temperatures above 207°C.

Table 3.1. Kinematic Viscosity vs Temperature [Viscosity ($10^{-6}m^2/s$)]

T (°C)	Ewing [8]	Kitajima [9] $NaK_{63.8}$	Kitajima [9] $NaK_{85.1}$	Macur [10]	Novikov [11]
-6.1				1.432	
				1.432	
				1.432	
0.				1.353	
				1.353	
				1.365	
				1.330	
				1.239	
				1.227	
				1.284	
20.					0.915
25.6				1.058	
				1.035	
				1.082	
				1.018	
				0.986	
				1.017	
40.					0.870
45					0.815
58.3	0.7224				
	0.7204				
65.					0.720
69.6	0.6397				
	0.6602				
70.					0.690
83.			0.567		
84.		0.605			
103.					0.635
					0.585
103.7	0.5499				
	0.5499				
104.		0.546			
113.			0.497		
120.8	0.5112				
121.4	0.5079				
128.		0.490			
134			0.456		
147.	0.4597	0.460			
	0.4596				
148.9				0.5357	
				0.5476	
				0.6429	
				0.5000	
154.			0.426		
155.					0.500
167.0		0.428			
167.4	0.4290				
	0.4295				
178.			0.392		
185.			0.386		
192.7	0.3972				
	0.3972				
193.5		0.387			
204.5		0.378			
205.					0.450
207.			0.366		

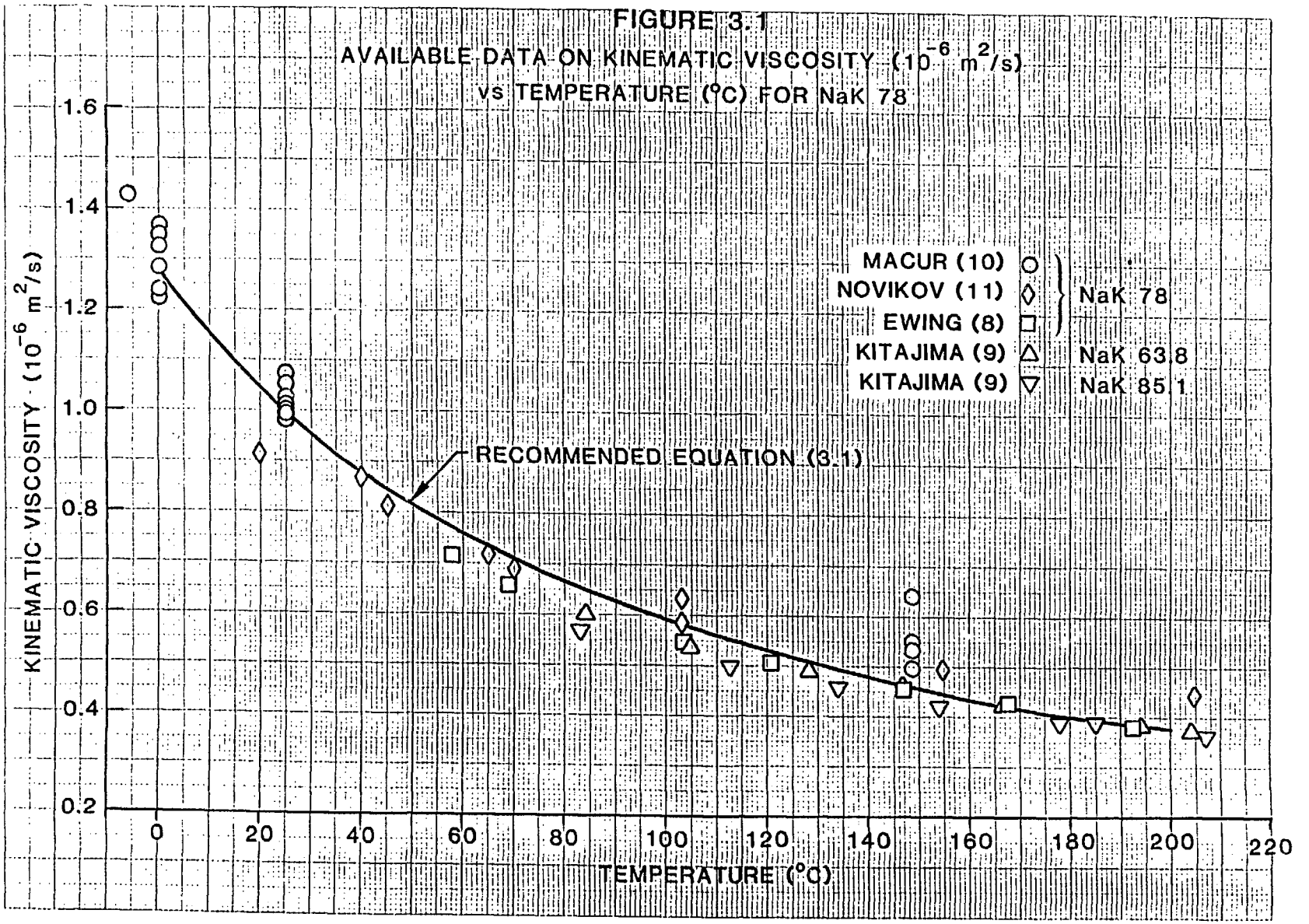


FIGURE 3.1
AVAILABLE DATA ON KINEMATIC VISCOSITY (10^{-6} m^2/s)
vs TEMPERATURE (°C) FOR NaK 78
KINEMATIC VISCOSITY · (10^{-6} m^2/s)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
20
40
60
80
100
120
140
160
180
200
220
TEMPERATURE (°C)
MACUR (10)
NOVIKOV (11)
EWING (8)
NaK 78
KITAJIMA (9)
NaK 63.8
KITAJIMA (9)
NaK 85.1
RECOMMENDED EQUATION (3.1)

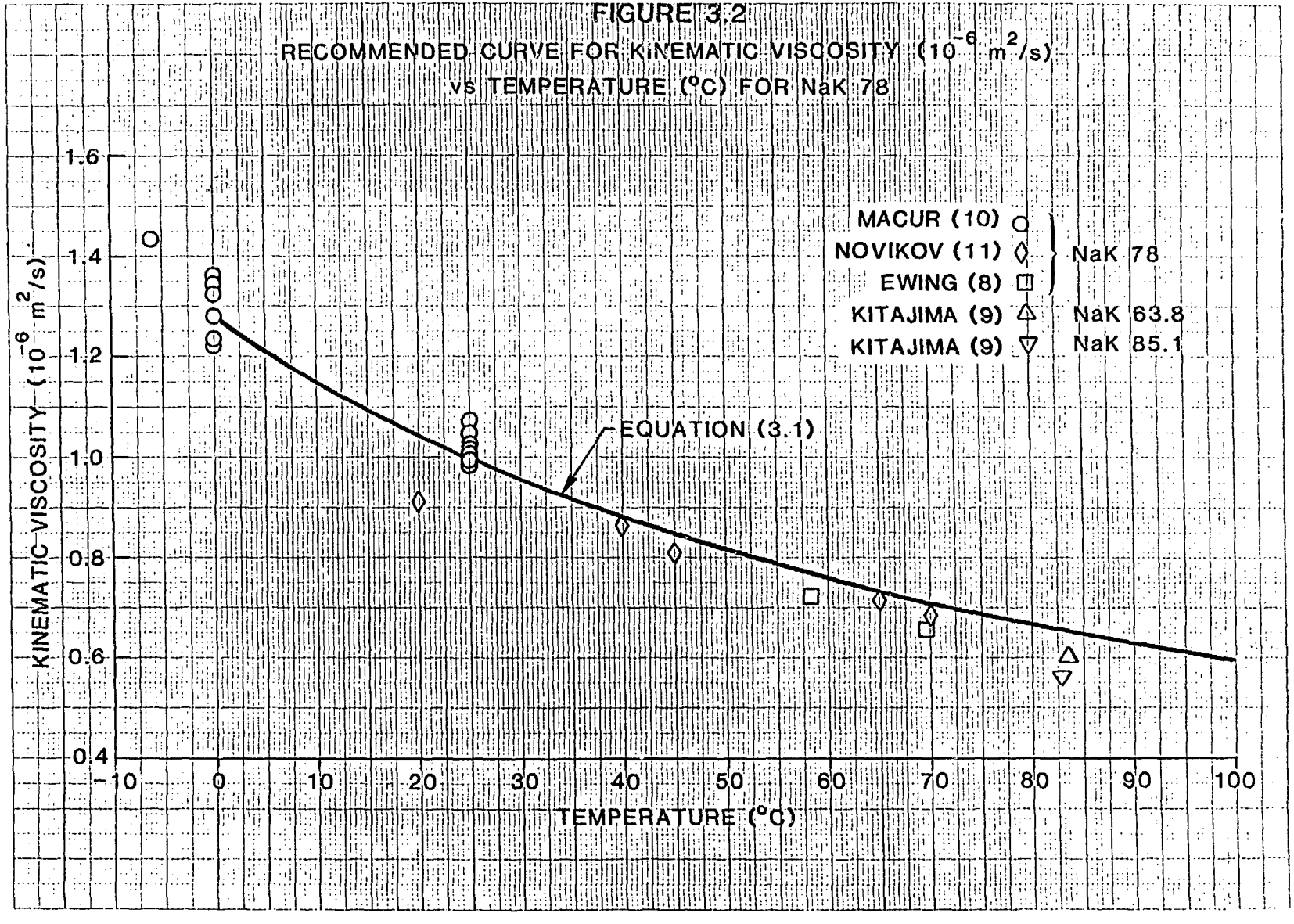


FIGURE 3.2
RECOMMENDED CURVE FOR KINEMATIC VISCOSITY (10^{-6} m^2/s)
vs TEMPERATURE (°C) FOR NaK 78
KINEMATIC VISCOSITY (10^{-6} m^2/s)
TEMPERATURE (°C)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
-10
0
10
20
30
40
50
60
70
80
90
100
MACUR (10)
NOVIKOV (11)
EWING (8)
NaK 78
KITAJIMA (9)
NaK 63.8
KITAJIMA (9)
NaK 85.1
EQUATION (3.1)

Table 3.2. Recommended Kinematic Viscosity vs Temperature

Temp. (°C)	ν ($10^{-6} m^2/s$)
0	1.28
5	1.21
10	1.15
15	1.10
20	1.05
25	1.00
30	0.961
35	0.922
40	0.885
45	0.851
50	0.819
55	0.789
60	0.762
65	0.736
70	0.711
75	0.689
80	0.667

4. ABSOLUTE VISCOSITY

No authors report direct measurements of absolute viscosity. Two sources report absolute viscosity (Ewing [8] and Macur [10]) but actually used an apparatus that measured kinematic viscosity (the Ostwald viscometer). Here, absolute viscosity was determined by multiplying the kinematic viscosity equation (Eq. 3.1) by the density to yield the following equation:

$$\mu(\text{Pa}\cdot\text{s}) = 7.681 \times 10^{-6}\ \rho^{1/3}\exp(0.851\ \rho/T) \qquad (4.1)$$

ρ (kg/m^3)

T (°K); T < 480 K

Of course, the density is determined using Eq. 2.2.

Recommended values of absolute viscosity are tabulated in Table 4.1. These values were generated using Eq. 4.1 (which follows directly from Eq. 3.1). Equation 4.1 is plotted in Figure 4.1.

Table 4.1. Recommended Absolute Viscosity (10^{-4}Pa·s) vs Temperature (°C)

T (°C)	ρ (kg/m^3)	ν (10^{-6}m^2/s)	μ (10^{-4}Pa·s)
0	873.4	1.28	11.2
10	870.8	1.16	10.1
20	868.2	1.05	9.12
30	865.6	0.961	8.32
40	863.0	0.885	7.64
50	860.5	0.819	7.05
60	857.9	0.762	6.53
70	855.3	0.711	6.08
80	852.7	0.667	5.69

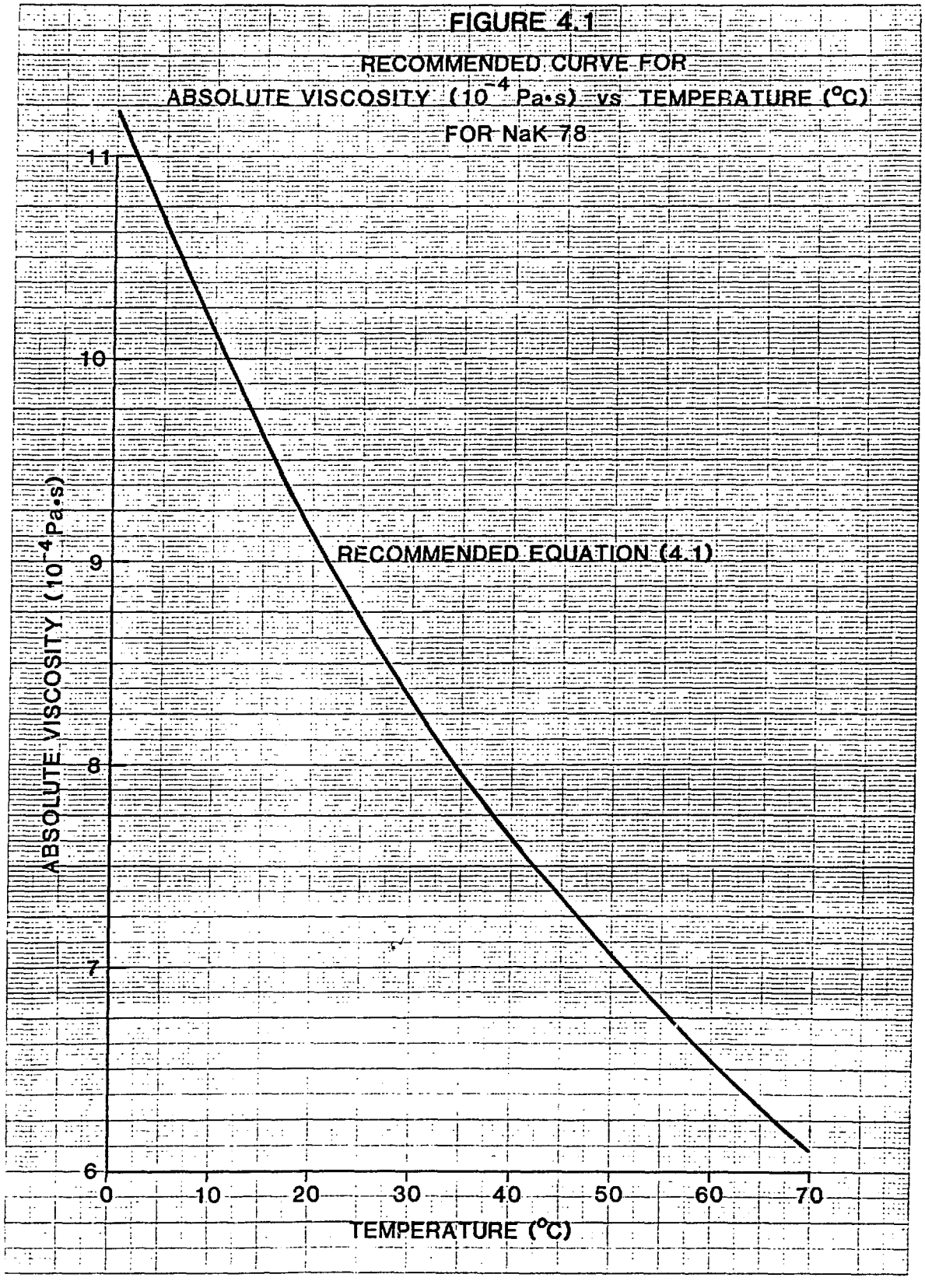


FIGURE 4.1
RECOMMENDED CURVE FOR
ABSOLUTE VISCOSITY (10^{-4} Pa•s) vs TEMPERATURE (°C)
FOR NaK-78
RECOMMENDED EQUATION (4.1)
ABSOLUTE VISCOSITY (10^{-4} Pa•s)
11
10
9
8
7
6
0
10
20
30
40
50
60
70
TEMPERATURE (°C)

5. THERMAL CONDUCTIVITY

There are three primary sources of information on the thermal conductivity of NaK_{78} [11,14-16]. Ewing et al. [14], Kutateladze et al. [7], and Krainova and Shpil'rain [15 and 16] all measured the thermal conductivity directly. Novikov et al. [11] measured thermal diffusivity and related it to the thermal conductivity. Tepper et al. [17] and Roehlich and Tepper [18] measured the electrical resistivity of NaK and related it to the thermal conductivity using an empirical equation proposed by Ewing [19]. They compared their experimental results with results from Ewing's equation to find an average deviation of 6.8%. (See Section 6.)

Krainova and Shpil'rain [16] compared their experimental results with a least squares fit of their data to find a mean deviation of 2.9%. Ewing [14] reported an error of 1%, due to the effects of radial heat exchange and axial heat flow in the insulation. Kutateladze [7] used the method of stationary states to directly measure the thermal conductivity of NaK. However, Shpil'rain [20] reports that several systematic errors occur in this method and estimated the error in Kutateladze's results at 16-20%.

Tepper [17] and Roehlich and Tepper [18] measured the electrical resistivity of NaK and then related it to the thermal conductivity first using the Wiedemann-Franz law and then using an empirical equation proposed by Ewing [19]. A relationship between thermal conductivity and electrical resistivity was first proposed by Lorentz who theorized that heat conduction in metals is almost entirely due to electron transport. The relationship between thermal conductivity and electrical resistivity, given by the Weidemann-Franz relation [17], is

$$L = \frac{k\rho_e}{T} \tag{5.1}$$

where k = thermal conductivity
ρ_e = electrical resistivity
T = absolute temperature
L = Lorentz number.

Since not all of the heat is conducted through electron transport, Roehlich and Tepper [18] suggested an extra term in the relation to include

lattice conduction (phonon interactions in the liquid state). While the idea of using the Lorentz number to determine the thermal conductivity of NaK is interesting, it is not precise enough to use except as a comparison.

Krainova and Shpil'rain [15,16] measured the thermal conductivity by the method of relative axial flow. The liquid metal was placed in a vertical tube where the heat flowed from top to bottom. In the absence of radial losses, the thermal conductivity was given by

$$k = \frac{Q}{S\frac{dt}{dx}} \tag{5.2}$$

where Q = heat flow

S = cross-sectional area of the liquid metal column

$\frac{dT}{dx}$ = axial temperature gradient

The authors used a relative method, meaning that the heat flow is measured through a material of known conductivity in place of the liquid metal column, rather than observing the power used in the heater. The temperature gradient was determined using six thermocouples placed along the length of the tube. To assure a one-dimensional heat flow, a system of lateral guard heaters, protective steel pipe, and insulating material was provided. This system served to minimize temperature gradients near the liquid metal. However, temperature gradients did occur, but the authors compensated for this factor in their calculations. Old data on eutectic NaK from Ref. [15], along with new data (a total of 72 data points) were presented in Ref. [16]. Based on those 72 points, the following empirical expression for thermal conductivity as a function of temperature was developed using the method of least squares:

$$k[W/(m\cdot K)] = 20.5 + 0.022T - 2.05\times10^{-5}T^2 \tag{5.3}$$

T (°C)

The data from Krainova and Shpil'rain [15,16] (which were not given in tabular form) are replotted in Figure 5.1. Equation 5.3 is also shown in Figure 5.1.

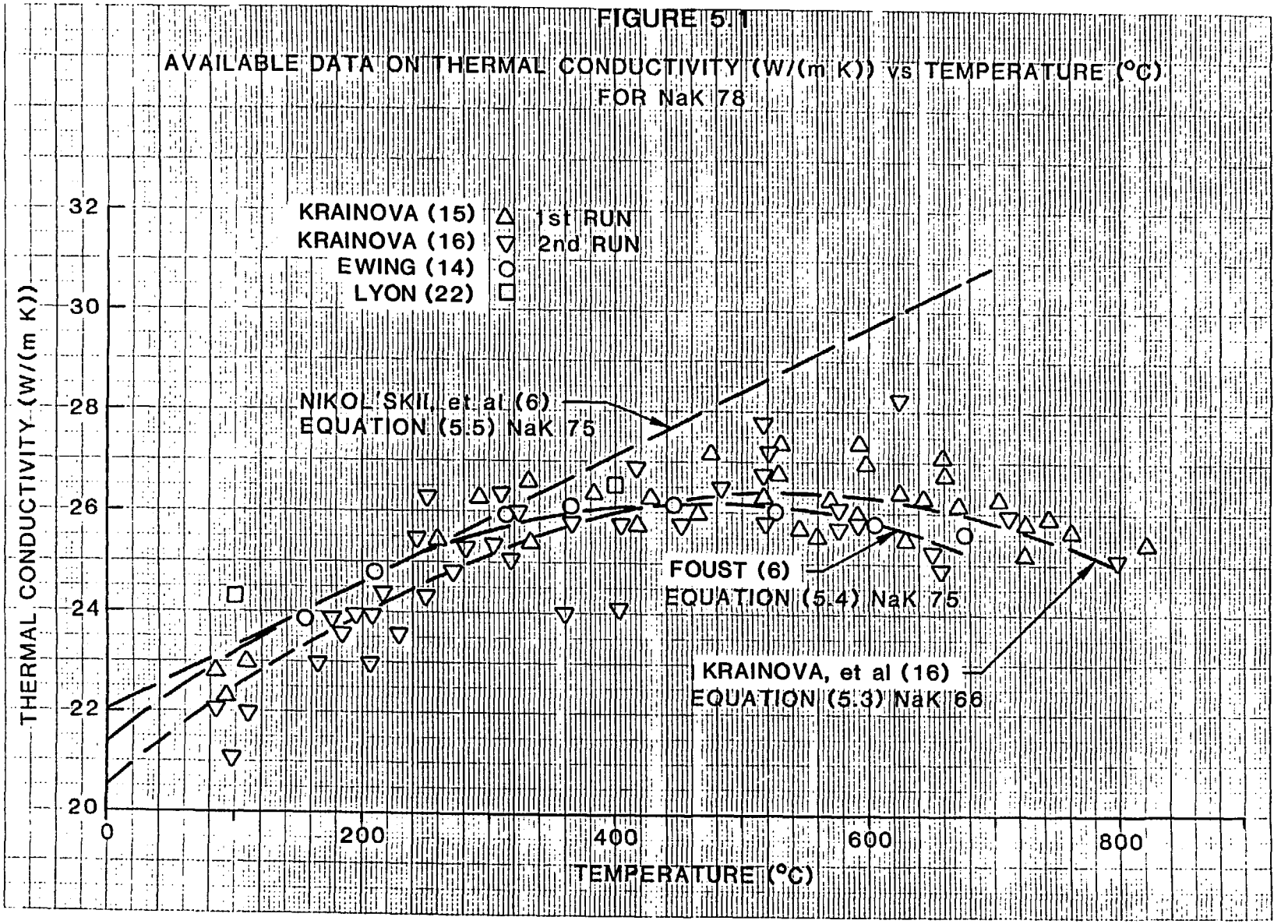


FIGURE 5.1
AVAILABLE DATA ON THERMAL CONDUCTIVITY (W/(m K)) vs TEMPERATURE (°C)
FOR NaK 78
KRAINOVA (15) 1st RUN
KRAINOVA (16) 2nd RUN
EWING (14)
LYON (22)
NIKOL SKII, et al (6)
EQUATION (5.5) NaK 75
FOUST (6)
EQUATION (5.4) NaK 75
KRAINOVA, et al (16)
EQUATION (5.3) NaK 66
THERMAL CONDUCTIVITY (W/(m K))
TEMPERATURE (°C)
32
30
28
26
24
22
20
0
200
400
600
800

Ewing et al. [14] used a method similar to that of Krainova and Shpil'rain. The primary differences were that Ewing used an absolute method, rather than the relative method; and precautions were taken to eliminate radial temperature gradients. Several precautions were made to assure maximum accuracy of the results. The investigated alloy was poured into a long stainless steel cylinder, the upper part of which was located in a heater. Upward thermal leakage was prevented by guard rings and a protective end heater. Radial heat exchange was prevented by a multisectional heater wound on a pipe and surrounded by a thick-walled stainless steel tube. Thirty-two thermocouples were located around the apparatus.

In their experiment, there was a temperature discontinuity between the stainless steel rod and the NaK because of the differences in their respective thermal conductivities. To establish a repeatable discontinuity, an elaborate heating-cooling system was included in their apparatus. The system took several days to reach steady state.

Ewing's data [14] was given in tabular form and is plotted in Figure 5.1. The following equation, given by Foust [6], was generated by applying a least squares fit to the data of Ewing et al. [14]:

$$k[W/(m\cdot K)] = 21.4 + 0.207T - 2.20\times10^{-5}T^2 \qquad (5.4)$$

T (°C)

This equation is also plotted in Figure 5.1. The rms deviation of Eq. 5.4 from Ewing's experimental data is about 0.8%.

Kutateladze et al. [7] measured thermal conductivity using the method of successive stationary states, a method similar to Ewing [14]. Later, Nikol'skii et al. [21] presented the same data but described the apparatus and procedure more fully. Data points were also presented in graphical form. At steady state, the heat generated by the upper heater proceeds along the axis to a cooling jacket without being transferred through the lateral surface. If a transition to a second steady state is made by changing the output of the end heater, the amount of heat taken up by the sample from the outside changes because of the change in temperature of the sample itself. Calculating the change in quantity of heat in going from one steady state to the other forms

the basis of the method of successive stationary states. However, Shpil'rain [20] noted several systematic errors in this method and estimated the error in Nikol'skii's results at 16-20%. Nikol'skii et al. did not present tabular results of the data points. The data were presented graphically and the following linear equation was fit to the data:

$$k[W/(m\cdot K)] = 21.98 + 0.0127T \qquad (5.5)$$

T (°C)

There were many data points in Nikol'skii's graph. Equation 5.5 is plotted in Figure 5.1 for comparative purposes.

Based on Shpil'rain's [20] critical remarks on Nikol'skii's results and their monotonic behavior as a function of temperature, Nikol'skii's results were dropped from further consideration.

For completeness, two points from Lyon [22] are included in Figure 5.1. These data were presented by Lyon as previously unpublished data from General Electric. No details regarding the experimental method used nor the accuracy of the data were given. These data are also listed in Table 5.1. The two data points from Lyon lend support and generally agree with the data from other authors.

The choice of which results are the most reliable is between Ewing [22], who did not give a chemical analysis of the sample but who did report an error of 1%, and Krainova and Shpil'rain [15,16], who reported that the impurity content of the NaK was less than 0.01%. They also reported that radial temperature gradients occurred, causing some systematic error in the experiment. References [15] and [16] did not include error analyses but did indicate that the mean deviation between the generated equation and the experimental results was 2.9%.

The data of Ewing [14] and Lyon [22] are tabulated in Table 5.1. The results from Eqs. 5.3, 5.4, and 5.5 from Krainova [16], Foust [6], and Nikol'skii [21], respectively, are also given in Table 5.1. The data presented by Krainova [16] in graphical form were digitized and are included in Appendix A.

Table 5.1. Thermal Conductivity [W/(m·K)] vs Temperature (°C)

T (°C)	Ewing [14] Data	Foust [6] Eq. 5.4	Nikol'skii [21] Eq. 5.5	Krainova [16] Eq. 5.3	Lyon [22] Data
0		21.4	22.0	20.50	
10		21.6	22.11	20.72	
15		21.7	22.17	20.83	
20		21.8	22.23	20.93	
25		21.9	22.30	21.04	
30		22.	22.36	21.14	
35		22.1	22.42	21.24	
40		22.2	22.49	21.35	
45		22.3	22.55	21.45	
50		22.4	22.62	21.55	
55		22.5	22.68	21.65	
60		22.6	22.74	21.75	
70		22.7	22.87	21.94	
80		22.9	23.00	22.13	
100		23.3	23.25	22.50	24.37
120		23.6	23.50	22.84	
140		23.9	24.01	23.18	
157.1	23.93	24.11	24.72	23.45	
211.4	24.87	24.8	25.94	24.23	
316.2	26.00	25.75	26.	25.41	
364.0	26.14	26.02	27.	25.79	
400		26.16	27.1	26.02	26.58
445.2	26.18	26.26	27.	26.23	
525.5	26.07	26.2	28.	26.40	
603.5	25.84	25.9	29.12	26.31	
676.3	25.63	25.3	29.86	26.00	

Although he has fewer data points, the results of Ewing are recommended because the methods he used in developing the apparatus eliminated systematic errors. There are no thermal conductivity data below 157.1°C. Recommended values for use in ALEX were extrapolated using Eq. 5.4, which is based on

Ewing's data. Recommended low temperature values are tabulated in Table 5.2. The recommended equation (Eq. 5.4) is also given in Table 5.2. Equation 5.4 is plotted in Figure 5.2.

Table 5.2. Recommended Values of Thermal Conductivity [W/(m·K)] vs Temperature (°C)

T (°C)	k [W/(m·K)]
0	21.4
10	21.6
20	21.8
30	22.0
40	22.2
50	22.4
60	22.6
70	22.7
80	22.9

The recommended equation (based on the data of Ewing) is:

$$k[W/(m\cdot K)] = 21.4 + 0.0207T - 2.2\cdot 10^{-5}T^2 \qquad (5.4)$$

$$T\ (°C);\quad T < 700°C$$

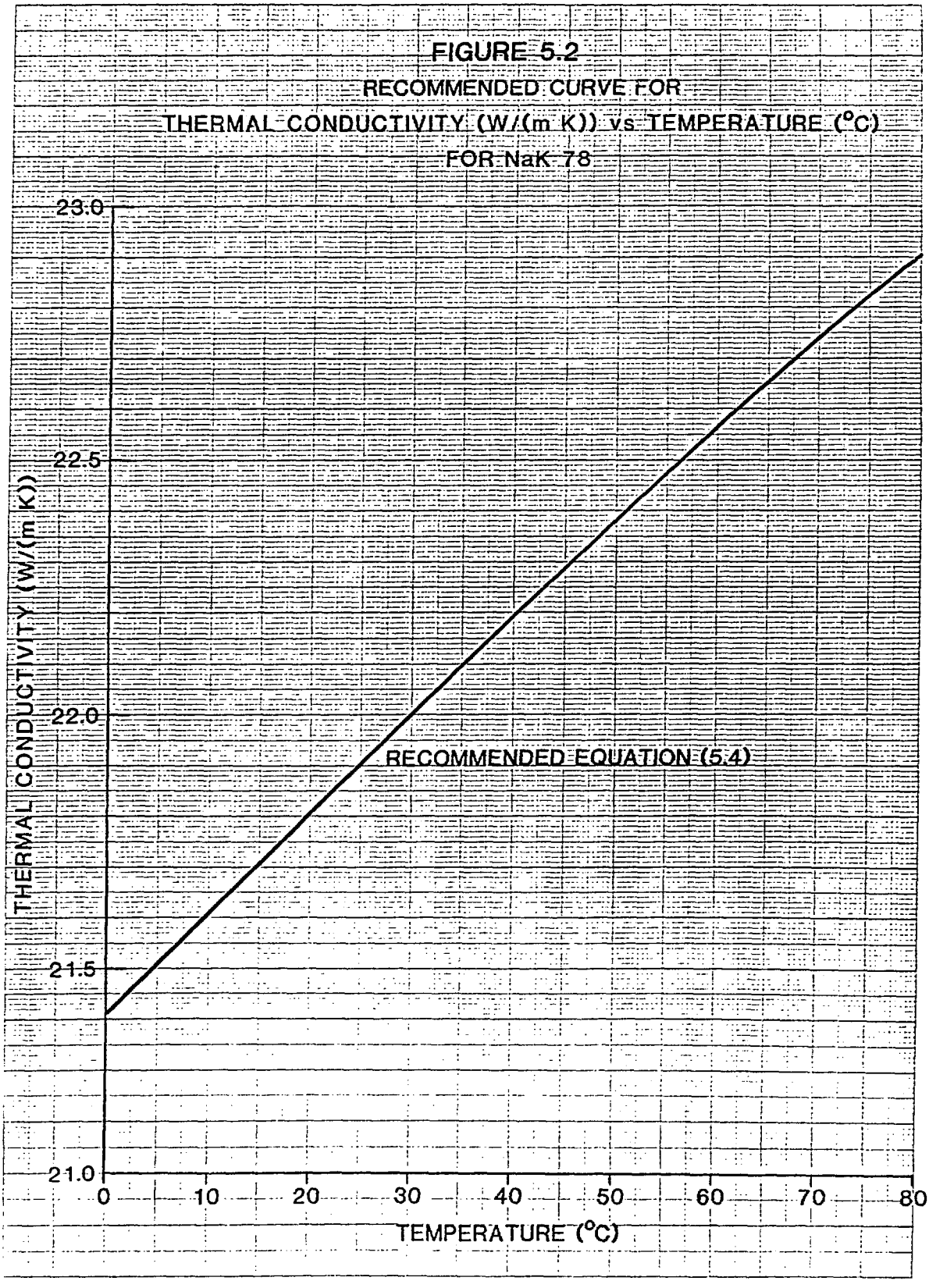


FIGURE 5.2
RECOMMENDED CURVE FOR
THERMAL CONDUCTIVITY (W/(m K)) vs TEMPERATURE (°C)
FOR NaK 78
23.0
22.5
22.0
21.5
21.0
THERMAL CONDUCTIVITY (W/(m K))
RECOMMENDED EQUATION (5.4)
0
10
20
30
40
50
60
70
80
TEMPERATURE (°C)

6. ELECTRICAL RESISTIVITY/ELECTRICAL CONDUCTIVITY

A. Electrical Resistivity

Three references cite information on electrical resistivity: Drugas et al. [23], Tepper et al. [17], and Hennephof et al. [24]. (Tepper's data first appeared in Ref. [17], then later in the open literature of Roehlich and Tepper [18]). Drugas and Hennophof investigated the resistivity of NaK as a function of both composition and temperature. Hennephof gave a $d\rho_e/dT$ coefficient as a function of composition for temperatures from the melting point to 125°C. He claimed an experimental error of less than 5% on the $d\rho_e/dT$ coefficient. Hennephof's data on ρ_e as a function of composition was presented at 100°C only. The eutectic value in Table 6.1 from Hennephof was interpolated from his graph. He gave an overall accuracy of his resistivity data of ±0.7%. Tepper et al. reported data from 0-2000°F (-17.8 - 1093°C) on eutectic NaK. Their results correspond well with those of Drugas and Hennephof (see Table 6.1). The Drugas report covered a temperature range from 86-1300°F (30-720°C). Neither Drugas nor Tepper indicated the magnitude of their experimental error.

The method all sources used to determine the electrical resistivity of NaK involved measuring the resistivity of a tube filled with NaK and the resistivity of the same tube without NaK. Since the tube filled with NaK is equivalent to two parallel resistors, appropriate circuit analysis may be used to determine the resistance of the NaK. From the resistance the resistivity is calculated.

It was decided to use primarily the information from Tepper et al. due to their consistency in a wide temperature range. Neither Drugas et al. nor Roehlich et al. included a chemical analysis of their alloys, so impurity effects are not known. Hennephof stated that a resistivity measurement on his nominally pure Na was 0.1% higher than that of a 99.95% pure Na sample and that a resistivity measurement on his nominally pure K was 2.5% higher than that of a 99.97% pure K sample.

Table 6.1 is a comparison of data from the three sources, as well as with the results of the data fit equation proposed by Tepper. Tepper's equation for electrical resistivity (Ref. [15]) is

$$\rho_e(\mu\Omega\cdot cm) = 32.557 + 3.2205\cdot 10^{-2}T - 9.27125\cdot 10^{-7}T^2 + 7.244\cdot 10^{-9}T^3 \qquad (6.1)$$

T (°F); $T < 2000$°F

The results from this equation are tabulated in Table 6.1. It can be seen that the equation corresponds well with all the data. Actual data from Tepper et al. compare quite well with the data from Drugas et al. as well.

Table 6.1. Available Electrical Resistivity Data $\rho_e(\mu\Omega\cdot cm)$ vs T(°C)

T (°C)	Drugas [23]	Tepper Eq. 6.1 [17]	Tepper [17]	Hennephof [24]
30	35.2	35.3		
36	35.5	35.7	36.26	
83			38.61	
102	39.0	39.5		39.3
127			41.11	
136	40.7	41.5		
174	43.0	43.8		
214	45.6	46.6		
243	47.4	48.2		
273	49.4	50.2		
302	51.3	52.2		
333	53.5	54.3		
368	56.3	56.9	56.67	
399	58.7	59.3		
438	61.9	62.4		
469	64.6	64.9		
480	65.4	65.9	65.85	
500	67.5	67.6	67.99	
518	69.0	69.3		
553	72.4	72.5		
600	77.4	77.2		
650	82.8	82.5		
712	91.0	89.7	89.63	
720	92.5	90.7		

Table 6.2 is a compilation of electrical resistivity values near room temperature. These values were calculated using Eq. 6.1 from Tepper.

Table 6.2. Recommended Electrical Resistivity vs Temperature

T (°C)	ρ_e (μΩ·cm)
0	33.59
10	34.17
20	34.74
30	35.32
40	35.89
50	36.47
60	37.05
70	37.62
80	38.19

The above data were calculated using Eq. 6.1.

B. Electrical Conductivity

Electrical conductivity is the reciprocal of electrical resistivity. The values of conductivity in Table 6.3 were found by inverting the recommended values of resistivity from Table 6.2. The values in Table 6.2 values were calculated using Eq. 6.1, proposed by Tepper [17]. The results are plotted in Figure 6.1. Low temperature data points from all references are also plotted in Figure 6.1.

The recommended equation for electrical conductivity is

$$\sigma\ (S/m) = 2.976 \cdot 10^6 - 5.050 \cdot 10^3 T + 7.188\ T^2 \qquad (6.2)$$

$$T\ (°C);\quad T < 80°C$$

which was found by a least squares fit of the above values of electrical conductivity; maximum deviation is 0.07%. Equation 6.2 is also plotted in Figure 6.1. Considering the method used to derive Eq. 6.2, its temperature range is limited to $T < 80°C$.

Table 6.3. Recommended Electrical Conductivity (S/m) vs Temperature (°C)

T (°C)	σ (10^6S/m)
0	2.977
10	2.926
20	2.878
30	2.831
40	2.786
50	2.742
60	2.700
70	2.658
80	2.618

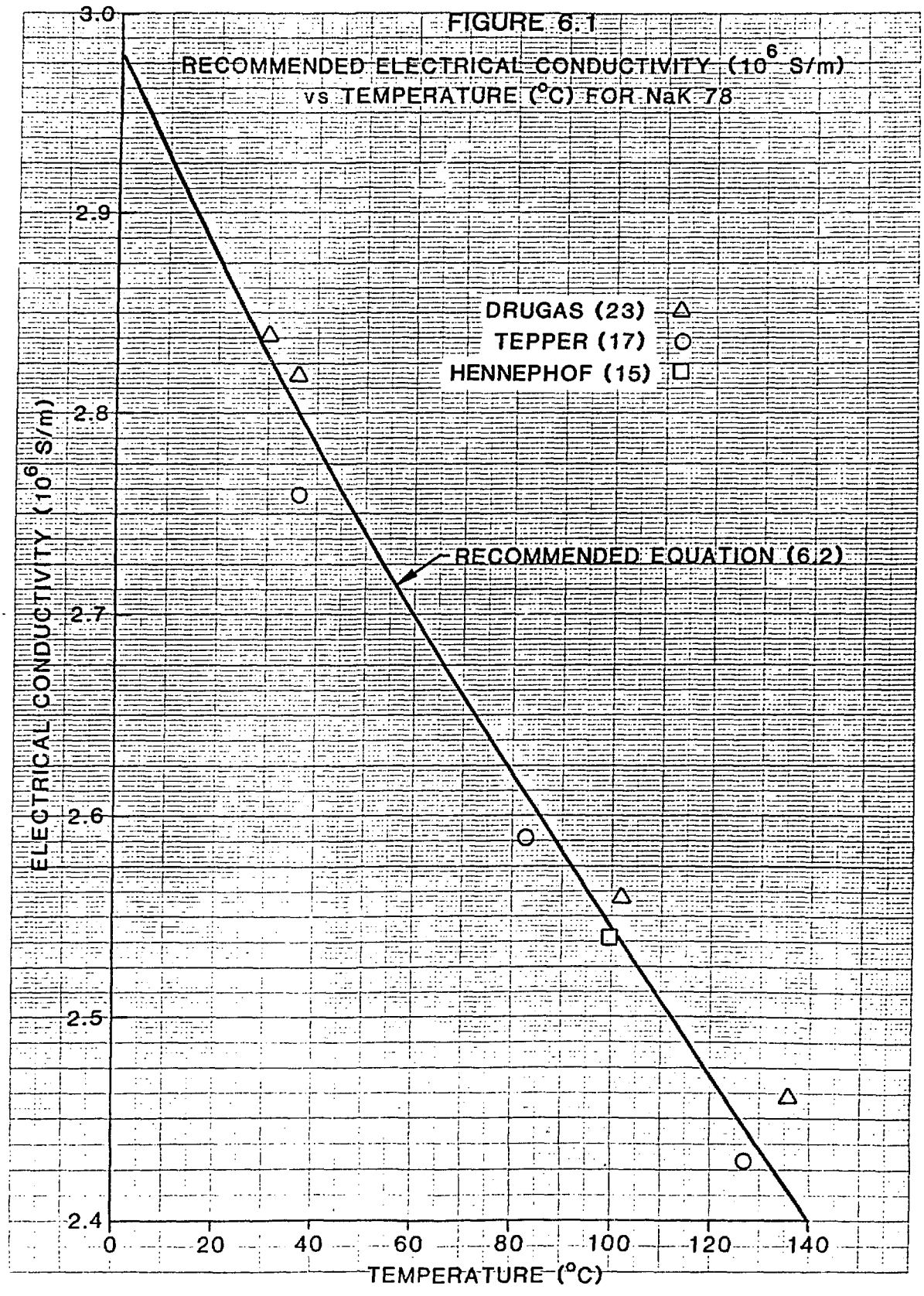


FIGURE 6.1
RECOMMENDED ELECTRICAL CONDUCTIVITY (10^6 S/m)
vs TEMPERATURE (°C) FOR NaK 78
DRUGAS (23)
TEPPER (17)
HENNEPHOF (15)
RECOMMENDED EQUATION (6.2)
ELECTRICAL CONDUCTIVITY (10^6 S/m)
3.0
2.9
2.8
2.7
2.6
2.5
2.4
0
20
40
60
80
100
120
140
TEMPERATURE (°C)

7. SPECIFIC HEAT

There are three primary sources of information on the specific heat of NaK. Using NaK_{75}, Kutateladze [5] employed the method of direct heating; he did not include a chemical analysis nor an error analysis in his report. (This same data appeared in a later publication by Nikol'skii [21] where a more complete account of apparatus and procedures was given while reproducing exactly the same data.)

Douglas et al. [25] and Shpil'rain et al. [26] used calorimeters to determine the specific heat of NaK_{78}. Douglas et al. reported trace amounts (less than 0.001%) of Al, Zr, Rb, Mn, Fe, and Si; they estimated the error in their results at 0.4%, although they indicated that it may be slightly greater at temperatures below 100°C. Shpil'rain et al. did not report on the purity of their sample, but did estimate errors in their measurements at 3-5%.

Kutateladze [7] investigated the heat capacity of several liquid metals (for NaK he used NaK_{75}) using the method of direct heating in an isothermal medium. He used a Nernst calorimeter, adapted for use at high temperatures, to determine the heat transferred from a tungsten filament to the liquid metal. From this, he determined the specific heat. He did not present tabulated values of data but rather tabulated values of smoothed curves passing through the data. Data points were shown on his plots.

Douglas et al. [25] used the method of mixing with an ice calorimeter to determine the specific heat of NaK up to 800°C. In his experiment, a container of NaK was heated in a furnace to a known temperature and then dropped into an ice calorimeter which measured the heat evolved as the sample cooled to 0°C. From the measured heats, the relative enthalpy as a function of temperature was determined (after corrections for the heat of condensation of the alkali metal vapors and the heat lost during the drop).

Shpil'rain et al. [26] used essentially the same method as Douglas et al. to determine the specific heat of NaK, except that Shpil'rain used a boiling water calorimeter. The heat introduced to a boiling calorimeter was measured by "noting the increase in the intensity of the steam produced."

Table 7.1 is a comparison of the data from the three sources; these data are plotted in Figure 7.1. The results of Kutateladze et al. are in very poor agreement with the other two sources. Kutateladze's values are roughly 20% greater. This probably reflects a systematic error in the experiment. It should also be pointed out again that Nikol'skii used NaK_{75}, which would have higher thermal conductivity than NaK_{78}. The difference in alloy compositions is not large enough to explain the discrepancy fully, however. A further confusing fact is that Kutateladze's pure Na and pure K specific heat data agree quite well with those of other authors. No satisfactory resolution for these inconsistencies can be offered. Since Shpil'rain's results correlate well with those of Douglas, both sets of data are used in what follows for the recommended specific heat of NaK_{78}. Douglas found a polynominal fit to his experimental results.

Table 7.1. Data Comparison of c_p vs T; c_p[J/(kg•K)]

Temp (°C)	Douglas [25]	Kutateladze [7]	Shpil'rain [26]
0	995.0	-	-
25	979.0	-	-
50	964.9	1230.	-
75	952.3	-	-
100	941.1	1143.	-
127	-	-	939.
150	927.5	1088.	-
200	907.9	1072.	-
227	-	-	910.
300	888.2	1038.	-
327	-	-	894.
400	877.7	1005.	-
427	-	-	881.
500	874.1	967.2	-
527	-	-	877.
600	875.9	933.7	-
627	-	-	883.
700	882.4	900.2	-
727	-	-	902.
800	893.3	-	-
827	-	-	930.
927	-	-	958.

Recommended specific heat values are listed in Table 7.2. They were generated using Eq. 7.1 which was proposed by Douglas [25]. Figure 7.2 presents the recommended curve of specific heat vs. temperature. The data points of Douglas et al. [25] in this temperature range are also shown for comparison. Equation 7.1 is valid for T < 800°C.

FIGURE 7.1

AVAILABLE DATA ON

SPECIFIC HEAT (10^2 J/(kg K)) vs TEMPERATURE (°C)

for NaK 78

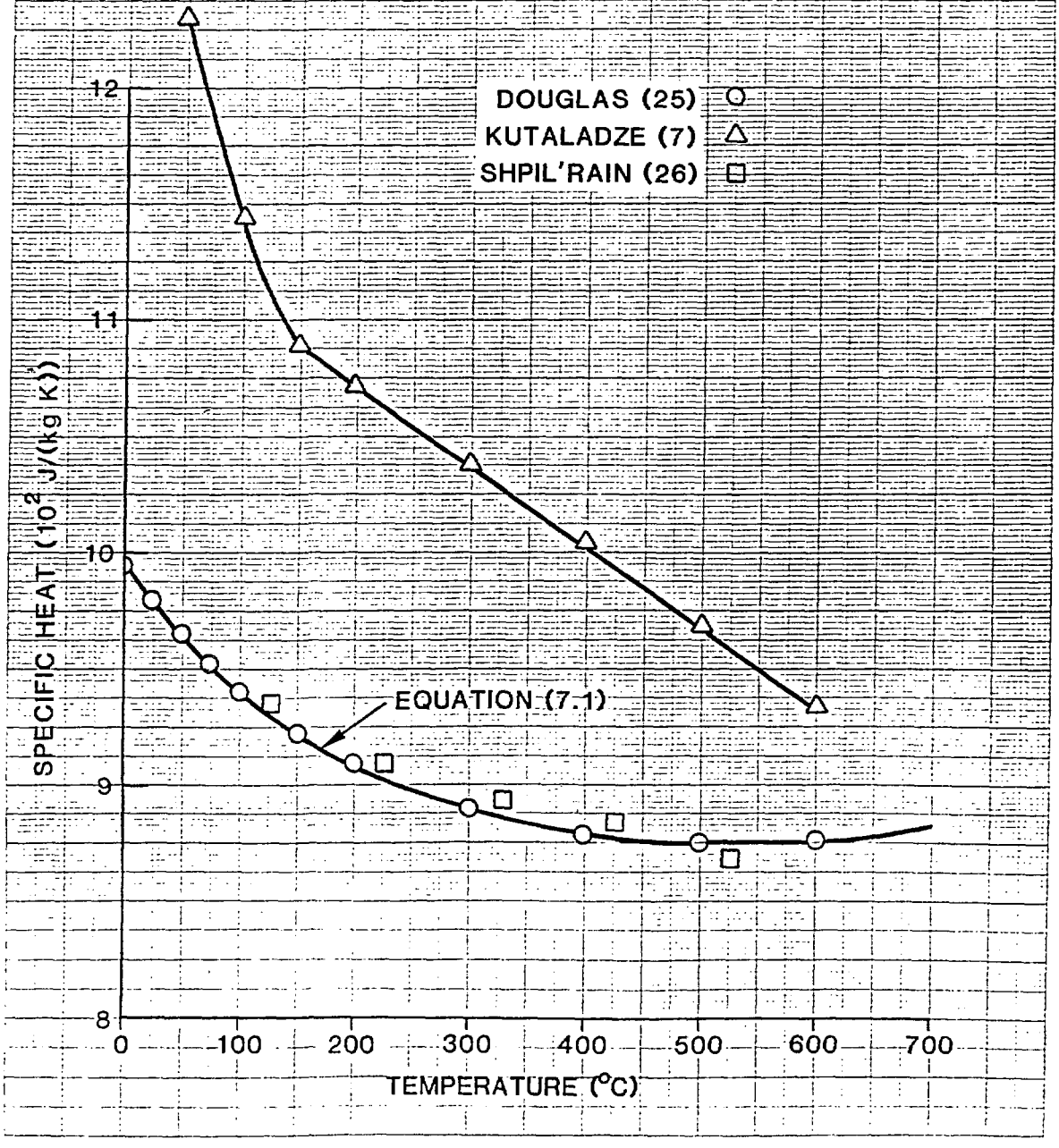


Table 7.2. Recommended Specific Heat vs Temperature

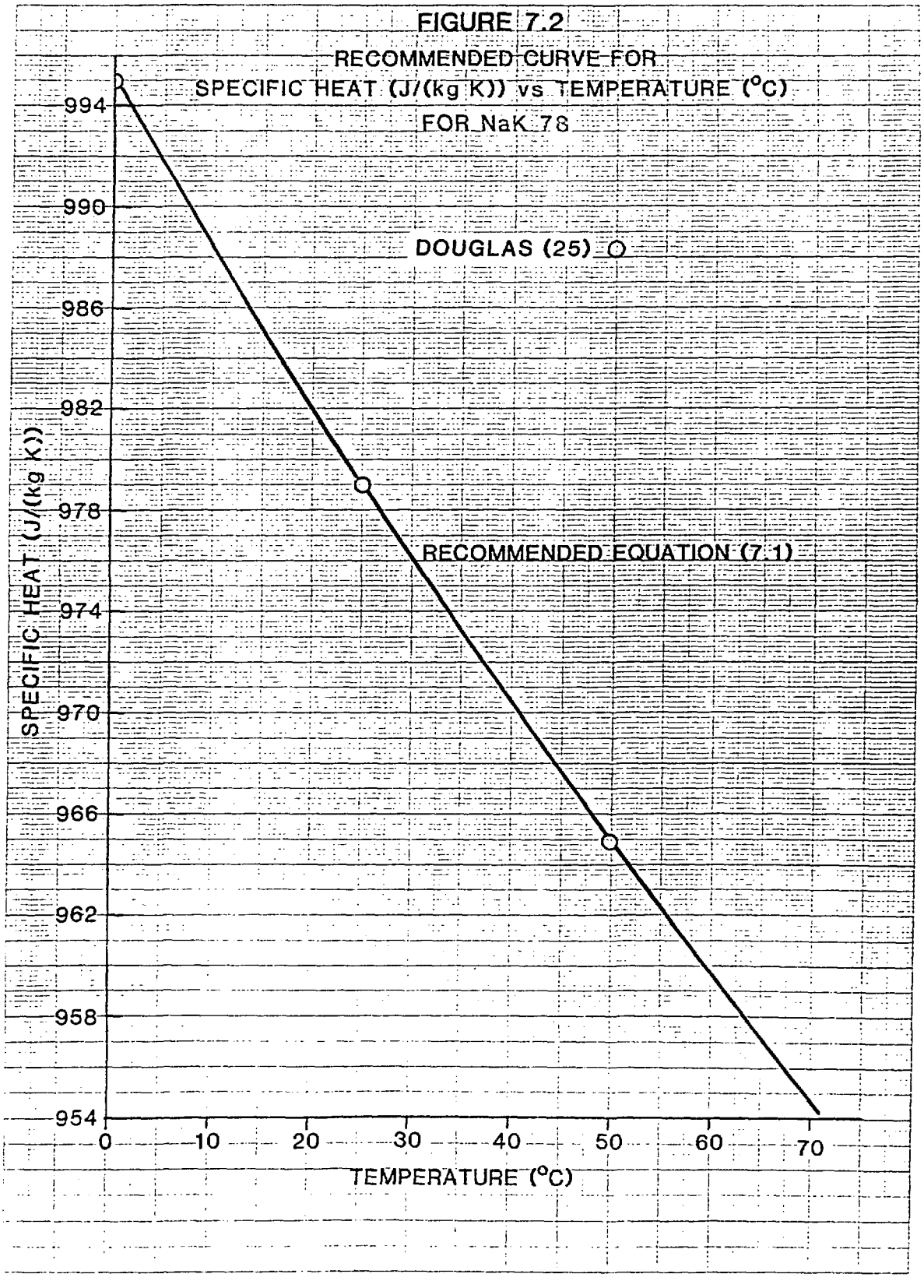
Temp. (°C)	c_p[J/(kg·K)]
0	995.0
10	988.4
15	985.2
20	982.1
25	979.0
30	976.0
35	973.1
40	970.3
45	967.6
50	964.9
55	962.2
60	959.6
65	957.1
70	954.7
75	952.3
80	949.9

The values in Table 7.2 values were calculated from the following recommended equation given by Douglas [25]:

$$c_p[J/(kg\cdot K)] = 938.6 - 2.1924\cdot 10^{-1}T + 2.1091\cdot 10^{-4}T^2 + 56.36(1 - 0.0040549T)e^{(-0.0040549T)} \qquad (7.1)$$

$$T\ (°C);\quad T < 800°C$$

FIGURE 7.2


RECOMMENDED CURVE FOR
SPECIFIC HEAT (J/(kg K)) vs TEMPERATURE (°C)
FOR NaK 78
DOUGLAS (25)
RECOMMENDED EQUATION (7.1)
SPECIFIC HEAT (J/(kg K))
994
990
986
982
978
974
970
966
962
958
954
0
10
20
30
40
50
60
70
TEMPERATURE (°C)

8. THERMAL DIFFUSIVITY

Novikov [11] used Angstrom's method of temperature waves to measure thermal diffusivity of NaK_{78}. In the experiment, the alloy was poured into a thin stainless steel tube with an open top to allow for thermal expansion. To prevent boiling, an inert cover gas was used to pressurize the tube. The upper part of the working tube was placed in a pulsed heater which was powered by a stabilized AC source. Two thermocouples were placed at 20 and 40 mm below the heater to measure the temperature along the specimen; the whole instrument was placed in an evacuated quartz pipe and surrounded by a copper shield. The experimental results were presented graphically - no numeric values were given. One data point at T ≈ 155°C (the lowest temperature) is presented in Table 8.1.

Table 8.1. Recommended Thermal Diffusivity vs Temperature

T(°C)	ρ(kg/m^3)	c_p[J/(kg•K)]	k[W/(m•K)]	α(10^{-5}m^2/s)	Novikov [11] α (10^{-5} m^2/s)
0	873.4	995.0	21.4	2.46	
10	870.8	988.4	21.6	2.51	
20	868.2	982.1	21.8	2.56	
30	865.6	976.0	22.0	2.60	
40	863.0	970.3	22.2	2.65	
50	860.5	964.9	22.4	2.695	
60	857.9	959.6	22.6	2.74	
70	855.3	954.7	22.7	2.785	
80	852.7	949.9	22.9	2.83	
155	833.4	920.9	24.1	3.14	1.53

The Novikov data is low by roughly a factor of two when compared to thermal diffusivity calculated according to the following equation:

$$\alpha\ (m^2/s) = k/\rho c_p \qquad (8.1)$$

The previously recommended values of density, specific heat, and thermal conductivity have been used to calculate recommended thermal diffusivity according to Eq. 8.1 and the results are tabulated in Table 8.1.

The method of least squares was used to fit the following equation to the recommended values of thermal diffusivity presented in Table 8.1.

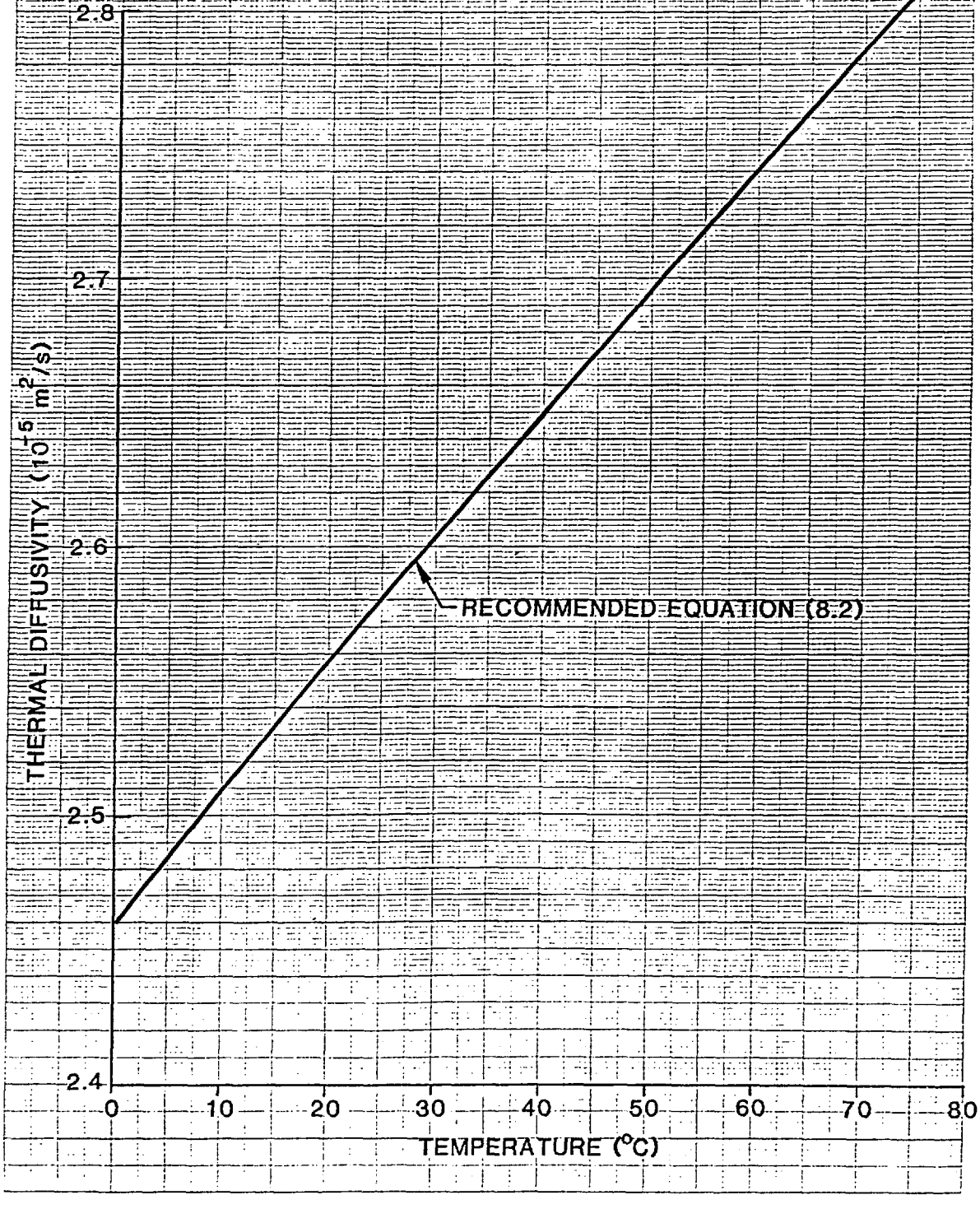
$$\alpha(m^2/s) = 2.461126 \cdot 10^{-5} + 4.8305 \cdot 10^{-8} T + 2 \cdot 10^{-11} T^2 \qquad (8.2)$$

$$T\ (°C);\quad T < 80°C$$

Equation 8.2 is recommended for calculating values of thermal diffusivity for NaK_{78} below 80°C. Equation 8.2 is plotted in Figure 8.1.

FIGURE 8.1

RECOMMENDED CURVE FOR THERMAL DIFFUSIVITY (10^{-5} m^2/s) vs TEMPERATURE (°C) FOR NaK-78



9. PRANDTL NUMBER

The Prandtl number was calculated using the following equation

$$Pr = \nu/\alpha \qquad (9.1)$$

and the previously recommended values of kinematic viscosity and thermal diffusivity. The values of kinematic viscosity, thermal diffusivity, and resulting Prandtl number appear in Table 9.1. The method of least squares was used to fit the following equation to the recommended values of Pr given in Table 9.1:

$$Pr = 5.1729\times10^{-2} - 5.85\times10^{-4}\ T + 3\times10^{-6}\ T^2 \qquad (9.2)$$
$$T\ (°C);\quad T < 80°C$$

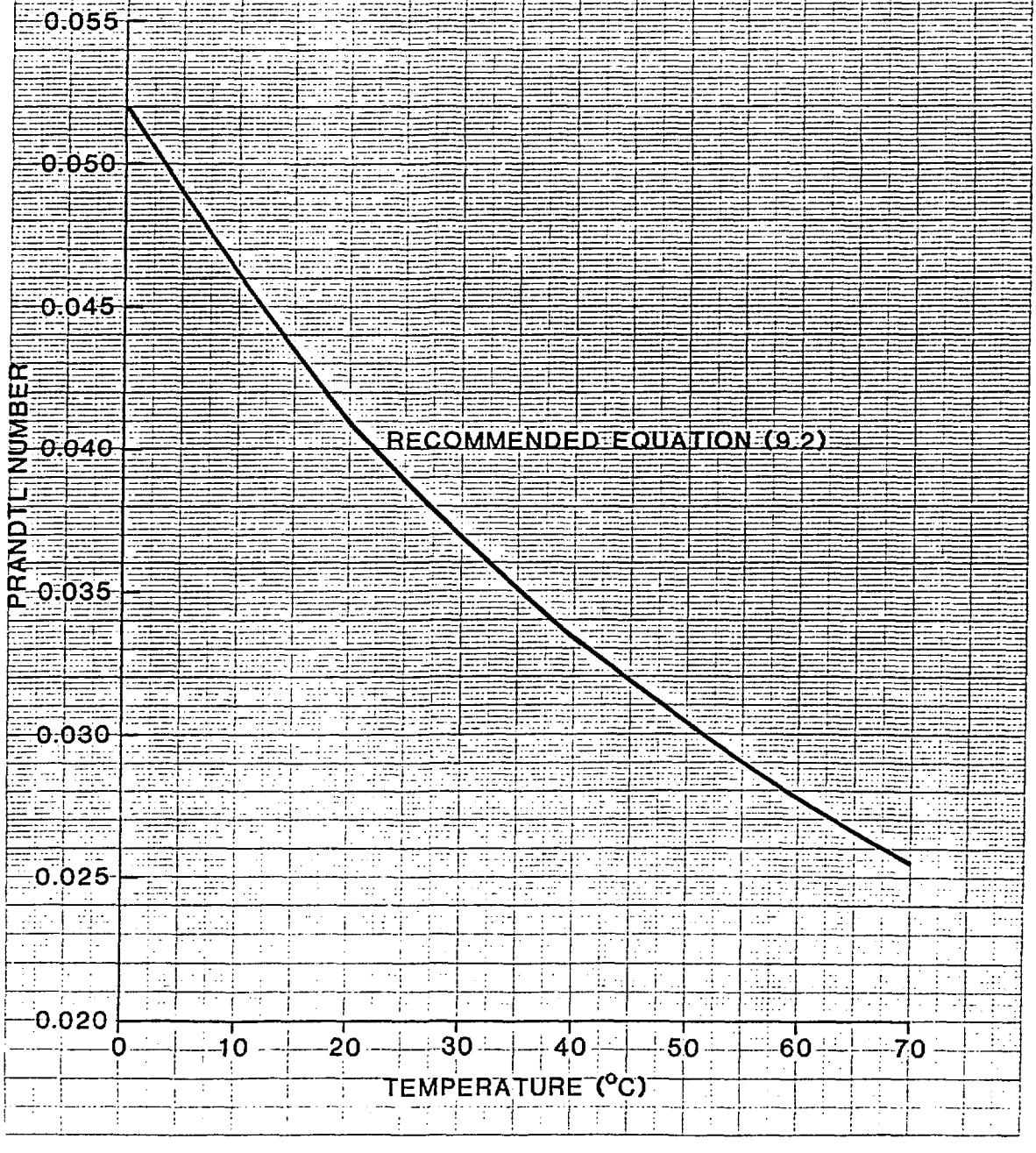
Equation 9.2 is recommended for calculating values of Prandtl Number below 80°C. Equation 9.2 is plotted in Figure 9.1.

Table 9.1. Recommended Prandtl Number vs Temperature

T (°C)	ν (10^{-6} m^2/s)	α (10^{-5} m^2/s)	Pr
0	1.279	2.46	0.052
10	1.155	2.51	0.046
20	1.050	2.56	0.041
30	0.961	2.60	0.037
40	0.885	2.65	0.033
50	0.819	2.695	0.030
60	0.762	2.74	0.028
70	0.711	2.785	0.026
80	0.667	2.83	0.024

FIGURE 9.1

RECOMMENDED CURVE FOR PRANDTL NUMBER vs TEMPERATURE (°C) FOR NaK 78



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APPENDICES

Appendix A:

Krainova and Shpil'rain [16]--Thermal Conductivity Data

1st Run			2nd Run		
No.	T(°C)	k(W/m·K)	No.	T(°C)	k(W/m·K)
1	86.5	22.83	1	88.8	22.13
2	98.0	22.39	2	98.7	21.09
3	108.9	22.97	3	112.8	22.01
4	260.9	25.56	4	167.2	23.23
5	296.2	26.28	5	175.6	23.90
6	337.8	25.43	6	189.6	23.59
7	335.0	26.66	7	195.4	24.01
8	385.4	26.38	8	208.7	23.02
9	417.0	25.84	9	209.2	23.98
10	429.5	26.30	10	218.2	24.42
11	468.3	26.03	11	231.6	23.57
12	473.5	27.30	12	246.2	25.51
13	518.9	26.25	13	253.7	26.32
14	532.0	26.79	14	255.1	24.29
15	533.9	27.39	15	275.2	24.83
16	548.4	25.75	16	283.0	25.31
17	560.7	25.60	17	304.3	25.35
18	575.6	26.16	18	312.2	26.38
19	590.2	26.03	19	318.0	25.14
20	591.6	27.42	20	325.4	26.14
21	599.3	27.13	21	360.9	24.05
22	628.5	26.43	22	366.6	25.86
23	632.9	25.53	23	405.2	24.13
24	644.9	26.28	24	406.9	25.84
25	661.0	27.15	25	415.7	26.93
26	661.4	26.83	26	454.2	25.82
27	675.8	26.17	27	463.6	26.48
28	705.0	26.27	28	519.5	25.82
29	727.0	25.76	29	516.9	26.74
30	725.9	25.19	30	521.6	27.20
31	743.6	26.04	31	516.8	27.83
32	762.3	25.72	32	590.8	25.65
33	822.8	25.46	33	578.4	27.09
			34	584.3	26.23
			35	628.4	28.26
			36	655.2	23.30
			37	658.5	24.93
			38	713.8	26.08
			39	798.9	25.17

Appendix B.

1. Tepper et al. [17]: Electrical Resistivity Data

TABLE 7 - ELECTRICAL RESISTIVITY DATA FOR EUTECTIC NaK

Heating Run Number	Temperature (°F)	Resistivity (μ-ohm cm)	(μ-ohm in)
1	98	56.26	14.28
	181	38.61	15.21
	261	41.11	16.19
2	316	42.70	16.81
	371	44.46	17.52
	425	46.38	18.27
	514	49.55	19.52
	558	51.21	20.16
	604	52.97	20.87
	652	55.04	21.69
	693	56.67	22.33
3	632	54.24	21.37
	759	59.71	23.51
	817	62.26	24.53
	855	63.99	25.21
	894	65.85	25.94
	954	67.99	26.79
	972	69.84	27.52
	1010	71.80	28.27
4	1044	75.49	28.95
	1083	75.65	29.81
	1118	77.84	30.67
	1159	80.20	31.60
	1197	82.30	33.33
	1232	84.66	33.35
	1274	87.19	34.35
	1312	89.63	35.31
	1352	92.46	36.43
5	1392	95.22	37.52
	1429	97.99	38.61
	1469	100.74	39.66
	1504	103.64	40.83
	1535	105.77	41.67
	1572	109.08	42.98
	1609	111.56	43.96
	1643	114.92	45.28
	1680	118.35	46.59
6	1685	118.01	46.50
	1720	121.65	47.92
	1756	125.24	49.35
	1795	128.99	50.78
	1852	132.97	52.39
	1871	136.92	53.95
	1907	141.01	55.56
	1948	145.45	57.31
	1995	151.28	59.61
7	529	50.27	19.81
8	485	48.60	19.15
	855	64.50	25.55

2. Drugas et al. [23]: Electrical Resistivity Data

Table IV

RESISTANCE DATA - NaK ALLOY (80w/o K)

Temperature (°C)	R_T (milliohms)	R_C (milliohms)	R_N (milliohms)	A (cm^2)	R (microhm cm)
30	3.62	76.2	3.80	0.282	35.2
36	3.65	76.2	3.83	0.282	35.5
102	3.99	76.8	4.21	0.282	39.0
136	4.17	77.2	4.41	0.282	40.7
174	4.37	77.5	4.63	0.282	43.0
219	4.64	78.0	4.93	0.282	45.6
243	4.79	78.2	5.10	0.283	47.4
273	4.98	78.5	5.32	0.283	49.4
302	5.17	78.7	5.54	0.283	51.3
333	5.37	79.0	5.76	0.283	53.5
368	5.62	79.4	6.05	0.284	56.3
399	5.84	79.6	6.30	0.284	58.7
438	6.13	80.0	6.64	0.284	61.9
469	6.37	80.3	6.92	0.285	64.6
480	6.44	80.4	7.00	0.285	65.4
500	6.62	80.6	7.21	0.285	67.5
518	6.75	80.8	7.37	0.285	69.0
553	7.06	81.1	7.74	0.285	72.4
600	7.48	80.1	8.25	0.286	77.4
650	7.95	80.6	8.83	0.286	82.8
712	8.65	81.2	9.67	0.287	91.0
720	8.77	81.3	9.83	0.287	92.5

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