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OFFICE OF SALINE WATER

APPROXIMATIONS FOR PHYSICAL PROPERTIES OF SEA SALT SOLUTIONS

J. V. Wilson

OAK RIDGE NATIONAL LABORATORY

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APPROXIMATIONS FOR PHYSICAL PROPERTIES OF SEA SALT SOLUTIONS

ABSTRACT

Approximate formulas of five or fewer terms are given for enthalpy, heat capacity, thermal conductivity, viscosity, boiling point elevation, and density of sea salt solutions.

Keywords: Physical Properties + Thermal Properties + Chemical Properties + Boiling Point Elevation + Seawater + Brine + Mathematical Model

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INTRODUCTION

The Office of Saline Water requested the Oak Ridge National Laboratory to recommend a set of simple approximations for calculating physical properties of sea salt solutions to an accuracy usually adequate for distillation plant data analysis. The emphasis was to be on simplicity rather than high accuracy. Accordingly, this memorandum presents a set of formulas of five or fewer terms for computation of the enthalpy, heat capacity, thermal conductivity, viscosity, boiling point elevation, and density of sea salt solutions. It also presents figures in which values calculated from the formulas are superimposed on the appropriate pages from the Distillation Plant Data Book,[1] which served as the data base for deriving the formulas, so that their accuracy and adequacy for any particular application can be readily determined.

These formulas are intended for use only in the range 60°F to 300°F and 0 to 11% sea salt concentration.

NOMENCLATURE

B = Boiling point elevation, °F

C = Concentration, weight fraction

C_p = Heat capacity, Btu/(lb·°F)

D = Density, lb/ft^3

H = Enthalpy, Btu/lb

K = Thermal conductivity, Btu/(ft·hr·°F)

S = Salinity, gm/kgm = 1000·C.

T = Temperature, °F

V = Viscosity, lb/(ft·hr)

FORMULAS

(a) Boiling Point Elevation

$$B = C(7.625 + 36.75C + T(.084583 + .154167C)) \quad (1)$$

(b) Heat Capacity of Brines (C = .03 to .11)

$$C_p = 0.982635 - 1.06915C + 1.08113 \cdot 10^{-4} T \quad (2)$$

Heat Capacity of Pure Water (Product)

$$C_p = 1.0055 - 1.5 \cdot 10^{-4} T + .75 \cdot 10^{-6} T^2 \quad (3)$$

Heat Capacity of Brackish Water (C = 0 to .035)

$$C_p = 0.98499 - 1.21301C + 1.211096 \cdot 10^{-4} T \quad (3a)$$

(c) Density

$$D = 62.6651 + 46.013C - .62338 \cdot 10^{-4} T^2 \quad (4)$$

This equation was derived by Electronic Associates, Inc.[2]

(d) Enthalpy of Brines (C = .03 to .11)

$$H = -30.7435 + 0.982635T - 1.06915CT + 5.40565 \cdot 10^{-5} T^2 + 13.626\ C \quad (5)$$

Enthalpy of Pure Water (Product)

$$H = -32.10739 + 1.0055T - .75 \cdot 10^{-4} T^2 + .25 \cdot 10^{-6} T^3 \quad (6)$$

Enthalpy of Brackish Water (C = 0 to .035)

$$H = -31.1161 + 0.98499T - 1.21301\ CT + 6.05548 \cdot 10^{-5} T^2 + 30.1465C \quad (6a)$$

(e) Thermal Conductivity

$$K = .29411 - .174C + .0008791T - 2 \cdot 10^{-6} T^2 \quad (7)$$

This equation was derived by Electronic Associates, Inc.[2]

(f) Viscosity

$$V = (-.30361 + 218.277/T - 2532.8/T^2)\ (1 + 2.76C) \quad (8)$$

Eq.(8) is a modification of an equation derived by Electronic Associates, Inc.[2]

DISCUSSION

Separate expressions have been given for enthalpy of fresh water and that of brine, and for the corresponding heat capacities for several reasons: (1) normally the fresh water system is separate from the brine system and a different set of equations applies, (2) use of separate expression allows significantly better accuracy for fresh water properties for the same number of terms, and (3) in many calculations, e.g., heat balances, a fairly accurate value of the enthalpy is desirable. The expressions for brine may be used for fresh or brackish water if desired and if accuracy shown in Table 1 is acceptable.

Other sets of formulas for these physical properties are available. More complicated but more accurate formulas are given in the ORNL reports on computer codes for designing distillation plants, for example. However, it should be noted that the expressions given there and in Ref. 2 for heat capacity and enthalpy are for NaCl solutions, and not for seawater or its concentrates.

ACCURACY

The figures show sets of circles showing physical properties as calculated from the formulas for salinity values 0, 35, 70 and 105, corresponding to concentrations 0, 0.035, 0.070, and 0.105 weight fraction respectively and approximating 0, 1, 2 and 3 times the concentration of ocean water. The circles are superimposed on photographic reproductions of figures from the Distillation Plant Data Book. No figure is included for enthalpy because no figure is given in that data book and errors large enough to be discernible on such a graph would be unacceptable.

Table 1 gives the differences in the enthalpies calculated by the formula for brine and those given in Table VI of Ref. 3.

TABLE 1

Concentration:		0	.035	.07	.105
Temperature °C	°F	Enthalpy from formula minus enthalpy from reference, Btu/lb			
15	59	.319	.069	-.020	.075
30	86	.071	-.010	-.029	.042
45	113	-.077	-.049	-.041	-.013
60	140	-.169	-.057	-.034	-.048
75	167	-.226	-.025	-.005	-.057
90	194	-.294	.013	.049	-.059
105	221	-.355	.039	.110	-.036
120	248	-.482	.055	.159	-.006
135	275	-.727	-.030	.144	-.024
150	302	-1.091	-.199	.063	-.071

CONCLUSIONS AND RECOMMENDATIONS

The expressions for physical properties of seawater solutions displayed in this report appear to fit the experimental data reasonably well and are suitable for most evaporator design or data analysis. Design calculations to be carried out on large digital computers could use more elaborate and precise equations for seawater properties, such as those prepared by Bromley.[3] When design computer programs are being prepared or updated, derivation of these more precise equations should be considered.

REFERENCES

1. A. E. Dukler et. al., Distillation Plant Data Book, OSW Contract 14-01-0001-2099, January 1971, U. S. Govt. Printing Office.

2. B. T. Fairchild and C. S. Rhee, Electronic Associates, Inc.: Simulation of a Multistage Flash Test Module; Report to OSW, February 1971.

3. L. A. Bromley et. al., J. Chem. Engineering Data, 15 246 (1970).

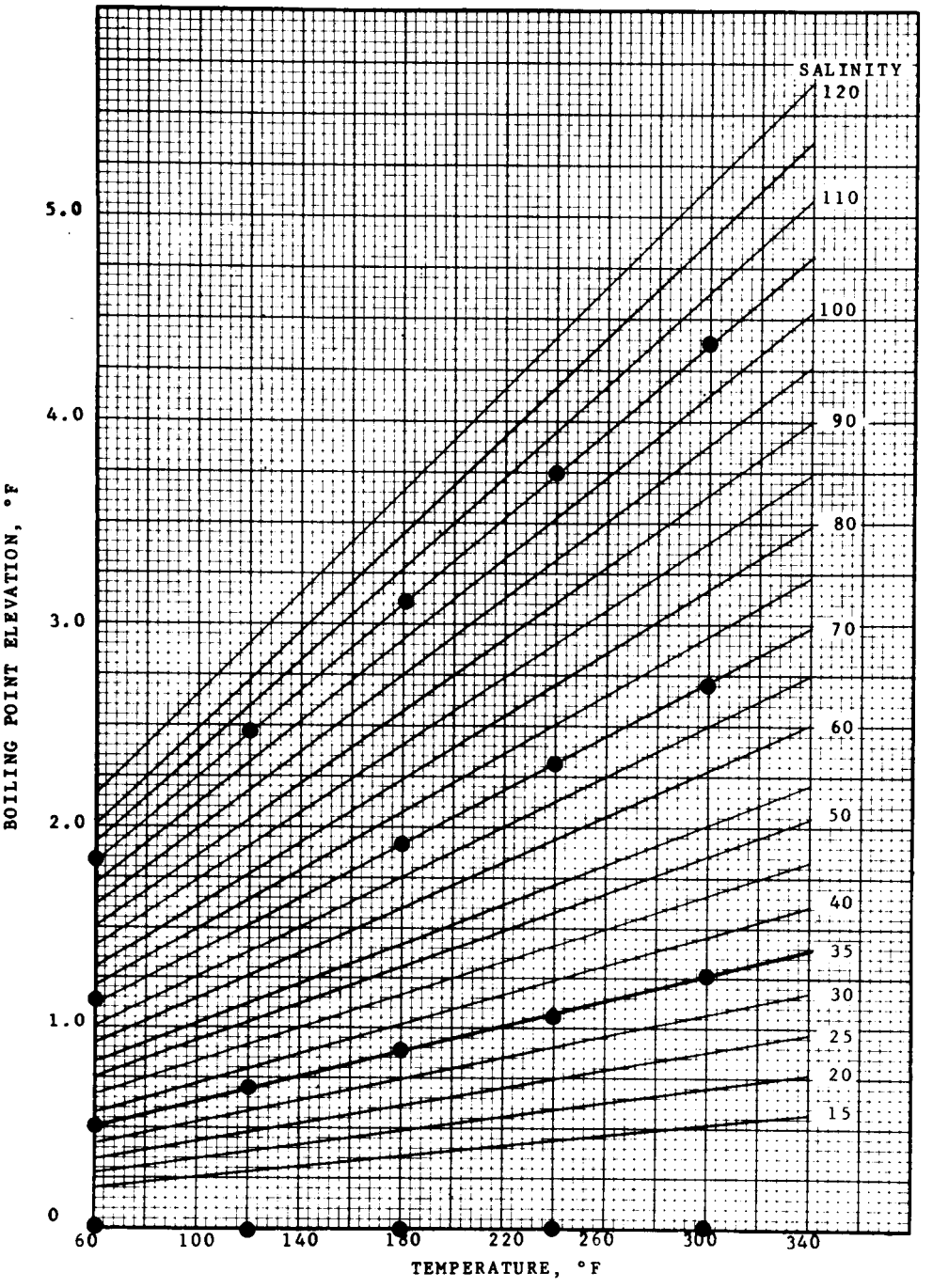

FIGURE 8.1. Boiling point elevation of sea water solutions.

The dots show calculated values for salinities of 0, 35, 70 and 105.

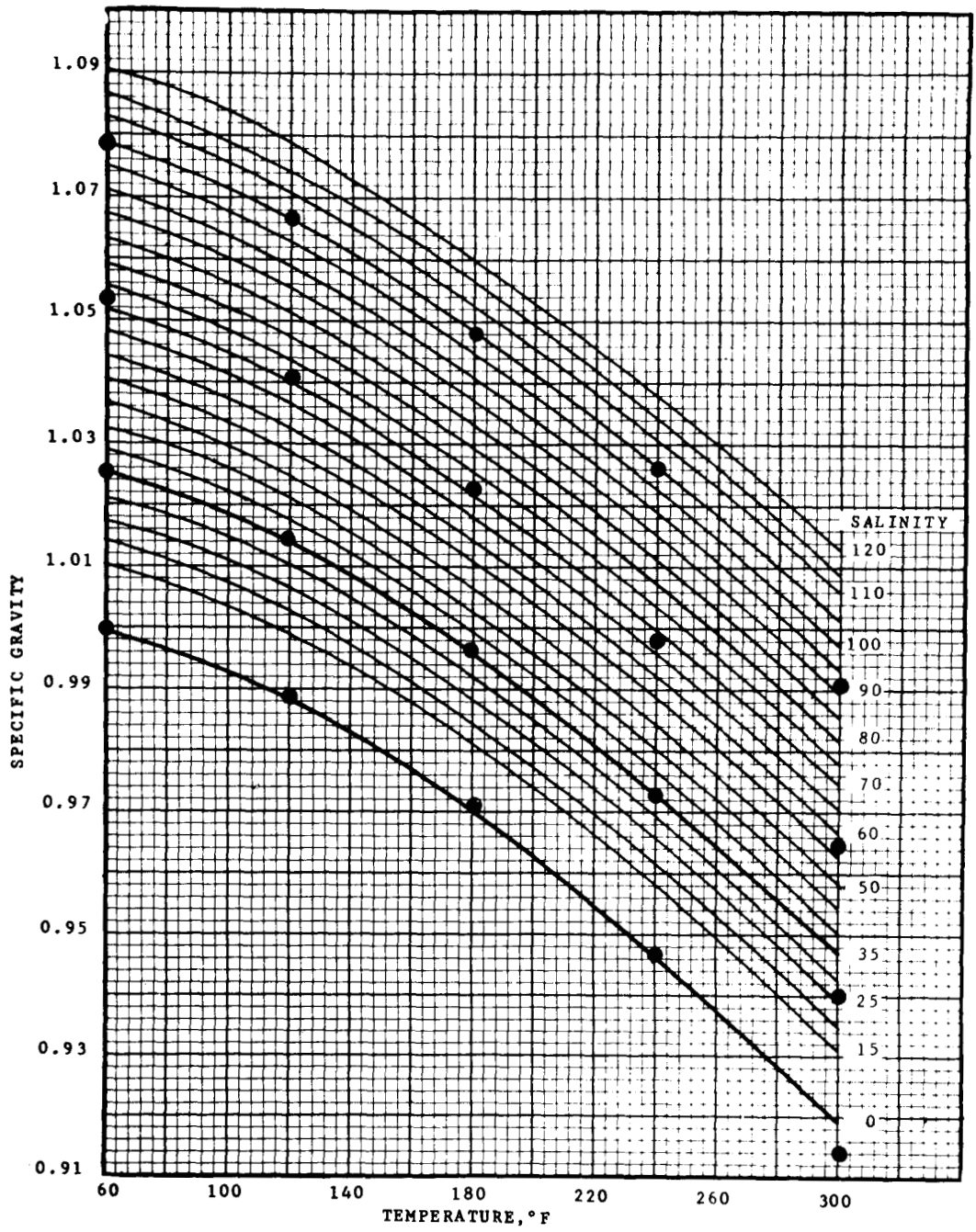

FIGURE 8.2. Specific gravity of sea water solutions.

The dots show calculated values for salinities of 0, 35, 70 and 105.

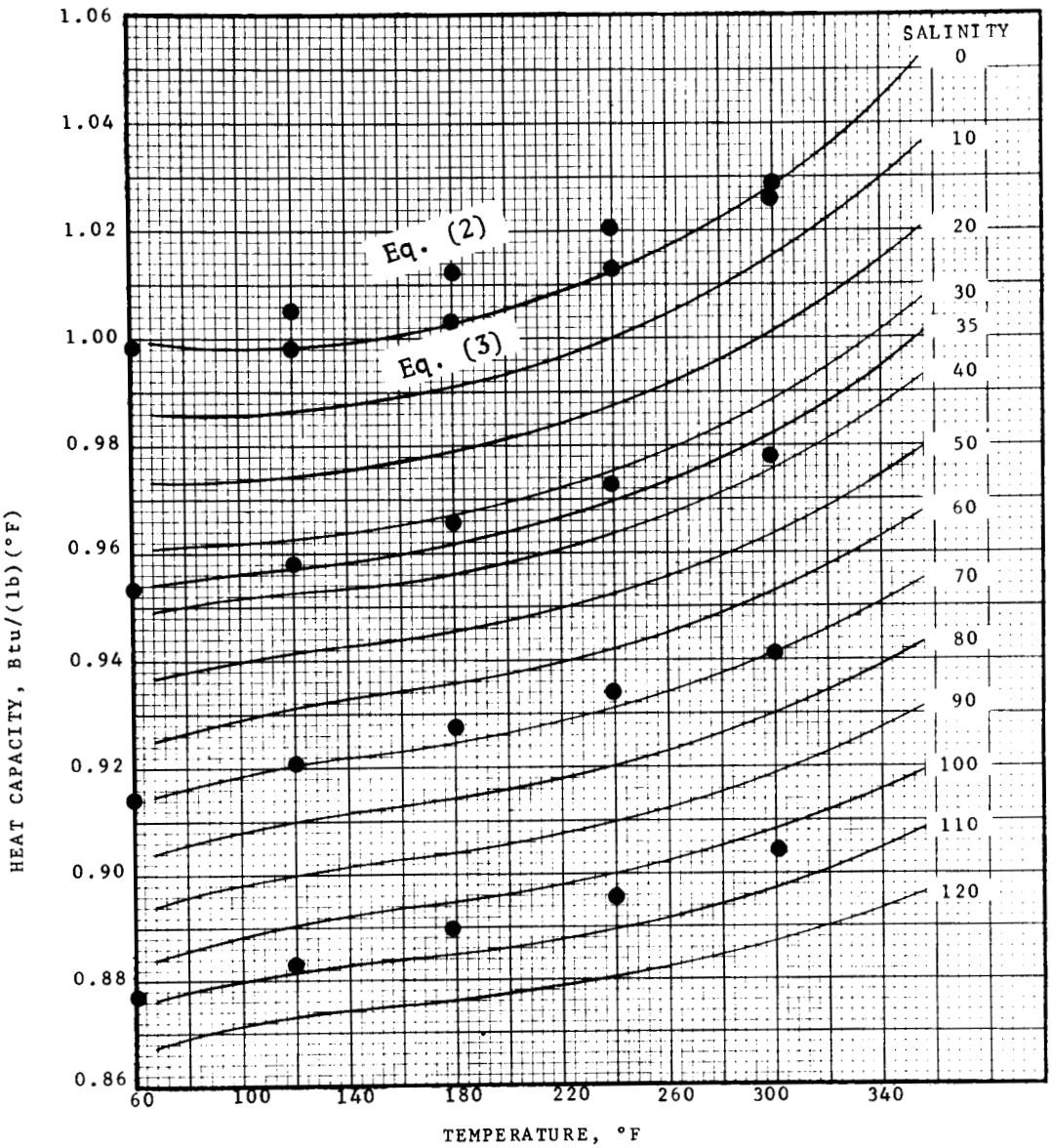

FIGURE 8.3. Heat capacity of sea water solutions.

The dots show calculated values for salinities of 0, 35, 70 and 105.

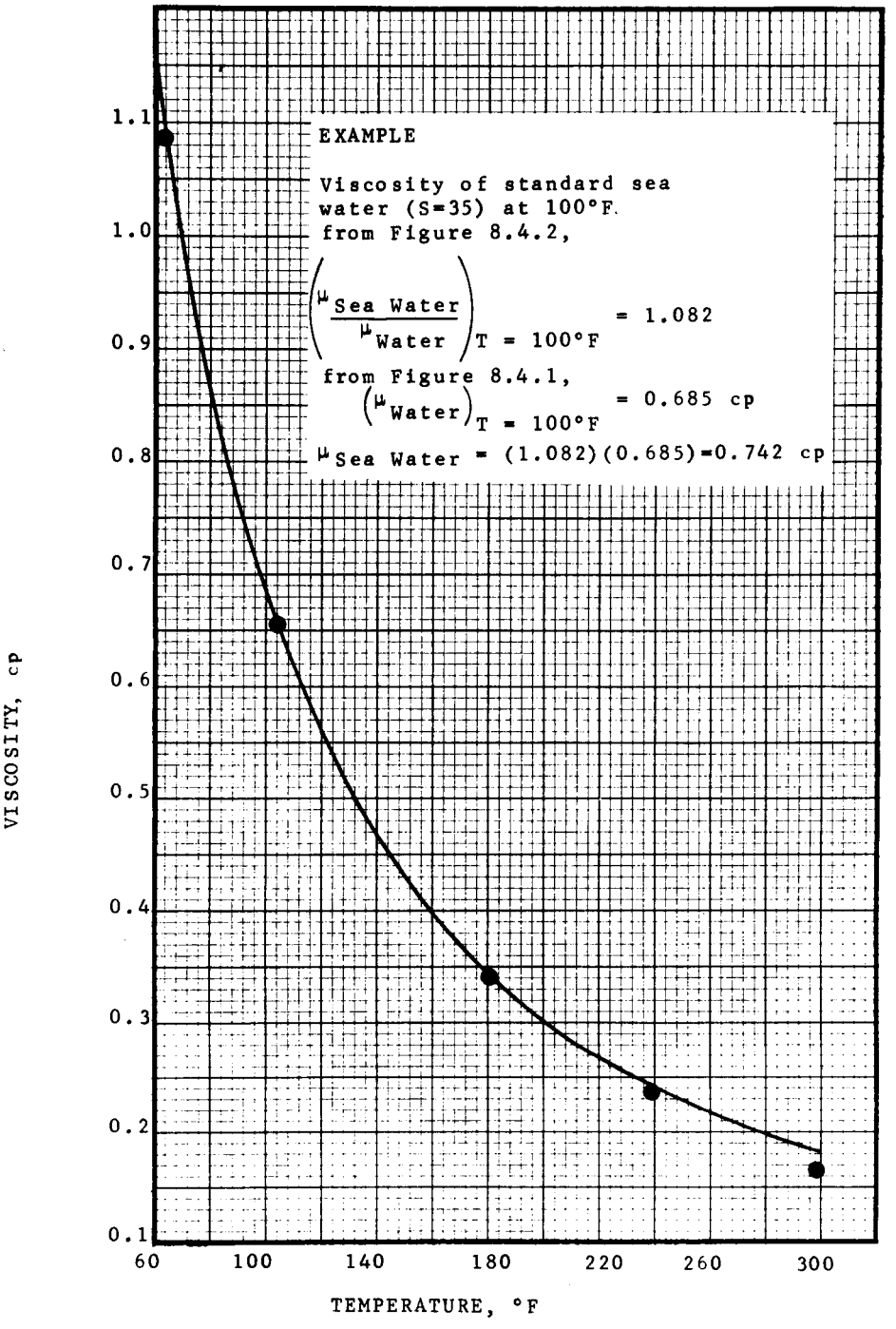

FIGURE 8.4.1. Viscosity of water.

The dots show calculated values.

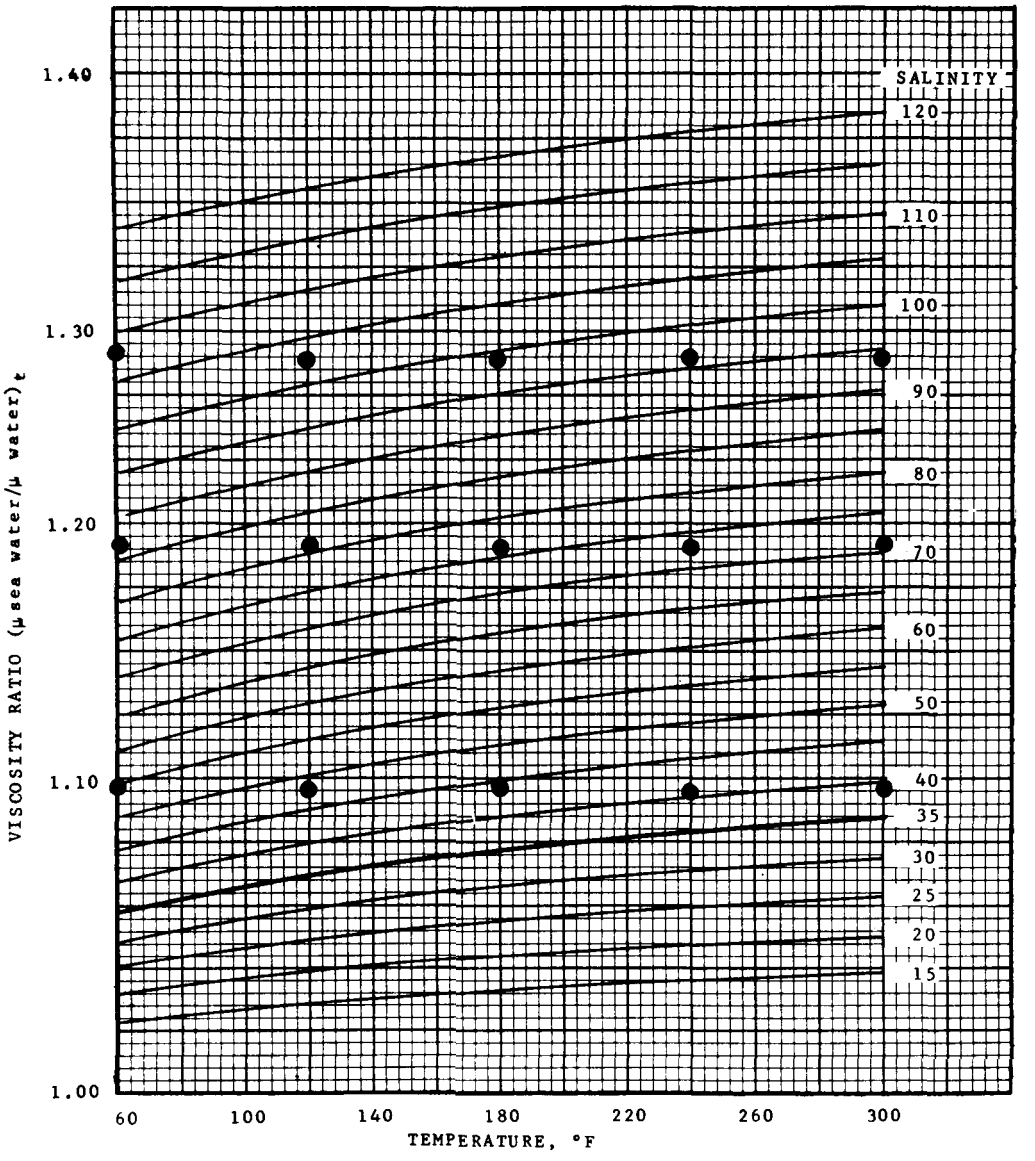

FIGURE 8.4.2 Viscosity ratio of sea water solutions.

The dots show calculated values for salinities of 0, 35, 70 and 105.

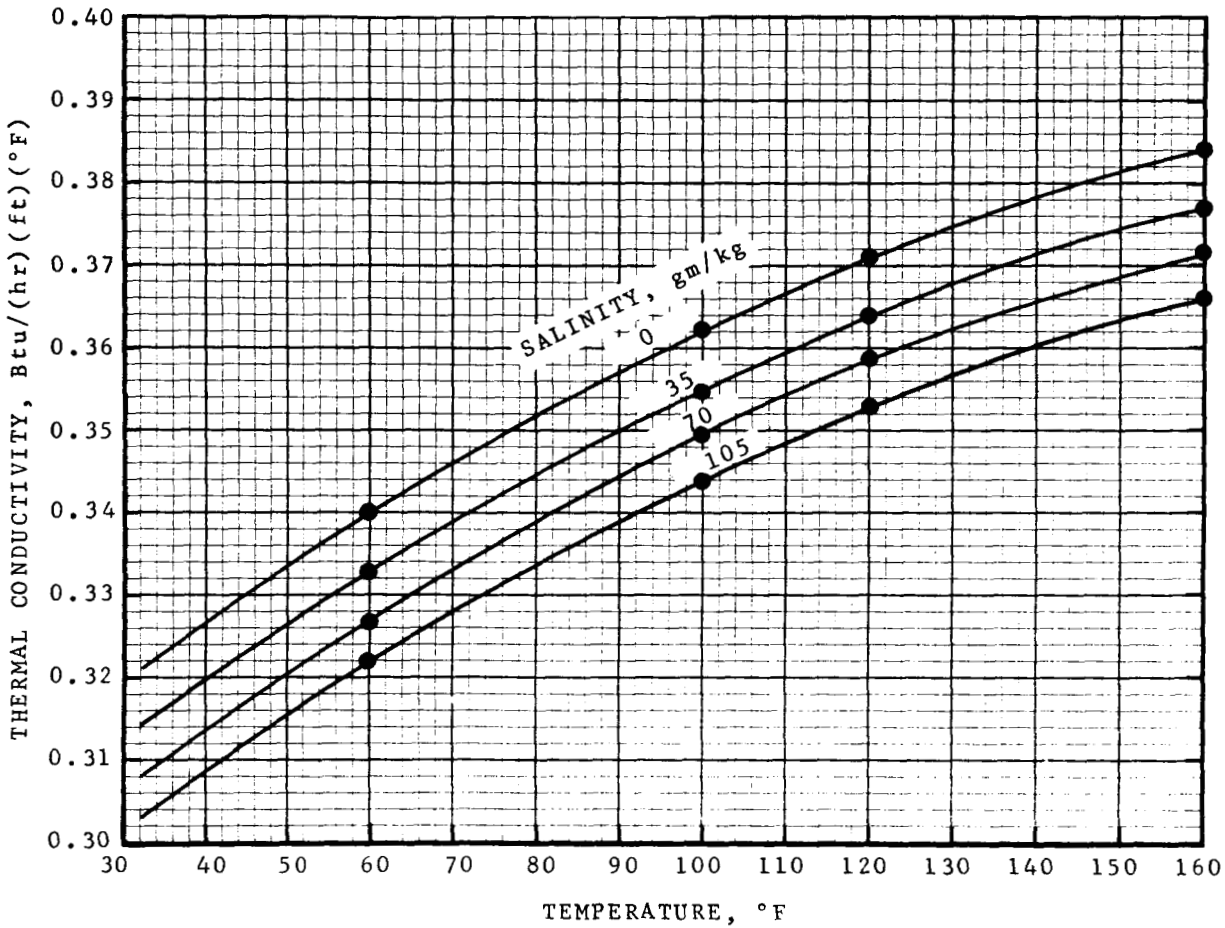

FIGURE 8.7. Thermal conductivity of sea water solutions.

The dots show calculated values for salinities of 0, 35, 70 and 105.

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