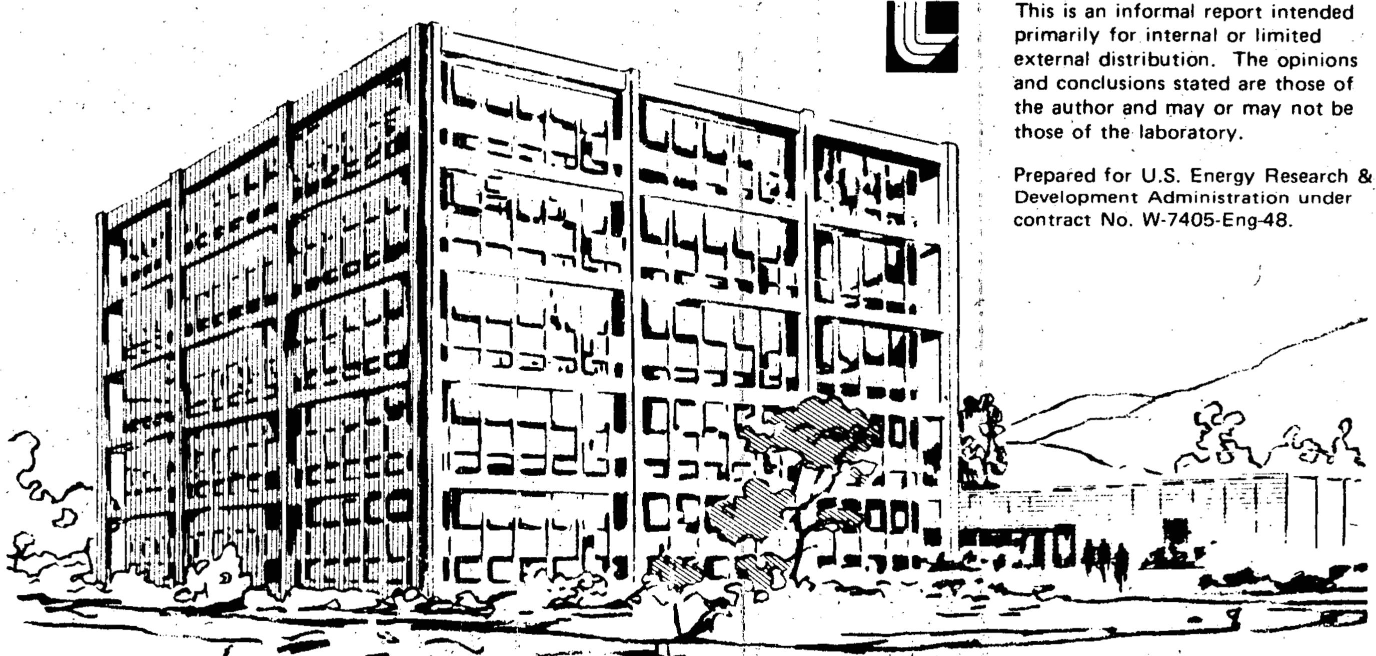
UCID- 17406

Lawrence Livermore Laboratory

CALCULATION OF BRINE PROPERTIES

Gerald L. Dittman

February 16, 1977



Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

DISCLAIMER

CALCULATION OF BRINE PROPERTIES

ABSTRACT

Simple analytical expressions are presented for estimating geothermal brine thermophysical properties above 80°F and for salt contents between 5 and 25 percent by weight.

Linear regression by the method of least squares is used to curve-fit saturated liquid enthalpy and density data on simulated brines. Brine saturation pressure is calculated as a percentage of the pure water saturation pressure at the same temperature. Saturated liquid brine entropy is determined from an approximation to the differential equation for entropy change using the previously determined relationships for the other property values needed.

Brine vapor properties are assumed equal to steam properties at the same temperature and pressure and are obtained from the ASME equation-of-state for pure water.

CALCULATION OF BRINE PROPERTIES

by

Gerald L. Dittman

Introduction

Simplified analytical expressions are currently needed to provide estimates of the equation of state for geothermal brines. These expressions can then be incorporated into various numerical codes developed for the Total Flow program that require predictions of Salton Sea brine thermophysical properties as functions of temperature and salt content [(1)].

Researchers at the Denver Research Institute - University of Denver have measured thermophysical properties in the laboratory using water solutions with varying weight percent solids with a constant concentration of potassium, calcium, and sodium chlorides in the ratio 1.00: 1.95: 3.55, respectively, to simulate Salton Sea geothermal brines [(2)]. Haas has produced a complex mathematical model for predicting, with high precision, the liquid saturation pressure and density corresponding to a saturation temperature for brine of constant composition using available data for vapor-saturated sodium chloride-water solutions [(3)]. Daley, et al, measured the enthalpy of several concentrates of natural seawater. From this data they developed a complex and precise mathematical expression for predicting the enthalpy which was then used in other analytical formulations to calculate entropy and specific heat as a function of temperature (to 400°F) for the several salinities chosen [(4)]. Grens has reviewed some of these, and additional data, and suggested the use of an approximation for predicting brine saturated liquid enthalpy based on the pure water value at the appropriate saturation temperature and the averaged heat capacity of the dissolved salts [(5)].

Potter and Haas have reviewed the published literature for data on the thermophysical properties of geotehrmal brines, simulated brines and seawater solutions of different salinities at various temperatures. Interpretation of this body of information coupled with additional experimental work of their own has led to a theoretical understanding and basis for accurately predicting geothermal brine physical and thermodynamic properties as a function of composition and temperature [(6)].

Comparisons between the measured or predicted properties of the simulated brines and actual Salton Sea brines is not possible at present since very little experimental data exists in the literature concerning the thermodynamic properties of the geothermal fluids at compositions and temperatures of interest. Complex and precise mathematical expressions for predicting geothermal brine properties based on simulations of the fluid do not seem warranted for now. Simple mathematical formulations are desired until experimental data is available. The approach used here is to curve-fit some of the data for the simulated brines presented in the references, using linear regression by the method of least squares [7]. The brine saturated vapor properties are assumed to be equal to the pure water values given by the ASME equation of state at the appropriate pressure and temperature [8]. It is also assumed that properties at other salt concentrations can be obtained by interpolation between the values used here.

Development of the expressions for brine saturation pressure, liquid and vapor density, enthalpy and entropy is explained in the following pages. A subsequent discussion compares the results of these expressions with the results produced in the cited references.

Nomenclature and Units

T, T1, T2 temperatures, °F

Pure Water Properties

PSAT(T), saturated vapor pressure at T, PSIA

SG(T), saturated vapor entropy at T, BTU/LBM-°R

SVG(T), specific volume of saturated water vapor at T, FT^3/LBM

Brine Properties

HB(T), saturated liquid enthalpy at T and X_s, BTU/LBM

HGB(T), vapor enthalpy at T and PSATB(T), BTU/LBM

PSATB(T), saturated vapor pressure at T and Xs, PSIA

RHOB(T), liquid density at T and Xs, LBM/FT^3

RHOGB(T), vapor density at T and PSATB(T), LBM/FT^3

SB(T), saturated liquid entropy at T and Xs, BTU/LBM-°R

SGB(T), vapor entropy at T and PSATB(T), BTU/LBM-°R

Xs, salt content, weight percent

a_1, averaged ratio of brine and pure water saturation pressures at T and Xs

a_2, a_3, a_4, a_5, regression coefficients

r, regression analysis coefficient of determination

Results

1. Brine Saturation Pressure, PSATB(T)

Using the data in Reference 3, Table A1 in the Appendix, the ratio of brine and pure water saturation pressures corresponding to the given saturation temperature (230°F to 626°F) was formed for each weight percent salt. An average value for this ratio over the temperature range was used for the coefficient, a_1. The brine saturation pressure is then determined from the results shown in Table 1.

TABLE 1

Brine Saturated Pressure Coefficients

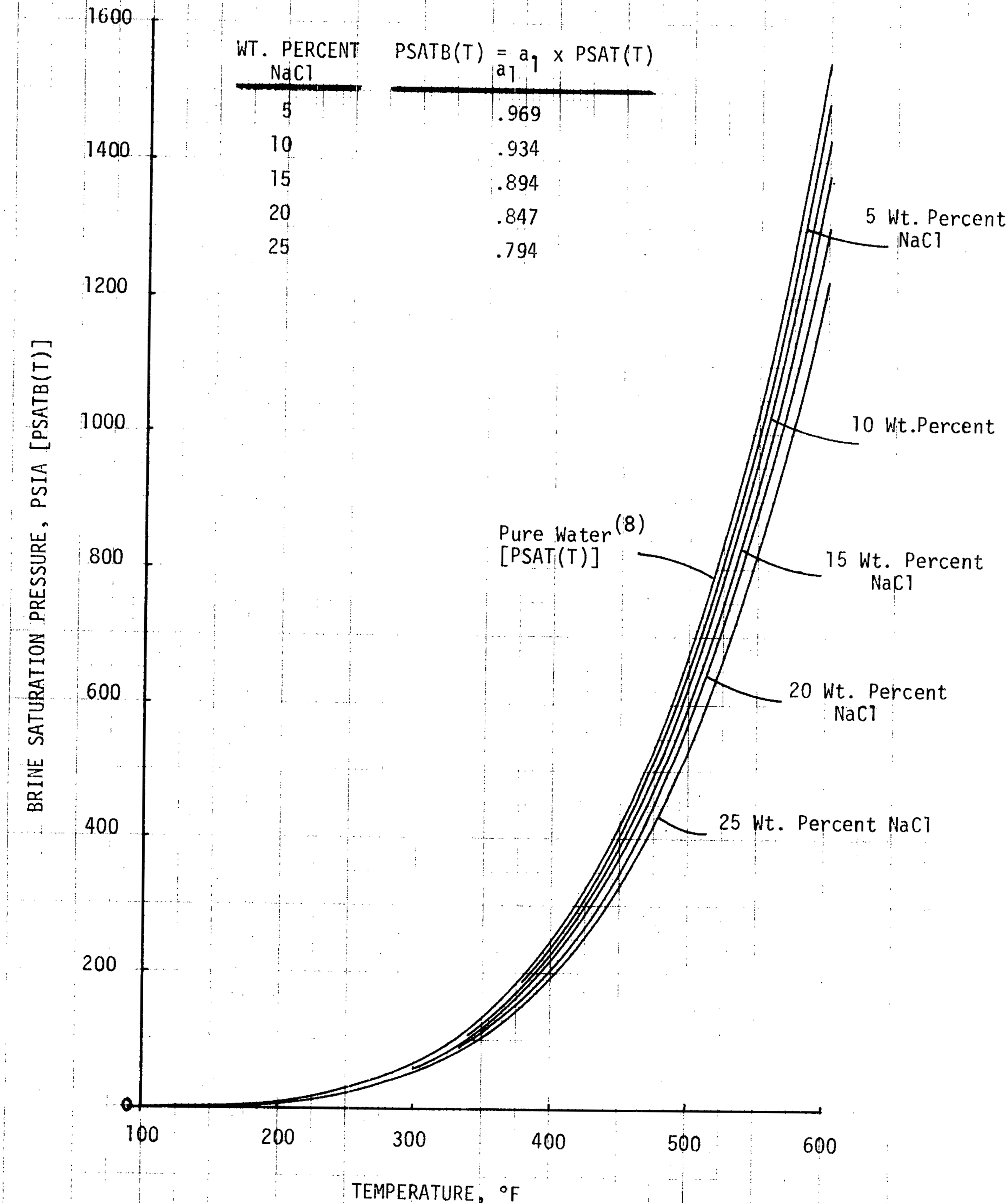
$$PSATB(T) = a_1 \times PSAT(T)$$

X_s, Wt. Percent	a_1
5	.969
10	.934
15	.894
20	.847
25	.794

Figure 1 is a plot of brine saturation pressure and temperature with salt content as a parameter.

FIGURE 1

CALCULATED BRINE SATURATION PRESSURE CURVES FROM DATA FOR DISSOLVED $NaCl-H_2O$ SOLUTIONS [3]



2. Brine Liquid Density, RHOB(T)

A linear relationship of the form RHOB(T) = $a_2 \times T + a_3$ is assumed and a regression analysis was performed using the data from Reference 3. The calculation is shown in the Appendix and tabulated in Table A2. The linear relationship appears to be a good fit to the data since the value of the coefficient of determination is very close to 1. Brine density is calculated from the results shown in Table 2.

TABLE 2

Brine Liquid Density Coefficients

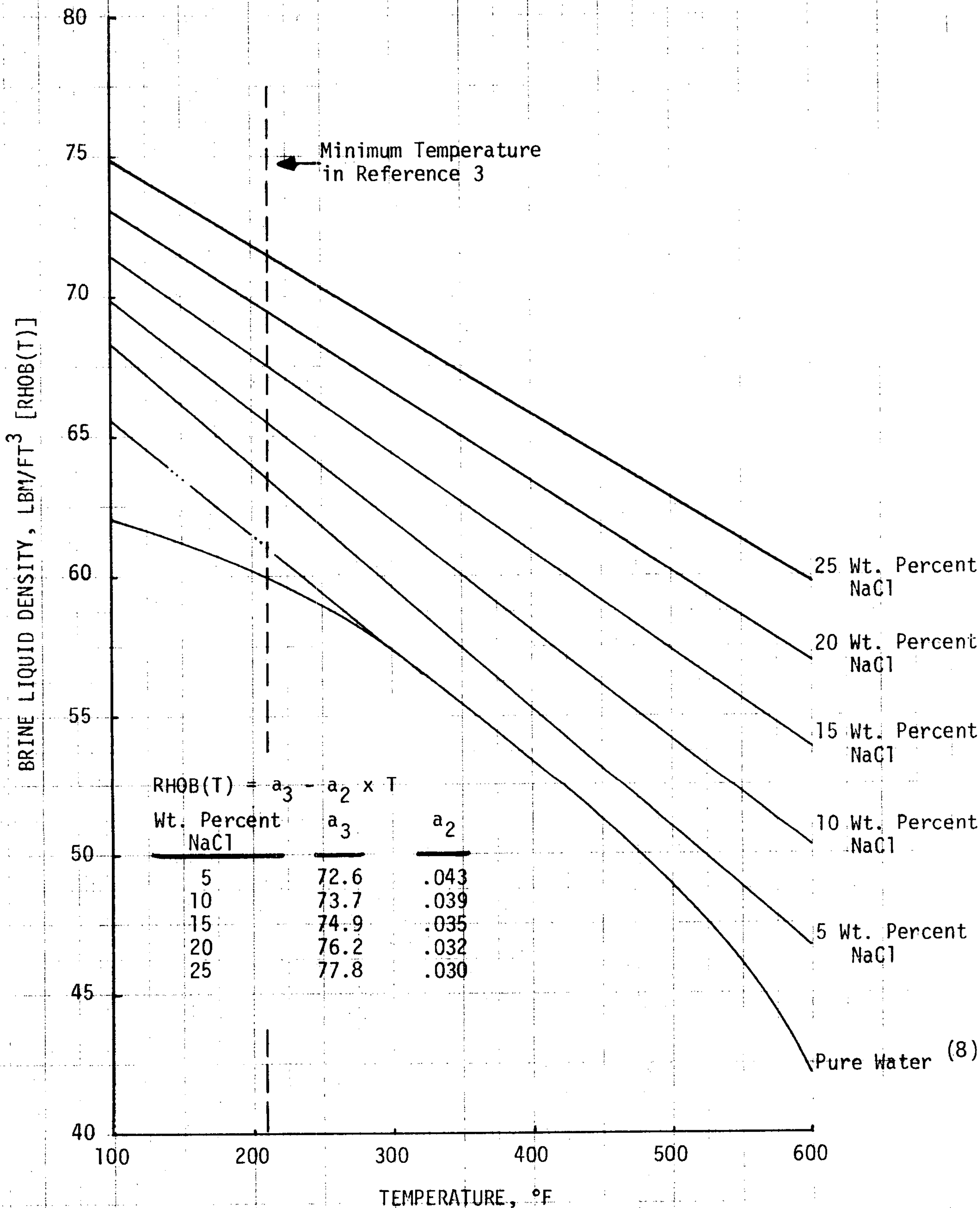
RHOB(T) = $a_2 \times T + a_3$

X_s, Wt. Percent	a_2	a_3	r^2
5	-.043	72.60	.9793
10	-.039	73.72	.9853
15	-.035	74.86	.9921
20	-.032	76.21	.9977
25	-.030	77.85	.9996

Figure 2 is a plot of brine liquid density and temperature with salt content as a parameter. The density relationship for pure water is shown for comparison. The slopes of the brine curves are the same as the slope of the pure water curve between about 250°F and 575°F. Above and below these values, pure water density departs significantly from a linear variation with temperature and the assumed relationship for the brine density variation is not accurate. The error between the actual pure water density value and the extrapolation of the slope back to 100°F is approximately 6%.

FIGURE 2

CALCULATED BRINE LIQUID DENSITY CURVES FROM DATA FOR DISSOLVED $NaCl-H_2O$ SOLUTIONS (3)



3. Brine Vapor Density, RHOGB(T)

The brine vapor density is determined from an isothermal perfect gas expansion from PSAT(T) to PSATB(T):

$$RHOGB(T) = \frac{PSATB(T)}{PSAT(T)} \times \frac{1}{SVG(T)}$$

$$RHOGB(T) = \frac{a_1}{SVG(T)}$$, where SVG(T) is determined from the pure water equation-of-state

4. Brine Saturated Liquid Enthalpy, HB(T)

A power curve relationship of the form, $HB(T) = a_4 (T)^{a_5}$, is assumed and a linear regression analysis was performed using the data from Reference 4. The analysis is shown in the Appendix and is tabulated in Table A3. The power law relationship appears to be a good fit to the data because the coefficient of determination is again close to 1. Saturated brine enthalpy is calculated using the coefficients shown in Table 3.

TABLE 3

Saturated Brine Enthalpy Coefficients

$$HB(T) = a_4(T)^{a_5}$$

X_s, Wt. Percent	a_4	a_5	r^2
5	.275	1.1996	.9985
10	.304	1.1746	.9990
15	.340	1.1480	.9992
20	.368	1.1274	.9994
25	.396	1.1087	.9995

Figure 3 is a plot of brine saturated liquid enthalpy and temperature with salt content as a parameter. Since the enthalpy measurements were not performed above 400°F, the brine enthalpy values above this temperature are extrapolated using the equations generated.

5. Brine Vapor Enthalpy, HGB(T)

The brine vapor is superheated compared to pure water because the brine saturation pressure is less than the pure water saturation pressure at temperature, T. The value is determined from the pure water equation of state at temperature, T and pressure, PSATB(T).

6. Brine Liquid Entropy, SB(T)

From the thermodynamic relationship, $ds = \frac{1}{T}(dh - \frac{dp}{\rho}$, an approximation for the entropy change between temperature T1 and T2 is given by:

$$SB(T2) - SB(T1) \cong \frac{[HB(T2) - HB(T1)] - \left[\dfrac{PSATB(T2) - PSATB(T1)}{\dfrac{RHOB(T2) + RHOB(T1)}{2}}\right] \dfrac{(12)^2}{J}}{(\bar{T} = 459.67)},$$

which can be reduced to:

$$SB(T2) - SB(T1) \cong \frac{a_4[(T2)^{a_5} - (T1)^{a_5}] - \dfrac{\alpha[PSAT(T2) - PSAT(T1)]}{1 - \beta\bar{T}}}{(\bar{T} + 459.67)},$$

where,

$$\alpha = \frac{(12)^2}{J} \bullet \frac{a_1}{a_3}, \ \frac{BTU\text{-}IN^2}{FT^3\text{-}LBF}$$

$$\beta = \frac{a_2}{a_3}$$

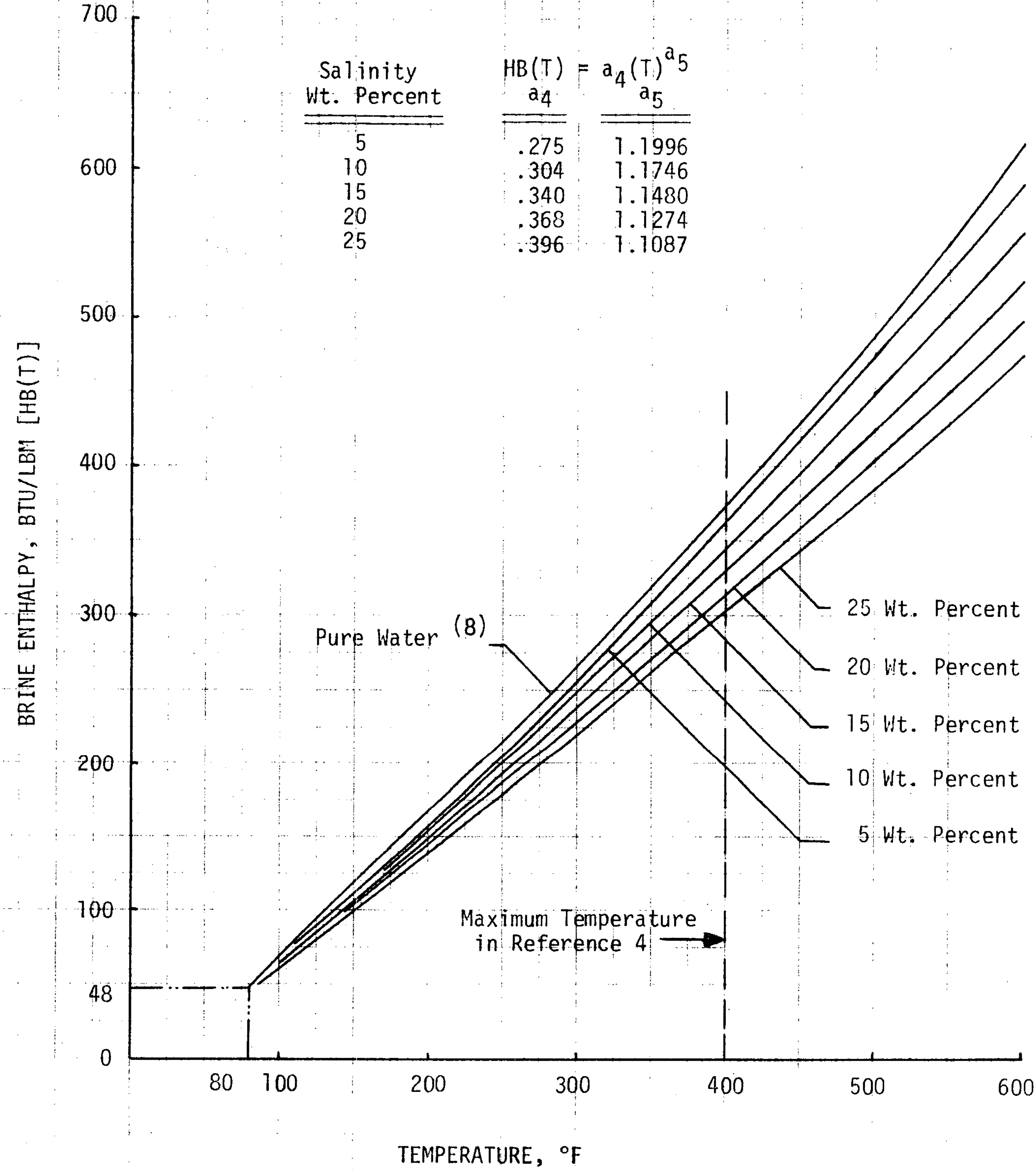
$$J = 778, \ \frac{FT\text{-}LBF}{BTU}$$

$$T = \frac{T1 + T2}{2}, \ °F$$

FIGURE 3

CALCULATED BRINE LIQUID ENTHALPY CURVES FROM DATA FOR NATURAL SEAWATER SOLUTIONS OF DIFFERENT SALINITIES [4]

Salinity Wt. Percent	$HB(T) = a_4(T)^{a_5}$ a_4	a_5
5	.275	1.1996
10	.304	1.1746
15	.340	1.1480
20	.368	1.1274
25	.396	1.1087



The relationship is accurate for small temperature differences.

Using the entropy predictions in Reference 4 at 80°F as a starting point, the brine liquid entropy for the different compositions was calculated and is tabulated in the Appendix as Table A4. The results are graphed in Figure 4 as a function of temperature with weight percent salt as a parameter.

7. Brine Vapor Entropy, SGB(T)

The brine entropy of vaporization is equal to the enthalpy of vaporization divided by the absolute temperature.

$$SGB(T) = SB(T) + \frac{HGB(T) - HB(T)}{(T + 459.67)}$$

and can be calculated using the previously determined thermodynamic properties.

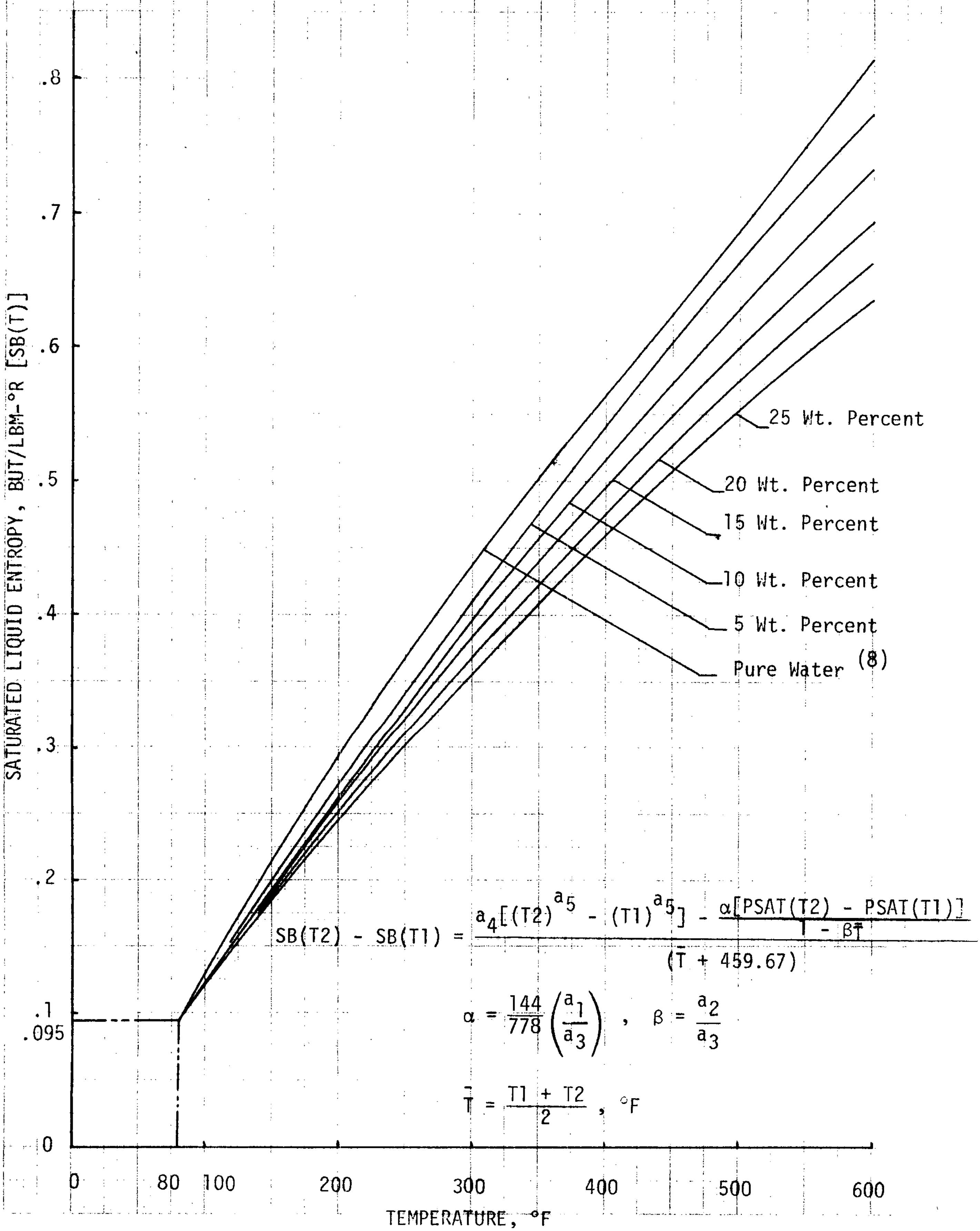
Discussion of Results

A comparison of the brine properties for several constant salt percentages and selected temperatures as tabulated in the references cited and predicted here is shown in Table 4 below. The assumed constant ratio relationship between brine and pure water saturation pressures (with a different value of the ratio for each different salt content) appears adequate to predict the brine saturation pressure as a function of temperature for the salt percentages considered. Excellent agreement between the pressure predictions (up to 400°F maximum) from References 2 and 3 is also shown.

Very good agreement between the linear curve fit and source data (Reference 3) is shown for liquid density. However, since the brine density variation with temperature really follows the shape of the pure water density curve, the linear assumption is not accurate and leads to brine density predictions that are high by about six percent at 100°F and 600°F. Again, excellent agreement exists between the two references (up to 400°F) for the density predictions at the salinities listed. The power law relationship between saturated brine enthalpy and temperature at the salinities considered is in good agreement with the source data (Reference 4). The DRI measurements, however, appear to be consistently

FIGURE 4

CALCULATED BRINE LIQUID ENTROPY CURVES
FROM DATA FOR NATURAL SEAWATER SOLUTIONS OF
DIFFERENT SALINITIES (4)



lower than the Daley, et al, measurements on seawater concentrates. On the other hand, the technique suggested by Grens predicts lower enthalpy at the lower salt content but higher enthalpy at the upper salt percentages. The relationship derived here will be considered adequate until experimental data is available for comparison.

Comparison of the values of saturated brine entropy calculated in Reference 4 and here for the several salinities considered and up to 400°F, shows reasonable agreement between results.

Summary

Simple mathematical expressions for estimating the brine properties of density, saturation pressure, enthalpy and entropy have been generated. They are based on existing data for constant composition water solutions of primarily sodium chloride and for several concentrates of natural seawater. Comparison of the properties predicted by the relationships employed here and the data used to generate the expressions, indicates very good agreement (less than 6 percent difference) for the temperatures and salinities considered.

More complex and precise mathematical expressions have been developed in the references cited for properties of the simulated brines and could be used in numerical applications. However, until data on actual Salton Sea brines are available and comparisons between predictive techniques made, use of the more simple expressions seem adequate.

TABLE 4

COMPARISON OF BRINE PROPERTIES AT SEVERAL SALT PERCENTAGES AND SELECTED TEMPERATURES

Weight Percent Salt	T, °F	Saturation Pressure, PSIA			Liquid Density, LBM/FT^3			Sat. Liquid Enthalpy, BTU/LBM				Sat. Liquid Entropy BTU/LBM-°R	
		Ref. 2	Ref. 3	PSATB(T)	Ref. 2	Ref. 3	RHOB(T)	Ref. 2	Ref. 4	Ref. 5	HB(T)	Ref. 4	SB(T)
5	200	11.3	11.6	11.2	62.2	62.3	64.0	154	162	161	158	.2831	.2712
	400	241.7	240.8	239.6	56.2	56.1	55.3	335	355	360	365	.5477	.5413
	600	- -	1496.8	1495.1	- -	45.9	46.8	- -	- -	592	590	- -	.7745
10	200	10.9	11.2	10.8	64.5	64.5	65.9	141	156	155	153	.2739	.2619
	400	235.4	232.1	231.0	58.7	58.6	58.2	301	340	345	345	.5163	.5156
	600	- -	1438.8	1441.1	- -	49.6	50.4	- -	- -	567	557	- -	.7319
15	200	10.4	10.2	10.3	67.0	66.5	67.9	132	151	148	150	.2659	.2569
	400	221.7	221.9	221.1	61.3	61.1	60.9	277	322	330	331	.4950	.4954
	600	- -	1373.5	1379.4	- -	53.2	54.0	- -	- -	541	525	- -	.6959
20	200	9.8	10.2	9.8	69.5	69.1	69.8	126	147	141	145	.2582	.2505
	400	210.8	210.3	209.5	63.8	63.7	63.4	265	312	315	315	.4758	.4761
	600	- -	1303.9	1306.8	- -	56.8	57.0	- -	- -	516	499	- -	.6638
25	200	9.3	9.7	9.2	72.0	71.6	71.8	124	142	134	140	.2511	.2452
	400	198.1	197.3	196.4	66.6	66.1	65.8	256	300	300	303	.4591	.4599
	600	- -	1232.8	1225.1	- -	60.2	59.9	- -	- -	491	476	- -	.6369

References

1. Austin, A. L., Higgins, G. H., Howard, J. H., "The Total Flow Concept for Recovery of Energy From Geothermal Hot Brine Deposits", April 3, 1973, UCRL-51366, Lawrence Livermore Laboratory, Livermore, California.

2. Report DRI No. 2151, University of Denver-Denver Research Institute, "Determination of Thermodynamic Properties of Brines", February 1964.

3. Haas, J. L. Jr., "The Effect of Salinity on the Maximum Thermal Gradient of a Hydrothermal System at Hydrostatic Pressure", Economic Geology, Vol. 66, 1971, pp. 940-946.

4. Daley, J. G., Hilding, W. E., Fisher, D. A. "Thermodynamic Properties of Seawater Concentrates", Proceedings 5th Symposium on Thermophysical Properties, October 1970.

5. Grens, J. Z., "The Effect of Salinity on Geothermal Well Performance", UCID-16791, May 14, 1975.

6. Discussions with R. W. Potter on February 22, 1977. Work to be published shortly.

7. Miller, I. and Freund, J. E., "Probability and Statistics for Engineers", Englewood Cliffs, N. J.: Prentice-Hall, 1965.

8. McClintock, R. B. and Silvestri, G. J., "Calculation of Properties of Steam", American Society of Mechanical Engineers, 1968.

Appendix

TABLE A1

BRINE SATURATION PRESSURE COEFFICIENTS FROM DATA IN REFERENCE 3

		WEIGHT PERCENT NaCl									
		5		10		15		20		25	
T, °F	PSAT(T), BARS	PSATB(T), BARS	PSATB(T)/PSAT(T)	PSATB(T) BARS	PSATB(T)/PSAT(T)	PSATB(T) BARS	PSATB(T)/PSAT(T)	PSATB(T) BARS	PSATB(T)/PSAT(T)	PSATB(T) BARS	PSATB(T)/PSAT(T)
230	1.4	1.4	1.0	1.3	.929	1.3	.929	1.2	.857	1.1	.786
248	2.0	1.9	.950	1.9	.950	1.8	.900	1.7	.850	1.6	.800
266	2.7	2.6	.963	2.5	.926	2.4	.889	2.3	.852	2.1	.778
284	3.6	3.5	.972	3.4	.944	3.2	.889	3.1	.861	2.9	.806
302	4.8	4.6	.958	4.4	.917	4.3	.896	4.0	.833	3.8	.792
320	6.2	6.0	.968	5.8	.935	5.5	.887	5.2	.839	4.9	.790
338	7.9	7.7	.975	7.4	.937	7.1	.899	6.7	.848	6.3	.797
356	10.0	9.7	.970	9.4	.940	9.0	.900	8.5	.850	8.0	.800
374	12.6	12.2	.968	11.7	.929	11.2	.889	10.6	.841	10.0	.794
392	15.6	15.1	.968	14.5	.929	13.9	.891	13.2	.846	12.4	.795
410	19.1	18.5	.969	17.8	.932	17.0	.890	16.2	.848	15.2	.796
428	23.2	22.5	.970	21.7	.935	20.7	.892	19.7	.849	18.5	.797
446	28.0	27.1	.968	26.1	.932	25.0	.893	23.7	.846	22.3	.796
464	33.5	32.5	.970	31.2	.931	29.9	.893	28.4	.848	26.7	.797
482	39.8	38.6	.970	37.1	.932	35.5	.892	33.7	.847	31.8	.799
500	46.9	45.5	.970	43.8	.934	41.9	.893	39.7	.846	37.5	.780
518	55.1	53.3	.967	51.3	.931	49.1	.891	46.6	.846	44.0	.799
536	64.2	62.2	.969	59.9	.933	57.2	.891	54.3	.846	51.3	.799
554	74.4	72.1	.969	69.4	.933	66.3	.891	62.9	.845	59.5	.780
572	85.9	83.2	.969	80.0	.931	76.5	.891	72.6	.845	68.6	.799
590	98.7	95.6	.969	91.9	.931	87.8	.890	83.3	.844	78.7	.797
608	112.9	109.3	.968	105.1	.931	100.3	.888	95.2	.843	90.0	.797
626	128.6	124.5	.968	119.1	.926	114.2	.888	108.4	.843	102.4	.796
		a_1 =	.969	a_1 =	.934	a_1 =	.894	a_1 =	.847	a_1 =	.794

Linear Curve-Fit Analysis [7]

Assuming the relationship, RHOB(T) = $a_2 \times T + a_3$

Let y = RHOB(T)

x = T

$\therefore y = a_2(x) + a_3$

Using paired data from Reference 3,

$(X_i, Y_i), i = 1, 2, ... n$

with all summations for i = 1, 2, ... n.

Regression Coefficients

$$a_2 = \frac{\sum_n X_i Y_i - \frac{\sum_n X_i \sum_n Y_i}{n}}{\sum_n X_i^2 - \frac{\left(\sum_n X_i\right)^2}{n}}$$

$$a_3 = \bar{y} - a_2 (\bar{x})$$

$$\bar{y} = \frac{\sum_n y_i}{n}$$

$$\bar{x} = \frac{\sum_n x_i}{n}$$

Coefficient of Determination

$$r^2 = \frac{\left[\sum_n x_i y_i - \frac{\sum_n x_i \sum_n y_i}{n}\right]^2}{\left[\sum_n x_i^2 - \frac{\left(\sum_n x_i\right)^2}{n}\right]\left[\sum_n y_i^2 - \frac{\left(\sum_n y_i\right)^2}{n}\right]}$$

TABLE A2

LINEAR CURVE FIT

REGRESSION COEFFICIENTS FROM PAIRED DATA IN REFERENCE 3

BRINE DENSITY, LBM/FT^3

T, °F	Weight Percent NaCl				
	5	10	15	20	25
230	61.53	63.77	66.08	68.45	70.95
248	61.03	63.27	65.58	68.02	70.45
266	60.53	62.84	65.15	67.52	70.01
284	60.03	62.34	64.65	67.08	69.51
302	59.47	61.78	64.15	66.58	69.01
320	58.91	61.28	63.65	66.02	68.52
338	58.34	60.72	63.09	65.52	67.95
356	57.72	60.09	62.52	64.96	67.45
374	57.10	59.53	61.96	64.46	66.89
392	56.41	58.91	61.40	63.90	66.33
410	55.72	58.28	60.78	63.34	65.83
428	55.04	57.60	60.15	62.71	65.27
446	54.29	56.91	59.53	62.15	64.71
464	53.48	56.22	58.91	61.53	64.15
482	52.67	55.47	58.22	60.96	63.59
500	51.79	54.66	57.53	60.34	63.02
518	50.92	53.85	56.78	59.72	62.52
536	49.98	53.04	56.10	59.09	61.96
554	48.92	52.10	55.35	58.47	61.46
572	47.86	51.17	54.54	57.84	60.96
590	46.68	50.17	53.73	57.16	60.47
608	45.36	49.11	52.85	56.53	60.03
626	43.93	47.92	51.92	55.91	59.53
a_3 =	72.602	73.720	74.864	76.214	77.849
a_2 =	-0.043	-0.039	-0.035	-0.032	-0.030
r^2 =	.9793	.9853	.9921	.9977	.9996

Power Law Curve-Fit Analysis [7]

Assuming the relationship, $HB(T) = a_4 (T)^{a_5}$

Let $y = HB(T)$

$x = T$

$y = a_4(x)^{a_5}$, $a_4 > 0$ and

$\ln y = a_5 \ln x + \ln a_4$, which is a linear equation.

Using the set of data points in Reference 4

$\left\{(x_i, y_i), i = 1, 2 \ldots n\right\}$, where $x_i > 0$ and $y_i > 0$,

n is a positive integer and $n \neq 1$.

Regression Coefficients

$$a_5 = \frac{\sum_n (\ln x_i)(\ln y_i) - \dfrac{\left(\sum_n \ln x_i\right)\left(\sum_n \ln y_i\right)}{n}}{\left(\sum_n \ln x_i\right)^2 - \dfrac{\left(\sum_n \ln x_i\right)^2}{n}}$$

$$a_4 = \exp\left[\frac{\sum_n \ln y_i}{n} - a_5\left(\frac{\sum_n \ln x_i}{n}\right)\right]$$

Coefficient of Determination

$$r^2 = \frac{\left[\sum_n (\ln x_i)(\ln y_i) - \dfrac{\left(\sum_n \ln x_i\right)\left(\sum_n \ln y_i\right)}{n}\right]^2}{\left[\sum_n (\ln x_i)^2 - \dfrac{\left(\sum_n \ln x_i\right)^2}{n}\right]\left[\sum_n (\ln y_i)^2 - \dfrac{\left(\sum_n \ln y_i\right)^2}{n}\right]}$$

TABLE A3

POWER LAW CURVE FIT-REGRESSION COEFFICIENTS FROM DATA IN REFERENCE 4

BRINE SATURATED ENTHALPY, BUT/LBM

T, °F	Weight Percent Salinity				
	5	10	15	20	25
80	48.95	49.33	49.43	49.27	49.09
90	58.32	58.18	57.90	57.39	56.90
100	67.69	67.03	66.36	65.61	64.68
110	77.06	75.88	74.83	73.61	72.47
120	86.42	84.74	83.29	81.72	80.24
130	95.79	93.61	91.76	89.82	88.02
140	105.16	102.48	100.23	97.92	95.79
150	114.53	111.37	108.70	106.01	103.54
160	123.19	120.26	117.17	114.11	111.31
170	133.30	129.16	125.65	122.20	119.06
180	142.69	138.08	134.14	130.30	126.81
190	152.09	147.01	142.63	138.40	134.57
200	161.51	155.95	151.13	146.51	142.32
210	170.93	164.91	159.64	154.62	150.10
220	180.38	173.89	168.16	162.74	156.85
230	189.83	182.89	176.70	170.87	165.64
240	199.31	191.90	185.25	179.01	173.42
250	208.80	200.94	193.81	187.16	181.21
260	218.32	210.00	202.39	195.32	189.01
270	227.85	219.08	210.99	203.49	196.83
280	237.42	228.19	219.60	211.68	204.66
290	247.00	237.32	228.24	219.89	212.50
300	256.61	246.48	236.90	228.11	220.35
310	266.25	255.67	245.57	236.35	228.23
320	275.91	264.89	254.28	244.61	236.12
330	285.61	274.13	263.01	252.89	244.02
340	295.35	283.42	271.76	261.20	251.97
350	305.12	292.73	280.54	269.52	259.91
360	314.92	302.08	289.35	277.88	267.89
370	324.75	311.46	298.19	286.25	275.88
380	334.63	320.88	307.06	294.66	283.91
390	344.55	330.34	315.96	303.09	291.97
400	354.51	339.84	322.20	311.56	300.04
a_4 =	.2745	.3040	.3398	.3682	.3957
a_5 =	1.1996	1.1746	1.1480	1.1274	1.1087
r^2 =	.9985	.9990	.9992	.9994	.9995
500	474.44	449.86	426.25	406.28	388.64
600	590.42	557.29	525.49	498.98	475.70

TABLE A4

CALCULATED BRINE ENTROPY, BTU/LBM-°R

	Weight Percent Salinity				
	5	10	15	20	25
T, °F	a_1 = .969 a_2 = .043 a_3 = 72.6 a_4 = .275 a_5 = 1.1996 $\alpha = 2.469\times10^{-3}$ $\beta = 5.923\times10^{-4}$	a_1 = .934 a_2 = .039 a_3 = 73.72 a_4 = .304 a_5 = 1.1746 $\alpha = 2.344\times10^{-3}$ $\beta = 5.29\times10^{-4}$	a_1 = .894 a_2 = .035 a_3 = 74.86 a_4 = .340 a_5 = 1.1480 $\alpha = 2.209\times10^{-3}$ $\beta = 4.675\times10^{-4}$	a_1 = .847 a_2 = .032 a_3 = 76.21 a_4 = .368 a_5 = 1.1274 $\alpha = 2.056\times10^{-3}$ $\beta = 4.199\times10^{-4}$	a_1 = .794 a_2 = .030 a_3 = 77.85 a_4 = .396 a_5 = 1.1087 $\alpha = 1.887\times10^{-3}$ $\beta = 3.854\times10^{-4}$
80 (4)	.0949	.0956	.0958	.0955	.0951
100	.1246	.1236	.1227	.1219	.1211
120	.1541	.1521	.1502	.1484	.1468
140	.1837	.1795	.1774	.1745	.1721
160	.2131	.2066	.2043	.2003	.1969
180	.2423	.2344	.2308	.2256	.2213
200	.2712	.2619	.2569	.2505	.2452
220	.2998	.2890	.2826	.2750	.2686
240	.3281	.3157	.3078	.2990	.2916
260	.3560	.3421	.3327	.3226	.3141
280	.3836	.3680	.3572	.3458	.3362
300	.4108	.3936	.3812	.3685	.3578
320	.4377	.4188	.4048	.3908	.3790
340	.4642	.4436	.4281	.4127	.3998
360	.4903	.4680	.4509	.4342	.4202
380	.5160	.4920	.4733	.4554	.4403
400	.5413	.5156	.4954	.4761	.4599
420	.5663	.5389	.5170	.4965	.4791
440	.5909	.5618	.5383	.5164	.4980
460	.6151	.5843	.5593	.5361	.5166
480	.6390	.6065	.5799	.5553	.5348
500	.6625	.6283	.6001	.5743	.5526
520	.6857	.6497	.6199	.5928	.5701
540	.7084	.6708	.6394	.6111	.5873
560	.7308	.6915	.6586	.6290	.6042
580	.7529	.7119	.6774	.6466	.6207
600	.7745	.7319	.6959	.6638	.6369

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $; Microfiche $3.00

Page Range	Domestic Price	Page Range	Domestic Price
001–025	$ 3.50	326–350	10.00
026–050	4.00	351–375	10.50
051–075	4.50	376–400	10.75
076–100	5.00	401–425	11.00
101–125	5.50	426–450	11.75
126–150	6.00	451–475	12.00
151–175	6.75	476–500	12.50
176–200	7.50	501–525	12.75
201–225	7.75	526–550	13.00
226–250	8.00	551–575	13.50
251–275	9.00	576–600	13.75
276–300	9.25	601–up	*
301–325	9.75		

*Add $2.50 for each additional 100 page increment from 601 to 1,000 pages; add $4.50 for each additional 100 page increment over 1,000 pages.