The International Association for the Properties of Water and Steam

Banff, Canada
October 2019

Guideline on the Surface Tension of Seawater

Please cite as: International Association for the Properties of Water and Steam, IAPWS G14-19, *Guideline on the Surface Tension of Seawater* (2019).

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Summary

The seawater surface tension formulation provided in this Guideline is based on a published correlation for the surface tension of seawater [1], and on the IAPWS formulation for the surface tension of pure water [2]. The range of validity has been extended by some experimental work on the surface tension of subcooled seawater [3]. The formulation is recommended for the computation of the surface tension of seawater for salinities ranging from 0 to 131 $g \cdot kg^{-1}$ at temperatures from 1 °C to 92 °C, and at salinities from 0 to 38 $g \cdot kg^{-1}$ at temperatures from –25 °C to 1 °C.

This Guideline contains 5 pages, including this cover page.

Further information about this Guideline and other documents issued by IAPWS can be obtained from the Executive Secretary of IAPWS (Dr. R.B. Dooley, bdooley@iapws.org) or from http://www.iapws.org.

Contents

1 Nomenclature

Symbol	Physical quantity	Unit
S	Reference-composition salinity[1]	$g \cdot kg^{-1}$
t	Celsius temperature	°C
σ	Surface tension of seawater	$mN \cdot m^{-1}$
σ_w	Surface tension of pure water	$mN \cdot m^{-1}$

2 Introductory Remarks

This Guideline is intended to provide a method for calculating the surface tension of seawater as a function of temperature and salinity. The method presented here describes the surface tension of seawater relative to that of pure liquid water as calculated from the IAPWS "Revised Release on the Surface Tension of Ordinary Water Substance" [2]. A discussion of the background, development, and validation of this formulation is presented in [1], and further validation for low temperatures, including subcooled liquid states, is described in [3].

[1] For seawater of Reference Composition [4], the Salinity S used in this work is related to the commonly measured Practical Salinity [5] S_P by $S = (35.165\,04/35)\,S_P$

3 Summary of the Formulation

The vapor-liquid surface tension σ of seawater is calculated as a function of Celsius temperature (t) and salinity (S), relative to that of the solvent (i.e., pure water) at the same temperature (surface tension of pure water – σ_w). The effect due to the presence of salts in seawater is given by:

$$\sigma = \sigma_w \left(1 + a_1 S + a_2 S t\right), \tag{1}$$

where $a_1 = 3.766\times10^{-4}$ kg·g^{-1}, $a_2 = 2.347\times10^{-6}$ kg·g^{-1}·°C^{-1}, and the surface tension, σ_w, of pure water is given by the IAPWS Revised Release on the Surface Tension of Ordinary Water Substance [2]. The IAPWS formula for pure-water surface tension is:

$$\sigma_w = B\tau^{\mu}(1+b\tau), \tag{2}$$

where
σ_w = surface tension of pure water
τ = $1 - T / T_c$
T = absolute temperature in K (= t + 273.15)
T_c = 647.096 K
B = 235.8 mN·m^{-1}
b = –0.625
μ = 1.256

4 Range of Validity and Estimates of Uncertainty

The formulation for the surface tension of seawater given in Eq. (1) is valid for the following conditions at states of vapor-liquid equilibrium, provided that the seawater is in the liquid phase:

$0 \le S \le 131$ g·kg^{-1} for 1 °C ≤ $t \le 92$ °C
$0 \le S \le 38$ g·kg^{-1} for –25 °C ≤ $t < 1$ °C

At some of these conditions, the liquid is metastable. The range of validity and the uncertainty in the formulation are summarized in Table 1.

Table 1 Summary of range of validity and expanded (k = 2) uncertainty of Eq. (1)

Region	S (g·kg^{-1})	t (°C)	$U(\sigma)$ (mN·m^{-1})	$U(\sigma)$ (%)
A	$0 \le S \le 131$	$1 \le t < 50$	0.38	0.50
B	$0 \le S \le 131$	$50 \le t \le 92$	0.43	0.60
C	$0 \le S \le 38$	$-25 \le t < 1$	0.46	0.59

For the region denoted by the salinities $38\ \mathrm{g\cdot kg^{-1}} \le S \le 131\ \mathrm{g\cdot kg^{-1}}$ and temperatures $-25\ ^\circ\mathrm{C} \le t < 1\ ^\circ\mathrm{C}$, no experimental data exist to verify Eq. (1), but it is expected that Eq. (1) can be extrapolated in this region in a physically reasonable way. Detailed comparisons of Eq. (1) with experimental data for Regions A, B, and C are available in Refs. [1], [1], and [3], respectively.

5 Computer-Program Verification

To assist the user in computer-program verification, Table 2 gives check values at several specified conditions.

Table 2 Numerical check values for calculating the surface tension of seawater

S ($\mathrm{g\cdot kg^{-1}}$)	t (°C)	σ_w ($\mathrm{mN\cdot m^{-1}}$)	σ ($\mathrm{mN\cdot m^{-1}}$)
35	–20	78.321 498 330	79.225 179 610
35	25	71.972 205 230	73.068 674 787
35	80	62.672 854 967	63.910 806 802
60	25	71.972 205 230	73.851 867 328
60	80	62.672 854 967	64.795 058 112
120	20	72.736 140 422	76.432 940 211
120	80	62.672 854 967	66.917 261 258

6 References

[1] Nayar, K.G., Panchanathan, D., McKinley, G.H., and Lienhard V, J.H., Surface Tension of Seawater. *J. Phys. Chem. Ref. Data* **43**, 043103 (2014).

[2] IAPWS R1-76(2014), *Revised Release on the Surface Tension of Ordinary Water Substance*, available from http://www.iapws.org/relguide/Surf-H2O.html (2014).

[3] Vinš, V., Hykl, J., and Hrubý, J., Surface tension of seawater at low temperatures including supercooled region down to –25 °C. *Marine Chemistry* **213**, 13-23 (2019).

[4] Millero, F.J., Feistel, R., Wright, D.G., and McDougall, T.J., The composition of Standard Seawater and the definition of the Reference-Composition Salinity Scale. *Deep-Sea Res. I* **55**, 50-72 (2008).

[5] Unesco, Background papers and supporting data on the Practical Salinity Scale 1978, Unesco Technical Papers in Marine Science 37, (United Nations Educational, Scientific and Cultural Organization, Paris, 1981).

Appendix A: Table of values for seawater surface tension

Table 3 reports the value for seawater surface tension calculated from the correlation presented in Eq. (1) for the region $0 \le S \le 131$ g·kg^{-1} for -20 °C $\le t \le 100$ °C.

Table 3 Values for the surface tension σ (in mN·m^{-1}) of seawater from Eq. (1)

	S / (g·kg^{-1})													
t / (°C)	0	10	20	30	35	40	50	60	70	80	90	100	110	120
–20	78.32	78.58	78.84	79.10	79.23									
–10	77.01	77.29	77.56	77.83	77.97									
0	75.65	75.93	76.22	76.50	76.64	76.79	77.07	77.36	77.64	77.93	78.21	78.50	78.78	79.07
10	74.22	74.52	74.81	75.11	75.26	75.41	75.71	76.00	76.30	76.60	76.89	77.19	77.49	77.78
20	72.74	73.04	73.35	73.66	73.81	73.97	74.28	74.58	74.89	75.20	75.51	75.82	76.12	76.43
30	71.19	71.51	71.83	72.15	72.31	72.47	72.79	73.10	73.42	73.74	74.06	74.38	74.69	75.01
40	69.60	69.92	70.25	70.58	70.74	70.91	71.23	71.56	71.89	72.22	72.54	72.87	73.20	73.53
50	67.94	68.28	68.62	68.95	69.12	69.29	69.62	69.96	70.29	70.63	70.96	71.30	71.64	71.97
60	66.24	66.58	66.92	67.27	67.44	67.61	67.95	68.29	68.64	68.98	69.32	69.67	70.01	70.35
70	64.48	64.83	65.18	65.53	65.70	65.88	66.22	66.57	66.92	67.27	67.62	67.97	68.32	68.67
80	62.67	63.03	63.38	63.73	63.91	64.09	64.44	64.80	65.15	65.50	65.86	66.21	66.56	66.92
90	60.82	61.17	61.53	61.89	62.07	62.25	62.60	62.96	63.32	63.68	64.03	64.39	64.75	65.11
100	58.91	59.27	59.63	59.99	60.17	60.35	60.71	61.07	61.43	61.79	62.15	62.51	62.87	63.23