

COMPUTATION OF THE VELOCITY OF SOUND IN SEA WATER

By

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I. Introduction

The tables of sound velocity in sea water, which are used widely today, are those of the British Admiralty⁽¹⁾ (1927) and KUWAHARA⁽²⁾ (1939). Recently Alfred WEISSLER⁽³⁾ (1951) and his co-workers measured the velocity of sound in sea water samples under atmospheric pressure and discussed the values in the above-mentioned tables. The physical constants of sea water which were used in the computation of sound velocity in these tables were determined about forty years ago. In order to improve the accuracy of computation, more accurate values of these constants must be known, but the present author could not find any such values in current literature. Among the computations made by many authorities up to this date, the one by Mr. KUWAHARA seems to be the most accurate. He transformed the formula of sound velocity to a form suitable for Tayler's expansion, and computed the differential coefficients of sound velocity with respect to salinity (S), temperature (t), and pressure (P). For example, he derived the formula of standard sound velocity at $S=35\%$, $t=0^\circ\text{C}$, $P=0$ db. and calculated the deviation from this value for other conditions which are near the adopted standard. The methods of other authorities are similar to KUWAHARA in principle. The density *in situ*, the compressibility and the ratio of specific heats of sea water which are used in the computation of sound velocity are very important physical quantities in oceanography. To know their behaviour under various values of salinity, temperature and pressure is in itself very interesting. Indeed, many eminent oceanographers attacked this

problem. But the numerical values of these quantities under degrees of temperature, salinity and pressure are, it seems to the author, relatively fragmental except those of the density *in situ*. In this paper, the author has tried to obtain these values systematically and computed the velocity of sound directly from them. The results almost agreed with those of KUWAHARA, which is an indirect proof that the calculated values of the density *in situ*, compressibility and the ratio of specific heats are reasonable. As these values are important in oceanography the author has presented them in tabular form in this paper. With its universal use in echo sounding and submarine communications, the velocity of sound in sea water is used in many fields and it is desirable to obtain the value of sound velocity with as simple a method as possible. But hitherto it has usually been obtained with the aid of several tables.

Based on the values of sound velocity computed by the present author, several diagrams were prepared with the aid of which the velocity may be obtained immediately for any temperature and salinity at any pressure or depth.

II. Computation of Sound Velocity in Sea Water

The velocity, V , of Sound in water is given by the following formula,

$$V = \sqrt{\frac{\gamma}{\rho_{sp}K}} \dots\dots\dots (1)$$

where, ρ_{sp} is the density *in situ* in sea water, K is the true compressibility in sea water, and γ is the ratio of the specific heat at constant pressure, C_p , to the specific heat at constant volume, C_v , i. e. $\gamma = \frac{C_p}{C_v}$.

1) Computation of the Density *in situ*

(ρ_{stp})

The values of ρ_{stp} are computed from the following formula by Ekman⁴⁾ (1908),

$$\rho_{stp} = \frac{\rho_{sto}}{1 - \mu P} \dots \dots \dots (2)$$

where, ρ_{sto} is the density under zero pressure (i.e. atmospheric pressure), P is the pressure "decibar" (db) unit, μ is the mean compressibility of sea water, and

$$10^9 \mu = \frac{4886}{1 + 0.0000183P} - [227 + 28.33t - 0.551t^2 + 0.004t^3] + 10^{-4}P[105.5 + 9.50t - 0.158t^2] - 1.5 \times 10^{-8}P^2t - (\sigma_{soo} - 28)[147.3 - 2.72t + 0.04t^2 - 10^{-4}P(32.4 - 0.87t + 0.02t^2)]10^{-1} + (\sigma_{soo} - 28)^2[4.5 - 0.1t - 10^{-4}P(1.8 - 0.06t)]10^{-2} \dots \dots \dots (3)$$

where, t is temperature ($^{\circ}\text{C}$), $\sigma_{soo} = (\rho_{soo} - 1)10^3$, and ρ_{soo} is the density at 0°C under zero pressure. The relation between σ_{soo} and salinity (S) or chlorinity (Cl) is given by Knudsen's⁽⁵⁾ (1901) experimental formula, namely,

$$\left. \begin{aligned} \sigma_{soo} &= -0.069 + 1.4708 Cl \\ &\quad - 0.001570 Cl^2 + 0.0000398 Cl^3 \\ &= -0.093 + 0.8149 S \\ &\quad - 0.000482 S^2 + 0.000068 S^3 \end{aligned} \right\} \dots \dots \dots (4)$$

The relation between the density at 0°C and $t^{\circ}\text{C}$ for any salinity and under zero pressure is as follows:—

$$\left. \begin{aligned} \sigma_{sto} = (\rho_{sto} - 1)10^3 &= -\frac{(t - 3.98)^2}{503.570} \cdot \frac{t + 283}{t + 67.26} \\ &\quad + (\sigma_{soo} + 0.1324)\{(1 - A_t + B_t) \\ &\quad \quad (\sigma_{soo} - 0.1324)\} \end{aligned} \right\} \dots \dots \dots (5)$$

where, $A_t = t(4.7867 - 0.098185t + 0.0010843t^2)10^{-3}$
 $B_t = t(18.030 - 0.8164t + 0.01667t^2)10^{-6}$

The values of ρ_{stp} are computed from the formula (2) to (5). In the present calculations, the values of σ_{soo} and σ_{sto} were derived from Knudsen's tables. As to the computation of mean compressibility, μ , from (3), the calculations were made at about every 5°C (at every 2°C below 0°C and every 2.5°C under high pressure), from $t = -2^{\circ}\text{C}$ to 30°C (the range of temperature decreased with the increase of pressure and ranged from 0°C to 5°C under maximum pressure [$P = 10,000$ db.]), at the pressures $P = 0, 100, 500, 1000, 1500, 2000, 4000, 6000, 8000, 10,000$ db., and for the density at every one unit from $\sigma_{soo} = 24$ to 32 . Putting the formula (4) in (3) the values of μ were also calculated at

every 1‰ from $S = 30\text{‰}$ to 40‰ . In Table 1, the values of $\mu \times 10^9$ thus obtained are shown. The values of ρ_{stp} are obtained from the formula (2) by substituting the values of μ . The result is given in Table 2 in the form σ_{stp} :— $\sigma_{stp} = (\rho_{stp} - 1)10^3$

2) Computation of True Compressibility (K)

Between true compressibility (K) and mean compressibility (μ) the following relation holds:

$$K = \left(\mu + P \frac{\partial \mu}{\partial P} \right) / (1 - \mu P) \dots \dots \dots (6)$$

Hence, K is computed from μ and $\frac{\partial \mu}{\partial P}$, the latter being obtained by differentiating the equation (3). In the actual calculations the range of temperature, pressure and salinity was similar to the case of μ . In the following computations of various physical quantities the range is always similar to the above. The obtained values of $K \times 10^9$ are shown in Table 3.

3) Computation of the Ratio of Specific

$$\text{Heats } \left(\gamma = \frac{C_p}{C_v} \right).$$

The experimental values of C_p for sea water are very few. The only existing one is that given by Otto KRÜMMEL⁽⁶⁾ (1907). According to him, the values of C_p at 17.5°C and under normal atmospheric pressure are

$S(\text{‰})$	0	5	10	15	20	25	30
$C_p(\text{cal/gr})$	1.000	0.982	0.968	0.958	0.951	0.945	0.939

$S(\text{‰})$ 35 40
 $C_p(\text{cal/gr})$ 0.932 0.926

The relation of C_p with temperature under atmospheric pressure has been studied only for distilled water. Adopting the temperature relation given by OSBORNE⁽⁷⁾ (1939) for distilled water and assuming that this relation also holds with sea water, a functional relation of C_p with salinity at 0°C is obtained from the KRÜMMEL's values given above, and is shown below:—

$$C_p = 1.0076 - 0.004136S + 0.0001098S^2 - 0.000001324S^3 \dots \dots \dots (7)$$

From the formula (7) and temperature relation given by OSBORNE the values of C_p of sea water under atmospheric pressure can be obtained at various degrees of temperature and salinity.

The values of C_p under various pressures are computed by the following formula,

$$\frac{dC_p}{dP} = -10^5 \frac{T}{J\rho_{sp}} \left(\frac{de}{dt} + e^2 \right) \dots\dots\dots(8)$$

where, P is the pressure in decibar units, K is the true compressibility, T is the absolute temperature, t is the temperature *in situ*, ρ_{sp} is the density *in situ*, e is the coefficient of the thermal expansion and J is the mechanical equivalent of heat, *i. e.* $J=4.185 \times 10^7$ erg/cal.

The values of e of (8) were given by EKMAN⁽⁸⁾ (1910). They may also be calculated from our Table 2.

All the other factors are known quantities. In the present computations, EKMAN's values for e were used. As the values of C_p at $P=0$ are already known, the values of C_p under any pressure are computed by integrating dC_p/dP with respect to pressure. As to the computation of C_v the following formula is used as usual:—

$$C_v = C_p - \frac{Te^2}{J\rho_{sp}K} \dots\dots\dots(9)$$

The notations in (9) are the same as the above. As all the values are already obtained by the above mentioned processes the values of $\gamma = \frac{C_p}{C_v}$ are easily calculated. The result is given in Table 4.

Accordingly, the velocity of sound is obtained directly from formula (1) by substituting the values of ρ_{sp} , K , and γ obtained in the preceding paragraphs 1), 2), and 3). The result of calculation is shown in Table 5.

III. Diagrams of Sound Velocity in Sea Water

When we wished to obtain the velocity of sound from temperature and salinity at any depth, we have so far used three to five tables. To avoid this inconvenience, some diagrams of sound velocity based on the British Admiralty tables are in practical use. But these diagrams are somewhat rough and troublesome to decipher (the depth is expressed in fathoms), so it is safer to use the tables of velocity. In order to improve this circumstance, the present author prepared diagrams of sound velocity based on the present computations which enable a very rapid and accurate estimation of sound velocity for any salinity,

temperature, and depth or pressure. They are shown in Fig. 1 to Fig. 7. To each of these diagrams a correction table is attached. This table gives the correction values for the depth at almost every 100 db or m. (in the interval 0~2000 db corrections are given in more detail). A correction table of gravity effect is also given for the depth under 2000 m. This correction table was taken from Kuwahara's paper. Of course, the correction for gravity is only necessary for the depth expressed in m.

IV. Discussion of the Computation of Sound Velocity

A comparison of the computations by the British Admiralty, KUWAHARA and the present author was made. Under atmospheric pressure, the values of the British Admiralty and those of the author coincide with each other or the difference between the two is 0.1 m/sec. The difference between the values of KUWAHARA and those of the author is smaller than 0.2 m/sec. Under the pressure $P=3000$ db, salinity $S=38\%$, temperature $t=0^\circ\text{C}$, the values of the British Admiralty, KUWAHARA, and the author are respectively 1502.9 m/sec, 1503.1 m/sec, 1503.0 m/sec. Throughout the entire range of calculations the values of KUWAHARA and the author coincide with each other or the difference is 0.1 m/sec in most cases. The cases when the difference amounts to 0.2 m/sec are not many. The accuracy of these three different computations seems to be of the same order of magnitude. Because the accuracy of measuring the propagation velocity of sound in sea water is about 1/1000, namely about 1.5 m/sec, any one of the three may be used in practice to the same effect.

In order to increase the accuracy we must, as KUWAHARA said, examine the experimental formula of EKMAN's mean compressibility, μ . The values of μ are very important for the computation of velocity, as well as for the calculation of ρ_{sp} and γ . As it is estimated that accuracy of μ of EKMAN's experimental formula is 0.3%, it causes an error of about 3 m/sec, or 0.2% to the velocity of sound. The value of the error of μ is equal to the difference between

Alfred WEISSLER's experimental values and computed values of sound velocity. Accordingly, it is desirable to obtain the corrected values of μ . When this is accomplished, many physical constants of sea water will have to be amended. In the computation of γ , it was assumed that the change of C_p with the temperature was the same both for sea water and distilled water. But considering the relation of the variation of γ with C_p , it is estimated that its effect on the velocity is at most less than 0.5m/sec.

Finally a comparison will be made between the values of γ given by MATTHEWS⁽⁹⁾ (1923) and quoted in various fields and those of the author. At $S=34.85\%$, $t=0^\circ\text{C}$, 30°C under atmospheric pressure, and $S=34.85\%$, $t=0^\circ\text{C}$ under $P=1000\text{db}$, the values of γ are the same in both cases. But at $S=34.85\%$, $t=0^\circ\text{C}$ under $P=10,000\text{db}$, the values of γ of MATTHEWS and those of the author become 1.0126 and 1.0133 respectively. The difference between these two values of γ causes an error of about 0.5 m/sec to the velocity of sound.

V. Conclusions

With the development of submarine acoustics in recent years, an exact knowledge of the submarine sound velocity becomes increasingly important. Using the same basic data as those used in previous computations the present author recomputed the sound velocity in sea water by a method independent of the former ones and found results which were practically the same with those of the British Admiralty and KUWAHARA which are both in current use.

The author calculated the values of ρ_{stp} , K and γ from basic data, and from these quantities the values of sound velocity were derived directly. As the author's values of sound velocity agree absolutely with the best values known to the present, the accuracy of the obtained values of ρ_{stp} , K and γ seems to show the possible level attained at the present. These values together with the velocity of sound are shown in tables.

In order to facilitate the determination

of sound velocity in various oceanographical works, the author prepared diagrams of velocity based on his computed values which enable a rapid, simple and accurate estimation of sound velocity at any temperature, salinity and depth or pressure.

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TABLE 1

MEAN COMPRESSIBILITY, $\mu \times 10^9$ P is the pressure in decibars.

P=0									P=100								
t(°C)	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20	25	30	
S(%)																	
30	4778.1	4717.0	4583.6	4475.6	4389.9	4323.6	4273.5	4236.8	4769.9	4709.0	4576.1	4468.4	4383.0	4316.9	4266.9	4229.9	
31	4765.6	4705.0	4572.6	4465.5	4380.5	4314.7	4265.1	4228.6	4757.4	4697.0	4565.1	4458.3	4373.6	4308.0	4258.5	4221.7	
32	4753.2	4693.0	4561.7	4455.4	4371.1	4305.9	4256.6	4220.4	4745.0	4685.0	4554.2	4448.3	4364.3	4299.2	4250.1	4213.6	
33	4740.8	4681.1	4550.8	4445.4	4361.8	4297.1	4248.2	4212.2	4732.7	4673.2	4543.3	4438.3	4355.0	4290.5	4241.7	4205.6	
34	4728.3	4669.1	4539.8	4435.3	4352.4	4288.2	4239.7	4203.9	4720.2	4661.2	4532.4	4428.2	4345.6	4281.6	4233.2	4197.4	
35	4715.9	4657.1	4528.9	4425.2	4343.0	4279.4	4231.3	4195.7	4707.9	4649.2	4521.4	4418.1	4336.2	4272.8	4224.8	4189.3	
36	4703.6	4645.2	4518.0	4415.2	4333.7	4270.6	4222.8	4187.5	4695.5	4637.4	4510.6	4403.1	4326.9	4264.0	4216.4	4181.1	
37	4691.4	4633.5	4503.7	4405.3	4324.5	4261.9	4214.6	4179.4	4683.4	4625.7	4499.9	4398.3	4317.8	4255.4	4203.1	4173.1	
38	4679.2	4621.7	4496.6	4395.4	4315.3	4253.2	4206.2	4171.2	4671.3	4614.0	4489.2	4388.4	4308.6	4246.7	4199.7	4165.0	
39	4667.2	4610.2	4486.0	4385.6	4306.2	4244.6	4197.9	4163.1	4659.3	4602.4	4478.6	4378.6	4299.5	4238.1	4191.1	4157.1	
40	4655.1	4598.5	4475.3	4375.8	4297.0	4235.9	4183.6	4155.0	4647.2	4590.8	4468.0	4368.8	4290.3	4229.4	4183.2	4149.0	
P=500									P=1000								
t(°C)	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20			
S(%)																	
30	4737.4	4677.3	4546.2	4440.0	4355.7	4390.3	4240.9	4204.3	4697.5	4638.4	4509.5	4405.1	4322.2	4257.8			
31	4725.1	4665.4	4535.3	4430.0	4346.4	4381.6	4232.5	4196.2	4685.3	4626.7	4498.8	4395.1	4313.0	4249.1			
32	4712.8	4653.6	4524.5	4420.0	4337.1	4872.9	4224.2	4188.1	4673.2	4615.0	4488.1	4385.3	4303.8	4240.5			
33	4700.5	4641.8	4513.7	4410.1	4327.9	4364.2	4215.9	4180.0	4661.1	4603.3	4477.4	4375.5	4294.7	4231.9			
34	4688.2	4629.9	4502.9	4400.1	4318.6	4355.4	4207.5	4171.9	4648.9	4591.6	4466.6	4365.6	4285.5	4223.2			
35	4675.9	4618.1	4492.0	4390.1	4309.3	4346.6	4199.1	4163.7	4636.8	4579.9	4455.9	4355.7	4276.3	4214.5			
36	4663.7	4606.3	4481.3	4380.2	4300.1	4337.9	4190.8	4155.6	4624.7	4568.2	4445.3	4345.9	4267.2	4209.5			
37	4651.7	4594.8	4470.7	4370.4	4291.0	4229.4	4182.6	4147.6	4612.8	4556.8	4434.8	4336.3	4258.2	4197.5			
38	4639.7	4583.1	4460.0	4360.6	4281.9	4220.7	4174.3	4139.5	4600.9	4545.3	4424.3	4326.6	4249.1	4188.9			
39	4627.8	4571.7	4449.6	4351.0	4272.8	4212.2	4166.1	4131.5	4589.2	4534.0	4413.9	4317.0	4240.2	4180.5			
40	4615.8	4560.1	4439.0	4341.2	4263.7	4203.6	4157.8	4123.5	4577.3	4522.6	4403.5	4307.3	4231.2	4172.0			
P=1500									P=2000								
t(°C)	-2	0	5	10	15	20			-2	0	5	10	15	20			
S(%)																	
30	4658.5	4600.4	4473.6	4370.9	4289.3	4225.8			4620.2	4563.0	4438.4	4337.4	4257.1	4194.5			
31	4646.4	4588.7	4462.9	4361.1	4280.2	4217.2			4608.2	4551.5	4427.8	4327.7	4248.1	4186.0			
32	4634.4	4577.1	4452.4	4351.4	4271.1	4208.7			4596.4	4540.1	4417.4	4318.1	4239.1	4177.6			
33	4622.4	4565.6	4441.8	4341.6	4262.1	4200.2			4584.6	4528.7	4406.9	4308.4	4230.2	4169.2			
34	4610.4	4554.0	4431.2	4331.8	4253.0	4191.6			4572.6	4517.2	4396.4	4298.7	4221.2	4160.7			
35	4598.4	4542.4	4420.6	4322.1	4243.9	4183.1			4560.8	4505.8	4386.0	4289.1	4212.2	4152.2			
36	4586.5	4530.9	4410.1	4312.4	4234.9	4174.4			4549.0	4494.4	4375.5	4279.5	4203.2	4143.8			
37	4574.7	4519.6	4399.7	4302.8	4226.0	4166.2			4537.4	4483.2	4365.3	4270.0	4194.4	4135.5			
38	4562.9	4508.3	4389.3	4293.2	4217.0	4167.7			4525.7	4472.0	4355.0	4260.5	4185.6	4127.1			
39	4551.3	4497.1	4379.0	4283.7	4208.2	4149.4			4514.2	4460.9	4344.8	4251.2	4176.8	4118.9			
40	4539.6	4485.8	4368.7	4274.2	4199.3	4141.0			4502.7	4449.7	4334.6	4241.7	4168.0	4110.6			
P=4000						P=6000				P=8000				P=10000			
t(°C)	-2	0	5	10		-2	0	2.5	5	0	2.5	5		0	2.5	5	
S(%)																	
30	4474.2	4420.8	4304.3	4209.8													
31	4462.9	4409.8	4294.2	4200.5													
32	4451.6	4398.9	4281.7	4191.3													
33	4440.3	4388.1	4274.2	4182.1	4312.2	4258.0	4202.1	4151.6	4137.6	4085.2	4037.8			4025.9	3976.8	3932.2	
34	4429.0	4377.1	4264.2	4172.8	4296.1	4247.6	4192.1	4142.0	4127.7	4075.7	4028.7			4016.5	3967.8	3923.6	
35	4417.7	4366.2	4254.2	4163.5	4285.4	4237.2	4182.2	4132.4	4117.9	4066.3	4019.7			4007.2	3958.8	3915.0	
36	4406.4	4355.3	4244.2	4154.4	4274.7	4226.9	4172.3	4122.9	4108.1	4056.9	4010.6			3997.9	3949.9	3906.4	
37	4395.4	4344.7	4234.4	4145.3	4264.2	4216.8	4162.5	4113.6	4098.4	4047.6	4001.7			3988.8	3941.1	3895.9	

TABLE 2

$$\sigma_{\text{stp}} = (\rho_{\text{stp}} - 1) \times 10^3$$

P is the pressure in decibars.

P=0									P=100							
$t(^{\circ}\text{C})$ $S(\text{‰})$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20	25	30
30	24.16	24.11	23.75	23.09	22.16	20.99	19.61	18.02	24.65	24.59	24.22	23.55	22.61	21.43	20.05	18.45
31	24.96	24.91	24.54	23.86	22.92	21.75	20.35	18.76	25.45	25.39	25.03	24.32	23.37	22.19	20.78	19.19
32	25.77	25.71	25.32	24.64	23.68	22.47	21.10	19.50	26.26	26.19	25.79	25.10	24.13	22.91	21.53	19.93
33	26.58	26.51	26.10	25.41	24.45	23.25	21.85	20.24	27.07	26.99	26.57	25.86	24.90	23.69	22.28	20.67
34	27.39	27.32	26.91	26.19	25.22	24.02	22.61	21.00	27.87	27.80	27.38	26.64	25.67	24.46	23.04	21.43
35	28.21	28.13	27.70	26.97	25.99	24.78	23.36	21.75	28.69	28.61	28.16	27.42	26.43	25.22	23.79	22.18
36	29.02	28.94	28.49	27.76	26.76	25.55	24.12	22.50	29.50	29.42	28.95	28.21	27.20	25.99	24.55	22.93
37	29.83	29.74	29.28	28.53	27.53	26.31	24.87	23.25	30.28	30.22	29.74	28.98	27.97	26.75	25.30	23.68
38	30.65	30.55	30.03	29.32	28.31	27.07	25.63	24.00	31.13	31.03	30.54	29.77	28.75	27.51	26.06	24.43
39	31.45	31.35	30.86	30.09	29.07	27.83	26.38	24.75	31.93	31.82	31.32	30.54	29.51	28.26	26.81	25.17
40	32.28	32.16	31.63	30.84	29.80	28.54	27.08	25.43	32.76	32.63	32.09	31.29	30.24	28.98	27.51	25.85
P=500									P=1000							
$t(^{\circ}\text{C})$ $S(\text{‰})$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20		
30	26.59	26.51	26.08	25.37	24.39	23.18	21.78	20.16	28.99	28.88	28.39	27.62	26.60	25.36		
31	27.39	27.31	26.87	26.13	25.15	23.94	22.52	20.91	29.78	29.67	29.17	28.38	27.35	26.11		
32	28.19	28.10	27.64	26.91	25.90	24.66	23.26	21.64	30.59	30.47	29.94	29.15	28.10	26.82		
33	29.00	28.93	28.42	27.68	26.67	25.44	24.01	22.38	31.39	31.26	30.71	29.92	28.87	27.60		
34	29.80	29.70	29.23	28.45	27.44	26.20	24.77	23.13	32.19	32.06	31.52	30.69	29.63	28.36		
35	30.62	30.51	30.01	29.23	28.21	26.96	25.51	23.88	33.00	32.86	32.30	31.46	30.40	29.12		
36	31.43	31.32	30.79	30.02	28.97	27.73	26.27	24.63	33.80	33.66	33.08	32.25	31.16	29.88		
37	32.23	32.11	31.59	30.78	29.74	28.48	27.02	25.38	34.60	34.45	33.86	33.01	31.92	30.64		
38	33.05	32.92	32.38	31.57	30.52	29.24	27.78	26.12	35.41	35.26	34.66	33.79	32.70	31.39		
39	33.84	33.71	33.16	32.34	31.27	30.00	28.52	26.87	36.21	36.05	35.43	34.56	33.45	32.14		
40	34.67	34.52	33.92	33.08	32.00	30.71	29.22	27.55	37.03	36.84	36.19	35.30	34.18	32.85		
P=1500									P=2000							
$t(^{\circ}\text{C})$ $S(\text{‰})$	-2	0	5	10	15	20			-2	0	5	10	15	20		
30	31.37	31.23	30.67	29.84	28.78	27.50			33.71	33.54	32.92	32.04	30.94	29.63		
31	32.17	32.01	31.44	30.60	29.53	28.25			34.48	34.33	33.69	32.80	31.69	30.38		
32	32.95	32.80	32.21	31.37	30.28	28.97			35.29	35.11	34.46	33.57	32.43	31.08		
33	33.75	33.59	32.98	32.13	31.04	29.74			36.08	35.89	35.22	34.32	33.19	31.85		
34	34.54	34.39	33.78	32.90	31.80	30.50			36.87	36.69	36.02	35.09	33.95	32.61		
35	35.35	35.18	34.56	33.67	32.56	31.25			37.68	37.48	36.79	35.85	34.71	33.36		
36	36.15	35.98	35.34	34.45	33.32	32.01			38.47	38.27	37.57	36.63	35.46	34.12		
37	36.95	36.77	36.12	35.21	34.08	32.76			39.26	39.06	38.35	37.39	36.22	34.87		
38	37.75	37.57	36.91	35.99	34.86	33.52			40.06	39.85	39.13	38.17	36.99	35.62		
39	38.54	38.35	37.68	36.75	35.61	34.27			40.85	40.63	39.90	38.92	37.74	36.37		
40	39.36	39.15	38.43	37.49	36.33	34.97			41.66	41.43	40.65	39.66	38.46	37.07		
P=4000				P=6000				P=8000				P=10000				
$t(^{\circ}\text{C})$ $S(\text{‰})$	-2	0	5	10	-2	0	2.5	5	0	2.5	5			0	2.5	5
30	42.82	42.55	41.68	40.61												
31	43.59	43.31	42.45	41.36												
32	44.37	44.08	43.20	42.11												
33	45.14	44.85	43.95	42.86	53.81	53.42	52.90	52.31	61.65	61.03	60.35			69.57	68.86	68.10
34	45.92	45.63	44.73	43.61	54.57	54.19	53.65	53.08	62.40	61.77	61.11			70.31	69.59	68.84
35	46.71	46.41	45.49	44.36	55.35	54.95	54.41	53.83	63.15	62.51	61.85			71.05	70.32	69.57
36	47.48	47.18	46.25	45.13	56.11	55.71	55.17	54.58	63.90	63.27	62.58			71.79	71.07	70.30
37	48.26	47.95	47.01	45.87	56.87	56.47	55.92	55.32	64.65	64.00	63.32			72.52	71.79	71.03

TABLE 3

TRUE COMPRESSIBILITY, $K \times 10^6$ P is the pressure in decibars.

P=0									P=100								
$t(^{\circ}\text{C})$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20	25	30	
S _(%)																	
30	4778.1	4717.0	4583.6	4475.6	4389.9	4323.6	4273.5	4236.8	4764.0	4703.2	4570.6	4463.3	4378.1	4312.0	4262.2	4225.1	
31	4765.6	4705.0	4572.6	4465.5	4380.5	4314.7	4265.1	4228.6	4751.5	4691.2	4559.7	4453.2	4368.7	4303.2	4253.8	4217.0	
32	4753.2	4693.0	4561.7	4455.4	4371.1	4305.9	4256.6	4220.4	4739.2	4679.3	4548.8	4443.1	4359.3	4294.4	4245.4	4208.9	
33	4740.8	4681.1	4550.8	4445.4	4361.8	4297.1	4248.2	4212.2	4726.8	4667.4	4537.9	4433.1	4350.0	4285.7	4237.0	4200.9	
34	4728.3	4669.1	4539.8	4435.3	4352.4	4288.2	4239.7	4203.9	4714.4	4655.5	4527.0	4423.0	4340.7	4276.8	4228.5	4192.7	
35	4715.9	4657.1	4528.9	4425.2	4343.0	4279.4	4231.3	4195.7	4702.0	4643.5	4516.1	4413.0	4331.3	4268.0	4220.1	4184.6	
36	4703.6	4645.2	4518.0	4415.2	4333.7	4270.6	4222.8	4187.5	4689.7	4631.7	4505.2	4403.0	4322.0	4259.3	4211.7	4176.5	
37	4691.4	4633.5	4507.3	4405.3	4324.5	4261.9	4214.6	4179.4	4677.6	4620.0	4494.6	4393.2	4312.9	4250.6	4203.4	4168.5	
38	4679.2	4621.7	4496.6	4395.4	4315.3	4253.2	4206.2	4171.2	4665.5	4608.3	4483.8	4383.3	4303.7	4241.9	4195.1	4160.4	
39	4667.2	4610.2	4486.0	4385.6	4306.2	4244.6	4197.9	4163.1	4653.5	4596.8	4473.3	4373.6	4294.6	4233.3	4186.9	4152.4	
40	4655.1	4598.5	4475.3	4375.8	4297.0	4235.9	4188.6	4155.0	4641.4	4585.1	4462.7	4363.8	4285.4	4224.7	4178.6	4144.4	
P=500									P=1000								
$t(^{\circ}\text{C})$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20			
S _(%)																	
30	4708.3	4648.9	4519.4	4414.5	4331.3	4266.6	4217.5	4180.9	4640.4	4582.8	4457.0	4355.2	4274.3	4211.2			
31	4696.0	4637.1	4508.6	4404.6	4322.0	4258.0	4209.2	4172.9	4628.4	4571.2	4446.4	4345.4	4265.2	4202.6			
32	4683.8	4625.4	4497.9	4394.7	4312.8	4249.2	4200.9	4164.8	4616.4	4559.6	4435.8	4335.7	4256.2	4194.1			
33	4671.7	4613.6	4487.1	4384.8	4303.7	4240.6	4192.7	4156.8	4604.5	4548.1	4425.3	4326.0	4247.2	4185.6			
34	4659.4	4601.8	4476.4	4374.9	4294.4	4231.9	4184.3	4148.7	4592.4	4536.5	4414.7	4316.2	4238.0	4177.1			
35	4647.2	4590.1	4465.6	4365.0	4285.1	4223.2	4176.0	4140.6	4580.5	4525.0	4404.1	4306.5	4229.0	4168.5			
36	4635.1	4578.4	4454.9	4355.1	4276.0	4214.5	4167.7	4132.6	4568.6	4513.5	4393.6	4296.8	4219.8	4160.0			
37	4623.2	4566.9	4444.4	4345.4	4267.0	4206.0	4159.7	4124.6	4556.9	4502.2	4383.3	4287.3	4211.1	4151.7			
38	4611.2	4555.4	4433.8	4335.7	4257.9	4197.5	4151.4	4116.6	4545.1	4490.8	4372.9	4277.7	4202.1	4143.3			
39	4599.4	4544.0	4423.4	4326.1	4248.9	4189.0	4143.2	4108.7	4533.5	4479.7	4362.7	4268.2	4193.3	4135.0			
40	4587.5	4532.5	4412.9	4316.4	4239.9	4180.5	4135.0	4100.7	4521.8	4468.4	4352.4	4258.7	4184.5	4126.6			
P=1500									P=2000								
$t(^{\circ}\text{C})$	-2	0	5	10	15	20			-2	0	5	10	15	20			
S _(%)																	
30	4574.4	4518.4	4396.5	4292.6	4218.8	4157.3			4510.2	4455.9	4337.5	4241.1	4164.9	4104.8			
31	4562.6	4507.0	4386.1	4287.9	4209.0	4148.9			4498.6	4444.7	4327.2	4231.6	4156.2	4096.5			
32	4550.8	4495.7	4375.7	4278.4	4201.0	4140.5			4487.1	4433.5	4317.0	4222.3	4147.5	4088.3			
33	4539.1	4484.4	4365.4	4268.8	4192.2	4132.2			4475.6	4422.5	4306.8	4212.9	4138.8	4080.1			
34	4527.3	4473.0	4355.0	4259.2	4183.2	4123.8			4464.0	4411.3	4296.2	4203.5	4130.0	4071.9			
35	4515.6	4461.7	4344.6	4249.7	4174.3	4115.4			4452.5	4400.2	4286.3	4194.1	4121.2	4063.7			
36	4503.9	4450.4	4334.3	4240.1	4165.5	4107.1			4441.0	4389.1	4276.3	4184.7	4112.5	4055.5			
37	4492.4	4439.4	4324.1	4230.8	4156.1	4098.8			4429.8	4378.3	4266.4	4175.5	4104.0	4047.4			
38	4480.9	4428.2	4313.7	4221.4	4148.0	4090.5			4418.5	4367.3	4256.4	4166.3	4095.4	4039.3			
39	4469.5	4417.2	4303.7	4212.1	4139.3	4082.4			4407.3	4356.6	4246.5	4157.2	4086.9	4031.3			
40	4458.0	4406.2	4293.6	4202.7	4130.6	4074.2			4396.1	4345.7	4236.6	4148.0	4078.3	4023.2			
P=4000						P=6000				P=8000				P=10000			
$t(^{\circ}\text{C})$	-2	0	5	10		-2	0	2.5	5	0	2.5	5		0	2.5	5	
S _(%)																	
30	4270.2	4222.1	4117.4	4032.2													
31	4259.5	4211.8	4107.9	4023.4													
32	4248.9	4201.6	4098.5	4014.7													
33	4238.4	4191.4	4089.2	4006.1	4026.0	3984.7	3937.3	3894.4	3799.6	3757.0	3719.9			3634.0	3597.2	3563.2	
34	4227.8	4181.1	4079.7	3997.3	4016.3	3975.3	3928.3	3885.8	3791.3	3748.9	3712.2			3626.6	3590.1	3556.4	
35	4217.2	4170.9	4070.4	3988.6	4006.8	3966.0	3919.4	3877.2	3782.9	3740.9	3704.4			3619.2	3583.0	3549.5	
36	4206.7	4163.7	4061.0	3980.0	3997.2	3956.8	3910.4	3868.7	3774.6	3732.8	3696.8			3611.9	3575.9	3542.7	
37	4196.3	4150.7	4051.8	3971.5	3987.8	3947.7	3901.8	3860.4	3766.5	3725.0	3689.2			3604.7	3569.0	3536.1	

TABLE 4

$$\gamma = \frac{C_p}{C_v}$$

P is the pressure in decibars.

P=0									P=100								
$t(^{\circ}C)$ $S(\%)$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20	25	30	
30	1.0000	1.0002	1.0015	1.0039	1.0070	1.0107	1.0151	1.0202	1.0000	1.0002	1.0016	1.0040	1.0071	1.0109	1.0152	1.0203	
31	1.0000	1.0002	1.0016	1.0040	1.0071	1.0109	1.0152	1.0203	1.0000	1.0003	1.0017	1.0041	1.0072	1.0110	1.0154	1.0204	
32	1.0000	1.0003	1.0017	1.0041	1.0073	1.0110	1.0154	1.0204	1.0000	1.0003	1.0018	1.0042	1.0074	1.0111	1.0155	1.0205	
33	1.0001	1.0003	1.0018	1.0042	1.0074	1.0112	1.0155	1.0205	1.0001	1.0003	1.0019	1.0043	1.0075	1.0113	1.0157	1.0206	
34	1.0001	1.0003	1.0019	1.0044	1.0075	1.0113	1.0157	1.0206	1.0001	1.0004	1.0020	1.0045	1.0076	1.0114	1.0158	1.0207	
35	1.0001	1.0004	1.0020	1.0045	1.0077	1.0115	1.0158	1.0207	1.0001	1.0004	1.0021	1.0046	1.0078	1.0116	1.0160	1.0208	
36	1.0001	1.0004	1.0021	1.0046	1.0078	1.0116	1.0159	1.0208	1.0001	1.0005	1.0022	1.0047	1.0079	1.0117	1.0161	1.0210	
37	1.0001	1.0005	1.0022	1.0047	1.0079	1.0117	1.0161	1.0210	1.0002	1.0005	1.0023	1.0049	1.0081	1.0119	1.0162	1.0211	
38	1.0001	1.0005	1.0023	1.0049	1.0081	1.0119	1.0162	1.0211	1.0002	1.0006	1.0024	1.0050	1.0082	1.0120	1.0164	1.0213	
39	1.0002	1.0006	1.0024	1.0050	1.0082	1.0120	1.0164	1.0212	1.0002	1.0006	1.0025	1.0051	1.0084	1.0122	1.0165	1.0214	
40	1.0002	1.0006	1.0025	1.0051	1.0084	1.0122	1.0165	1.0214	1.0002	1.0007	1.0026	1.0052	1.0085	1.0123	1.0167	1.0215	
P=500									P=1000								
$t(^{\circ}C)$ $S(\%)$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20			
30	1.0001	1.0004	1.0020	1.0044	1.0076	1.0114	1.0158	1.0208	1.0002	1.0007	1.0024	1.0050	1.0083	1.0120			
31	1.0001	1.0004	1.0021	1.0045	1.0078	1.0115	1.0159	1.0209	1.0003	1.0007	1.0025	1.0052	1.0084	1.0122			
32	1.0001	1.0005	1.0022	1.0047	1.0079	1.0117	1.0161	1.0210	1.0003	1.0008	1.0027	1.0053	1.0086	1.0123			
33	1.0002	1.0005	1.0023	1.0048	1.0080	1.0118	1.0162	1.0211	1.0003	1.0008	1.0028	1.0054	1.0087	1.0125			
34	1.0002	1.0006	1.0024	1.0049	1.0082	1.0120	1.0163	1.0212	1.0004	1.0009	1.0029	1.0056	1.0089	1.0127			
35	1.0002	1.0006	1.0025	1.0051	1.0083	1.0121	1.0165	1.0213	1.0004	1.0009	1.0030	1.0057	1.0090	1.0128			
36	1.0003	1.0007	1.0026	1.0052	1.0085	1.0123	1.0166	1.0215	1.0005	1.0010	1.0031	1.0059	1.0092	1.0130			
37	1.0003	1.0008	1.0027	1.0053	1.0086	1.0124	1.0168	1.0217	1.0005	1.0011	1.0032	1.0060	1.0093	1.0131			
38	1.0003	1.0008	1.0028	1.0054	1.0087	1.0125	1.0169	1.0218	1.0006	1.0012	1.0033	1.0061	1.0094	1.0133			
39	1.0004	1.0009	1.0029	1.0056	1.0088	1.0127	1.0171	1.0219	1.0006	1.0013	1.0034	1.0062	1.0096	1.0134			
40	1.0004	1.0009	1.0030	1.0057	1.0090	1.0129	1.0172	1.0221	1.0007	1.0013	1.0036	1.0064	1.0097	1.0136			
P=1500								P=2000									
$t(^{\circ}C)$ $S(\%)$	-2	0	5	10	15	20											
30	1.0004	1.0010	1.0030	1.0057	1.0090	1.0128											
31	1.0005	1.0011	1.0031	1.0059	1.0091	1.0129											
32	1.0005	1.0011	1.0032	1.0060	1.0093	1.0131											
33	1.0006	1.0012	1.0033	1.0061	1.0095	1.0132											
34	1.0007	1.0013	1.0034	1.0063	1.0096	1.0134											
35	1.0007	1.0013	1.0035	1.0064	1.0098	1.0136											
36	1.0008	1.0014	1.0037	1.0066	1.0099	1.0137											
37	1.0008	1.0015	1.0038	1.0067	1.0100	1.0139											
38	1.0009	1.0016	1.0039	1.0068	1.0101	1.0140											
39	1.0010	1.0017	1.0041	1.0069	1.0102	1.0142											
40	1.0010	1.0017	1.0042	1.0071	1.0103	1.0144											
P=4000						P=6000				P=8000			P=10000				
$t(^{\circ}C)$ $S(\%)$	-2	0	5	10	-2	0	2.5	5	0	2.5	5	0	2.5	5			
30	1.0023	1.0033	1.0059	1.0090													
31	1.0024	1.0034	1.0060	1.0091													
32	1.0025	1.0035	1.0062	1.0092													
33	1.0026	1.0036	1.0063	1.0094	1.0050	1.0062	1.0078	1.0093	1.0095	1.0110	1.0126	1.0130	1.0145	1.0161			
34	1.0027	1.0037	1.0065	1.0096	1.0052	1.0064	1.0079	1.0094	1.0096	1.0111	1.0128	1.0132	1.0147	1.0163			
35	1.0028	1.0038	1.0066	1.0097	1.0053	1.0066	1.0080	1.0096	1.0098	1.0113	1.0129	1.0133	1.0149	1.0164			
36	1.0029	1.0039	1.0068	1.0099	1.0055	1.0067	1.0082	1.0097	1.0099	1.0114	1.0130	1.0135	1.0150	1.0167			
37	1.0030	1.0040	1.0070	1.0100	1.0056	1.0068	1.0083	1.0099	1.0100	1.0116	1.0132	1.0137	1.0152	1.0169			

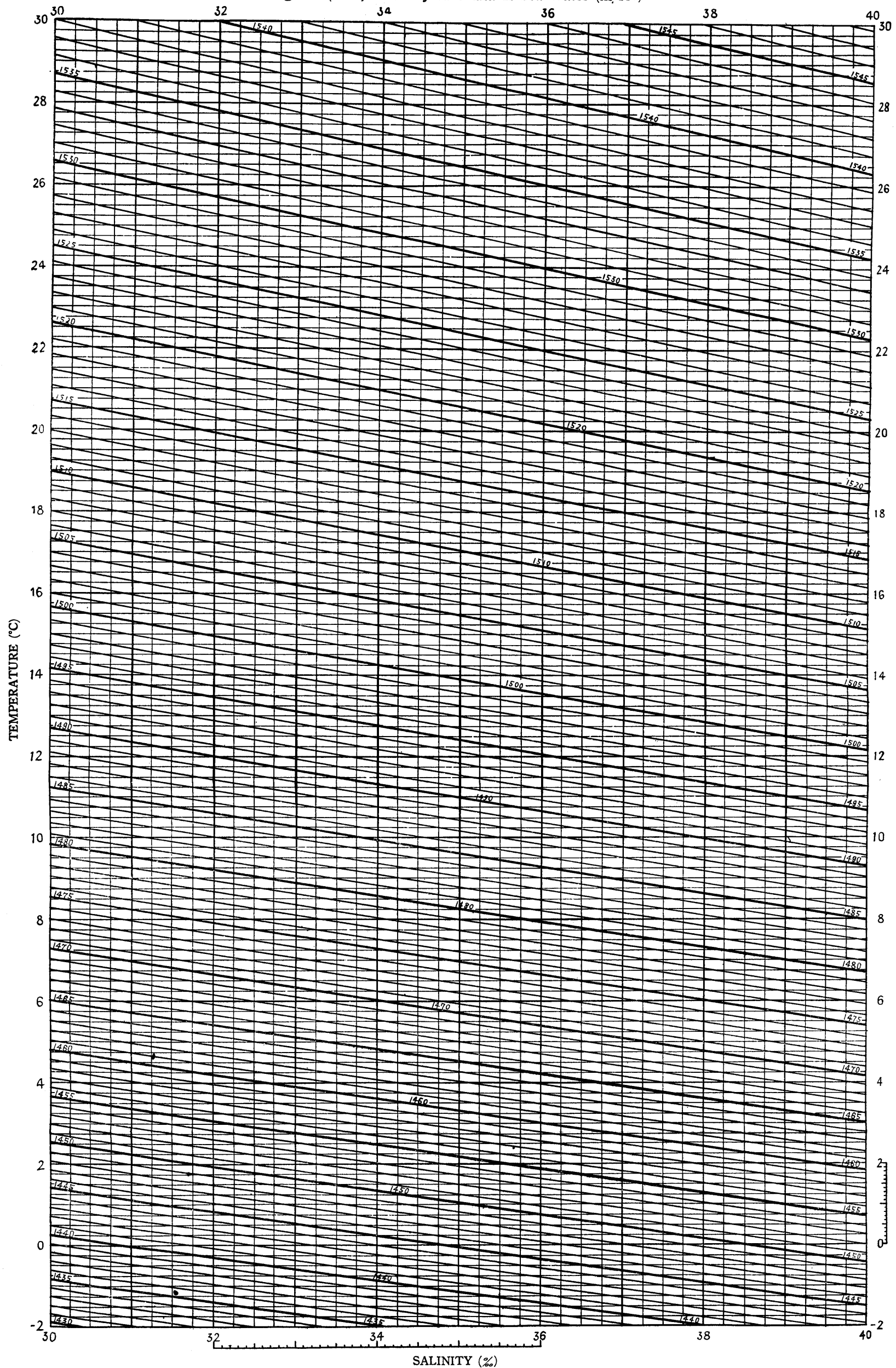
TABLE 5

VELOCITY OF SOUND (m/sec)

P is the pressure in decibars.

P=0									P=100								
$t(^{\circ}\text{C})$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20	25	30	
$S(\%)$																	
30	1429.5	1438.9	1460.9	1480.7	1498.0	1513.1	1526.3	1538.0	1431.3	1440.7	1462.7	1482.5	1499.8	1515.0	1528.1	1539.8	
31	1430.8	1440.2	1462.2	1481.9	1499.2	1514.3	1527.4	1539.0	1432.6	1442.0	1464.0	1483.7	1500.9	1516.1	1529.2	1540.8	
32	1432.1	1441.5	1463.4	1483.1	1500.4	1515.4	1528.5	1540.0	1433.9	1443.3	1465.2	1484.8	1502.1	1517.2	1530.2	1541.8	
33	1433.5	1442.8	1464.7	1484.3	1501.5	1516.5	1529.5	1541.0	1435.2	1444.6	1466.5	1486.1	1503.3	1518.3	1531.3	1542.8	
34	1434.8	1444.1	1466.0	1485.5	1502.6	1517.6	1530.6	1542.0	1436.6	1445.9	1467.8	1487.3	1504.4	1519.4	1532.4	1543.8	
35	1436.2	1445.4	1467.3	1486.7	1503.8	1518.7	1531.6	1543.1	1437.9	1447.3	1469.1	1488.5	1505.6	1520.5	1533.5	1544.8	
36	1437.4	1446.7	1468.5	1487.9	1504.9	1519.8	1532.7	1544.1	1439.2	1448.6	1470.4	1489.7	1506.7	1521.6	1534.5	1545.8	
37	1438.7	1448.1	1469.8	1489.1	1506.1	1520.9	1533.8	1545.2	1440.6	1449.9	1471.6	1491.0	1507.9	1522.7	1535.6	1546.9	
38	1440.1	1449.4	1471.0	1490.3	1507.2	1522.0	1534.8	1546.2	1441.9	1451.2	1472.9	1492.2	1509.0	1523.8	1536.7	1548.0	
39	1441.4	1450.7	1472.3	1491.5	1508.4	1523.1	1535.9	1547.2	1443.2	1452.5	1474.1	1493.3	1510.2	1524.9	1537.7	1549.0	
40	1442.7	1452.0	1473.6	1492.7	1509.6	1524.2	1537.0	1548.3	1444.5	1453.8	1475.4	1494.5	1511.4	1526.0	1538.8	1550.0	
P=500									P=1000								
$t(^{\circ}\text{C})$	-2	0	5	10	15	20	25	30	-2	0	5	10	15	20			
$S(\%)$																	
30	1438.5	1447.9	1470.0	1489.6	1507.0	1522.1	1535.3	1547.0	1447.3	1456.8	1478.8	1498.5	1515.8	1530.9			
31	1439.8	1449.2	1471.3	1490.8	1508.2	1523.2	1536.3	1548.0	1448.7	1458.1	1480.1	1499.7	1517.0	1532.1			
32	1441.1	1450.5	1472.5	1492.1	1509.3	1524.3	1537.4	1549.0	1450.0	1459.4	1481.4	1500.9	1518.2	1533.2			
33	1442.4	1451.8	1473.8	1493.3	1510.4	1525.4	1538.5	1550.0	1451.3	1460.7	1482.7	1502.1	1519.3	1534.3			
34	1443.8	1453.2	1475.0	1494.5	1511.6	1526.5	1539.5	1551.0	1452.7	1462.1	1484.0	1503.4	1520.5	1535.4			
35	1445.1	1454.5	1476.3	1495.7	1512.8	1527.6	1540.6	1552.1	1454.1	1463.4	1485.3	1504.6	1521.6	1536.5			
36	1446.5	1455.8	1477.6	1496.9	1514.0	1528.8	1541.7	1553.2	1455.5	1464.8	1486.6	1505.9	1522.8	1537.6			
37	1447.8	1457.2	1478.9	1498.1	1515.1	1529.8	1542.8	1554.3	1456.8	1466.1	1487.8	1507.1	1524.0	1538.7			
38	1449.1	1458.4	1480.1	1499.3	1516.2	1530.9	1543.8	1555.3	1458.2	1467.5	1489.1	1508.3	1525.1	1539.9			
39	1450.5	1459.7	1481.4	1500.5	1517.3	1532.0	1544.9	1556.3	1459.5	1468.8	1490.3	1509.5	1526.3	1541.0			
40	1451.8	1461.0	1482.7	1501.8	1518.5	1533.2	1546.0	1557.4	1460.8	1470.1	1491.6	1510.8	1527.4	1542.1			
P=1500								P=2000									
$t(^{\circ}\text{C})$	-2	0	5	10	15	20		-2	0	5	10	15	20				
$S(\%)$																	
30	1456.2	1465.7	1487.8	1507.4	1524.8	1539.8		1465.1	1474.5	1496.6	1516.2	1533.4	1548.5				
31	1457.5	1467.1	1489.0	1508.7	1526.0	1540.9		1466.5	1475.9	1497.9	1517.4	1534.6	1549.6				
32	1458.9	1468.4	1490.3	1509.9	1527.1	1542.1		1467.8	1477.2	1499.2	1518.7	1535.7	1550.7				
33	1460.3	1469.7	1491.6	1511.1	1528.3	1543.2		1469.2	1478.5	1500.5	1519.9	1536.9	1551.8				
34	1461.7	1471.1	1492.9	1512.4	1529.4	1544.3		1470.5	1479.9	1501.7	1521.2	1538.0	1552.9				
35	1463.0	1472.4	1494.2	1513.6	1530.6	1545.4		1471.9	1481.3	1503.0	1522.4	1539.2	1554.1				
36	1464.4	1473.8	1495.5	1514.9	1531.8	1546.5		1473.2	1482.7	1504.3	1523.7	1540.4	1555.2				
37	1465.7	1475.1	1496.8	1516.1	1533.0	1547.6		1474.6	1484.0	1505.6	1524.9	1541.6	1556.3				
38	1467.1	1476.5	1498.1	1517.3	1534.0	1548.7		1476.0	1485.4	1506.9	1526.1	1542.7	1557.4				
39	1468.5	1477.8	1499.4	1518.5	1535.1	1549.9		1477.4	1486.7	1508.2	1527.3	1543.9	1558.5				
40	1469.8	1479.1	1500.7	1519.8	1536.2	1551.0		1478.7	1488.1	1509.5	1528.5	1545.0	1559.6				
P=4000					P=6000				P=8000				P=10000				
$t(^{\circ}\text{C})$	-2	0	5	10	-2	0	2.5	5	0	2.5	5		0	2.5	5		
$S(\%)$																	
30	1500.3	1509.8	1531.4	1550.7													
31	1501.7	1511.1	1532.7	1551.9													
32	1503.0	1512.5	1534.1	1553.1													
33	1504.4	1513.8	1535.3	1554.4	1539.1	1548.3	1559.2	1569.3	1581.9	1592.5	1602.2		1614.4	1624.4	1634.0		
34	1505.8	1515.2	1536.6	1555.7	1540.5	1549.7	1560.5	1570.6	1583.2	1593.8	1603.5		1615.6	1625.6	1635.1		
35	1507.2	1516.6	1538.0	1556.9	1541.9	1551.1	1561.8	1571.9	1584.5	1595.1	1604.7		1616.8	1626.8	1636.2		
36	1508.6	1517.9	1539.3	1558.1	1543.3	1552.4	1563.1	1573.2	1585.8	1596.4	1605.9		1618.0	1627.9	1637.4		
37	1510.0	1519.2	1540.7	1559.3	1544.7	1553.8	1564.4	1574.5	1587.1	1597.6	1607.1		1619.2	1629.1	1638.6		

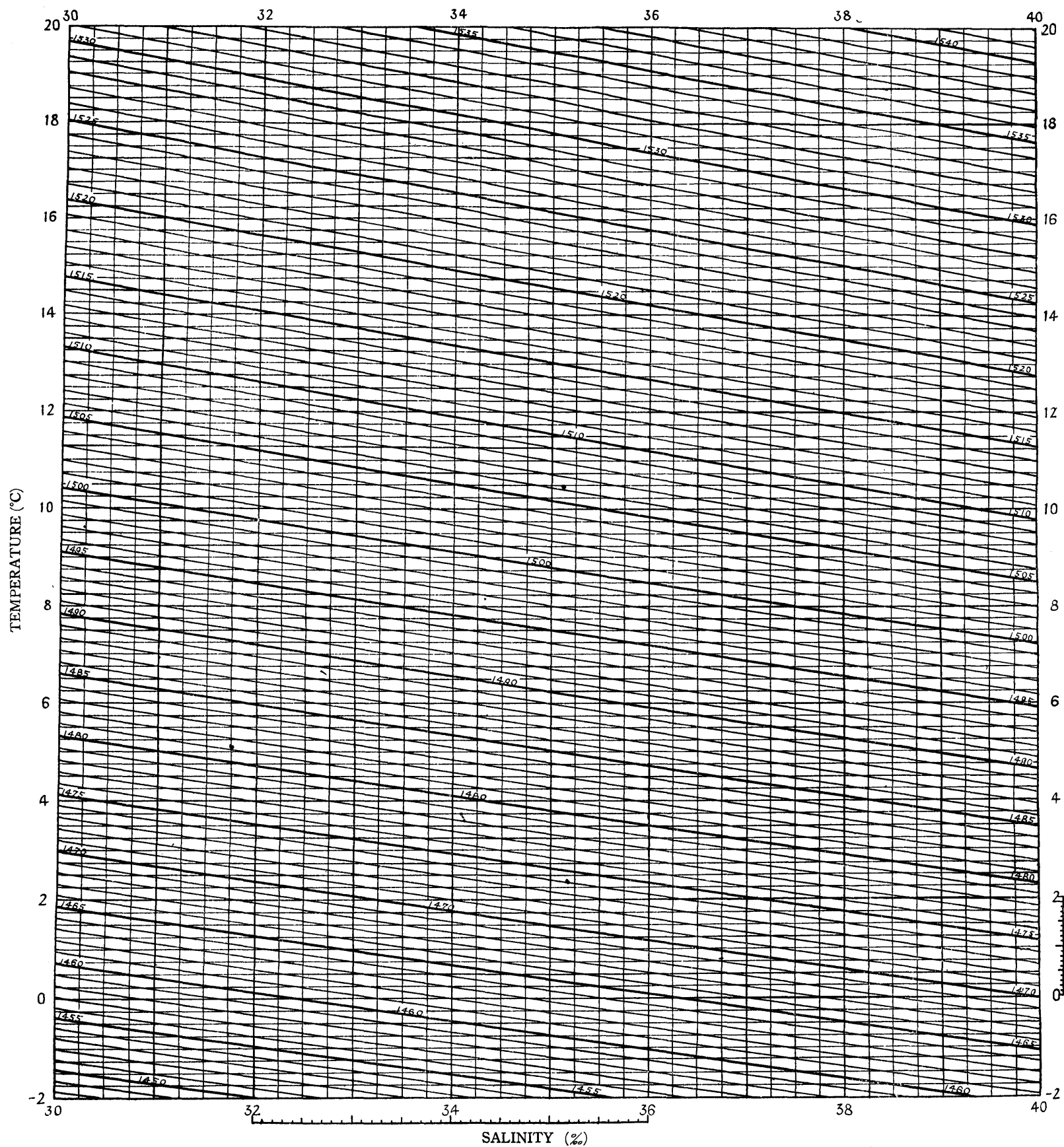
Fig. 1. (P=0) Velocity of Sound in Sea Water (m/sec)



Correction Table:— This table applies to the depths of P=0~500db. or m.

depth db. or m.	Correction Values (m/sec)	
	for db.	for m.
0	0	0
10	0.2	0.2
25	0.5	0.5
50	0.9	0.9
75	1.4	1.4
100	1.8	1.8
150	2.7	2.7
200	3.6	3.6
300	5.4	5.5
400	7.2	7.3
500	9.0	9.1

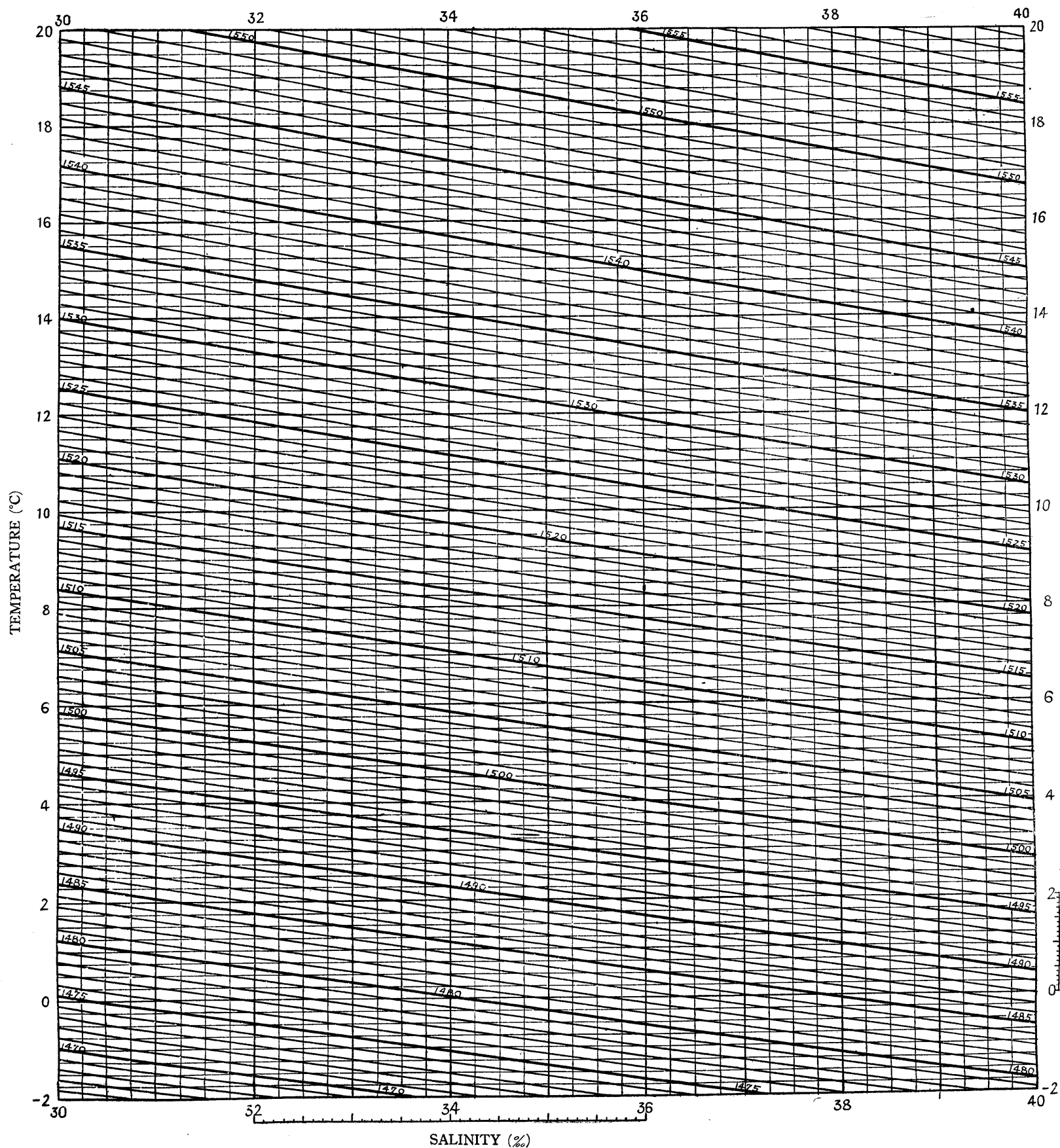
Fig. 2. (P=1000db.) Velocity of Sound in Sea Water (m/sec)



Correction Table:— This table applies to the depths of P=500~1500 db. or m.

depth db. or m.	Correction Values (m/sec)	
	for db.	for m.
500	-8.9	-8.8
600	-7.1	-7.0
700	-5.3	-5.2
800	-3.6	-3.5
900	-1.8	-1.7
1000	0	0.2
1100	1.8	2.0
1200	3.6	3.8
1300	5.3	5.5
1400	7.1	7.4
1500	8.9	9.2

Fig. 3. (P=2000 db.) Velocity of Sound in Sea Water (m/sec)



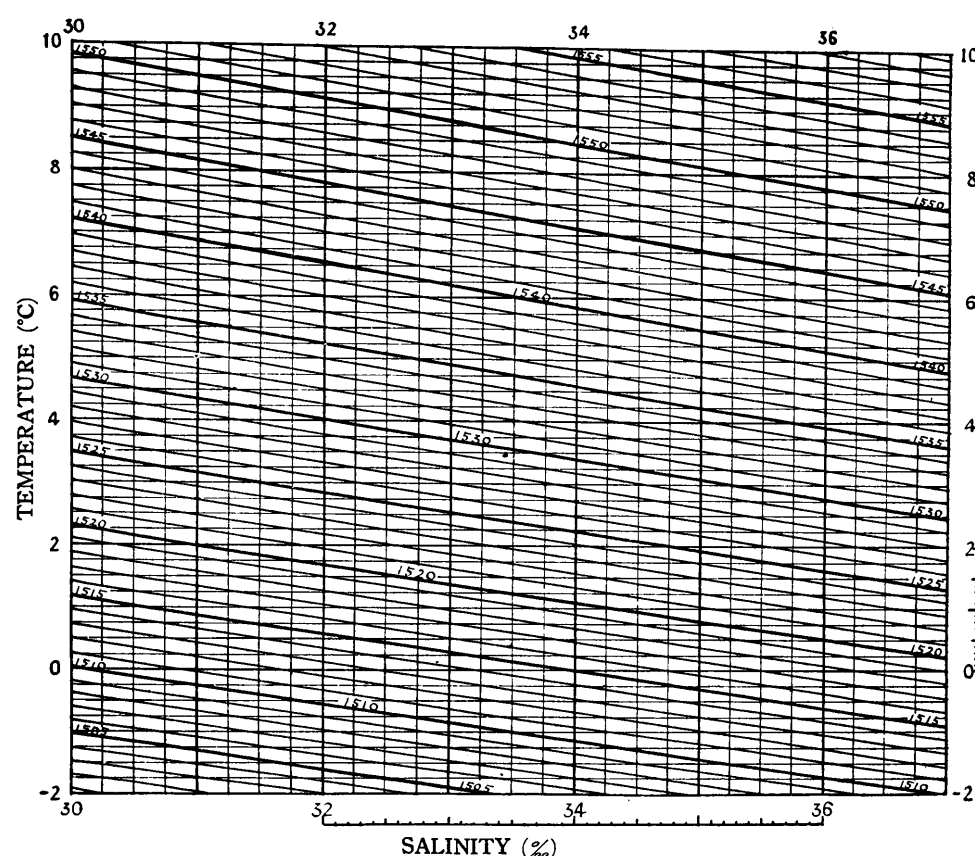
Correction Table:—This table applies to the depths of P=1500~3000db. or m.

depth db. or m.	Correction Values (m/sec)		Temp. (°C)	for db.			for m.		
	for db.	for m.		0	5	10	0	5	10
1500	-8.9	-8.6	2300	5.3	5.2	5.2	5.8	5.7	5.7
1600	-7.1	-6.8	2400	7.1	7.0	6.9	7.7	7.5	7.4
1700	-5.3	-5.0	2500	8.8	8.7	8.6	9.4	9.3	9.1
1800	-3.5	-3.1	2600	10.6	10.5	10.4	11.2	11.1	10.9
1900	-1.8	-1.4	2700	12.4	12.2	12.1	13.0	12.8	12.7
2000	0	0.4	2800	14.1	14.0	13.8	14.8	14.7	14.4
2100	1.8	2.2	2900	15.9	15.7	15.5	16.6	16.4	16.1
2200	3.5	4.0	3000	17.7	17.5	17.3	18.5	18.2	18.0

Correction for Gravity

depth(m)	2000	3000
Lat(°)	m/sec	m/sec
0	-0.1	-0.1
10	-0.1	-0.1
20	-0.1	-0.1
30	0	0
40	0	0
50	0.1	0.1
60	0.1	0.1
70	0.1	0.2
80	0.1	0.2
90	0.1	0.2

Fig. 4 (P=4000 db.) Velocity of Sound in Sea Water (m/sec)

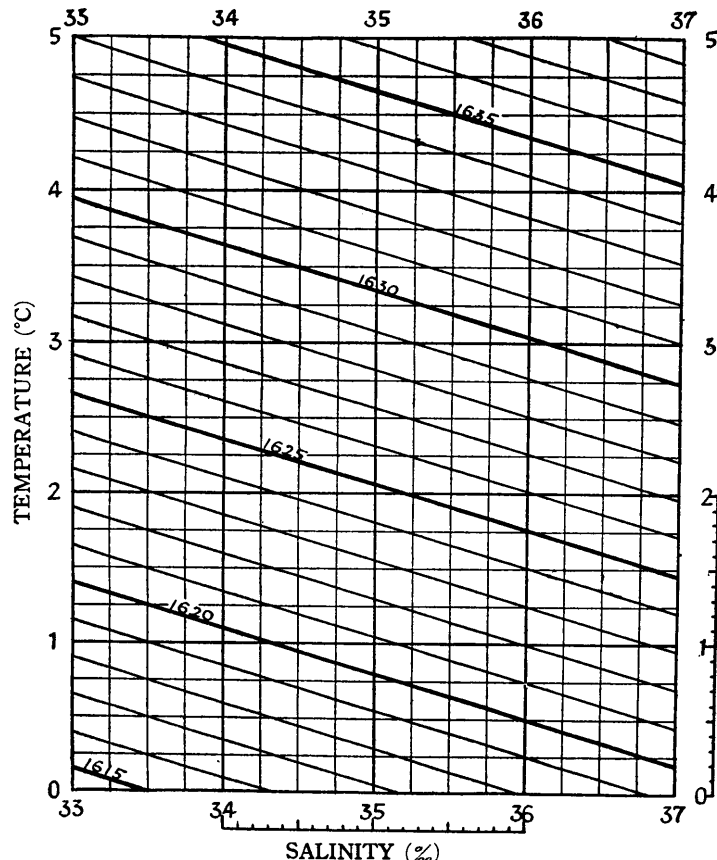


Correction Table

This table applies to the depths of P=3000~5000 db. or m.

depth db or m	for db.			for m.			depth db or m	for db.			for m.		
	0	5	10	0	5	10		0	5	0	5	0	5
3000	-17.7	-17.5	-17.3	-16.9	-16.8	-16.6	4100	1.7	1.7	2.9	2.8		
3100	-15.9	-15.7	-15.5	-15.1	-15.0	-14.8	4200	3.5	3.4	4.8	4.6		
3200	-14.1	-14.0	-13.8	-13.3	-13.2	-13.1	4300	5.2	5.1	6.5	6.3		
3300	-12.4	-12.2	-12.1	-11.5	-11.4	-11.3	4400	6.9	6.8	8.2	8.1		
3400	-10.6	-10.5	-10.4	-9.7	-9.6	-9.6	4500	8.6	8.5	10.0	9.8		
3500	-8.8	-8.7	-8.6	-7.8	-7.8	-7.7	4600	10.4	10.2	11.8	11.6		
3600	-7.1	-7.0	-6.9	-6.1	-6.0	-6.0	4700	12.1	11.9	13.6	13.3		
3700	-5.3	-5.2	-5.2	-4.3	-4.2	-4.2	4800	13.8	13.6	15.3	15.0		
3800	-3.5	-3.5	-3.5	-2.4	-2.5	-2.5	4900	15.5	15.3	17.1	16.8		
3900	-1.8	-1.7	-1.7	-0.7	-0.7	-0.7	5000	17.3	17.0	18.9	18.5		
4000	0	0	0	1.2	1.1	1.0							

Fig. 6 (P=8000db.) Velocity of Sound in Sea Water (m/sec)



Correction Table

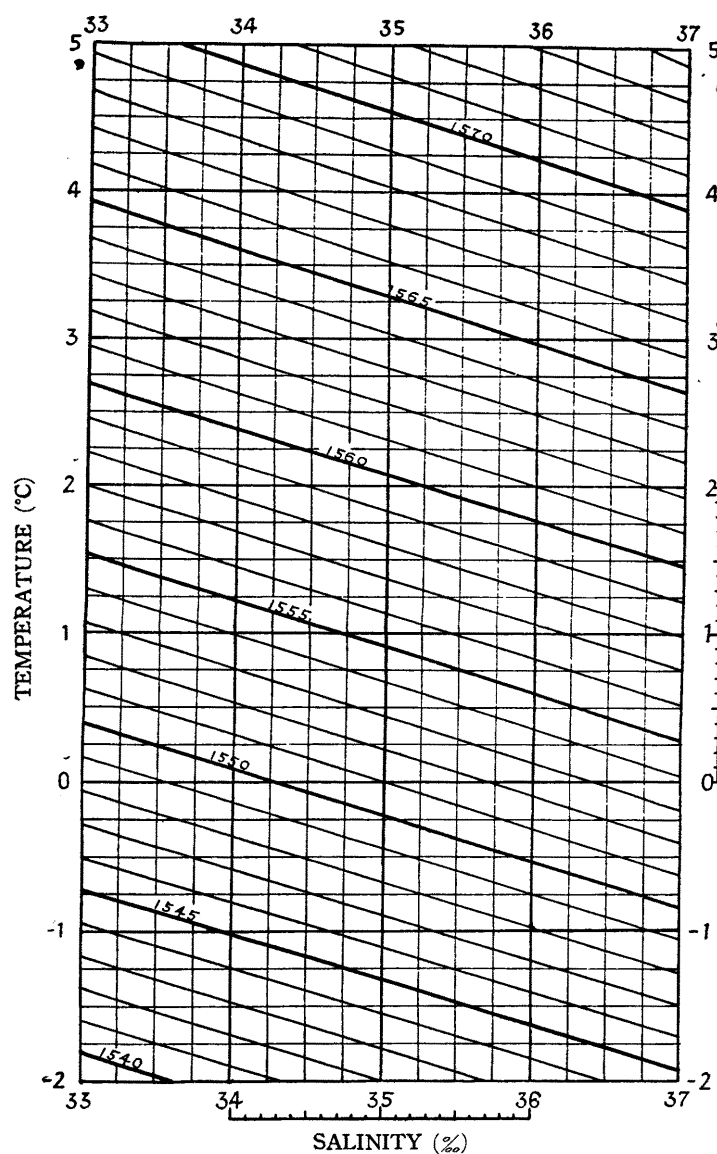
This table applies to the depths of P=7000~9000 db. or m.

depth db or m	for db.			for m.			depth db or m	for db.			for m.		
	0	5	10	0	5	10		0	5	0	5	0	5
7000	-16.8	-16.4	-14.1	-13.8			8100	1.6	1.6	4.9	4.7		
7100	-15.1	-14.8	-12.3	-12.2			8200	3.2	3.2	6.5	6.4		
7200	-13.4	-13.1	-10.6	-10.4			8300	4.8	4.7	8.3	8.0		
7300	-11.7	-11.5	-8.8	-8.8			8400	6.5	6.3	10.0	9.6		
7400	-10.1	-9.8	-7.1	-7.0			8500	8.1	7.9	11.7	11.3		
7500	-8.4	-8.2	-5.4	-5.3			8600	9.7	9.5	13.4	13.0		
7600	-6.7	-6.6	-3.6	-3.6			8700	11.3	11.0	15.1	14.5		
7700	-5.0	-4.9	-1.8	-1.8			8800	12.9	12.6	16.7	16.2		
7800	-3.4	-3.3	-0.2	-0.2			8900	14.5	14.2	18.4	17.9		
7900	-1.7	-1.6	1.6	1.5			9000	16.2	15.8	20.2	19.6		
8000	0	0	3.3	3.1									

Correction for Gravity

depth(m)	3000	5000	7000	9000	10000
L at(°)	m/sec	m/sec	m/sec	m/sec	m/sec
0	-0.1	-0.2	-0.2	-0.3	-0.3
10	-0.1	-0.1	-0.2	-0.2	-0.3
20	-0.1	-0.1	-0.1	-0.2	-0.2
30	0	0	-0.1	-0.1	-0.1
40	0	0	0.1	0.1	0.1
50	0.1	0.1	0.2	0.2	0.2
60	0.1	0.2	0.3	0.3	0.4
70	0.2	0.2	0.3	0.4	0.5
80	0.2	0.3	0.4	0.5	0.5
90	0.2	0.3	0.4	0.5	0.6

Fig. 5 (P=6000db.) Velocity of Sound in Sea Water (m/sec)

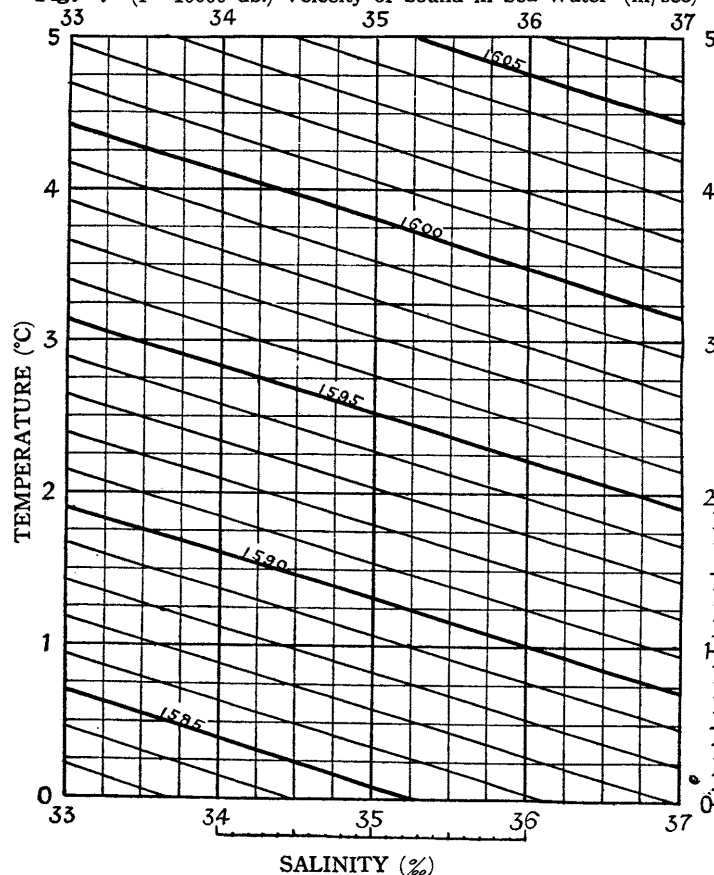


Correction Table

This table applies to the depths of P=5000~7000 db. or m.

depth db or m	for db.			for m.			depth db or m	for db.			for m.		
	0	5	10	0	5	10		0	5	0	5	0	5
5000	-17.3	-17.0	-15.7	-15.5			6100	1.7	1.6	3.9	3.6		
5100	-15.5	-15.3	-13.8	-13.7			6200	3.4	3.3	5.6	5.4		
5200	-13.8	-13.6	-12.1	-12.0			6300	5.0	4.9	7.3	7.1		
5300	-12.1	-11.9	-10.3	-10.2			6400	6.7	6.6	9.0	8.8		
5400	-10.4	-10.2	-8.6	-8.5			6500	8.4	8.2	10.8	10.5		
5500	-8.7	-8.5	-6.8	-6.7			6600	10.1	9.8	12.6	12.1		
5600	-6.9	-6.8	-4.9	-4.9			6700	11.7	11.5	14.2	13.9		
5700	-5.2	-5.1	-3.2	-3.2			6800	13.4	13.1	16.0	15.5		
5800	-3.5	-3.4	-1.4	-1.4			6900	15.1	14.8	17.7	17.3		
5900	-1.7	-1.7	0.4	0.3			7000	16.8	16.4	19.5	19.0		
6000	0	0	2.2	2.0									

Fig. 7 (P=10000 db.) Velocity of Sound in Sea Water (m/sec)



Correction Table:—This table applies to the depths of P=9000~10,000 db. or m.

depth db or m	for db.			for m.		
	0	5	10	0	5	10
9000	-16.2	-15.8	-12.1	-12.0		
9100	-14.5	-14.2	-10.4	-10.4		
9200	-12.9	-12.6	-8.8	-8.7		
9300	-11.3	-11.1	-7.1	-7.1		
9400	-9.7	-9.5	-5.4	-5.4		
9500	-8.1	-7.9	-3.7	-3.7		
9600	-6.5	-6.3	-2.1	-2.1		
9700	-4.8	-4.7	-0.3	-0.4		
9800	-3.2	-3.2	1.4	1.2		
9900	-1.6	-1.6	3.1	2.8		
10000	0	0	4.8	4.5		