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Comments on the Determination of the Pressure Factor, "Q", of Unprotected Reversing Thermometers

By

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Director

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INTRODUCTION

During the last half of 1951, a large number of pressure factor ("Q") determinations were made on some 80 unprotected reversing thermometers of various ranges and manufacture. These included Richter & Wiese, Negretti & Zambra, G. M., Kahl, and Taylor instruments. In the course of some 1,100 individual pressure tests, several features warranting further investigation were noted.

REPRODUCIBILITY

To begin with, the degree of reproducibility obtained during the pressure tests did not seem to be as high as might be expected. The method and controls were examined for flaws which might account for this, and after due deliberation, it appeared that what had seemed to be an excessive maximum spread in the readings was probably about normal, consistent with the method of determination employed, and that individual pressure determinations made under apparently identical conditions might well vary as much as .0005/kg/cm². However, since the final "Q" values were based on the average of five or more tests at a given test pressure, the final results might be expected to be accurate to within ± 1.5 meters of depth for a given pressure level. Quite probably, the most significant error that may affect the value of any one test is the interpolation of scale correction necessarily applied to the thermometer under test to arrive at the "Q". Scale corrections for unprotected thermometers are determined at five degree intervals, and unless the pressure reading happens to fall at or very near one of these calibration points, it is necessary to interpolate the correction, and this interpolation error may be considerable if the actual condition existing in the thermometer is not the straight line or smooth curve used in the interpolation. This same source of error, of course, arises again when the thermometer is read at sea, which tends still further to affect the accuracy of the final thermometric depth determination. It is obviously impractical to make a scale correction test at the exact point at which the mercury column stands for each thermometer under each pressure and temperature condition existing during a given pressure determination test, or to control the temperature of reversal of the pressure tests so that each thermometer reads at or very near one of the standard calibration points at a given test pressure. This being the case, one must be resigned to a certain degree of inaccuracy which may be considered to be inherent and unavoidable. It is generally thought that accuracy of ocean depth measurement to within 5 meters is about as good as can be expected.

THERMAL EFFECT OF PRESSURE

Certain tests were conducted to determine whether the application of pressure had any observable thermal effect on the unprotected thermometers. In these tests, the thermometers were allowed to stand upright in the pressure tank for one hour prior to reversal to ensure that they were in thermal equilibrium with the surrounding water. "Q" values were determined from tests in which the thermometers had been held under pressure at the test level for thirty minutes before reversal and compared with values determined from other tests in which the pressure had been brought abruptly up to the test level and the thermometers reversed at once. No differences in these "Q" values were apparent. The assumption is that the thermal effect of pressure on the glass of the thermometer is insignificant, and the mercury itself is, of course, not brought under pressure at all, since it is free to move upward into the capillary; therefore, no thermal effect of the pressure on the mercury can exist. In all subsequent tests, pressure has been brought up to the test level and the thermometers reversed immediately.

TEMPERATURE EQUILIBRIUM PERIOD

Another series of tests was conducted to discover for how long it was necessary for the thermometers in the pressure vessel to stand upright to ensure that the unprotected thermometers had come into thermal equilibrium with the surrounding water temperature and with the protected control thermometer. This might be called the thermal equilibrium, or waiting period.

The equilibrium period, which originally had been set at one hour, was cut down by stages in a series of tests. Down to about thirty minutes, the results showed no apparent divergence from the known "Q". With a thirty minute equilibrium period, occasional divergent "Q" values were noted. Under thirty minutes, the results were generally erratic and definitely divergent from the known "Q", indicating that not only were the unprotected thermometers not in equilibrium with the water temperature and the control thermometer, but were also frequently not in equilibrium with each other.

Using a forty minute equilibrium period, results were consistently uniform within the usual limits of error and agreed with the known "Q", so this period was fixed as the minimum safe waiting period to guarantee accurate results. Such a long waiting period is necessary because there is no circulation of water within the pressure vessel. If some practical method of stirring the water inside the pressure vessel were available, the equilibrium period could, no doubt, be cut down to fifteen minutes or less.

Tests in the 7-1/2 cubic foot calibration tank with the water being stirred indicate that 10 minutes is an adequate interval to permit an unprotected thermometer to come to equilibrium with the surrounding water after a temperature drop of 17°C. This is comparable to actual conditions existing at sea.

SHIFT OF "Q" AT DIFFERENT PRESSURE LEVELS

It was noted that in more than half of the 80 instruments tested, the "Q" apparently did not maintain the same value at all pressure levels. Analysis of the amount of variation showed that the "Q" for 32 thermometers was the same for all pressures at which they were tested (100 and 200 kg/cm^2, and where applicable, 300 and/or 400 kg/cm^2) and only divergent by .0001/kg/cm^2 for 26 instruments. This is definitely within the probable limits of error, so that at least 58 of the 80 thermometers might be considered to have a pressure factor which was uniform for all depths. Nine thermometers showed a divergence of .0002/kg/cm^2 (four increasing and five decreasing with an increased pressure level), which might well be explained by interpolation error. Four instruments were divergent by .0003/kg/cm^2 and two by .0004/kg/cm^2. Three others, basically unreliable in performance as observed in scale correction tests, showed divergences of .0007/kg/cm^2, and one reliable instrument exhibited a steady drift, with "Q" values of .0793, .0794, .0796, and .0799/kg/cm^2 for pressures of 100, 200, 300, and 400/kg/cm^2 respectively.

One typical instrument, of nominal range -2°C. to 30°C., considered to be average or better in general performance, gave the below-listed results in 85 tests between 11°C. and 2°C. The average "Q" value, figured at various stages during the tests and at the completion of all tests was consistently .1335/kg/cm^2.

Indicated "Q"	.1332	.1333	.1334	.1335	.1336	.1337	.1338
No. of tests at 100/kg/cm^2	1	4	8	11	13	6	3
at 200/kg/cm^2	-	1	9	21	6	1	1
Total	1	5	17	32	19	7	4

Of considerable interest was the performance of one particular instrument which had showed a small, substantially uniform scale correction and good reproducibility during calibration, but had an inordinately large "Q" of .1600/kg/cm^2, about twice the normal amount. This instrument indicated a "Q" of .1594 at 100 kg/cm^2, .1595 at 140 kg/cm^2, .1596 at 160 kg/cm^2, and .1603 at 180 kg/cm^2. It can only be assumed, the reservoir being of substantially normal size, that the extremely large "Q" and the abnormal behavior between 160 and 180 kg/cm^2 was perhaps due to an unusually weak reservoir wall. Some 40 tests were run on this instrument with uniformly consistent results over temperature ranges from .17°C. to 2.31°C. No conclusion can be drawn from this, but it is an interesting example of eccentricity in an otherwise excellent instrument.

A number of pressure tests were run on selected thermometers at 25 and 50 kg/cm^2. The results of these tests were erratic and divergent by .0005 to .0010/kg/cm^2 from the previously established "Q" values. It is difficult to state a definite reason for this behavior, as the glass is presumed to be perfectly elastic, and should react in a uniform manner to external pressure of any amount, but it tends to bear out the experience of observers that the results obtained with unprotected thermometers at relatively shallow depths are frequently inconsistent and unreliable. It is, of course, also true that the method used to calculate the pressure factor tends to multiply any error at pressures less than 100 kg/cm^2.

EFFECT OF TEMPERATURE OF REVERSAL ON "Q"

A further investigation was undertaken with another selected group of unprotected thermometers to determine the effect of the temperature of reversal on the pressure factor. The "Q" of these instruments having been determined at 100 kg/cm^2 in the usual manner by tests at temperatures near 0°C., further tests were run at temperatures in the vicinity of 16.5°C., and a very definite increase of .0005 to .0006/kg/cm^2 in the "Q" value was noted, tending to indicate that the "Q" increased at the rate of about .0001/kg/cm^2 for each 3°C. rise in the temperature of reversal. To check this, additional tests were run between 13°C. and 13.5°C. and also in the vicinity of 10°C., which corroborated the results of the previous tests at 16.5°C. Unfortunately, at this point, the test thermometers were required for use at sea, and ceased to be available for continuation of the tests through the logical stages of 6.5°C. and 3°C. for final confirmation. It is felt, however, that the two stages of these tests which were completed are enough to prove that the temperature of reversal has an effect on the "Q", and that this effect therefore may need to be taken into consideration when making depth corrections.

The assumption is that this change in "Q" is the result of an increase in the elasticity (reduction of rigidity or resistance to deformation) of the glass of the thermometer as a result of the increase in temperature. If so, it can probably be correlated to the nominal size of the "Q" itself, which is essentially dependent on the size, shape, and wall thickness of the reservoir, but not enough has been done as yet to be able to state this as a fact. It is proposed to run tests in the future on a considerable number of unprotected reversing thermometers, determining the nominal "Q" first by tests near 0°C., and then running check tests at some elevated point, say 15°C., and note the correlation between the nominal size of the "Q", and nominal range of the thermometer (which to a considerable extent determines the size of the reservoir), the make of the thermometer, the type of glass used, and the size of the increase of the "Q" in relation to the increase in the temperature of reversal.

From this, one should either be able to formulate a general rule of behavior to cover this increase in "Q" value, or should arrive at the conclusion that no general rule can be applied, and that each instrument should be individually tested at an elevated temperature as well as near 0°C.

In most deep sea work, the temperature of reversal is probably so near the temperature used in the laboratory to determine the "Q" (near 0°C.) that any error would be so small as to be negligible, but in the case of fairly shallow casts in tropical waters and deep casts in the Mediterranean the change may well be large enough to be of significance in correcting depth readings.

CHANGE OF "Q" WITH AGE

One phase of the pressure factor work which has not been gone into as yet is the possible change of the "Q" in relation to the age of the instrument. It is entirely possible that ageing of the glass may effect its elasticity and hence the "Q", but this is an investigation which must necessarily be conducted over an extended period of time, and at present no results from which to draw any conclusions are available.

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