THE SEA SAMPLER[1]

By

ATHELSTAN F. SPILHAUS AND ARTHUR R. MILLER

Woods Hole Oceanographic Institution[2]
Woods Hole, Massachusetts

INTRODUCTION

The original sea sampler, as described by Spilhaus (1940), consisted of six bottles, each built somewhat like a small version of a standard Nansen bottle. These surrounded a cylinder containing a releasing block which was operated by an ordinary bathythermograph pressure element. The tripping block, which was moved by the pressure element, was scored and grooved to accommodate a series of triggers, one for each bottle, which closed the stop-cocks in turn as the whole instrument reached predetermined pressures. The tripping block was arranged so that the triggering points of the different bottles could be varied at will. The instrument was designed for use with the bathythermograph, which was described earlier (Spilhaus, 1938 and 1940), and therefore the next step was to combine the two instruments so that a single pressure assembly operated the tripping block for the sea sampler and carried the slides for the record of the bathythermograph temperature.

Extensive observations with the combined thermographic sea sampler were made during the summer of 1940 and are described by Spilhaus (1941). This series of observations, designed to demonstrate the rapid measuring technique made possible by this instrument, provided 200 soundings, giving 200 temperature-depth curves and 1,400 salinity and oxygen values, all obtained in a continuous period of three and a half days. This represents an average of one sounding (giving temperature against depth, and seven oxygen and salinity values) every twenty-two and one-half minutes, or every two miles at the speed of the vessel utilized, which was 5½ knots. During World War II, and because of its immediate application to the operating problems of underwater sound, considerable refinement of the bathythermograph was made by Dr. Ewing and his associates at the Woods

[1] Contribution No. 440 from the Woods Hole Oceanographic Institution.

[2] The construction and testing was done in the course of work by the Woods Hole Oceanographic Institution under contract with the Office of Naval Research.

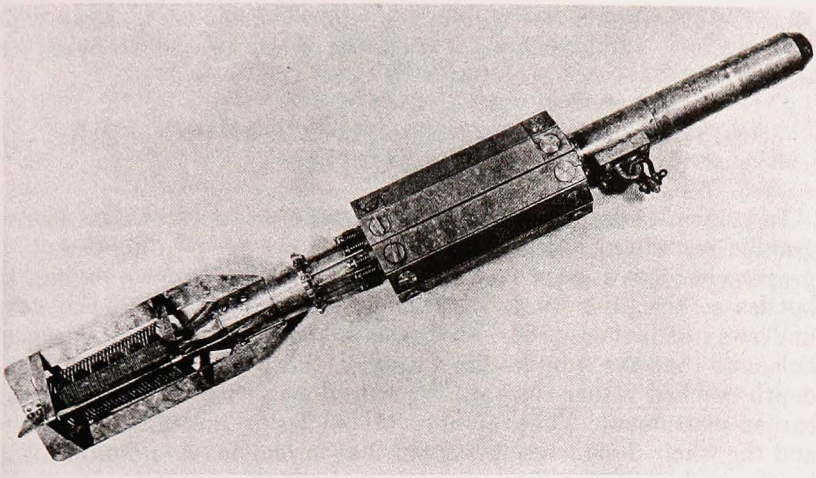

Figure 1. The new thermographic sea sampler.

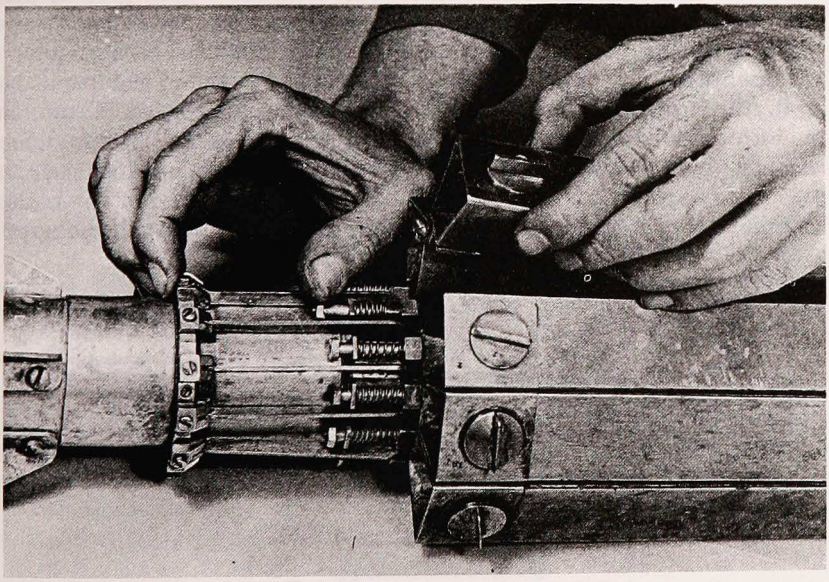

Figure 2. The sampler bottles showing method of removal.

Hole Oceanographic Institution, but improvement of the sea sampler was deferred until last year when the work described below was started.

DESCRIPTION OF THE NEW THERMOGRAPHIC SEA SAMPLER

In principle, the present instrument differs little from the thermographic sea sampler described earlier. However, two important improvements have been made. These are, first, streamlining the bottles so that the whole instrument may be used with the vessel underway at higher speeds, and second, arranging the tripping mechanism so that the samples are taken on the way up from the lowest depth reached rather than on the way down, as was the case in the earlier instrument. The number of bottles is increased to twelve, and the whole design is so arranged that in one or two minutes all the bottles and triggers can be removed without the use of any tools; the instrument is then identical to an ordinary bathythermograph and may be used as such.

STREAMLINING

So that this addition to the bathythermograph would give as little drag as possible, the bottles, twelve in number, were made in a trapezoidal shape and were fitted around the instrument to form a smooth cylinder of not much greater diameter than the width of the fins on the bathythermograph (Figs. 1, 2 and 3). Furthermore, to maintain the smooth exterior of the cylinder, the connecting bar and spring, which are necessary on each bottle to effect the simultaneous closing of the two rotary stop-cocks, were placed on the inside surface of the bottle; that is, on the side of the bottle that faces the bathythermograph

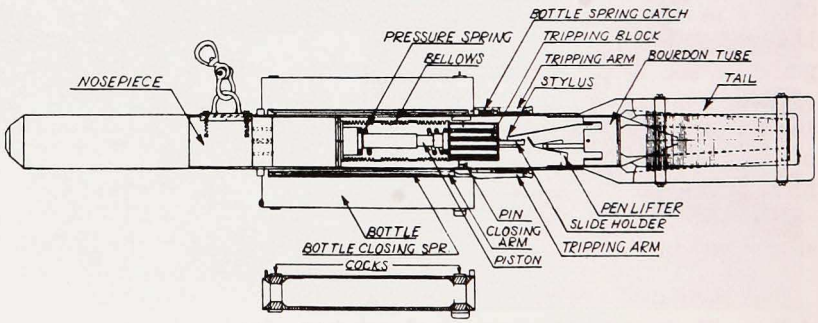

Figure 3. Diagram of Sea Sampler

cylinder. This has the additional advantage that the mechanism is protected from damage. The result of this streamlining as it affects the rate of fall of the combined thermographic sea sampler is well illustrated in Fig. 4, which shows a comparison between the drop of a bathythermograph and that of the sea sampler (with six of the twelve bottles attached). These tests, which show that the sampler dropped as fast as the bathythermograph, were made at a speed of 8½ knots and therefore indicate that the former should be utilizable at as high speeds as the latter. In the tests made, it took longer to bring in the sea sampler than the bathythermograph, but this is merely a matter of the power of the winch.

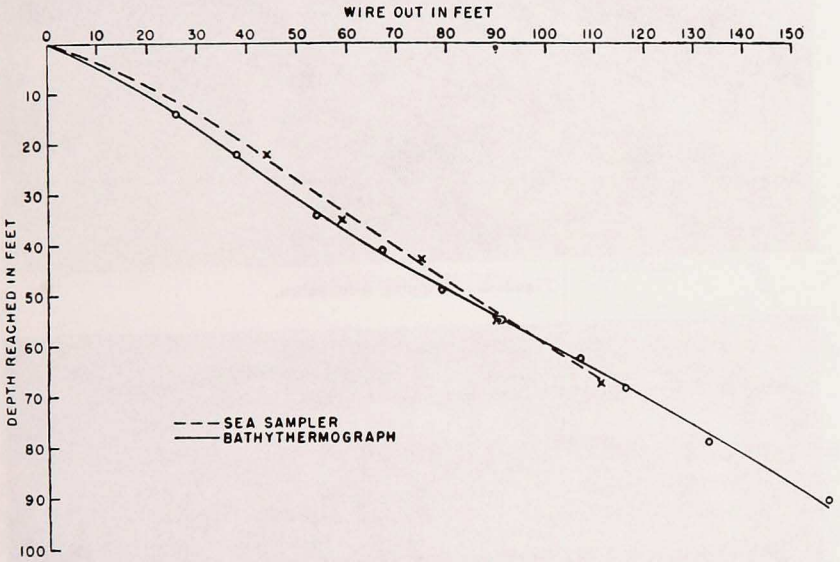

Figure 4. Comparison of the Rate of Drop of Sea Sampler and Bathythermograph with respect to Length of Wire Out while Underway at 8½ Knots

TRIPPING MECHANISM

The tripping mechanism is now designed so that water is trapped as the whole instrument ascends to the sea's surface. Thus the sample is never immersed in denser water, and more thorough washing of the bottle is accomplished. A further alteration is that the adjustment of the depth of tripping is now made by simple exchange of the tripping bars on the exterior of the instrument. In the earlier model these depths could be changed only by replaceable grooves in the tripping

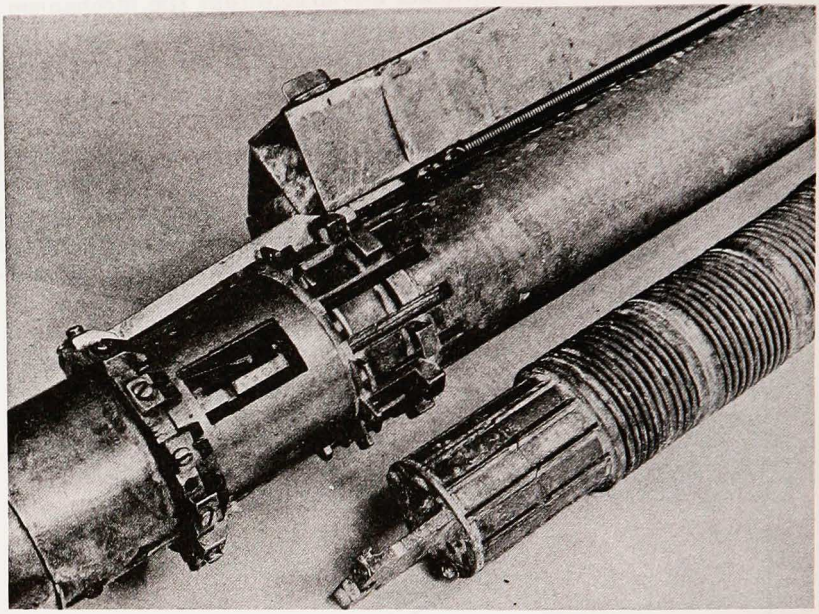

Figure 5. Tripping mechanism.

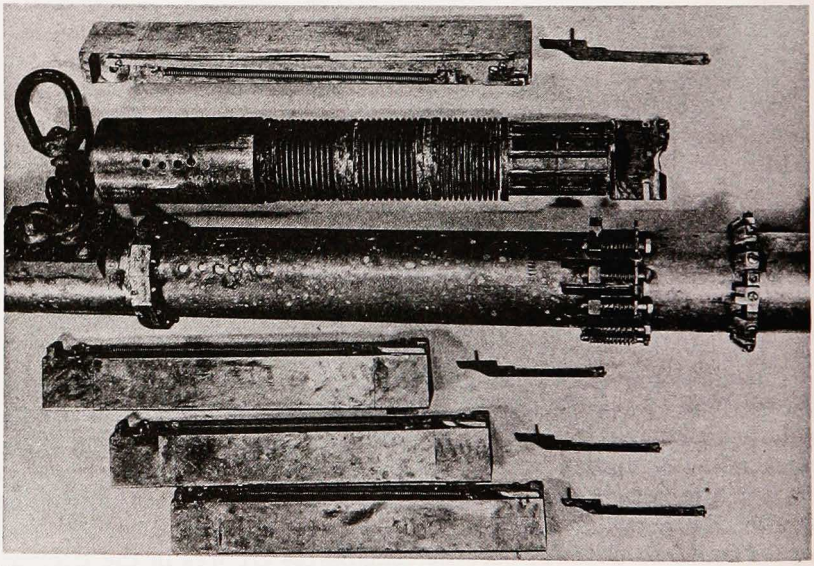

Figure 6. Sea sampler with bottles and triggers removed and a pressure unit carrying the tripping block.

block, which was inconvenient, since the pressure mechanism had to be withdrawn in order to do this. Figs. 5 and 6 and the diagram in Fig. 7 indicate the manner in which the tripping is achieved in the present instrument. Calibration of tripping depth can be carried out either in a pressure tank or by the use of an auxiliary device which withdraws the pressure element and then pushes it back into place,

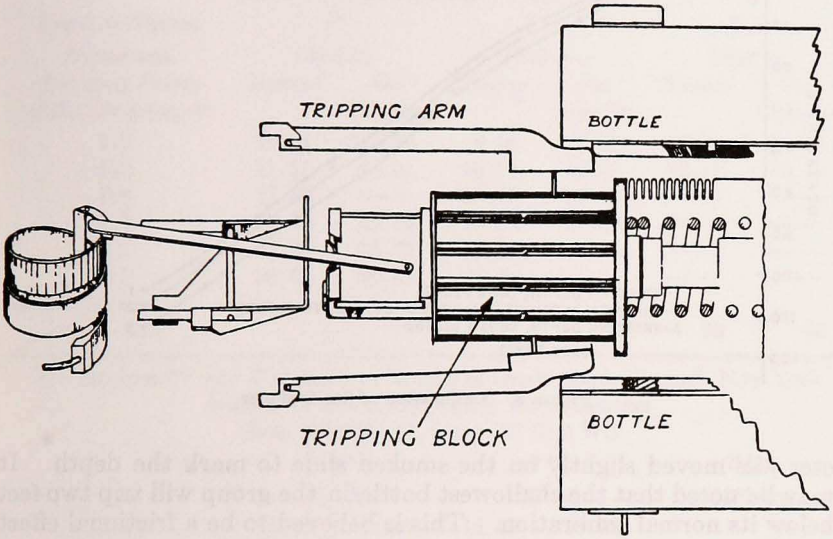

Figure 7. Diagram of Tripping Mechanism

thus simulating on the bench the compression of the sylphon and the spring due to water pressure. Fig. 8 shows calibration curves obtained by both methods. In this case, in order to show up any frictional errors to their maximum extent, a shallow pressure unit (120 feet) was utilized. Owing to the size of the pressure tank available, only three bottles could be used at one time in the tank tests. The method of test was to place the sea sampler in the tank, then build up the pressure until the deepest bottle was in a cocked position. The water pressure was then slowly decreased until a sharp crack, indicating the tripping point of the bottle, was heard. The pressure at this point was noted for each bottle and with each tripping bar. Repeated tests showed excellent consistency, any slight variation being attributable to the accuracy of reading the pressure scale. The bench tests were conducted in a similar manner, but, by withdrawing the pressure assembly and then pushing it back with the device described above. At the point of tripping, the stylus of the thermom-

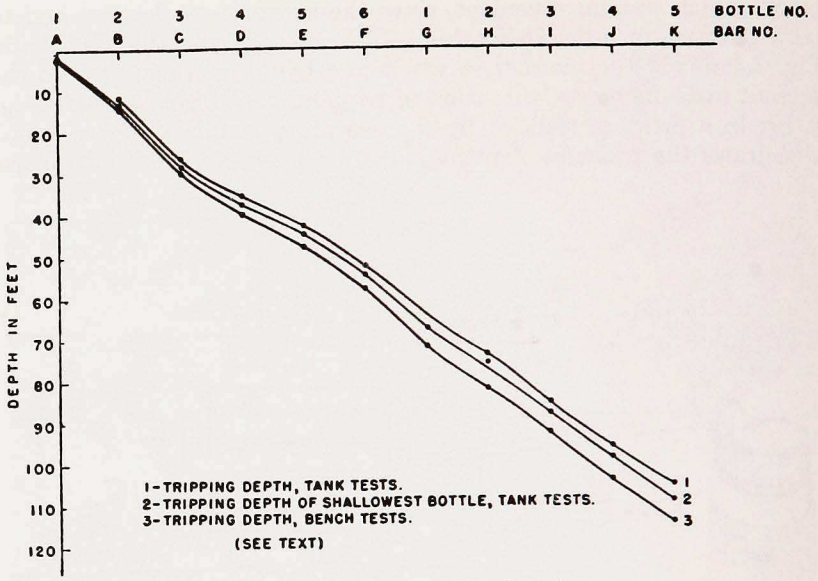

Figure 8. Calibration of Sea Sampler

eter was moved slightly on the smoked slide to mark the depth. It may be noted that the shallowest bottle in the group will trip two feet below its normal calibration. This is believed to be a frictional effect which may be minimized when all twelve bottles are in position around the instrument so that the sideways pressure of the tripping bars is evenly distributed rather than one-sided as in the case of these tests.

TRIALS AT SEA

Some tests of the thermographic sea sampler were made from the research vessel BALANUS in order to compare salinities obtained by it with those obtained by the Nansen bottle technique. The purpose of these tests was twofold: first, to check the over-all performance of the sea sampler under conditions of practical use, and second, to study the effect of throttling, which prevents the complete interchange of water within the sampling bottles due to the constriction of the stop-cocks. The shallow bathythermograph pressure unit was used in order to magnify any frictional effect, and the station was chosen in the Narrows of New York Harbor, where an extreme salinity gradient was found. Under these conditions any errors due to the throttling of the stop-cocks of the sample bottles would be shown up by marked

differences of salinity between the sea sampler and the corresponding Nansen bottle. Test numbers 1, 2 and 3 (Table IA) were made at this

TABLE I. Salinities (‰) Obtained in Tests of the Sea Sampler and Nansen Bottles on Balanus Cruise B-19, March 25, 1948

A. Stations I, II and III at Anchor in Narrows, near Quarantine, New York (Lat. 40° 36.8′ N., Long. 74° 03.4′ W.)

Depth of Nansen Bottles and Tripping Points of Sea Sampler, m.	*I** 0950 hr. Nansen	*I** 0950 hr. Sea Sampler	*II** 1025 hr. Nansen	*II** 1025 hr. Sea Sampler	*III†* 1130 hr. Nansen	*III†* 1130 hr. Sea Sampler
1.2	10.91	12.85	9.56	10.95	10.21	10.86
4.0	11.51	16.51	10.14	14.42	10.72	10.99
7.6	17.38	——	15.12	22.65	——	——
9.8	22.03	23.82	21.37	24.83	——	——
13.7	23.84	25.77	25.95	——	——	——
16.2	25.61	26.47	26.78	——	——	——
Depth (max.) on B. T. (ft.)		77		78	55	68

B. Stations IV and V at Anchor, Middle of Sandy Hook Channel, New York
Station VI Underway, Sandy Hook Channel
(Lat. 40° 28.7′ N., Long. 74° 01.2 W.)

	*IV** 1325 hr.		*V** 1345 hr.		*VI‡* 1410 hr.	
1.2	14.51	14.87	14.63	15.12		——
4.0	15.17	15.81	14.97	15.81	None	14.76
7.6	15.82	16.04	15.86	16.06	Underway	15.91
9.8	16.09	——	15.97	16.11		——
13.7	16.20	——	16.02	17.79		——
16.2	16.94	——	17.07	——		——
Depth (max.) on B. T. (ft.)	55	65	55	67		70

B. T. 6 ft. below lowest Nansen Bottle. Vessel speed 8½ knots.

* Sea Sampler's vertical rate of ascent, 60 ft. in 10 sec.

† Sea Sampler brought up very slowly with stops.

‡ Sea Sampler's vertical rate of ascent, 60 ft. in 35 sec.

Temperature approximately 40° F. and homogeneous.

station in a depth of about 78 feet of water just off Quarantine. The salinities here were very low, ranging from about 9 ‰ at the surface to 27 ‰ at 50 feet. This gradient of salinity provided ideal and stringent conditions for tests on the throttling effect of the bottles. Numbers 1 and 2 were made by lowering Nansen bottles set at exactly the tripping depth of the six bottles used on the sea sampler. The

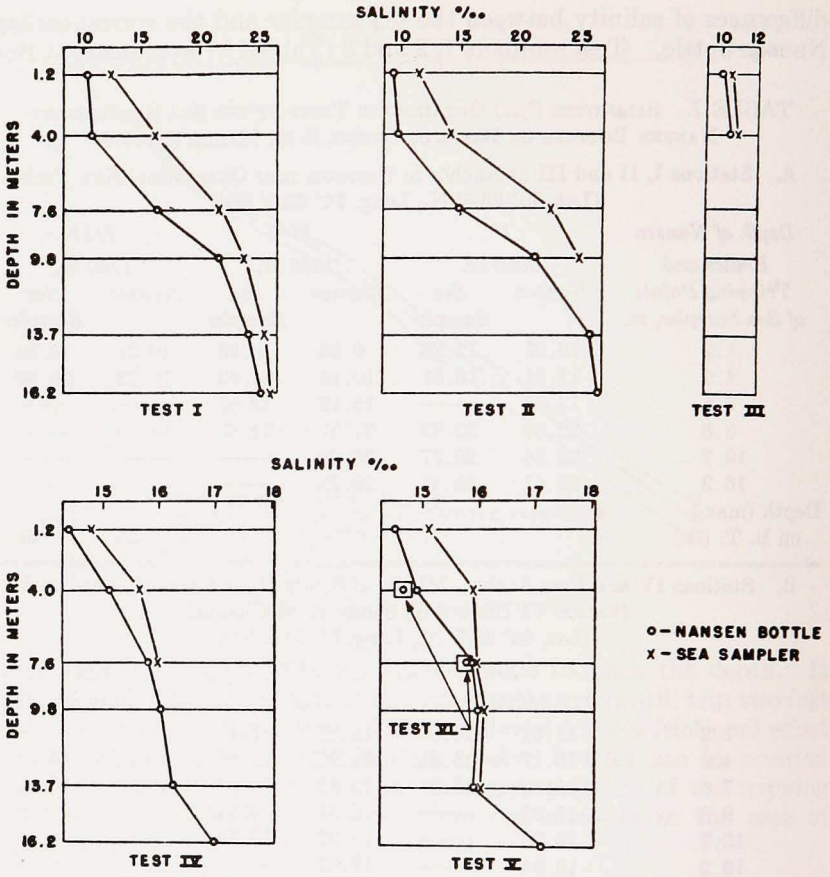

Figure 9. Tests of Sea Sampler Compared with Nansen Bottles

messenger was released to reverse the Nansen bottles at the same time as the sea sampler was withdrawn from the bottom.

In both these tests the sea sampler was brought up at the rate of about 60 feet in 10 seconds. Marked differences between the salinities were observed. These are shown in the curves in Fig. 9. The differences were systematic, however, and in the right sense to indicate that error was due to the throttling lag of the sampler bottles. Therefore, in test number 3 (Fig. 9), the sea sampler was brought up very slowly, with frequent stops to permit the complete interchange of water. It is immediately seen in this test that the differences between the Nansen bottles and the sea sampler are very materially reduced.

A further series, 4, 5, and 6 (Table IB), were made in about 70 feet of water just off Sandy Hook. Here the gradient of salinity was much less, varying from about 14½ °/₀₀ to 17 °/₀₀. Tests 4 and 5 were made with exactly the same procedure as tests 1 and 2. They show the same systematic excess of salinity obtained by the sea sampler over that of the corresponding Nansen bottle (Fig. 9). In this case, the difference is less because the gradient of salinity is less.

Immediately following test 5, the ship was put underway. As the test area was passed over at the speed of 8½ knots, the sea sampler was lowered for test 6. Here, the salinities obtained by the sea sampler were far closer to those of the Nansen bottles. This great reduction of the throttling error when the instrument is used underway is to be expected from two factors. First, in using the instrument underway, far more wire is played out to reach a particular depth; thus, in this case, it took 35 seconds to raise the instrument vertically through 60 feet of water compared to 10 seconds for the same depth at anchor. Second, with the vessel moving forward at the rate of 8½ knots, the relative velocity of the water through the bottles is much greater (even though the vertical speed of the bottle through the water is less than in a lowering made while hove to). These two factors both act to reduce the throttling error. The increased relative velocity of the water causes a greater rate of exchange in the bottle with time. The decreased vertical velocity of the bottle through the gradient causes a decreased rate of change of concentration with time, both factors tending to reduce the error. These effects are discussed quantitatively below.

THE LAG OF A SAMPLER DUE TO THROTTLING

In the pressure-operated sea sampler, a sample is taken by closing a container at a certain point as the whole instrument is moving through an environment with varying concentration of the constituent to be measured. In such a case there will be a certain error in the concentration determined from the entrapped sample due to imperfect exchange of the fluid through the container.

The diagram (Fig. 10) shows the arrangement of the cocks and the arrow shows the motion of the water relative to the sampler at a speed, v_r; then, if p_1 and p_2 are the pressures in front and at the back of the bottle respectively, the volume of water passing through the bottle in unit time is

$$Q = C_q\, a \sqrt{\frac{2(p_1 - p_2)}{\rho}},$$

where C_q is an orifice coefficient for the bottle, a is the area of the stop-

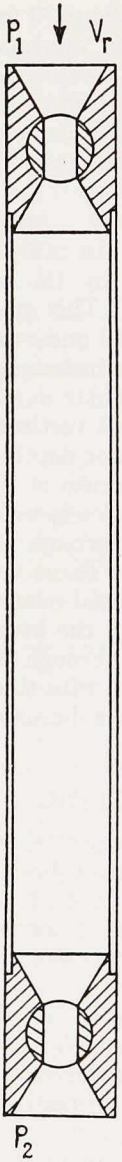

Figure 10. Diagram of Sampler Bottle

cock openings and ρ is the density of water. $p_1 - p_2$ will be proportional to the impact pressure of the water $= K\rho v_r^2/2$, where K is a constant less than unity due to any streamlining effect. Substituting,

$$Q = C_q\sqrt{K}\, a v_r .$$

Putting $C_q\sqrt{K} = k$, a constant for the instrument, the rate of mass flow into the container is

$$\frac{dM}{dt} = \rho k a v_r .$$

Let the concentration of the constituent be $C = M_s/M$, where M_s is the mass of the constituent and M is the mass of water. In an interval of time dt, suppose the sampler moves up a distance $-dz$, where the concentration in the environment has changed from C to $C - dC$. Then, if the concentration in the container was originally C_i, and complete mixing inside is assumed, an amount of water dM with this concentration has flowed out, and has been replaced by a similar amount dM with concentration

$$\frac{C + (C - dC)}{2} = C - \frac{dC}{2} .$$

The concentration in the container, assuming complete mixing[3], is then

$$C_i + dC_i = \frac{(M - dM)C_i + (C - dC/2)\, dM}{M}$$

$$dC_i = -\frac{(C_i - C)}{M} dM ,$$

so that the rate of change of concentration inside is then

$$\frac{dC_i}{dt} = -\frac{(C_i - C)}{M}\frac{dM}{dt} = -(C_i - C)\frac{V_r}{\xi} ,$$

[3] If *no* mixing is assumed, the rate of change of concentration inside is doubled, and hence all errors due to throttling are halved.

where $M = \rho V$ and $ka/V = 1/\xi$, which is a characteristic of the sampler bottle on the instrument.

Suppose, first, that the sampler is being raised through water which has a concentration C_o, constant for a considerable depth (so that the water in the container may be assumed also to be C_o). Further, that upon reaching a certain point, there is a sudden discontinuity of concentration which drops to C and remains constant with further decrease of depth. Integrating the equation for the rate of change of concentration in the container, we obtain

$$\frac{C_i - C}{C_o - C} = e^{-v_r t/\xi} ,$$

if t is counted zero at the discontinuity. ξ/v_r is the lag coefficient of the sampler in units of time, similar to the lag coefficient of a thermometer (see for example Middleton, 1941: 56–58). ξ/v_r represents the time for the difference of concentration in the container C_i, and in the environment C, to reduce itself to $1/\epsilon$ of its original value.

When the concentration varies with depth z, measured positive downwards with a gradient $\alpha = dc/dz$, then, if the whole sampler is moving upward at a rate $v_v = -dz/dt$, the concentration changes at a rate

$$\frac{dc}{dt} = - v_v \alpha .$$

Then

$$C = C_o - V_v \alpha t,$$

where C_o is the concentration at some lower point from which t is counted zero. The rate of change of concentration in the container is then

$$\frac{dC_i}{(C_i - C_o + v_v \alpha t)} = - \frac{v_r}{\xi} dt ,$$

or

$$\frac{dC_i}{dt} = - \frac{V_r}{\xi} \left[C_i - (C_o - v_v \alpha t) \right],$$

and

$$C_i - C = - \xi \alpha \left(\frac{v_v}{v_r} \right) \left(1 - e^{-v_r t/\xi} \right),$$

after $t >> \xi/v_r$

$$C_i - C = - \xi \alpha \left(\frac{v_v}{v_r} \right) = - \frac{V}{ka} \alpha \left(\frac{v_v}{v_r} \right).$$

If the sampler is being used from a vessel at anchor in no current, then $-v_s = v_r$,

and
$$\frac{C_i - C}{\alpha} = \frac{V}{ak} = \xi .$$

If, however, it is being towed at a forward speed, then $-(v_s/v_r) = \cos\beta$, where β is the inclination of the path of the instrument to the vertical, or approximately the wire angle,[4] then

$$\frac{C_i - C}{\alpha} = \xi \cos\beta .$$

In a constant gradient of concentration, the indicated gradient, α_i, will equal the actual gradient α. Thus, the expression shows that if the characteristic ξ of the sampler is known, and if β is known, the indications may be corrected if necessary.

THE LAG COEFFICIENT AND "CHARACTERISTIC LENGTH" OF A SAMPLER

As the lag coefficient ξ/v_r of a sampler depends on the relative speed of the instrument to the water, it is more convenient to discuss lag in terms of ξ, which is a characteristic of the instrument alone. ξ has the dimensions of length. An ideal sample bottle with no obstruction to flow through it would have k = unity. Then $\xi = V/a$, and as the area a would be the area of cross section of the bottle for no obstruction, ξ would represent the actual length of this ideal bottle. In the case of real bottles with stop-cocks, k must always be less than unity, and it is then convenient to define ξ as the "equivalent length" of an ideal bottle. Equivalent length then is the length of a bottle with no throttling, which would have the same lag. If we assume that the tripping depth is at the depth of the top of the bottle, then in a steady gradient of salinity the actual sample in the bottle will always represent the salinity at the bottom of the equivalent ideal bottle. Thus

$$C_i = C + \alpha\xi \cos\beta \text{ (see Fig. 11).}$$

[4] β is only equal to the wire angle δ with the vertical, when the drag of the wire is considered negligible and when the speed of hauling in wire, v_w, is negligible compared to the forward speed of the vessel, v_f. In other cases, β is always larger than δ. If the assumption is made that the sea sampler lines up with the direction of the flow of water relative to it, then if the instrument has a drag equal to b times the square of the relative velocity v_r, and a weight W, it can be shown that $\cos\beta = b/w\, v_w v_f \cos\delta/\tan\delta$.

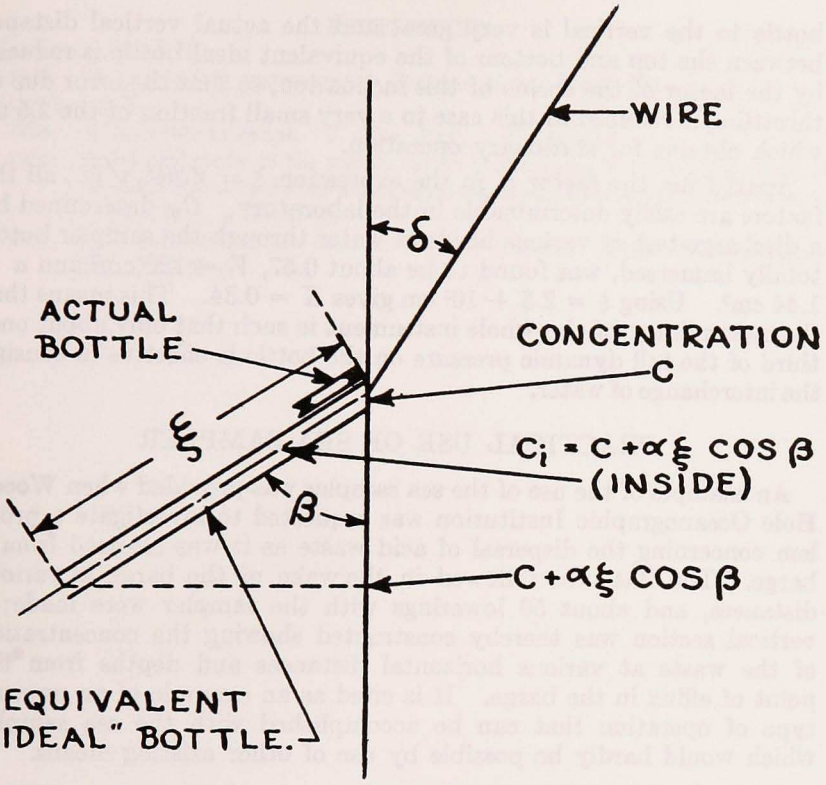

Figure 11. Equivalent Length of the Sampler Bottle in Relation to Lag in a Constant Gradient of Concentration

EXPERIMENTAL DETERMINATION OF THE EQUIVALENT LENGTH OF THE SEA SAMPLER

From tests 1, 2, 4 and 5, which were performed with the vessel stationary, $(C_i - C)/\alpha$ has an average value of about 2.5 m. (Fig. 9).[5] Therefore, 2.5 m. is the equivalent length of the present sea sampler. When used underway at 8½ knots, however, the inclination of the

[5] This value was computed in the following manner:
In tests 1 and 2 (Fig. 9) the gradient α was computed between the depths 9.8 m. and 4 m. where it is fairly constant. The error $(C_i - C)$ was measured at 4 m., assuming that there had been time enough to attain constant lag (5.8 m. $> \xi$). In the case of tests 4 and 5 (Fig. 9), the gradient between 7.6 m. and 1.2 m. and the error, at 1.2 m., were utilized. The value of the equivalent length from tests 4 and 5 agrees fairly well with that for tests 1 and 2, which were in different water.

bottle to the vertical is very great and the actual vertical distance between the top and bottom of the equivalent ideal bottle is reduced by the factor of the cosine of this inclination, so that the error due to throttling is reduced in this case to a very small fraction of the 2.5 m. which obtains for stationary operation.

Apart from the factor K in the expression $\xi = V/aC_q\sqrt{K}$, all the factors are easily determinable in the laboratory. C_q, determined by a discharge test at various heads of water through the sampler bottle totally immersed, was found to be about 0.57, $V = 120$ cm^2 and $a = 1.44$ cm^2. Using $\xi = 2.5 + 10^2$ cm gives $K = 0.34$. This means that the streamlining of the whole instrument is such that only about one-third of the full dynamic pressure on the bottle is effective in causing the interchange of water.

PRACTICAL USE OF SEA SAMPLER

An example of the use of the sea sampler was provided when Woods Hole Oceanographic Institution was requested to investigate a problem concerning the dispersal of acid waste as it was released from a barge. The BALANUS followed in the wake of the barge at various distances, and about 50 lowerings with the sampler were made; a vertical section was thereby constructed showing the concentration of the waste at various horizontal distances and depths from the point of efflux in the barge. It is cited as an example of an unusual type of operation that can be accomplished with the sea sampler which would hardly be possible by use of other existing means.

SUMMARY

An improved model of the thermographic sea sampler (a sea sampler combined with a conventional bathythermograph) is described. It consists of twelve sample bottles attached to a standard bathythermograph and arranged to trip at various pressures (depths) which can be chosen at will. Comparisons of samples taken in this manner with those obtained by the use of Nansen bottles are shown and a theory for the lag of a sampling device of this kind is given. Theory and observation indicate that the errors of the sea sampler are small when used underway. The theory further permits correction of observations for lag when necessary in terms of a single "characteristic length" of the instrument and the angle of inclination of its path through the water.

REFERENCES

MIDDLETON, W. E. K.
1941. Meteorological instruments. Toronto Univ. Press. 213 pp.

SPILHAUS, A. F.
1938. A bathythermograph. J. Mar. Res., *1* (2): 95–100.
1940. A detailed study of the surface layers of the ocean in the neighborhood of the Gulf Stream with the aid of rapid measuring hydrographic instruments. J. Mar. Res., *3* (1): 51–75.
1941. Fine structure of the edge of the Gulf Stream. Trans. Amer. geophys. Un., *22:* 478–484.