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A TIDAL-POWERED WATER SAMPLER

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A Tidal-Powered Water Sampler[1]

A tidal-powered compositing water sampler has been designed to operate over a wide range of tides. It can sample water over long periods without attention and can be constructed from inexpensive hardware components and 2 check valves. The working principle of the sampler is to use the reduction of pressure by the falling tide and the stored pressure from the previous high tide to pump water into a collection bottle. The sampler is capable of producing a constant volume of water per tidal cycle over a tide range of 2 to 4 m.

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Water samplers designed for collecting composited samples in remote locations have depended on an external source of power such as compressed gas or electrical energy. Care and attention have been necessary to prevent corrosion of components and battery discharge in these samplers. A compositing water sampler has been developed at Savannah River Laboratory which is powered by the tides and constructed from inexpensive components. Yet it samples for long periods without attention. This sampler is intended for use where the parameters to be measured are conservative, the water samples do not require special treatment, such as cooling, and composited samples are needed. The water sample is collected during the rising tide and deposited during the falling tide.

The working principle of this sampler is to use the reduction of pressure by the falling tide and the stored pressure from the previous high tide to pump water into a sample chamber and ultimately to a collection bottle (Figure 1).

Even though the working principle is fairly straightforward, it was found that seven variables affect the volume of water pumped: the tide ranges (ZHI and ZLO); the diameters of the suction tube (DS), booster tube (BT), delivery tube (DB); the heights of the booster tube (ZBTOP) and the sample chamber (ZSAMP); and the volume of the sample chamber (SOLD).

The description of the operation of the sampler (Figure 1) will begin with the sampler installed at the low tide. As the tide rises, the suction tube fills with water up to the high water mark, exhausting air through the sample chamber and hence through the collection bottle. At the same time, the sample check valve opens admitting water into the delivery tube and exhausting the air from the delivery tube through the collection bottle. The air space in the booster tube is pressurized by a rise in the booster tube liquid level.

As the water recedes, the check valves close and the pressure in the sample chamber decreases because of a drop in the water level. The pressure differential between the booster tube and the lower pressure in the sample chamber then forces the water up the delivery tube and into the sample chamber. The water fills the sample chamber up to the height of the excess sample return tube in the sample chamber, and then the overflow drains back into the ocean. As the tide comes back in, the next sample enters through the sample check valve and as the pressure in the sample chamber increases, the top check valve opens and the sample remaining drains into the collection bottle. In this manner, a standard size sample is taken at each tidal cycle and the volume of the sample can be varied by changing the height of the excess sample return tube in the sample chamber.

It would be difficult to evaluate all of the variables involved in the design of this sample experimentally, so equations were developed to describe the operation and a design for the sampler. The sampler was optimized for size, sample, volume, a tide range of 1.83 to 3.35 m, and use of standard size hardware and PCV pipe components. The purpose was to design a sample chamber that would deliver from 15 to 60 cc to the collection bottle per tidal cycle, yet maximize the water passing through the sample chamber to ensure a good sample. The 15 to 60 cc range would be determined by the height of the sample return tube.

The maximum tide height is the most critical parameter, because it determines the height of the sample chamber and collection bottle. A typical tide range for Savannah, Georgia, is 1.83 to 3.3 m. Since the high tide is less than 12 ft (3.6 m), the sample chamber should be located about 12 ft (3.6 m) above low water to prevent access of sea water into it. The design equations for the sample indicate the system is only capable of pumping to a height equal to twice the tide height range. Hence, the sampler will not pump water for tides less than 1.83 m. In the Savannah, Georgia, area, only 2% of the tides are less than 1.83 m, so little sample biasing is expected for time-integrated water samples.

Design equations were used to determine the dimensions of the suction, booster, and delivery tubes (Figure 1). Delivery tubes that are small in diameter are more subject to pluggage, and large diameter tubes decrease the volume of water pumped. The suction tube was long enough so that the bottom was always under water at low tide. From the design analysis, a unit diameter increase in the booster tube would pump about twice as much water as the same increase in the suction tube diameter. The effect of varying the diameter of the suction and booster tube on the amount of water pumped is shown in Figure 2. A sample chamber of 310 m was used because of construction convenience.

Prediction of the quantity of water taken by a tidal sampler of given dimensions can be made from principles of fluid mechanics. The representation of the sampler for calculation is shown in Figure 3.

The following idealizations underlie the analysis:

(1) Air temperature is constant over the tidal cycle

(2) Apparatus is sheltered from wave action

(3) Capillarity and other surface tension effects within the apparatus are negligible.

Table 1 lists the equations governing the system.

Although these equations may be solved directly algebraically, a trial and error approach was found to be less tedious and more amenable to programming a calculator or computer.

These equations ensure that a planned sampler will work. The relative diameters of the tubes, the sample space volume, and the tide range are all interrelated, and all affect the volume sampled per cycle. The design equation predicted the pressures, water heights, and water volumes in a small sampler about 1 m long to within measurement accuracy.

The design equations simulated a sampler that did not have an excess water supply return tube. This was necessary in order to estimate the amount of water to be pumped by varying the parameters that control water volume. The design equations were verified by making up a small sampler about 1 m long and measuring water volume, water heights, and pressure in the small sampler. The design equations predicted the experimental measurements.

Following construction, the sampler was tested in the Savannah River estuary in an area protected from large waves. The sampler was hung from a piling and weighted on the bottom with 23 kg of lead. The lead was necessary to prevent excessive swaying of the sampler due to fast tidal currents (up to 2 knots) in the estuary. The sampler could have been rigidly attached, but it was easier to hang it. The sampler was left in for 22 days or 56 tidal cycles, and the tide range during this period was from 1.8 to 3 m. Nine hundred and eighty cubic centimeters of water were collected during the 56 tidal cycles (an average of 21 cc per tidal cycle). This is within the limit of 24 cc set by the sample chamber. A slight reduction in volume might occur if the currents caused excessive sway of the sampler.

The design of this tidal-powered sampler could be used in other areas with similar tides or could be scaled up or down for other locations depending on the locale. Since the water sample is collected during the rising tide and deposited in the sample bottle during the falling tide, some sampling bias may occur. This sample bias would occur in areas where the constituent concentration has a phase lead or lag with the tide.

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Table 1

Fluid Mechanics Equations for System (Figure 3)

Initial Conditions (1st high tide)	Subsequent low tides
1) $(P_B V_B)_{\text{Low Tide}} = (P_B V_B)_{\text{High Tide}}$	1) $P_S = P_{ATM} - W\,(Z_{SL} - Z_{LOW})$
2) $\frac{P_{atm}}{W}(Z_{BTOP} - Z_{Low})\,A_B = [\frac{P_{atm}}{W} + (Z_{High} - Z_{BTOP}) + Y] \cdot Y$	2) $P_S = P_B - W\,(Z_{SAMP} - Z_{BL})$
3) $Z_{BH} = Z_{BTOP} - Y$	3) Δ Volume of B $= [(Z_{BTOP} - Z_{BL}) - Y]\,A_B - (Z_{SAMP} - Z_{HIGH})\,A_T + \text{Sample}$
4) $P_B = P_{Atm} + (Z_{High} - Z_{BH}) \cdot W$	4) $(P_B V_B)_{HIGH} = (P_B V_B)_{LOW}$
	or $(P_B)_{LOW} = \frac{(P_B)_{HIGH} \cdot Y\,A_B}{(Z_{BTOP} - A_{BL})\,A_B}$
	5) $(P_S V_S)_{HIGH} = (P_S V_S)_{LOW}$
	or $(P_S)_{LOW} = \frac{(P_S V_S)_{HIGH}}{(V_S)_{HIGH} + (Z_{HIGH} - Z_{SL})A_S - (Z_{TL} - Z_{HIGH})A_Y - \text{Sample}}$
Symbols are shown in Figure 3.	

TABLE 1. Fluid Mechanics Equations for System (Figure 3)

FIGURE 1. Tidal-powered water sampler. Design variables that affect the volume of water sampled are indicated with an asterisk.

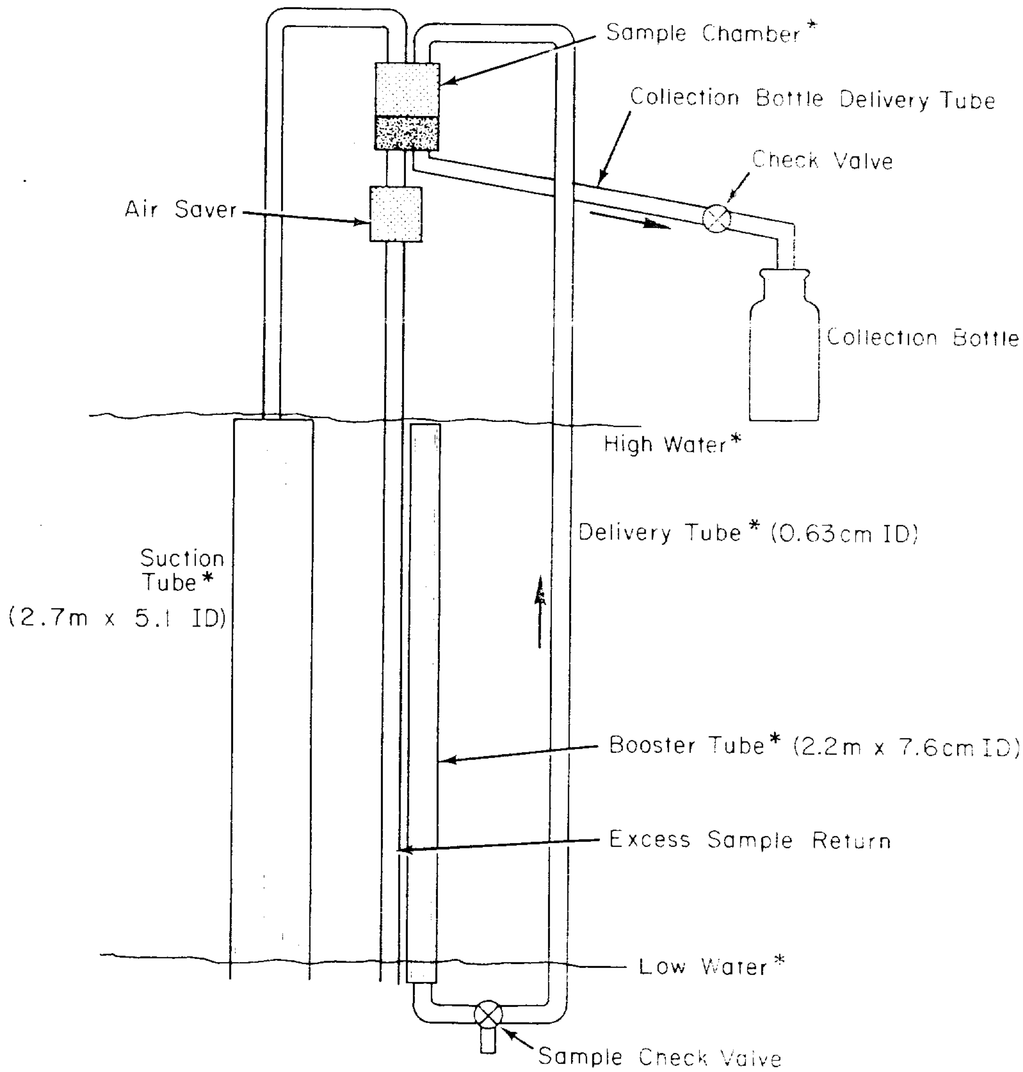
FIGURE 2. The effect of varying the diameter of the booster or suction tube on the amount of water pumped. Sample chamber volume - 310 ml; height of chamber above low water - 3.6 m; tide range - 2.2 m; delivery tube diameter - 0.63 cm.

FIGURE 3a. Variables for fluid mechanics equations (Table 1)

FIGURE 3b. Initial conditions and variables: First high tide after installation

FIGURE 3c. Conditions and variables at low tide after sample is collected

FIGURE 3. Model for Tidal Sampler Analysis



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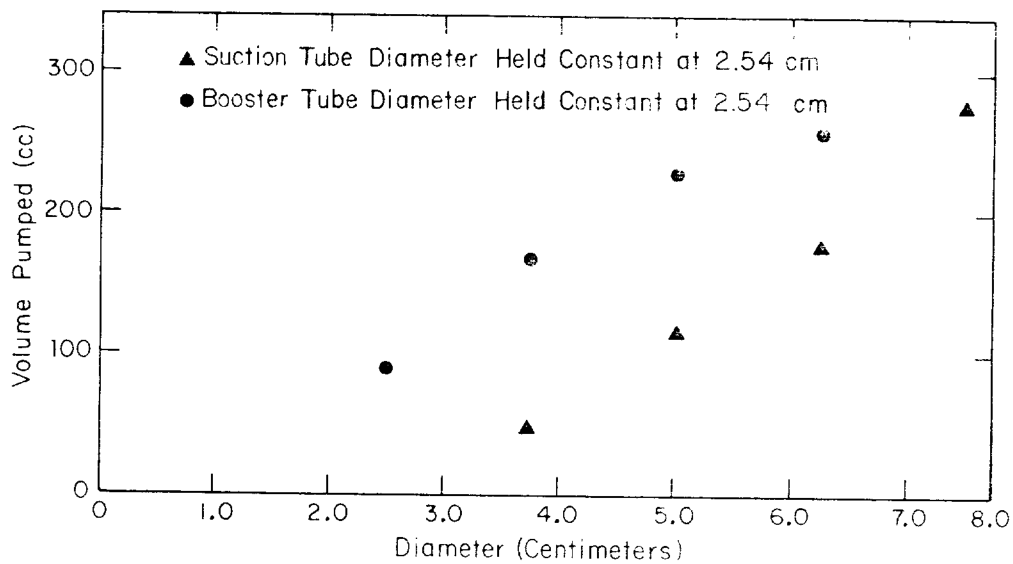

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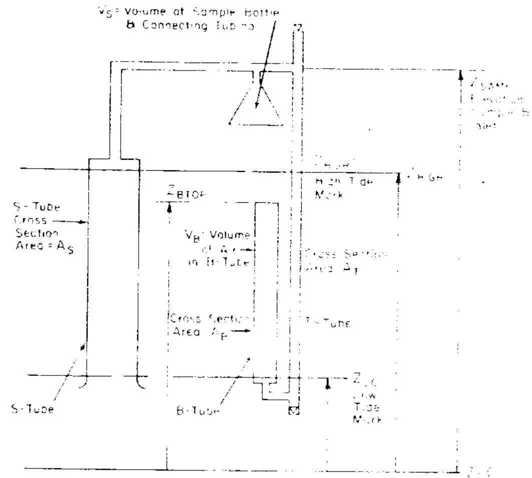
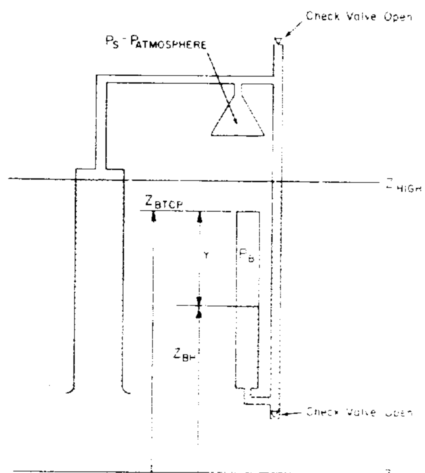
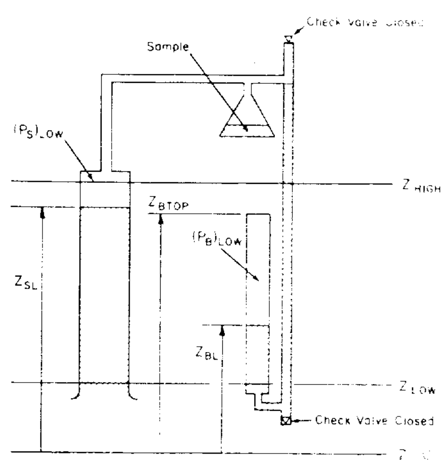


VS = Volume of Sample Bottle & Connecting Tubing
S-Tube Cross Section Area = AS
ZBTOP
VB = Volume of Air in B-Tube
Cross Section Area AB
High Tide Mark
Cross Section Area AT
T-Tube
Low Tide Mark
S-Tube
B-Tube



Check Valve Open
PS = PATMOSPHERE
Z HIGH
ZBTOP
Y
PB
ZBH
Check Valve Open



Check Valve Closed
Sample
(PS)LOW
Z HIGH
ZBTOP
(PB)LOW
ZSL
ZBL
Z LOW
Check Valve Closed