

1 **Deriving Useful Power from the Osmotic Potential Between**  
2 **Solutions**

3  
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7

8 **Abstract**

9 A device was constructed to enhance mariculture by moving  
10 nutrient-rich deep water to the surface. This is done by  
11 injecting fresh water at the bottom of a long vertical tube,  
12 allowing the fresh water to mix with salt water and having the  
13 brackish mixture rise because of buoyancy. While testing  
14 prototypes, it was discovered that the mixture flowed through the  
15 device much faster than that which could be accounted for by  
16 buoyancy or the transfer of kinetic energy. It is presumed that  
17 the additional energy comes from the same force that causes  
18 osmosis and diffusion. A flow of one cubic meter per second of  
19 fresh water into sea water can theoretically generate 3,000  
20 kilowatts.

21  
22 **Introduction**

23 Osmosis is so venerable that it appears in texts from first  
24 year biology <sup>1</sup> to graduate level physical chemistry <sup>2</sup>. It is

1 defined as the flow of water through a selectively permeable  
2 membrane when there is a difference in concentration between the  
3 two sides. It is a colligative property. It is not dependant on  
4 the nature of the solute, only on the total molar concentration  
5 of all dissolved species. The water flow across the membrane is  
6 always from a lower concentration of solute to a higher one. Pure  
7 water is defined as having an osmotic potential of zero and all  
8 solutions have varying degrees of negative osmotic potential.  
9 Many references discuss osmotic potential in terms of pressure  
10 across the osmotic membrane since the easiest way to measure the  
11 effect is to apply pressure to the side of the membrane with  
12 lower osmotic potential until the net flow is canceled.

13 The original intent of our experiments was to characterize  
14 the behavior of a patented device <sup>3</sup> that enhances mariculture  
15 (farming of the sea for food and other resources). <sup>4</sup> The device  
16 consists of a pair of tubes. A large "UpTube" that carries deep  
17 ocean water to the surface and a much smaller "DownTube" that  
18 connects a source of fresh water to the bottom of the UpTube. The  
19 idea is to pump fresh water through the DownTube, encourage it to  
20 mix with as much ocean water as possible, and have the resulting  
21 brine travel to the surface because of its increased buoyancy.

22 We calculated the amount of power available to pump the  
23 brine by adding the kinetic energy of the fresh water as it  
24 exited the DownTube to the buoyancy of the fresh water. To

1 calculate the efficiency of the energy transfer from fresh water  
2 to salt water, we monitored the salinity of the brine exiting the  
3 UpTube. In all of our experiments there was more brine flowing  
4 from the UpTube than our theoretical maximum. Firmly believing in  
5 the conservation of energy, we went looking for the source of  
6 this power. It turns out that the device is directing how a fluid  
7 with high osmotic potential is flowing into a fluid with low  
8 osmotic potential. In the process it allows one to capture useful  
9 work.

10 If this force can be captured with significant efficiency,  
11 then it will be possible for electrical power to be generated  
12 anywhere a river flows to the sea. If large power plants are  
13 commercially viable, this is a pollution-free source of energy  
14 that will disrupt the environment far less than the fossil fuel  
15 plants it will replace. There should also be lots of fish.

## 16 **Experimental Design**

17 The experimental apparatus was tested in a large body of  
18 salt water. 1800 Kg (2 tons) of sea salt <sup>5</sup> was dissolved into a  
19 50,000 liter (15,000 gallon) tank (in-ground swimming pool). This  
20 resulted in a salinity of approximately 35 parts per thousand  
21 (ppt). <sup>6</sup> Throughout the experiments the salinity was measured  
22 with a Myron L, DS Meter (model 512T5).

23 The experimental apparatus (see Figure 1) consisted of a  
24 pair of vertical tubes, one inside the other. The larger, outer

1 tube was called the "UpTube". In these experiments, it had an  
2 inner diameter (ID) of 15 cm (6 inch, schedule 40 PVC) and was  
3 1.5 meters long. The smaller inner tube was called the "DownTube"  
4 and had an ID of 1.8 cm ( $\frac{1}{2}$  inch, schedule 125 PVC) and was 1  
5 meter long. The end of the DownTube was fastened with two 90°  
6 elbows and a short length of pipe such that the fresh water exits  
7 upwards. This apparatus was suspended from a float 15 cm below  
8 the surface of the salt water tank with nylon cable ties.

9 The DownTube was connected to a graduated reservoir by means  
10 of a flexible rubber hose with the same ID. The reservoir was  
11 kept at a constant level by filling to overflowing with fresh  
12 (tap) water. Experiments were initiated by opening a valve at the  
13 bottom of the reservoir.

14 There were three independent variables: salinity of the  
15 fresh water, salinity of the salt water, and height of the  
16 reservoir. The dependent variables were: flow of fresh water  
17 through the DownTube and salinity of the water coming out the  
18 UpTube.

19 The salinity meter had two ranges (0 - 5000 ppm and 0 - 50  
20 ppt) and was accurate to  $\pm 50$  ppm on the low range and  $\pm 0.5$  ppt  
21 on the high range. The fresh water measured a consistent 300 ppm  
22 of dissolved solids, the salt water varied between 34 and 36 ppt  
23 depending on the evaporation from the tank.

1           Height of the reservoir was measured from the water surface  
2 in the reservoir to the surface of the salt water and was  
3 measured with a tape measure and is accurate to 2.5 cm. Flow was  
4 measured by timing how long it took for the reservoir to lose ~30  
5 liters (two gallons) of water. Accuracy was  $\pm 1$  second, which  
6 translated into a flow accuracy of  $\pm 3\%$  in the range of our  
7 experiment.

8           Experiments were started by filling the DownTube with water  
9 to eliminate air bubbles, adjusting the height of the reservoir,  
10 and filling the reservoir with water. When the stopcock at the  
11 base of the reservoir was opened, fresh water flowed into the  
12 UpTube.

13           Salinity measurements of the salt water and the fresh water  
14 were taken before and after a day of experiments. Salinity at the  
15 top of the UpTube was measured either by manually transferring it  
16 into the salinity meter with a large bulb pipette or, in later  
17 experiments, with a sampling pump.

18           The temperature of both types of water was the same in any  
19 individual experiment (18 to 20 °C) since the salt water tank was  
20 set in the ground and the fresh water came directly out of buried  
21 pipes. There was no temperature difference between the brine  
22 exiting the UpTube and the salt water tank. There were five  
23 experiments during a month and a half period.

1           As the experiments progressed, it distressed us that the  
2 effect was only apparent after taking inconvenient measurements  
3 and performing much math. We wanted a device that would, all by  
4 itself, demonstrate the increase in kinetic energy. To that end  
5 we designed the apparatus shown in Figure 3.

6           The Demonstration Device is a piece of 6" PVC pipe with a 6"  
7 turbine roof vent attached to one end. The vent is held in place  
8 with caulk and duct tape. The bottom is fitted with a 6" PVC  
9 coupling that has been drilled to allow the insertion of a ½" PVC  
10 'U' which is securely glued in place. The entire apparatus is  
11 suspended from a float (in this case, a couple of one gallon  
12 thermos bottles) with nylon cable ties.

13           The 'U' is connected to a ¾" garden hose with a hose clamp.  
14 The other end of the hose is similarly attached to a reservoir  
15 with a valve (beverage dispenser or carboy). One of the vanes of  
16 the vent was painted to allow for the counting of rotations.

17           This device is placed in a body of salt water and the  
18 reservoir is continuously filled to overflowing. It is important  
19 that all of the air be eliminated from the DownTube. The  
20 experiment consists of two operations. First, opening the  
21 reservoir valve and timing the revolutions of the turbine.  
22 Second, removing whatever is keeping the reservoir full and  
23 timing how long it takes for the reservoir to empty. We ran the

1 experiment with salt water in the reservoir and then tested again  
2 with fresh water (see Table 3).

3 The attorneys have requested that it be pointed out that  
4 there are patents pending on adapting this device (as well as  
5 others) for the generation of power. It is presented here for  
6 non-commercial purposes to further the scientific study of this  
7 phenomenon, not to place it in the public domain.

### 8 **Analysis**

9 Our original assumption was that a certain amount of power  
10 would be needed to overcome buoyant forces as the fresh water  
11 traveled from Point 1 to Point 3. Any additional power, in the  
12 form of kinetic energy, would be available to move some salt  
13 water towards the surface. The complete transfer of kinetic  
14 energy from the fresh water to the salt water would result in a  
15 flow of salt water at Point 4 equal to the flow at Point 3  
16 divided by the density of the salt water. Therefore, at 100%  
17 efficiency, the flow at Point 2 would contain all of the fresh  
18 water plus a somewhat lesser quantity of salt water. We assumed  
19 that the maximum salinity expected at Point 2 would be dependant  
20 only on the salinity of the salt water and its density. Table 1  
21 shows the expected maximum salinity as well as the observed  
22 salinity along with the equations based on this assumption.

23 The observed salinity was far higher than we expected. This  
24 implies that far more salt water was being accelerated up through

1 the UpTube than could be explained by buoyancy and transfer of  
2 kinetic energy.

3 Table 2 quantifies the flows and kinetic power output for  
4 the points indicated on Figure 1. Since there was a continuous  
5 tube from Point 1 to Point 3, their salinity and flow are  
6 identical. Since the only inlets to the UpTube are from Point 3  
7 and Point 4, the flow at Point 2 equals the sum of the flows from  
8 Point 3 and Point 4.

9 The equation for the flow at Point 4 is derived from:

10 If:

11  $Q_i = \text{Flow at point } i$

12  $= W_T / \rho \text{ per second}$

13  $S_i = \text{Salinity at point } i$

14  $= (W_S / W_T)$

15  $W_S = \text{Weight of Salt in a Solution}$

16  $W_T = \text{Total Weight of Solution}$

17 Then:

18  $S_2 = W_{S2} / W_{T2}$

19 And since the flow past Point 2 comes from either Point 3 or  
20 Point 4:

21  $S_2 = (W_{S3} + W_{S4}) / (W_{T3} + W_{T4})$

22 Substituting in:

23  $W_S = S W_T$

24 Results in:

1 
$$S_2 = (S_3 W_{T3} + S_4 W_{T4}) / (W_{T3} + W_{T4})$$

2 Substituting in:

3 
$$W_T = Q \rho \text{ seconds}$$

4 Results in:

5 
$$S_2 = (S_3 Q_3 \rho_3 + S_4 Q_4 \rho_4) / (Q_3 \rho_3 + Q_4 \rho_4)$$

6 Which gives an equation that has one unknown variable ( $Q_4$ ).

7 
$$Q_4 = Q_3 (\rho_3 / \rho_4) (S_2 - S_3) / (S_4 - S_2)$$

8 It can be assumed, within the accuracy of this experiment, that:

9 
$$S_3 = 0$$

10 and

11 
$$\rho_3 = \rho_4$$

12 Which leaves:

13 
$$Q_4 = Q_3 S_2 / (S_4 - S_2)$$

14 The power values are derived from:

15 If:

16 
$$A = \text{Cross Sectional Area}$$

17 
$$= \pi d / 4$$

18 
$$d = \text{Tube Diameter}$$

19 
$$M_q = \text{Mass Flow}$$

20 
$$= Q \times \rho$$

21 
$$\rho = 1 + (S_i / 1000)$$

22 
$$v = \text{Velocity}$$

23 
$$= Q / A$$

24 Then:

$$\begin{aligned}
1 \quad P_k &= \text{Power from Kinetic Energy} \\
2 \quad &= \frac{1}{2} M_q v^2 \\
3 \quad &= \frac{1}{2} (\rho Q) (16Q^2 / \pi^2 d^4) \\
4 \quad &= 8Q^3 \rho / \pi^2 d^4
\end{aligned}$$

5 Table 2 shows that the flow of brine at Point 2 cannot be  
6 explained by the transfer of kinetic energy between the fresh  
7 water at Point 3 and the salt water at Point 4.

### 8 **Discussion**

9 What had started as a series of engineering experiments in  
10 fluid flow had turned into a physical chemistry examination of  
11 the possibility of capturing the force behind osmosis. In the  
12 course of our experiments we referred to this force as  
13 hydrocratic potential energy, or hydrocratic forces.

14 Consider a hypothetical experiment where a 34 cubic meter  
15 container of salt water is supported just under the surface of a  
16 large body of fresh water. There is an osmotic membrane between  
17 the two types of water and attached to the vessel of salt water,  
18 extending up, out of the fresh water, is a tall tube with a  
19 volume of exactly one cubic meter (see Figure 2). At the start of  
20 the experiment the water level in both containers is identical.  
21 The fresh water will flow into the container of salt water  
22 through the membrane and raise the level in the tall tube.  
23 Clearly the hydrocratic force is doing work on the water in the  
24 tube through the mechanism of osmosis. What are the dimensions of

1 the tube if the weight of one cubic meter of water in the tall  
2 tube exactly cancels the osmotic pressure? (This is analogous to  
3 the 34:1 dilution seen in our device.) How much work has been  
4 done?

5 For small concentrations of an ideal solution, van't Hoff's  
6 formula for osmotic pressure ( $\Pi$ ) is:

$$7 \quad \Pi = -CRT$$

8 Where;

$$9 \quad C = \text{Molar Concentration}$$

$$10 \quad R = \text{Gas Constant}$$

$$11 \quad T = \text{Absolute temperature}$$

12 In this thought experiment there are two ions per molecule and:

$$13 \quad w_{\text{NaCl}} = 58.5 \text{ g}$$

$$14 \quad T = 20^\circ \text{ C}$$

$$15 \quad = 293^\circ \text{ K}$$

$$16 \quad R = 8.3144 \text{ J / mole } ^\circ\text{K}$$

$$17 \quad C = 34 \text{ ppt}$$

$$18 \quad = 34,000 \text{ g / m}^3$$

$$19 \quad = (34,000 \times 2 / 58.5 \text{ moles}) / \text{m}^3$$

$$20 \quad = 1200 \text{ moles / m}^3$$

$$21 \quad \Pi = -(1200 \text{ moles/m}^3) (8.3144 \text{ J/mole } ^\circ\text{K}) (293^\circ \text{ K})$$

$$22 \quad = -2.9 \times 10^6 \text{ J / m}^3$$

$$23 \quad = -2.9 \times 10^6 \text{ Pa}$$

$$24 \quad = -29 \text{ atm}$$

1 Pascal's Law says:

$$2 \quad p = \rho gh$$

3 Setting  $p$  (pressure due to the height of a column of liquid)  
4 equal to  $\Pi$  (the osmotic pressure) and solving for the height of  
5 the column ( $h$ ) gives:

$$6 \quad \rho = 1034 \text{ Kg/m}^3$$

$$7 \quad g = 9.8 \text{ m/s}^2$$

$$8 \quad h = (2.9 \times 10^6 \text{ J / m}^3) / (1034 \text{ Kg/m}^3) (9.8 \text{ m/s}^2) \\ 9 \quad = 290 \text{ m}$$

10 The work done to move the water to this height is:

$$11 \quad W = \frac{1}{2} Mgh$$

$$12 \quad = (0.5) (1034 \text{ Kg}) (9.8 \text{ m/s}^2) (290 \text{ m})$$

$$13 \quad = 1.5 \times 10^6 \text{ Joules}$$

14 This states that one cubic meter of fresh water, when mixed  
15 with 34 cubic meters of sea water in this manner could  
16 theoretically produce  $1.5 \times 10^6$  Joules of energy.

17 Let's take the above example and solve for the work done as  
18 a function of initial concentration and initial volume. In this  
19 case:

$$20 \quad C_0 = \text{Initial Concentration}$$

$$21 \quad V_0 = \text{Initial Volume}$$

22 Setting  $\Pi = p$  results in:

$$23 \quad \rho gh = CRT$$

$$24 \quad h = CRT/\rho g$$

1 Substituting this into the equation for work:

$$2 \quad W = \frac{1}{2} (Mg) (CRT/\rho g)$$

3 Fixing the volume of the tall tube at 1 cubic meter, means that:

$$4 \quad C = C_0 V_0 / V_0 + 1$$

$$5 \quad M = \rho \text{ cubic meters}$$

6 Substituting these into the work equation:

$$7 \quad W = \frac{1}{2} (\rho g) (RT/\rho g) (C_0 V_0 / V_0 + 1)$$

$$8 \quad = \frac{1}{2} RTC_0 (V_0 / V_0 + 1)$$

9

10 While the tall tube thought experiment is analogous to the  
11 experimental system, it is not a perfect analogy. The  
12 experimental apparatus continuously generates water at the  
13 ultimate dilution. Therefore work (W) should be changed to power  
14 (P), volume (V) to flow (Q), and the constant ( $\frac{1}{2}$ ) to unity (1):

$$15 \quad P = RTC_0 (Q / Q + 1)$$

16

17 It is important to remember that

18 1) Q refers to the flow of solution not the flow of pure  
19 water.

20 2) This equation is true only when the flows are normalized  
21 to a fresh water flow of one cubic meter per second.

22 3) The units are off because of the substitution of density  
23 for mass.

24 A more general form is:

1 
$$P = RTC_4 (Q_4 / Q_4 + Q_3 ) m^3$$

2 This states that the potential power available from flowing  
3 a cubic meter of pure water into a solution is equal to the gas  
4 constant times the absolute temperature times the molar  
5 concentration of the solution times the solution's dilution ratio  
6 expressed as a fraction. One cubic meter of fresh water, when  
7 continuously mixed with 34 cubic meters of sea water, could  
8 theoretically produce  $3.0 \times 10^6$  watts of power.

9 While the demonstration device is less definitive than our  
10 primary experiment, it provides good proof that something  
11 interesting is happening. Since the DownTube flows are  
12 essentially equal, there is no difference in the input energy,  
13 however the turbine spins much faster when fresh water is used.

14 How is the experimental system capturing this energy? On a  
15 macroscopic level there is an osmotic pressure difference between  
16 the inside and the outside of the UpTube. Since the fresh water  
17 is already flowing in one direction (up) the salt water diffuses  
18 into the flow at two points: at the bottom of the UpTube and well  
19 away from the top of the UpTube. While the diffusion goes to  
20 completion, it is separated spatially and one can capture the net  
21 flow through the UpTube to do work.

22 The experimental apparatus in this paper generates 0.98  
23 watts with a fresh water flow of  $2.4 \times 10^{-4}$  cubic meters. This is  
24 equivalent to 4 kilowatts per cubic meter of fresh water per

1 second, about 0.15% efficient. Unpublished experiments indicate  
2 that larger devices and smaller salinity differences raise the  
3 efficiency.

4 How would a power generating facility based on this effect  
5 compare with other methods? If it is assumed that 30% of the  
6 flow from the Columbia River<sup>7</sup> could be funneled through such an  
7 underwater device at 100% efficiency, it would generate 6,300  
8 megawatts. For comparison's sake, the current hydroelectric  
9 facility of the Grand Coulee Dam on the Columbia River generates  
10 6,800 megawatts<sup>8</sup>. If the flow from the Weber River<sup>9</sup> into the  
11 Great Salt Lake<sup>10</sup> could be funneled through such a device, it  
12 would generate 400 megawatts.

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**Table 1 - Expected vs. Observed Flow at Top of UpTube**

Height of Reservoir (meters)	Flow of Fresh Water ( $10^{-4}$ m <sup>3</sup> /sec)	Salinity of Brine at Top of UpTube (ppt)	
		Expected	Observed
0.23	1.3	17	34
0.55	2.4	17	34

Salinity of Salt Water (ppt) ..... 35  
 Salinity of Fresh Water (ppt) ..... 0.3  
 Density of Salt Water (Kg/l) ..... 1.035  
 Expected Maximum Salinity .....  $S_4 / (1+\rho_4)$

**Table 2 - Flow and Kinetic Energy**

Height of Reservoir (meters)	Salinity at Point 2 (ppt)	Flow ( $10^{-4}$ m <sup>3</sup> /sec)				Kinetic Power (watts)			
		Point 1	Point 2	Point 3	Point 4	Point 1	Point 2	Point 3	Point 4
0.23	34	1.3	45.5	1.3	44.2	0	0.16	0.02	0.14
0.55	34	2.4	84.0	2.4	81.6	0	0.98	0.11	0.90

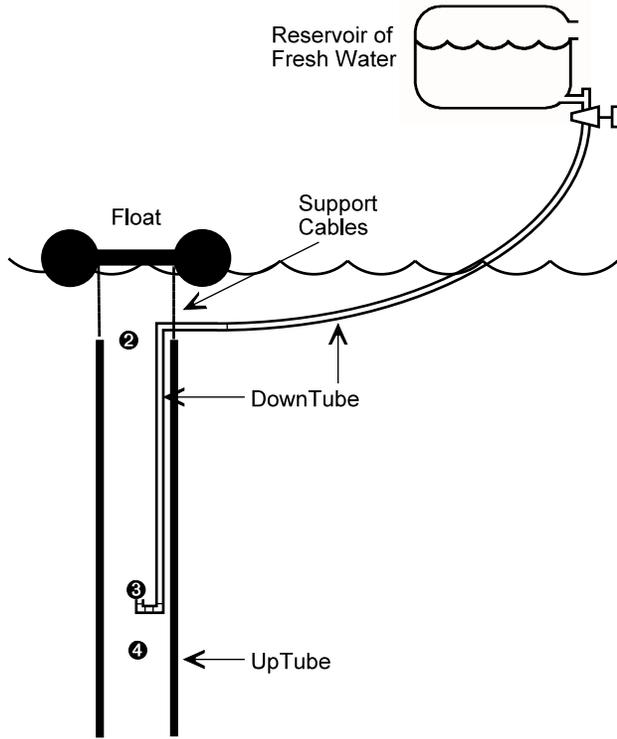
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**Table 3 - Demonstration Device**

	DownTube Flow ( $10^{-4}$ m <sup>3</sup> /sec)	Turbine Speed (rpm)
Fresh Water (0.3 ppt)	2.4	5.6
Salt Water (36 ppt)	2.3	2.3

Reservoir Height (meters) ..... 0.55  
 Flow ( $10^{-4}$  m<sup>3</sup>/sec) ..... 2.4

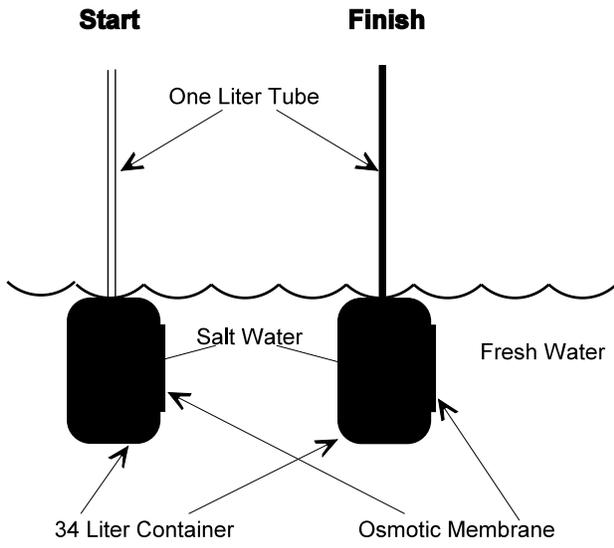
Figure 1. - Cross Section of Apparatus



- ① Fresh Water Reservoir
- ② Top of Uptube
- ③ Exit of DownTube
- ④ UpTube Below DownTube

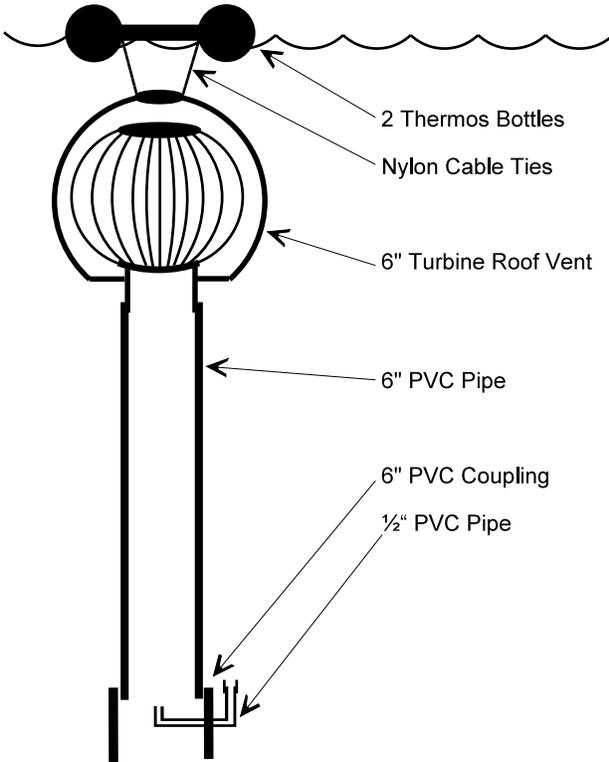
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**Figure 2 - Thought Experiment Showing Work Performed by Osmosis**



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**Figure 3 - Demonstration Device**



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1. Campbell, N. A.; Mitchell, L. G.; Reece, J. B. *Biology: Concepts & Connections*, 2<sup>nd</sup> ed.; Benjamin/Cummings, Menlo Park, 1997; Chapter 5, Sections 14 - 15.
  2. Atkins, P. *Physical Chemistry*, 6<sup>th</sup> ed.; W. H. Freeman: New York, 1998; pp. 180-181.
  3. U. S. Patent #4,189,379, Warren T. Finley
  4. Castro, P.; Huber, M. E. *Marine Biology*, 2nd ed.; WCB McGraw Hill, San Francisco, 1997; p 372.
  5. Solar Evaporated Sea Salt, manufactured by Western Salt, San Diego.
  6. Gross, M. G.; Gross, E. *Oceanography, A View of the Earth*, 7<sup>th</sup> ed.; Simon & Schuster, Upper Saddle River, 1996; Chapter 4.
  7. Columbia River,  
<http://hano.tricity.wsu.edu/~pkeller/tc/geography/Columbia.html>
  8. Grand Coulee Dam, Washington,  
<http://www.usbr.gov/cdams/dams/grandcoulee.html> .
  9. Water Atlas of Utah - Water Resources,  
<http://www.engineering.usu.edu/uwrl/atlas/ch4/> .
  10. Salinity and Water Quality of Great Salt Lake,  
<http://wwdutslc.wr.usgs.gov/salinity/salinity.html> .