Check valves for entirely passive solar water heating systems.

Excerpts from a book by W.A. Shurcliff.

Excerpted by David M. Delaney

Check valves, or one-way valves, permit flow in one direction only. In certain solar water heating systems, a check valve prevents a reverse (cooling) flow through the solar water heater when the heater is cold.

A check valve for an entirely passive solar water heating system must be very sensitive. In an entirely passive solar water heating system, water can move through the solar water heater only by natural convection – a movement produced only by the small difference of gravitational force acting on the density difference between warmer and cooler parts of the water.

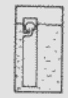
Descriptions of two suitable check valves are presented below. They are from New Inventions in Low Cost Solar Heating, 100 Daring Schemes Tried and Untried, William A. Shurcliff, 1979, Brick House Publishing Company, Andover, Mass., ISBN: 0-931790-02-6.

The first excerpt, pp. 62-65 of Shurcliff's book, describes Shawn Buckley's thermic diode, which uses Buckley's fluidic check valve (U.S. patent 4,245,617, patent date: 1981). Buckley's very sensitive check valve uses an auxiliary fluid, for example, oil, that differs slightly from water in density. (See also Chapter 23, The Thermic Diode, from Shawn Buckley's book Sun Up to Sun Down, 1979, McGraw-Hill, ISBN 0-07-008790-3, pp. 133-137, and the patent.)

The second excerpt, pp. 66-69 of Shurcliff's book, describes Shurcliff's proposal for a novel floating check valve that requires no auxiliary fluid, but is less sensitive than Buckley's check valve.

The first excerpt starts on the next page. This document can be read more easily in the Adobe Acrobat Reader if the Fit Visible option of the Zoom control is activated.

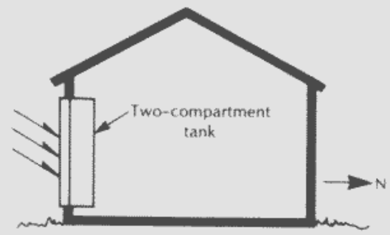
THE BUCKLEY TWO-COMPARTMENT, THERMOSIPHON, NON-REVERSING, SOLAR-ENERGY-ABSORBING-AND-STORING, WATER-FILLED TANK



INTRODUCTION

Shortly before 1974 Shawn Buckley of Massachusetts Institute of Technology invented a special kind of tank designed to be incorporated in the south wall of a house (see the accompanying figure) and to absorb solar radiation on sunny days, store the absorbed energy, release the energy to the house-interior during the night, and *not* lose energy to the outdoors at night.

Such a tank has two compartments, called S and N, comprising the south and north parts of the tank. Both contain water. Compartment S, which receives the solar radiation and becomes especially hot, is thin; it contains only a small amount of water. Glazing may be applied to its south face. Compartment N is much thicker—10 or 20 times thicker—and contains a very large quantity of water. Between the two compartments there is a vertical insulating partition, or septum. There are openings through the septum at top and bottom which permit flow of liquid from one compartment to the other. Associated with the upper opening there is a special valve, employing oil, that greatly improves performance, as explained in a later paragraph. Appropriate faces of the assembly are thermally insulated.



Buckley tank installed in south wall of house. Vertical cross section, looking west.

HOW THE VALVE WORKS

To facilitate the account of how the system operates and to make it clear why the special valve is so helpful, we consider first a simple device, shown in Fig. 2, that has no special valve and is incapable of performing properly. The only liquid used is water. The tank has been filled just full enough so that, ordinarily, the septum projects about ½ inch above the level of the water; thus no water can flow over the top.

When the sun comes out and heats the water in compartment S, the level of the surface of the water here tends to rise—see Fig. 3—because water, when heated, expands, i.e., becomes less dense (more buoyant). But it does not rise enough to permit flow of water over the top of the septum. Thus no solar energy received by compartment S can be transferred to compartment N.

If the compartments had initially been filled to a higher level, flow over the top of the septum might have occurred on a sunny day; but unfortunately a reverse flow might have occurred under some circumstances and much heat might have been lost to the outdoors.

Now we consider a tank that has a check valve that employs oil (mineral oil, e.g.) and we show how this valve facilitates circulation

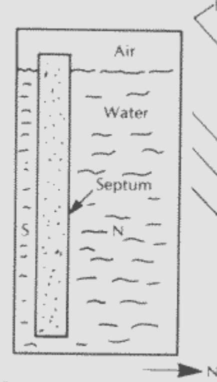


Fig. 2. System that has no valve. Nighttime

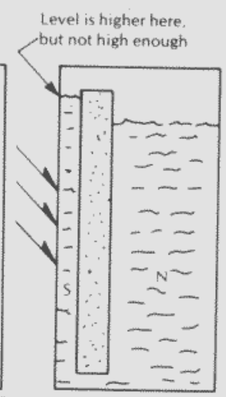


Fig. 3. System that has no valve. Sunny day

of hot water from S to N and yet prevents reverse flow on cold nights or cold overcast days. We consider an over-simplified design of valve, shown in Fig. 4. The oil, which does not mix with water, is assumed to have a density 0.9 times that of water; thus the oil permanently floats on the water. The oil layer is, say, 2 inches deep, and extends well above the top of the septum.

The interesting fact is that if the water in compartment S is heated to high enough temperature that, in the absence of any oil, the surface would rise by 0.2 inches, when the oil is present the surface tends to rise by about ten times this amount, i.e., about 2 inches. But this is more than ample to allow the water to pass over the top of the septum into compartment N. See Fig. 5. In summary, the overlying layer of oil acts as a height-change amplifier, or more exactly an amplifier of change in level of the surface of the water. The closer the density of the oil is to the density of water, the greater the amplification. In practice, the amplification is great enough so that flow of water, and transfer of heat, from S to N commences as soon as S is 1 or 2 F degrees hotter than N. The more intense the solar radiation and the greater the temperature difference between compartments S and N, the faster the flow.

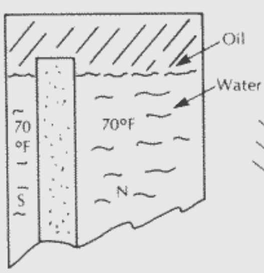


Fig. 4 System equipped with oil-type valve. System is in equilibrium.

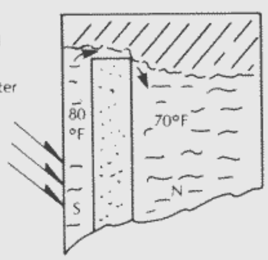


Fig. 5. Sun is shining, water flows from S to N over the top of the septum.

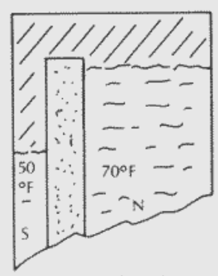


Fig. 6. Cold night. No reverse flow occurs.

WHAT HAPPENS ON A COLD NIGHT?

On a cold night compartment S, being very close to the outdoors, cools off rapidly. Does one expect, then, that water will flow (over the top of the septum) from N to S?

No. The valve (that is, the combination of the oil and the top of the septum) prevents this. It prevents it because of a crucial asymmetry: a crucial inequality of areas. In compartment N the water-vs.-oil interface area is very large while in compartment S the interface area is very small. Accordingly, even if the level of the water in S were to fall 1 inch, the rise in level of the water in N would be only a small fraction of an inch—not enough to permit water to flow over the top of the septum.

Notice that the oil continues to act as a height-change amplifier, and it amplifies height changes in both compartments. But because the interface area of N is much greater than that of S, the height change in N is negligible even after amplification. (Ten times practically nothing is still practically nothing.) Thus no water flows over the top of the septum from N to S.

In summary, it is very easy for a large water-height-change to occur is S but a large change cannot occur in N. Thus when the sun shines water can flow over the top of the septum from S to N, but on a cold night the reverse flow cannot occur. The oil valve does its job excellently—it permits one-way flow only, and even this flow does not occur except when it is advantageous, i.e., when S is hotter than N.

Buckley calls the system a *thermal diode* because it performs analogously to the common kind of electronic diode tube, which permits only one-way flow of electrons. The name seems to me not fully suitable since (a) some diodes do not have this property, (b) some triodes, pentodes, etc. *do* have the property, and (c) a diode is a kind of valve, but Buckley's device is mainly a storage system—the valve representing only about 1% of the volume and 1% of the cost.

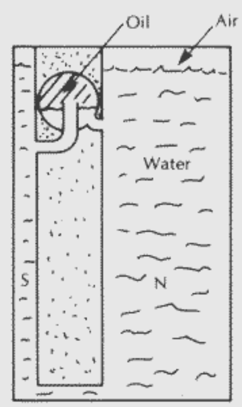


Fig. 7. Small oil valve with central vertical tube. Drawing not to scale.

SMALL SIZE OF VALVE

In practice, the oil valve is small. Instead of occupying the entire top of the tank, it consists of a small chamber (which retains the key feature of having two areas that are of very different size). And the water, instead of flowing into the chamber via one of its sides (which would mean that the valve would perform poorly if the assembly were slightly tilted), flows in centrally via a central vertical tube. Also, the valve is situated somewhat lower down, so that it will perform properly even if the tank has been slightly underfilled. Fig. 7 indicates, schematically, the location and design of a small valve with central tube.

ACTUAL DIMENSIONS

In practice the tank may be 8 ft. high, 4 ft. wide, and about 10 in. thick overall. Compartment S is extremely thin, to minimize warm-up time and minimize the amount of energy lost from it at the end of a sunny day. Usually the south face is glazed (and, in summer, the space between glazing and compartment S may be vented to make sure that the water in S will never get so hot that it boils.) The tank faces that are not intended to receive or distribute energy are well insulated. Distribution of heat may be facilitated by incorporation of air-ducts within or immediately adjacent to compartment N. The overall weight of the panel, filled, is about 600 lb.

Is Antifreeze Needed?

In some types of Buckley tank, compliant (deformable) elements are incorporated in the north wall of compartment S, with the consequence that freezing of the water in this compartment does no damage. Of course, antifreeze could be used if appropriate precautions were taken.

Compartment N requires no special precautions. It is almost inconceivable that the water in this large indoor compartment would freeze.

Application to Heating a House

If a great many of the Buckley tanks were incorporated in the south wall of a building, or if a quantity of (modified) devices were incorporated in the south-sloping roof of the building, a large fraction of the winter's heat need might be supplied by the sun.

The system could easily be modified to provide heat for domestic hot water.

Status of Project

Late in 1978 efforts to arrange for commercial production of the Buckley device were continuing.

A Final Question

One might ask this question: Inasmuch as the tank includes two compartments and each must be insulated from the other, why not use *two separate tanks?* One of them (the thin one) could be mounted on the vertical south wall of the house and the other (the thick one could be mounted somewhat higher up, close to the ceiling, or just above the ceiling. Then, because the larger tank is higher up, no valve at all would be needed. Gravity convection, via connecting pipes, would do the entire control job automatically. Also, less prime space would be taken up and leakage of heat from the big compartment to the small one would be entirely avoided. Admittedly, there are impressive advantages in having the two tanks teamed together as one integral unit; but there are impressive advantages the other way also; if two separate tanks are used, installation and maintenance may in some situations be easier and there is much greater freedom of choice as to where to place the larger portion of the equipment.

A big variation would be to place the larger tank in the basement and employ a small pump to circulate water from the smaller tank (on vertical south wall or on the sloping south roof) to the basement tank. But this is a conventional active, water-type solar heating system!

Thus the question is: Why, or in what situations, does one wish to combine the thin absorbing collector and the thick storage system into a single assembly?

References

The Buckley solar-energy-absorbing-and-storing device is described in *Solar Energy Digest*, Jan. 1977, in *Solar Energy 20*, 495 (1978), in *Solar Age*, p. 22 (April 1978), in *Proceedings of the 2nd National Passive Solar Conference*, Vol. 2, pp. 271 and 469 (1978), and in many special reports.

TWO-COMPARTMENT, THERMOSIPHON, SOLAR-ENERGY-ABSORBING-AND-STORING, WATER-FILLED TANK WITH FLOATING OUTLET THAT PREVENTS REVERSE FLOW

Scheme S-48
9/28/74

INTRODUCTION

The scheme proposed here is much like Buckley's scheme and performs approximately similarly. However, a very different kind of valve is used—a floating valve that is simple and performs well in a great many respects. No oil is used. The proposed system is less sensitive than Buckley's, but may be superior in some ways.

PROPOSED SCHEME

Figure 1 shows a simple embodiment of the proposed scheme. The main component is a rectangular, 4-ft.-high tank of galvanized iron. It is placed so as to form part of the south wall of a house. The south face of the tank is black on the outside; on sunny days it absorbs much solar radiation. The north face of the tank is either bare or insulated: bare when the occupants want the tank to deliver heat to the rooms, and covered with a 2-in.-thick insulating plate at other times. The other four faces are permanently insulated.

The tank is about 95% filled with water, and a vertical, 2-in.-thick insulating septum divides the tank interior into two compartments (south, S; north, N) the thicknesses of which are in the ratio of 1-to-30. The septum is sealed to the tank sides and top so that no water can pass through it except via a horizontal slot at the bottom and via a ½-in.-dia. hole about 40 in. above the bottom. At the top of the septum there is a notch, or "saw-cut", to allow air-pressure equalization in the tops of the two compartments.

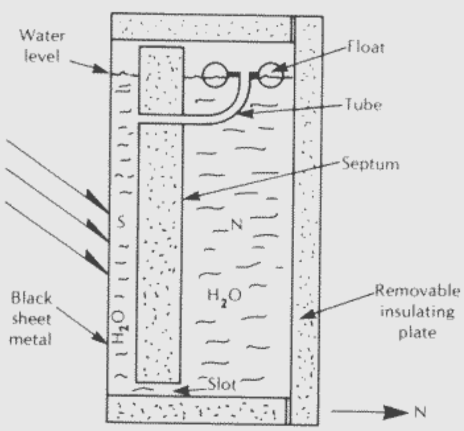


Fig. 1. Vertical cross section (not to scale)

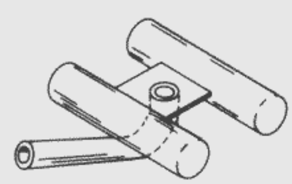


Fig. 2. Float and tube, perspective view.

There is a float on the water in Compartment N. It supports the north end of a flexible, ½-in.-dia. tube and holds this (open) end 0.01 in. above the level of the waterline of the float. The S end of the tube engages the hole in the septum. See Fig. 2.

The tank top is separate; it can be lifted off; it is not hermetically sealed.

OPERATION

If the tempertures T_S and T_N of the south and north compartments are the same, the water densities here are the same, and accordingly the water levels are the same. Nothing tends to make the liquid level in the north end of the tube higher than the float waterline, and no liquid emerges from this end of the tube. In summary, there is no circulation of liquid. See Fig. 3.

If the weather is cold and overcast, the temperature of the south compartment slowly decreases, the density here increases (height of water column decreases), but the total mass of water in this compartment remains constant. Thus, there is no tendency for any flow to occur through the slot or through the tube. In summary, there is no circulation of liquid. See Fig. 4.

If intense sunlight strikes the south face of the tank, the water in the south compartment heats up and expands (the density decreases). And because the mass of water here remains unchanged (initially), the height of the water column increases, the pressure within the tube increases, the liquid in the north end of the tube tends to rise—and after it has risen more than 0.01 in. it begins to overflow into the north compartment as a whole. Thus water is transferred from S to N. Whereupon, water at the bottom of the tank begins to flow, via the slot, in the opposite direction: from N to S. In summary, clockwise circulation starts. See Fig. 5.

In conclusion: during the sunny daytime the system accepts and stores energy, and on cold nights it refrains from losing energy to the outdoors. Thus it is an effective solar-energy-collection-and-storage system.

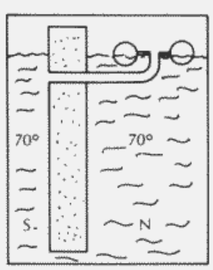


Fig. 3 $T_S = T_N = 70°F$

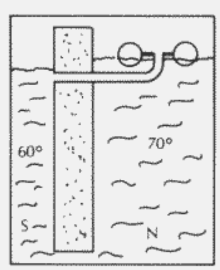


Fig. 4 $T_S < T_N$

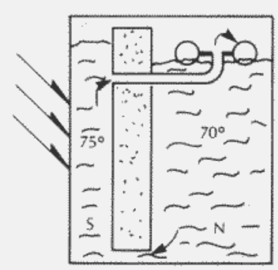


Fig. 5 $T_S > T_N$

SENSITIVITY

At the start of a sunny day in winter, as T_S slowly increases and exceeds T_N, when does the (desired) clockwise flow start? It starts when T_S exceeds T_N by about 2½°F. Water at 72½°F is less dense by 0.03% than water at 70°F; hence the heights of liquid in the two compartments differ by 0.03%. Note that 0.03% of the 40-in. nominal height is 0.012 in.—which slightly exceeds the height increment built into the float-and-tube-end system. Therefore flow of liquid starts.

DISCUSSION

The system is very stable. Its sensitivity remains unaffected by modest-size changes of many kinds. For example, the sensitivity remains the same even if

- a little too much (or too little) water has been put into the tank (the float retains the same crucial increment in relative height),
- some water gradually evaporates, lowering the water levels,
- the tank sides gradually bulge more and more or are dented in by some children playing nearby,
- the septum slowly becomes warped, compressed, or soaks up some water,
- the tank is mounted with a slight slant in any direction,
- a 1/8-in. layer of sediment accumulates on the bottom of the tank,
- a liter of water is ladled out, to fill a hot-water bottle, say.

It is essential, however, that the buoyancy and mass of the float remain constant, so that the built-in increment in height will remain constant. The float must be made of dimensionally stable, water-impervious material (brass, glass, or certain plastics). The tube must be flexible enough so as always to exert the same downward force on the float.

COMPARISON WITH THE PIONEERING SCHEME BY S. BUCKLEY

The Buckley scheme, with its oil valve, has order-of-magnitude greater sensitivity, when operating normally; but I'm not sure that such sensitivity is needed. The proposed floating outlet provides, I think, fully adequate sensitivity. If the Buckley oil valve is expensive (which I expect it is not) or fails to be highly durable, the scheme proposed here may deserve attention. It has been tried out by S. C. Baer and, I understand, performed well.

MODIFICATIONS

Summer-vs.-Winter Reversible Scheme

Use an especially slender float and mount it in the *south* compartment. Connect the crucial control tube to this float. This makes the system operate in opposite manner: circulation occurs only when the *north* compartment is the hotter one. Such operation is desired in summer—to *cool* the main quantity of water.

Various alternative schemes could be used for reversing the operation. For example, the float could remain in the N compartment and could be connected to a tube running from a hole near the *bottom* of the septum (the slot there would be closed, and the hole near the top of the septum would be left open).

Putting the Stored Hot Water to Additional Uses

One could use the large compartment full of hot water in conjunction with the domestic hot water system, to provide solar-preheating of this water. One could install a faucet near the top of the large compartment so that persons could extract small quantities of hot water for preparing a cup of hot cocoa, for filling a hot water bottle, for washing their hands, etc. At the same time, a cold-water inlet pipe would be installed near the bottom of this tank and a conventional float-valve would be employed to keep the tank filled to approximately a constant extent. Occasional small changes in liquid level and occasional addition or removal of a small amount of water would not interfere with the collection and storage of solar energy.