UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

THE SOLAR HEATER

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BULLETIN 469
June, 1929

UNIVERSITY OF CALIFORNIA PRINTING OFFICE
BERKELEY, CALIFORNIA
1929

THE SOLAR HEATER

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Many people living in the interior valleys of California, where sunshine is abundant, have found solar heaters practical and satisfactory for supplying hot water. Although many of the heaters are 'home made,' there are also a large number of commercial manufacture.

The average household needs much water at temperatures of 120° to 150° F, and more would be used if the cost of heating could be reduced. Dairies and manufacturing plants also use much water at temperatures well below that obtainable with solar heaters.

The University of California has had numerous requests for information regarding the construction and performance of solar heaters. These, together with a desire to assist the California farmer in obtaining an economical means of warming water for his household and dairy, have resulted in a study of the problem by the Agricultural Engineering Division. The points investigated were:

1. The availability of solar energy.
2. Design of a practical solar water heater.
3. The heat-absorbing power of a simple glass-covered absorber with a plain iron coil.
4. The heat-absorbing power of an open-type absorber without glass, and with a plain iron coil.
5. The heat-absorbing power of a glass-covered absorber with an iron coil embedded in concrete.
6. The heat absorbing power of an absorber without a glass cover but with the water coil embedded in concrete.
7. The characteristics of a recirculating type of solar heater.
8. The effect of insulation of the absorber upon the temperature obtained.
9. The operation of a solar heater under practical conditions.

AVAILABILITY OF SOLAR ENERGY

Studies were made of the United States Weather Bureau records at various California and Arizona stations to determine the average hours of sunshine per month and the average number of clear and cloudy days during the year. Data from these studies are shown in tables 1 and 2. It will be observed that the percentage of sunshiny

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days for the months of December, January and February at weather stations located in the Sacramento and San Joaquin valleys is relatively low in comparison to the Arizona stations. The latter are more typical of the weather conditions in the Imperial Valley.

TABLE 1

*AVERAGE HOURS OF SUNSHINE PER MONTH AT VARIOUS WEATHER BUREAU STATIONS

Station	Average sunshine per month		Average sunshine for January		Average sunshine for July		Average for December, January, and February.	Average for other nine months
	Hours	Per cent of possible	Hours	Per cent of possible	Hours	Per cent of possible	Hours per month	Hours per month
Sacramento	289.6	75	104.9	34	449	99	158.3	333.5
Fresno	293.2	76	134.0	44	430	96	153.3	340.1
Phoenix	314.2	84	236.0	75	401	94	238.7	339.4

* Averages for California stations are for 1887–1925.
Average for Arizona station is for 1895–1926.

TABLE 2

AVERAGE CLEAR AND CLOUDY DAYS DURING THE YEAR AT VARIOUS STATIONS
(Averages from continuous records for 15 or more years.)

Station	Yearly average		
	Clear days*	Partly cloudy days*	Cloudy days*
Sacramento	224	77	64
Los Angeles	175	134	56
Fresno	231	71	63
San Francisco	168	112	85
Phoenix	236	89	40
Yuma	296	53	16

* Clear=sun obscured for 0.0–0.3 of day; partly cloudy=obscured for 0.4–0.7 of day; cloudy=sun obscured for 0.8–1.0 of day.

Figure 1 shows the hours of sunshine for each month at Fresno, California, and figure 2 shows the same for Phoenix, Arizona, in graphic form.

The Solar Radiation.—The solar constant, K, which changes slightly from year to year because of disturbances in the solar system, is usually evaluated by giving the quantity of heat in small calories received in one minute from the sun at its mean distance from the earth, by one square centimeter of a perfect absorbing surface presented at right angles to the sun's rays. The actual radiation at the earth varies from day to day and from hour to hour. It is largely dependent upon the clearness of the atmosphere, that is, the freedom from smoke, water vapor, and dust particles. The energy as measured by different investigators varies considerably. Table 3 shows some of the values obtained.

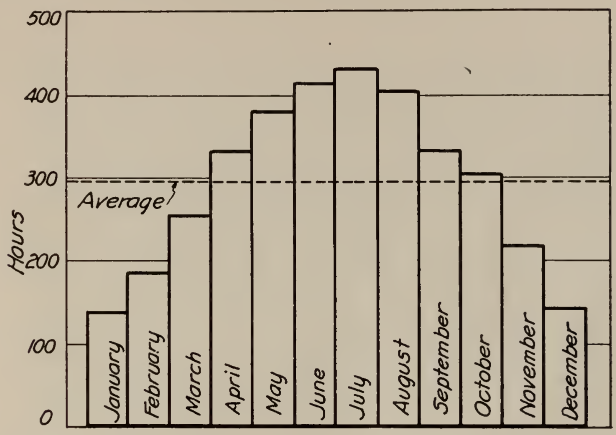


Fig. 1.—Monthly distribution of hours of sunshine at Fresno, California, 1887–1925.

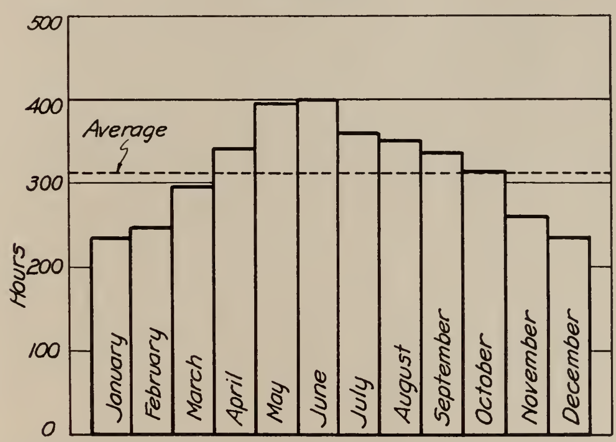


Fig. 2.—Monthly distribution of hours of sunshine at Phoenix, Arizona, 1895–1926.

TABLE 3

VALUE OF SOLAR CONSTANT AS DETERMINED BY VARIOUS INVESTIGATORS

Observer	K*	Place
Viole	2.5	Top of Mt. Blanc
Langley	3.0	Top of Mt. Whitney
Savelief	3.4	Kief (ground covered with snow)
Angstrom	4.0	Ixele
C. G. Abbott	1.925	Numerous observations (considered most accurate)

* Expressed as small calories per square centimeter per minute.

For practical conditions in California the radiation at the earth's surface may be taken as roughly 5 B.t.u.[2] per sq. ft. per minute.

The intensity of the sun's radiation is important because it varies considerably during the day. No specific data are available for California conditions, but data given in Bulletin 261 of the Vermont Experiment Station show that the radiation per square centimeter per minute at the earth on a clear day may vary from 0.94 to 1.36 calories between 9:20 A.M. and 4:53 P.M.

From the foregoing, it is evident that the amount of energy which can be taken from the sun is variable. Data show that over a period of nine months of the year in California, there is an average of 333.5 hours of sunshine per month in the interior valleys, or an average of 11.1 hours of sunshine per day. During the other three months, the average is only 153 hours per month, or 5.1 hours per day. It would seem that solar heat could not be depended upon during this time. In localities such as Phoenix, Arizona, conditions would be much better, because the minimum average sunshine for the three winter months is 238 hours.

DESIGN OF A SOLAR WATER HEATER

One should consider the number and distribution of days of sunshine in a locality before deciding upon the installation of a solar heater there. It is possible to obtain records from the United States Weather Bureau office covering these points. One can then decide whether or not there is enough sunshine to pay to make the installation. In the warm interior valleys of California it is usually considered sufficient for water heating seven to nine months of the year. In general, it seems that there should be an average of at least six hours of sunshine a day during the period in which the solar heater is used.

The solar heater is normally used for heating water for general household purposes, dairies, or summer resorts, or temporary quarters used only in the season of the year when there is an abundance of sunshine.

The use will largely determine the type of construction. Figure 3 shows an artistically designed heater mounted upon the roof of a building in such a manner that it is attractive. Many installations, such as that for a dairy, need not be so elaborate.

[2] B.t.u. = British thermal unit, or the amount of heat required to raise the temperature of one pound of water 1° F.

The temperature obtained by a solar heater is dependent largely upon the relationship between the size of absorber and the amount of water used and upon the insulation of the system. By using good insulation on the absorber and tank, and all connecting lines, one can obtain a water temperature approaching the boiling point. Insulation is of further value in making the apparatus more efficient on cold and cloudy days. It also protects pipes from freezing during moderately cold weather.

Fig. 3.—Commercial-type solar heater installed on a dwelling house in southern California. Note that the absorber is made in two sections.

Types of Solar Heating Systems.—The solar heating system may be constructed simply as shown in figure 4, or it may be more elaborate as shown in figure 5.

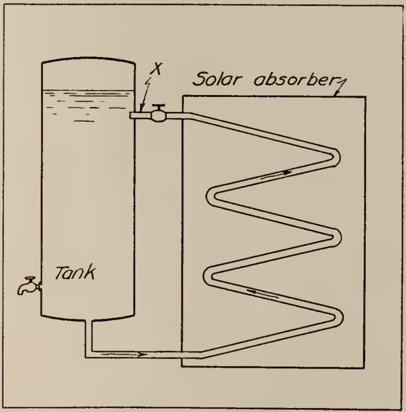


Fig. 4.—Diagram of a simple solar water heater system.

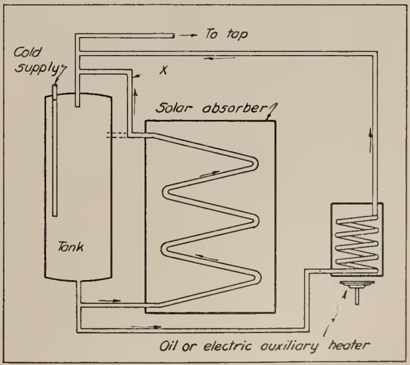


Fig. 5.—Diagram of a pressure-type, recirculating, solar water heater equipped with auxiliary heater.

The principal elements of the system are (*a*) the absorber, (*b*) the storage tank, (*c*) the connections, and (*d*) the auxiliary heater.

The general arrangement and action are as follows: The system is filled with water (or other liquid), which as it becomes heated from contact with the absorber *a,* rises and circulates through a pipe "X" to the top of the tank, *b* replacing the cold water, which settles down to the bottom and which in turn circulates to the bottom of the absorber, where heating takes place; the cycle is then repeated, thus forming a continuous thermo syphon system. Warm water is drawn off from the top of the tank and unheated is added at the bottom, thus making warm water available before the entire tank is heated.

The advisability of an auxiliary heater (see fig. 5) should be considered, for it is usually best to use an oil, gas, or electric heater to warm the water when the sun does not shine. Many people find that hot water coils placed in the furnace take care of their problem very satisfactorily.

The non-freezing type of system may be used in a cold country; it is ordinarily best, however, to drain the absorber in cold weather and not use it until winter is past.

The Solar Absorber.—The absorber is the heart of the solar heater, for it must trap the sun's rays and change these from light into heat. A practical absorber should embody the following features: (*a*) The absorber surface should be placed with its face at an angle of 90° with the maximum light rays. (*b*) The absorber surface should be of such color and materials as to change this light into heat; black surfaces are best. (*c*) The absorber surface should be covered with a glass to serve as a valve to admit light to the surface and to restrict the escape of the heat. (*d*) The absorber should be insulated to prevent conduction of heat to media other than the water. (*e*) The water coil should be of sufficient area and conductivity to transmit the heat effectively to the water.

It is not practicable to build an absorber which will automatically hold its surface at right angles to the light rays. Movable absorbers are intricate, expensive, and difficult to keep in order. For these reasons the stationary type is preferred, even though it must be made larger than the movable type. For general use the absorber should be at an angle of 35° to the horizontal at latitudes the same as Davis, California. Farther north it should be at a greater angle.

The absorber should be located preferably on a roof with south exposure and protected from wind and shade. It may need to be built in two sections. For thermo-syphon action, it should always be installed with the bottom lower than the bottom of the storage tank, as shown in figure 6.

The size of the absorber will be determined by the amount of water to be heated, the temperature rise required, and the time of exposure. Under normal conditions, one square foot of absorber surface should be allowed for each gallon of water to be heated to a temperature of 140° to 150° F.

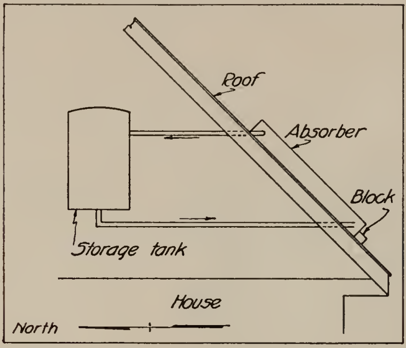


Fig. 6.—Diagram of a solar heater installed on a roof.

The following bill of materials shows the approximate cost of a solar heater of a size to supply 40 gallons or more of hot water a day. Under favorable conditions it should supply much more than this amount.

Materials required to build a solar water heater of 40 gallons per day capacity:

MATERIALS	COST
Absorber box—	
8, 18″ X 48″ single light window sash	$12.80
2 pcs. 2″ × 4″ × 12′ S.1S.&1E.	1.15
2 pcs. 2″ × 4″ X 4′ S.1S.&1E.	0.35
12 pcs. 1″ × 4″ × 12′ T.&G. redwood	3.00
50 sq ft. 2″ cork board	10.00
7 pcs. ½″ × 3″ × 4′ battens	0.70
8 pcs. ¾″ × 4″ × 4′ cleats	1.00
3 doz. 2½ No. 12 wood screws	0.50
Assorted wire nails	0.50
½ sack Portland cement	0.50
⅕ cu. ft. lime	0.25
4 cu. ft. sharp sand	0.40
1 qt. black asphalt paint	1.00
1 qt lead and oil paint	1.00
Coil—	
121 ft. ¾″ standard black iron pipe (random lengths)	9.60
(10 pcs. 10′ length)	
(2 pcs. 10′ 6″ length)	

11 ¾″ close return bends	2.20
24 pipe straps for ¾″ pipe	0.50
2 ¾″ tees	1.00
2 ¾″ plugs	0.30
Connections—	
25 ft. ¾″ galv. iron pipe	2.25
Tank—	
1 40 gal. range boiler	12.00
24 sq. ft. 2″ cork board	5.00
Total	$66.00

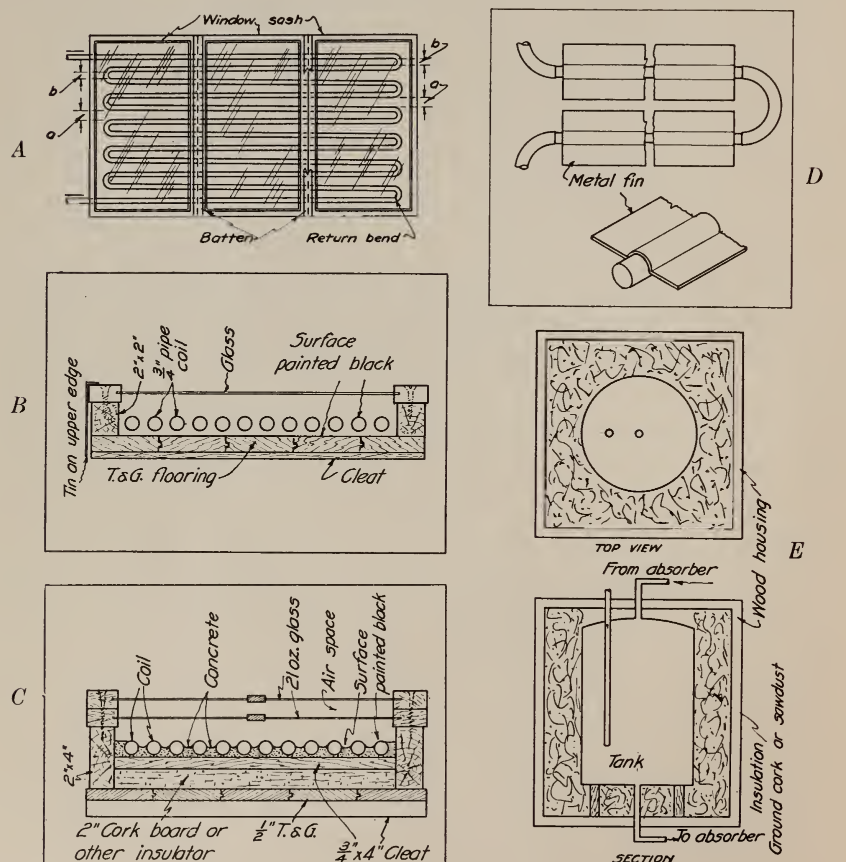


Fig. 7.—Detail of solar heater construction.

A, Front view of absorber, showing method of placing coils and glass.

B, Cross section of plain uninsulated absorber.

C, Cross section of well insulated absorber. Note method of placing concrete about coils to improve conductivity.

D, Method of using fins on pipes to increase efficiency.

E, Cross section of insulated tank set-up. Insulation may be any dry, light-weight material such as cork, asbestos, magnesia, rags, saw-dust, or rice hulls.

The box shown in figure 7 is easily constructed. Figure 7*A* shows the general shape and the manner in which the coils are installed; figure 7*B* shows a detail of the cross section of a simple uninsulated box. The box is made for standard size window panes, which can be screwed down tight against the edges. The upper part of the sash can be covered over with sheet metal, as shown, to prevent entrance of moisture.

Figure 7*C* shows recommended construction when insulation is used. It is similar to that in figure 7*B* except that the bottom of the box is filled with 2 in. of cork board to which the coils are attached. Note that a concrete mixture is troweled in around the pipes to improve their conductivity. This mixture is made of 1 part cement, 4 parts sand, and 1/5 part lime. The concrete should fill the box to 1/2 the depth of the coils, as shown in detail of figure 7*C*.

The glass may be placed in 1 or 2 layers as shown. The double glass and 2 in. of insulation are desirable if high temperatures and efficient heat utilization are desired. Wooden or metal sash may be used. Narrow cross members which offer little obstruction to sunlight are preferred. A 21-oz. glass is satisfactory for ordinary sash, although lighter weight may be used if the sections are small. Care should be taken to see that the glass is tightly set in good putty in order to make an air and water-tight job. Coils may be made readily of standard pipe, by the use of return bends. For most efficient absorption of heat the box should have the pipes as close together as possible, and then the intervening spaces should be filled with concrete, as shown in figure 7*C*. Care should be taken to spread the coils as shown in figure 7*A*, making the distance *a* always greater than distance *b*, in order to provide good circulation and to avoid air pockets. The size of pipe depends upon the capacity of the heater, but ordinarily 3/4-in. pipe will be found satisfactory; it is large enough to give good circulation and at the same time is easy to handle. Figure 7*D* shows how pipe with metal fins could be used for increasing the surface exposed to the sun's rays.

When pipe is cut for the coils, all except the bottom and top pipes should be made of equal length; these two, however, should be made long enough to extend 4 in. beyond the edge of the absorber box, so that union connections can be made. The joints should all be screwed up tightly and properly leaded, using white or red lead.

The number of feet of pipe can be reduced by the use of finned pipes as mentioned above. The principal consideration, if high efficiency is desired, is to make the area of pipe exposed to the direct rays of the sun as near the area of the glass as possible, and to use concrete or other conducting material to fill in the spaces between the pipes.

Painting is desirable for two reasons: first, for protection from the elements; and second, for increasing the efficiency of heat absorption. The outside of the box should be given 3 coats of a good lead and oil paint, red lead being used on all metal surfaces, as a primer. The outer coats can be any color which harmonizes with the surroundings.

The pipes and inside of the absorber box should be painted a dull black, for this color is most effective in absorbing the light rays and converting them into heat. The connection between the absorber and the storage tank should be as direct as possible and with no loops or sags which might cause air to trap in the system. Unions should be provided on both the inlet and outlet of the absorber in order to facilitate erection and repairs. The pipe should be of the same size as the pipe in the coils. It may be necessary to install a valve in one of the lines, preferably the discharge line between the absorber and the tank, to prevent back circulation at night.

In a pressure system, the discharge line from the absorber to the tank should be brought in at the top of the tank if hot water is desired quickly. For an open system, such as that shown in figure 4, the discharge pipe from the absorber to the tank must always be below the water level in the tank, or circulation and heating will not take place.

The Storage Tank.—The storage tank may be an ordinary range boiler, as in the case of the pressure system (fig. 5) or it may be a barrel or tank, as illustrated in figure 4. The size of the tank must conform to the water requirements and absorber area. For ordinary household use, a 40 or 60-gallon tank is desirable.

For high efficiency, insulation should be provided around the tank, as shown in figure 7*E*. A satisfactory method is to apply 2 in. of asbestos, sil-o-cell, magnesia, or cork insulation material with metal housing. A cheaper method is to build a wood box about the tank and fill in between the tank and the box with a coarse dry material such as sawdust, ground cork, or rice hulls. All water lines, especially those to and from the absorber, should be insulated with asbestos or magnesia.

Care of the Heater.—Proper care of the solar heater consists mainly in keeping the absorber glass clean and free from dirt. If it is mounted on a roof the best method of cleaning is to hose it off at weekly or monthly intervals. The absorber box must be kept tight and well painted with a good lead and oil paint. Neglecting to drain the water in freezing weather may result in burst pipes.

TESTS OF SOLAR HEATERS AND ABSORBERS

In order to study the application of solar heaters for water heating a number of tests have been conducted. The apparatus used consisted of a solar absorbing device, as shown in figure 8. The general set-up was an absorber mounted on a skid and so arranged that its angle of incidence to the sun's rays could be varied as desired

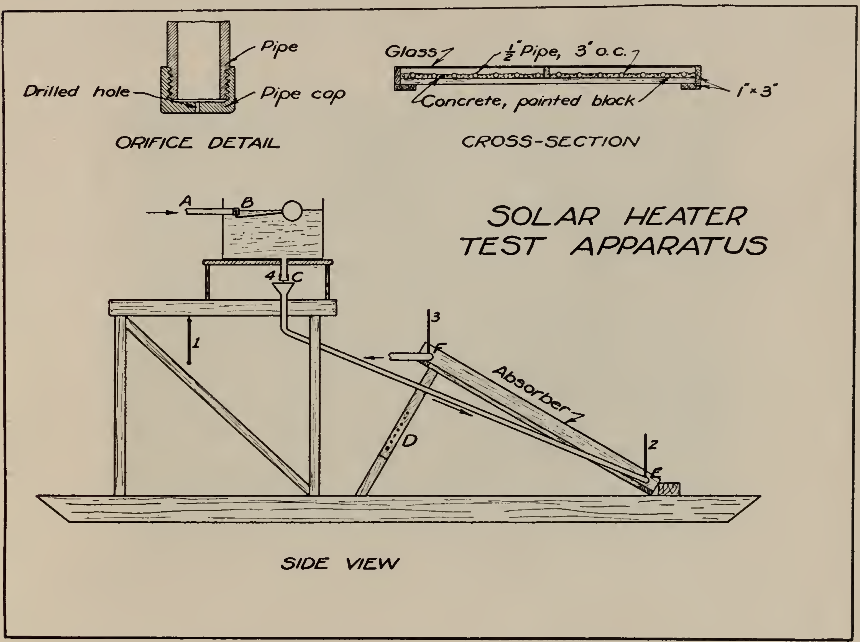


Fig. 8.—Diagram of apparatus used in testing solar absorbers.

by adjustable arm *D*. *A* float chamber (as shown) was fitted with a float valve *B* and an orifice *C*. The absorber had the following dimensions: glass area 10.8 sq. ft., length 41 in., depth 1¾ in., and width 41 in. Provision was made to add cork insulation if desired. The coil was made of ½-in. black iron pipe, welded together as shown in figure 9, with the pipe in an oblique position. During a part of the tests the pipes were embedded in concrete, as will be described later. The coil area was 10.8 sq. ft., constructed from 13 pieces of ½-inch pipe 36 inches long and 2 pieces of 1-inch pipe 40 inches long.

The float chamber was connected to the University Farm water supply of approximately 40 lbs. pressure, and water entered at *A* (fig. 8), passed through valve *B* down through the orifice *C* of 0.10-in. diameter, and on to the lower part of the absorber *E*. It was then forced up and out to the overflow at *F*. The funnel at *C* was higher than the top of the absorber, so that there was always sufficient head to force the water through, without backing up and running over at the funnel.

The orifice (detail drawing in fig. 8) shows how this part was constructed through the use of a regular galvanized iron pipe cap. The apparatus was placed in a position on the ground about 15 feet from the south side of a large building, so that it was more or less protected from the north winds.

Fig. 9.—Set-up of apparatus used in the study of solar absorbers.

Thermometers used were all of the standard chemical type and calibrated for correctness within the ranges for which they were to be used. Thermometer No. 1 (fig. 8) was used to measure the air temperature and was hung in the shade of the platform of the apparatus. Thermometer No. 2 was placed in a tee in the water inlet at the bottom of the absorber. Thermometer No. 3 was placed in a tee at the water outlet of the absorber. Thermometer No. 4 was used to take the temperature of the water at the orifice. The temperature variation at this point was not sufficient to cause a great variation in flow through the orifice. Thermometer No. 5 was laid against the bottom, or back, of the absorber, so that its bulb was ⅛ inch out from the surface (fig. 9).

Other apparatus consisted of a ½-gallon receptacle for checking the flow of water, also a scale for weighing the water flow.

Method of Conducting the Tests.—The apparatus set up as described, was operated for a number of days on preliminary runs, before the test data were taken. The data obtained show a flow of from 1.22 to 1.30 lbs. of water per minute, with an average of 1.27 lbs., which has been taken as the flow for all calculations. A good agreement of the data taken on successive days shows that the variables were well controlled. No attempt was made to measure the solar radiation constant during these tests. It is believed, however, that the radiation was so nearly the same on the bright, clear days during which the tests were made that a fairly close comparison of data can be made. It is evident that of the variables tested, all were of such magnitude that their effect was easily noticeable.

A series of tests was laid out, calling for the measurement of temperature characteristics, and of heat absorption, using various combinations of absorbers and glass.

In carrying out the tests, the water was turned on at 8 A.M. each morning and the temperature of the various thermometers read at 1-hour intervals until 5 P.M. The flow was determined by catching the water for 2 minutes at the overflow (*F*, fig. 8) of the absorber. Special procedure is described under each test series.

A Simple Glass-covered Absorber with an Iron-Pipe Coil.—The object of this series was to determine the heat-absorbing characteristics of an absorber, glass covered and painted black, fitted with plain black iron coils.

The apparatus consisted of the standard absorber box described above. The black iron coil pipes were attached to the back of the absorber box, which was made of ¾-in. matched wood flooring. No special insulating material was used. The glass cover was standard 21-oz. window pane.

TABLE 4

TESTS OF PLAIN GLASS-COVERED ABSORBER WITH BLACK IRON COIL

Test	Temperature, °F					B.t.u. absorbed per minute	B.t.u. absorbed per minute per square foot of absorber
	Atmosphere	Absorber	Water				
			In	Out	Rise		
A-1	58.9	94.9	65.7	81.1	15.4	....	....
A-2	65.0	104.7	72.0	88.0	16.0	....	....
A-3	69.6	105.4	73.7	89.5	15.8	....	....
——	64.5	101.6	70.4	86.2	15.7	19.9	1.85

Water flow was at the rate of 1.27 pounds per minute.
Tests started at 8 a.m. and ended at 5 p.m.

The absorber was exposed to the sun at right angles to the rays at 12 o'clock noon. The standard set-up and procedure were followed. Table 4 and figure 10 show the data obtained.

From table 4 it will be noted that the average temperature rise for the day was 15.7° F, with a minimum of 15.4° F and a maximum of 16.0° F. This would make the heat absorption by the water 19.9 B.t.u. per minute, or 1.85 B.t.u. per minute per sq. foot of glass area.

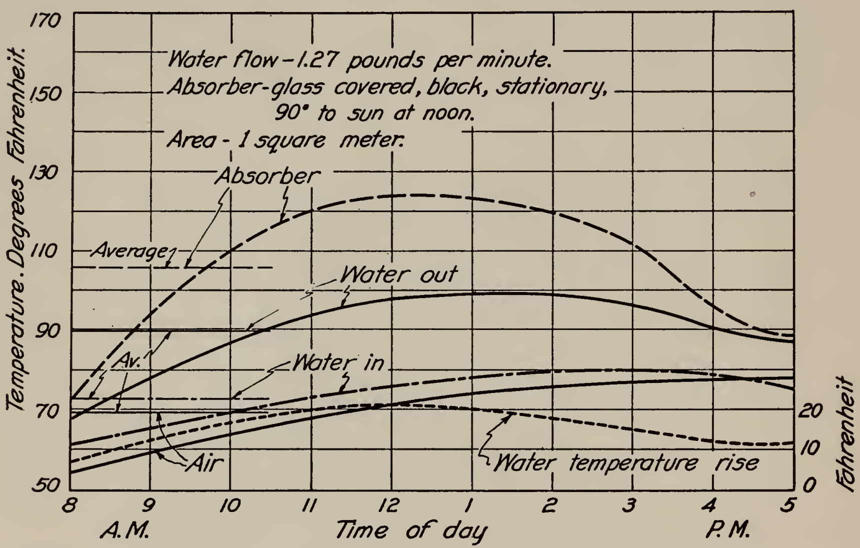


Fig. 10.—Temperatures of the absorber and water during the test of a plain glass-covered absorber fitted with plain iron pipe water coil.

Figure 10 shows that the temperature of the water and absorber, as well as the temperature rise of the water, varied during the day. It will be noted also that the absorber temperature rose rather quickly and reached a maximum of 126° F between 12 o'clock noon and 1 o'clock P.M. As the angle of the sun became more oblique, the rate of absorption was reduced. It is significant that the maximum temperature rise of the water was 22° F, which was at 12 M., and that the minimum was 8° F at 8 A.M.

There seemed to be a considerable difference in temperature between the water and the absorber air. This difference reached a maximum of 50° F at 12 M. to 1 o'clock P.M. Apparently more coil surface or a better heat-transferring medium was needed to keep this absorber temperature down and prevent excessive loss from conduction through the walls.

An uncovered Absorber with Plain Iron Coil.—The object of this series was to obtain data regarding the effect of the glass cover on an absorber, and to determine the efficiency of an uncovered absorber.

The apparatus was the same as in the first series except that no glass was used on the absorber. The procedure also was the same.

TABLE 5

Tests of Plain Absorber Without Glass Covering

Test	Temperature, °F					B.t.u. absorbed per minute	B.t.u. absorbed per minute per square foot of absorber
	Atmosphere	Absorber	Water				
			In	Out	Rise		
B-1	72.0	78.0	74.3	83.0	8.7	....	....
B-2	70.1	80.5	76.2	85.6	9.4	....	....
B-3	70.5	79.4	76.3	85.4	9.1	....	....
Average....	70.86	79.3	75.6	84.6	9.06	11.5	1.064

Water flow was at the rate of 1.27 pounds per minute.
Tests started at 8 a.m. and ended at 5 p.m.

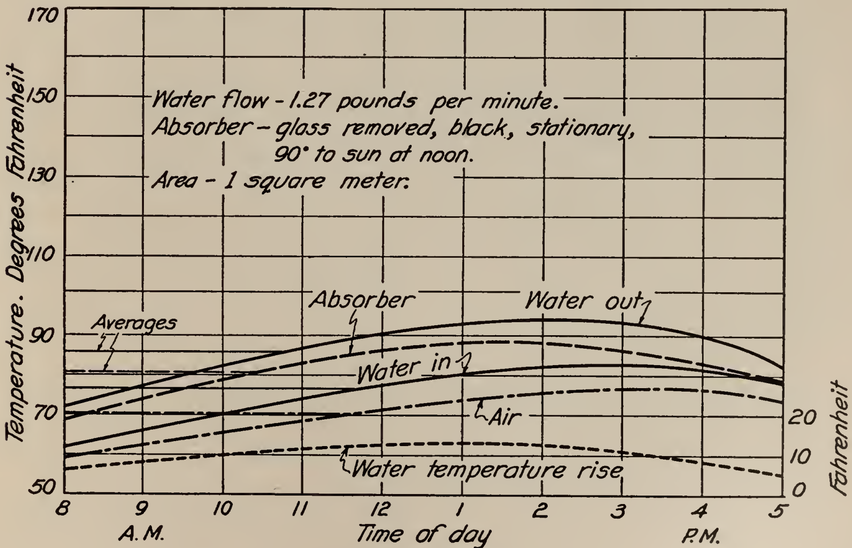


Fig. 11.—Temperatures of the absorber and water during the test of a plain absorber, without glass, but with iron pipe water coil.

Table 5 and figure 11 and figures 14, 15, and 16 show the data obtained. From table 5 it is seen that the average temperature rise per day during all tests was only 9.06° F, with a minimum of 8.7° F and a maximum of 9.4° F.

This shows a heat absorption by the water of 11.5 B.t.u. per minute or 1.069 B.t.u. per square foot per minute.

Figure 11 shows how the various temperatures ranged during the day. It is evident that the absorber temperature is very low, in fact lower than the water temperature in the hottest part of the absorber; heat, therefore, is not only not absorbed from the air but is actually given off or lost to the air from the pipes. The only really effective heating is that which is absorbed from the light rays which strike the pipes directly. It appears that the efficiency of this type of absorber is very low, but it could be greatly improved by making the coil surface against which the light impinges of practically the same area as the absorber. A flat tank used in place of the coil would be typical of such a design. The addition of material such as concrete between the pipes would also tend to conduct the heat to them more readily and thereby increase the efficiency.

A Glass-covered Absorber with Iron Coil Embedded in Concrete.—The object of this series was to determine the heat-absorbing characteristics of the absorber, when the pipes were embedded in concrete. The same equipment was used as in previous tests, but the coil was embedded in a 1–4 mix of concrete with the surface enameled black.

The procedure was the same as in the first series.

The theory of embedding the coils is that concrete, having a higher conductivity than air, will carry the heat to the coils, with a lower temperature differential, so that for a given amount of heat absorbed in the pipes, a lower absorber temperature will be required. This results in less radiation from the exterior of the absorber, and consequently a larger proportion of the heat liberated in the absorber is utilized in heating water.

TABLE 6

TESTS OF GLASS-COVERED ABSORBER WITH COILS EMBEDDED IN CONCRETE

Test	Temperature, °F					B.t.u. absorbed per minute	B.t.u. absorbed per minute per square foot of absorber
	Atmosphere	Absorber	Water				
			In	Out	Rise		
C-1	70.3	105	79	98	19	24.13	2.24
C-2	70.9	104.9	79.3	98.8	19.5	24.76	2.29
C-3	74.1	106.5	81.1	99.1	18.0	23.00	2.13
—						71.89	
Average						23.96	2.23

Water flow was at the rate of 1.27 pounds per minute.
Tests started at 8 a.m. and ended at 5 p.m.

Any material which has good conductivity and can be put in place would serve the same purpose as concrete. A better method might be to have metal fins soldered or welded on to the pipes.

It is evident from table 6 that there is a good absorption of heat with concrete, for the average temperature rise was 18.8° F. With the average flow of water 1.27 lbs. per minute, the absorption would be 23.96 B.t.u. per minute or 2.33 B.t.u. per square foot per minute. Table 6 shows average values for three similar tests on three different days. The absorption was very nearly the same on the different days. Figure 12 shows a typical time and temperature curve for this series. It will be noted that the heat absorption was very nearly constant from 10 a.m. to 2 p.m.

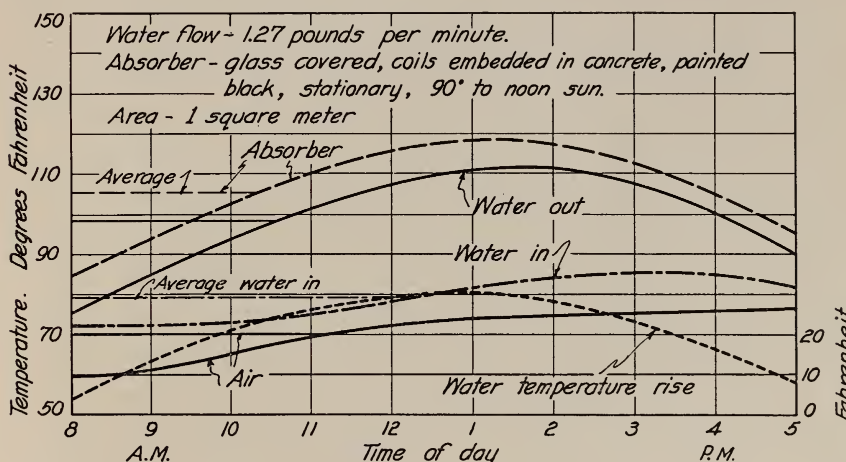


Fig. 12.—Temperatures of the absorber and water during the test of a plain glass-covered absorber, fitted with iron pipe water coil embedded in concrete.

It should be pointed out that the absorber temperature and the outgoing water temperature were almost the same. A good rate of absorption of heat by the concrete and pipes is therefore apparent. The absorber temperature also is relatively low; evidently the heat radiated to the atmosphere is less than in the first series. The temperature of the outgoing water also held up well into the late afternoon. The minimum water temperature rise during the day was 4° F at 8 a.m.; the maximum was 28° F at 12 m. and 2 p.m. The average was 19° F.

The orifice temperature varied from 62° to 94° F. The absorber temperature maximum was 118° F at 1 p.m. and the minimum was 85° F at 8 a.m. The mean temperature difference between absorber and water was 7° F. The maximum was 9° F at 8 a.m. and minimum 4° F at 5 p.m.

The conclusion seems justified that embedding of the coils in concrete improves heat transfer to the coils, decreases the temperature of the absorber, reduces the heat lost to the outside of the absorber, and results in transferring to the water a greater percentage of the solar energy. It offers a method which is inexpensive and can be easily installed by any worker. It improves the efficiency of the heater, and at the same time provides a system which is adapted to pressures.

An Uncovered Absorber with Iron Coil Embedded in Concrete.—The object of this series was to determine the heat-absorbing characteristics of the absorber without a glass covering, but with pipes embedded in concrete.

The apparatus and procedure were the same as in the preceding series except that the glass covering was removed.

The supposition in this case is that the sunlight striking the pipe surface will be absorbed as heat; the sunlight striking the concrete in which the coils are embedded will also be absorbed as heat, which will then be transferred more readily to the pipes than if they were merely in contact with air. Such reasoning indicates that on account of this better conduction to the pipes, a larger percentage of heat will be absorbed and utilized as useful heat than if such a conducting medium were not used. Concrete is not so good a conductor of heat as metals, and probably a higher efficiency would be obtained if the pipes were fitted with metal fins or if they were replaced altogether by a shallow tank upon which the sun's rays could strike directly. Evidently some heat is radiated out to the atmosphere from both the concrete and the coils, but the amount carried to the pipes must be greater than that radiated to the atmosphere, on account of the relatively good conductivity of the concrete as compared to air.

Table 7 and figure 13 show results of this test.

TABLE 7

TEST OF ABSORBER WITHOUT GLASS BUT WITH COILS EMBEDDED IN CONCRETE

Test	Temperature, °F					B.t.u. absorbed per minute	B.t.u. absorbed per minute per square foot of absorber
	Atmosphere	Absorber	Water				
			In	Out	Rise		
D-1	77.6	88.9	83.2	99.0	15.8	....	....
D-2	78.9	88.0	81.6	96.8	15.2	....	....
D-3*	69.8	77.7	77.7	89.9	12.2	....	....
Average....	78.2	88.4	82.4	97.9	15.5	19.70	1.83

Water flow was at the rate of 1.27 pounds per minute.
Tests started at 8 a.m. and ended at 5 p.m.

* Not averaged.

The heat absorption was satisfactory, with an average of 19.7 B.t.u. per minute for the entire absorber, or 1.83 B.t.u. per square foot per minute.

The average daily temperature rise was 15.5° F, with a maximum daily average of 15.8° F and a minimum of 15.2° F.

The maximum temperature rise during the day was 22° F, which occurred at noon. While this test series is not strictly comparable with series B, the data indicate that the heat absorption is greater with the pipes embedded in concrete than when they are exposed to

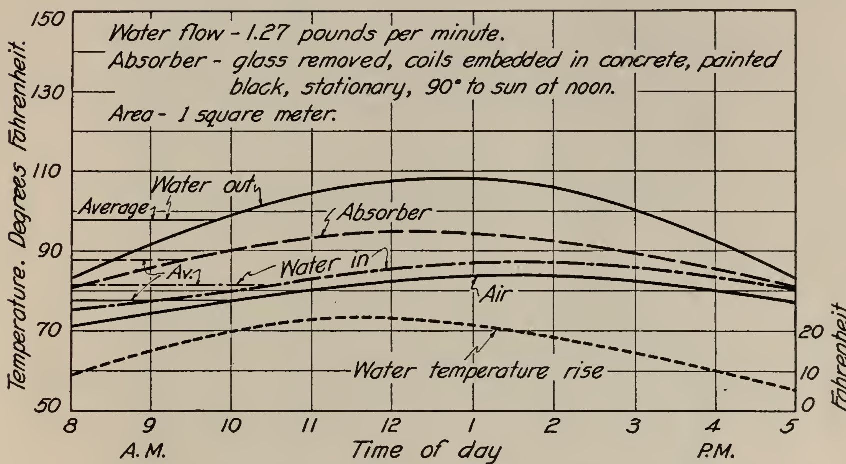


Fig. 13.—Temperatures of the absorber and water during the test of a plain absorber, without glass covering, but fitted with iron pipe water coil embedded in concrete.

air. The relative average heat absorption was 19.70 B.t.u. for the former as against only 11.5 B.t.u. for the latter. The data in test D–3 (table 7) are not averaged, for they were taken on a cool day, when a strong wind was blowing directly against the absorber surface. They are shown only for contrast. The effect of weather conditions was very noticeable on these days, for the average temperature rise of the water dropped from 15.5° to 12.2° F. This is as would be expected, because the atmosphere came into direct contact with the absorbing surface.

Figure 13 shows temperatures of the various parts of the absorber throughout the day.

Figures 14, 15, and 16, show a comparison of the general temperature characteristics of the four types of absorbers studied.

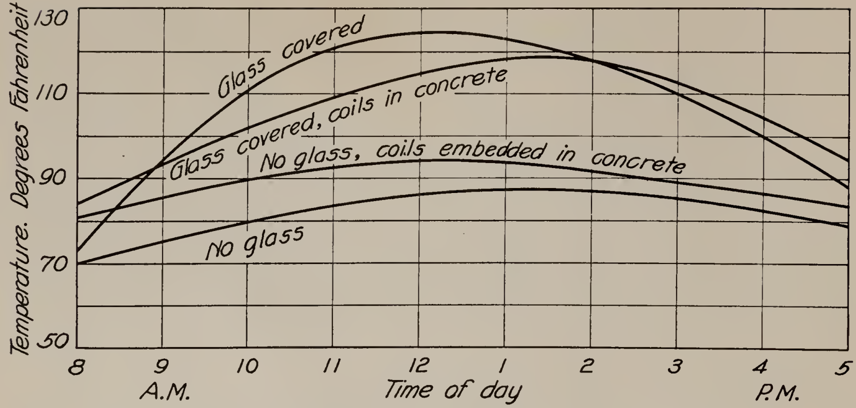


Fig. 14.—Temperature of the air in the absorber, under conditions with and without glass covering of the absorber, and with and without coils embedded in concrete.

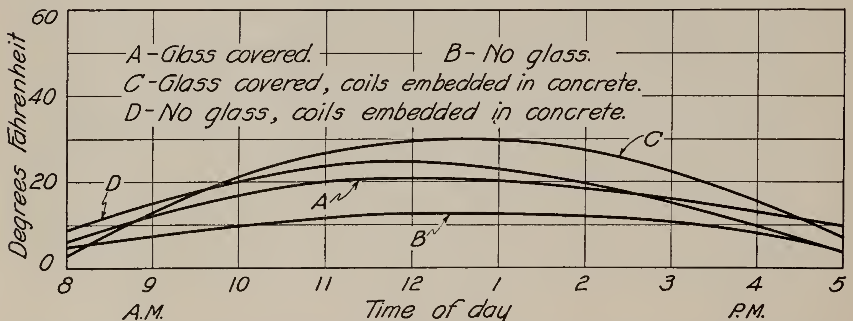


Fig. 15.—The temperature rise of the water as it passed through the solar heater under the various conditions mentioned in figure 14.

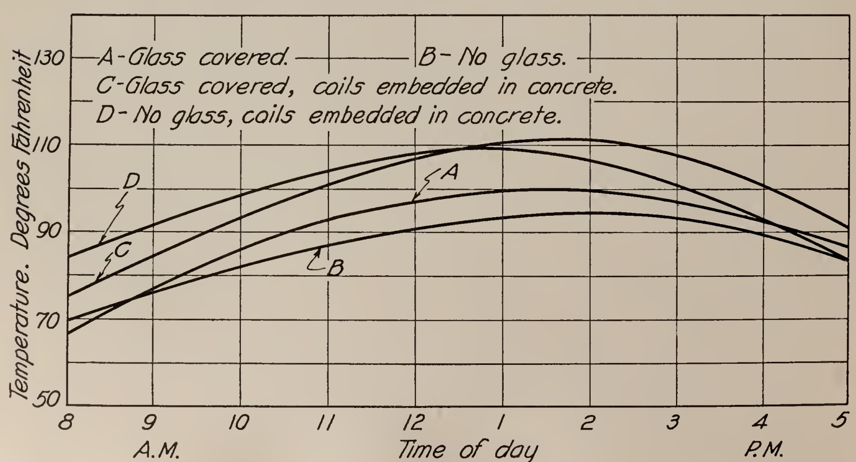
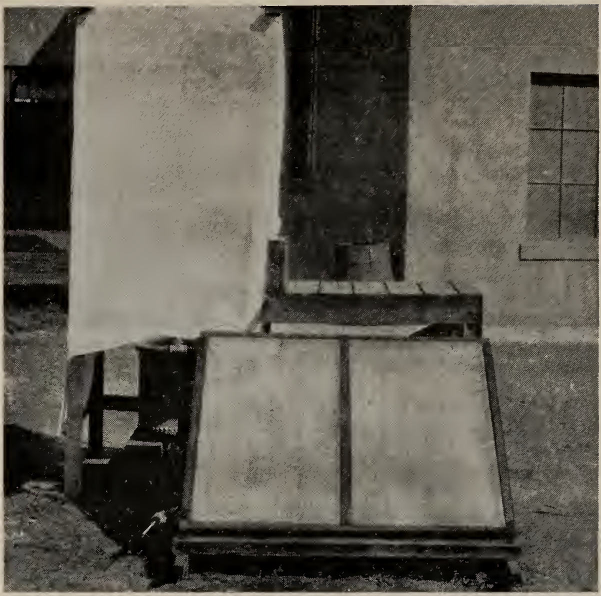
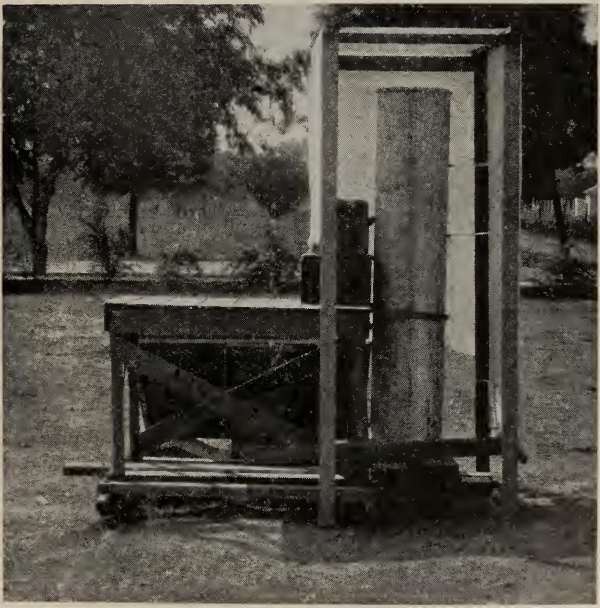


Fig. 16.—The temperature of the water at outlet of the solar absorber under the various conditions mentioned in figure 14.



A



B

Fig. 17.—The recirculating type of solar heater used in making tests.

A, Front view; note that the absorber was painted white at the time the picture was taken. Black, however, is the proper color for absorbers. *B*, Back view.

A Recirculating Type of Solar Heater.—The temperature and operating characteristics of a recirculating type of solar water heater were determined with a 30-gallon range boiler attached to the absorber used in previous tests. Figure 17 shows a photograph of the set-up. Note how the connections were made, also that the tank was protected from direct sunlight by a screen made from a double thickness of white cheese-cloth.

During the tests, temperature readings were taken at 1-hour intervals from 8 A.M. to 5 P.M. No water was drawn off during the test. Temperature measurements of water in the storage tank were taken with 4 thermometers inserted through corks in the tank wall and located 1 ft., 2 ft., 3 ft., and 4 ft. respectively above the bottom. No attempt was made to secure high temperatures, since the apparatus was not adapted to high-temperature work. Higher temperatures could be obtained by using a larger absorber or by insulating the tank or by a combination of the two means.

TABLE 8

DATA OBTAINED WITH RECIRCULATING-TYPE SOLAR WATER HEATER

	Series B		Series W	
	1	2	2	3
Average atmosphere temperature, °F	83.3	85.4	87.5	85.3
Average absorber temperature, °F	121.9	121.4	108.8	107.6
Average temperature of water into absorber, °F	85.2	83.1	84.0	79.8
Average temperature of water out of absorber, °F	107.3	106.3	100.7	99.2
Average water temperature rise in the absorber, °F	22.1	23.4	16.7	19.3
Average water temperature in absorber during test, °F	97.4	96.8	92.5	90.2
Average temperature No. 4 thermometer, °F†	103.7	103.5	97.7	95.2
Average water temperature in the tank at start, °F	65.2	63.5	68.5	63.5
Average water temperature in the tank at end, °F	119.2	119.0	109.2	109.0
Average temperature rise of water in the tank, °F	54.0	55.5	40.7	45.5
Weight of water in the system	240.6	240.6	240.6	240.6
‡Net B.t.u. absorbed by water in the tank	13,290	13,640	10,000	10,947
*B.t.u. loss from tank by radiation	5,400	4,360	1,910	1,930
B.t.u. delivered to tank in 9 hrs	18,690	18,000	11,910	12,877
B.t.u. delivered to tank in 1 hr	2,076	2,000	1,323	1,431
B.t.u. delivered to tank in 1 min	34.6	33.3	22.0	23.8
B.t.u. delivered to tank in 1 min. per 1 sq. ft. absorber	3.20	3.08	2.04	2.20
Maximum water temperature, °F	124	126	106	112
Date	Sept.	Sept.	Sept.	Sept.

* Calculated using K=2.5 B.t.u. per hour per square foot per degree difference in temperature.
† No. 4 thermometer was placed 1 foot from the top of the tank.
‡ Net absorption=total absorption minus radiation loss.

Table 8 shows results obtained from observations which were taken on different days but in which temperature and sunlight were comparable. Series B-1 and B-2 of table 8 show data obtained when the absorber was painted black, while series W-2 and W-3 are data from the same absorber, after it had been painted white.

Figure 18 shows temperatures in the different parts of the system during a typical test.

In test B-1 and B-2 (table 8) the total heat absorbed by 240.6 lbs. of water was 13,690 and 13,640 B.t.u. respectively, with a water temperature rise of 54° F and 55.5° F respectively. During this time, however, the radiated heat loss was equivalent to 5,400 B.t.u. and 4,360

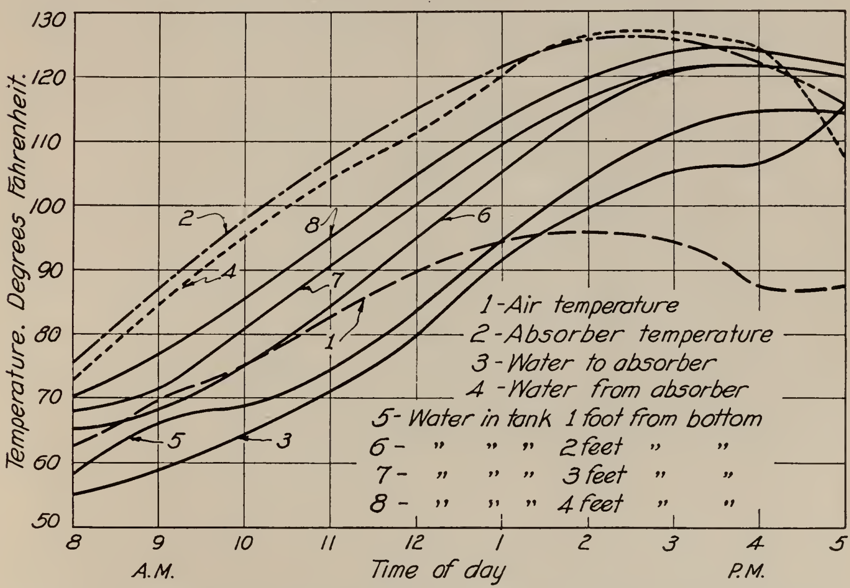


Fig. 18.—Temperatures of various parts of the recirculating system during a typical test.

B.t.u. respectively, as calculated from the area of exposed tank surface and the temperature difference between tank and air and the radiation constant. If the radiation losses are taken into account, the actual amount of heat delivered to the tank was 18,690 B.t.u. and 18,000 B.t.u. respectively, which indicates an effective absorption of 3.20 B.t.u. and 3.08 B.t.u. per hour per square foot of absorber area at the absorber. This average of 3.14 B.t.u. as compared to the total assumed solar radiation of 5.00 B.t.u. gives 66 per cent of the theoretical.

The maximum water temperatures in the tank in tests B-1 and B-2 were 126° F and 124° F respectively, or an average of 125° F. The effect of color on the rate of heating is shown by comparing data from tests W-3 and W-2 with those of B-1 and B-2. As against an average of 12,393 B.t.u. absorbed by the former, there were 18,345 B.t.u. absorbed by the latter. Calculation shows an average of 2.12 B.t.u. per minute per square foot for series W as compared to 3.14 B.t.u. for the series B tests; the former is only 67.5 per cent as efficient as the latter.

The maximum temperature obtained with the white absorber was only 109° F (average), as compared to 125° F for the black. These data show the importance of painting the absorber surface black.

If the above figures are translated into terms of gallons of water heated from 70° to 120° F, it is found that the type B absorber

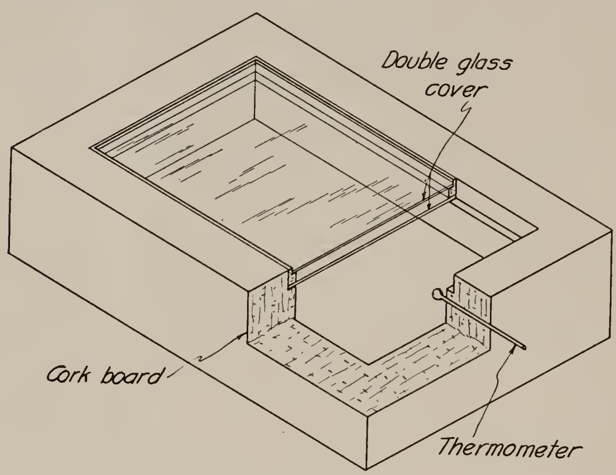


Fig. 19.—Highly insulated solar absorber which attained a temperature of 283° F. Insulation consisted of 3 in. of cork board and two panes of 21-oz. glass. The inside dimensions of the box were 9 in. by 20 in. by 2 in.

actually heated the equivalent of 32.2 gallons, while if the radiation losses had been prevented, it would have been 43.8 gallons, or 2.99 and 4.06 gallons respectively per square foot of absorber-glass area. The above results were obtained on a bright September day.

A solar heater for satisfactory results should be built with at least a 100 per cent over capacity in order to furnish a reserve for hazy days. It is suggested that the ratio of 1 square foot of absorber surface to 1 gallon of water to be heated is about right for ordinary conditions.

The water circulation in the system was good. Calculations showed that the rate of flow was approximately 1 pound per minute. The variations of water temperature in the tank is shown in figure 18. Back circulation took place readily late in the afternoon after the sun was low, as is evident also from a study of curves 3 and 4, figure 18. In a simple system such as that used in the test, it would be necessary to install in the absorber circuit a valve which could be closed at night, if temperatures are to be maintained. A well-insulated absorber would minimize this trouble.

A Highly Insulated Absorber.—It is logical that higher temperatures should be obtained in a solar absorber if insulation is used to prevent radiation losses. To test this point, a small insulated absorber, as shown in figure 19, was built with dimensions 15 in. by 26.5 in. by 5¼ in. and insulated with 3 in. of cork board. This was tested with

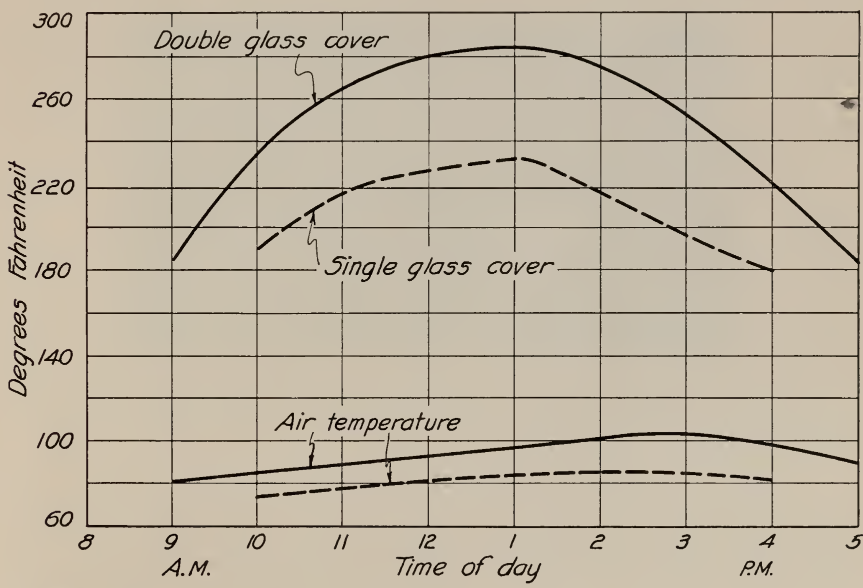


Fig. 20.—The temperature of the air inside the highly insulated solar heater box during the use of single and double glass covers respectively.

single and double glass covers respectively and the temperature measured with thermometers. Figure 20 shows in curve form the data obtained. Note that the highest temperature, 283° F, was obtained with double glass cover, this being considerably above the boiling point of water. With the single glass covering, the maximum temperature was only 232° F. The advantages of the double covering are evident.

A Commercial Solar Heater.—In order to determine the temperatures actually obtained in a practical commercial heater, a number of observations were made on one located in the vicinity of Davis. This heater (figure 21) was installed on the south slope of the roof of a house and furnished water for general household use for a family of three. It was of the 'non-freezing' type, using a special mixture to circulate through the coil on the roof and through a heater coil in the water tank. It had been installed for approximately four years and had given satisfactory service. It was connected in parallel with an auxiliary heater, attached to the furnace for water heating in the winter time. This arrangement, according to the owner, enabled the family to have hot water the year around. The only attention required was an occasional cleaning of the absorber glass, to remove any dust or foreign material which collects.

Fig. 21.—A commercial-type solar heater absorber. This absorber was mounted on the south side of the house, in a place where it was protected from winds and free from shade.

Temperatures were measured at the 'tap' on three different days at approximately 3 P.M. Three gallons of water were drawn off before the temperature was measured. Table 9 shows the temperature to be 137° F maximum and 118° F minimum. These data were taken on clear, bright days in October. These temperatures are satisfactory for practically all washing purposes.

TABLE 9

Temperature of Water Obtained at the Faucet on a Commercial-Type Solar Water Heater

(Field Observations, October, 1928)

Date	Time of day	Atmosphere	Room temperature °F	Gallons of water drawn	Temperature, °F at sink	Cleanliness of absorber	Wind
October 5	3:10 P.M.	Bright	80	3	118	Dusty	Strong north wind
October 17	3:30 P.M.	Bright	74	3	137	Clean	Slight southeast wind
October 19	3:10 P.M.	Bright	78	3	131	Dusty	Slight southwest wind

The heater was in regular use by a family of three persons. Water was used for washing dishes and clothes, as well as for the bath.

CONCLUSIONS

1. The solar heater seems to offer a practical means of supplying hot water for dairy and household purposes. It should be used in conjunction with a well insulated water-storage tank, and for continuous service it should have an auxiliary oil, gas, or electric heater.

2. For average conditions in the warm interior valleys of California, one square foot of glass-absorber area should be used per gallon of water to be heated per day.

3. The most efficient location for the absorber is on the south slope of an unshaded roof.

4. Tests show that temperatures of 280° F are obtainable under the glass of a well insulated solar heater.

5. Daily averages of as high as 3 B.t.u. per square foot per minute between the hours of 8 A.M. and 5 P.M. are easily obtained by simple solar heaters.

6. The absorber box should be insulated against heat loss. Good cork insulation is recommended. If high temperatures are desired, it is best to use a double glass cover with air space between.

7. A tight glass should be placed over the absorber box in order to retain the heat and to prevent air currents from cooling off the pipes.

8. The area of the pipe or absorbing surface in direct contact with the sun's rays should approach the area of the glass as nearly as possible, for maximum absorption.

9. Embedding coils in concrete or other materials having good conduction greatly increases the efficiency of the absorber. This type works fairly satisfactorily in protected places, without the use of a cover glass.

10. The inside of the absorber and the exposed part of the water coils should be painted a dull black.

11. The absorber should be set at an angle such that it will be most efficient in the early spring months, rather than in the summer; 35° angle to horizontal is suggested for places with the latitude of Davis, California.

12. The maximum heat absorption takes place when the plane of the absorber is kept at 90° to the sun's rays; the most satisfactory practical installation, however, is to build the absorber stationary and of a size sufficient to furnish the required amount of heat under all conditions.

13. Some heat is absorbed by the solar heater even on hazy and cloudy days.

14. Solar heating systems should have a large storage or reserve capacity.

15. The percentage of solar radiation reaching the earth is largely affected by atmospheric conditions, and also varies from day to day at the source.

16. It seems desirable that some manufacturer build and offer for sale unit-type solar absorbers, which can be assembled by the farmer or local plumber, at a low cost.

17. A shut-off valve in the discharge line between the absorber and the tank may be advantageous in some installations, where it is desired to stop the back circulation due to cooling of the absorber at night.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the various United States weather bureau stations in California and Arizona which very kindly contributed data. Thanks are also due to Miss Rowe of the Agricultural Engineering Division for stenographic assistance; to Professor H. B. Walker and Mr. J. P. Fairbank of the Agricultural Engineering Division for suggestions and criticisms of the manuscript; and to Professor E. J. Stirniman for suggestions in carrying on the work.

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314. Termites and Termite Damage.

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