PRINCIPLES OF ACTION OF CYCLIC REVERSE THERMOSIPHON

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Abstract

A new kind of heat exchanger is represented in this paper. It is a cyclic reverse thermosiphon: a self-acting liquid flow circuit with passive heat transfer downwards that is in a direction opposite to the direction of natural convection. Local heat, which has to be transferred in the circuit, powers this device. The difference between saturated vapour pressure in warm and cold branches of closed-circuit heat transfer loop is used to move the warm liquid heat-carrier downward. The device has a simple design and operates when the temperature difference between warm and cold branches is equal to a few degrees. Experimental testing of laboratory models was successfully completed. The device can be used instead of electrical circulating pumps in cases where the heat source is located above consumers of heat, in particular in solar installations.

KEYWORDS

Reverse thermosiphon (reverse termosyphon), passive heat transfer downwards, self-acting, self-controlled, powered by heat, circulating pump

INTRODUCTION

Flow circuits with natural convection of liquid heat-carriers (simple thermosiphon) are often used for heat transfer. Convective movement of the liquid starts when liquid in the loop is heated, causing it to expand and become less dense, and thus more buoyant than the cooler water in the bottom of the loop. Convection moves heated liquid upwards in the system as it is simultaneously replaced by cooler liquid returning by gravity. In many cases the liquid flows easily because the thermosiphon is designed to have very little hydraulic resistance.

If heat causes steam generation, the natural convection will be considerably intensified because the difference between the density of liquid and vapour is more essential in comparison with a difference of density of a cold and warm liquid. Such devices are named phase-change thermosiphon.

The great advantage of liquid flow circuits and phase-change thermosiphons with natural convection is self-action. Unfortunately, these devices transfer heat only upwards.

There are some technical proposals to force convective heat transfer downward. Roberts and others have given a survey of ten various such designs [5]. These and other devices, which are known from other publications [1, 2, 4, 6–9], are not used in practice owing to their shortcomings. The main shortcomings are following: usage of external sources of energy, short vertical distance between consumer and sources of heat, great difference of temperature between warm and cold branches of circuit, underpressure in the device, complicated design, or high cost. Only one device for heat transfer downwards is widely used in practice. It is a flow circuit with mechanical pump. It operates with the help of external energy sources usually with electricity, which is the major shortcoming of this method.

A great difference in pressure is not needed to put liquid into motion, because the difference in the density of liquids in warm and cold branches is small, if both branches are filled by liquid. For example, the difference of pressure at natural convection is equal to only 0,1–0,4 kPa (12–38 mm H_2O) in a circuit filled with water, if difference of temperature is 5ºC, the height of circuit is 10 m, and temperature is between 20 and 100 ºC.

At the same time, when the difference of temperature is the same (5 ºC), the difference of saturated water vapour pressure is from 0,9 to 20 kPa (90–2000 mm H_2O). Therefore, the saturated vapour difference between warm and cold branches is considerably more in comparison to the difference of pressure at liquid natural convection. It can easily move warm liquid in a direction opposite to the direction of natural convection.

PRINCIPLES OF ACTION

For using saturated vapour pressure, the upper part of the flow circuit must be free from liquid. In such a circuit, when one branch (1) is warm and another branch (2) is cold and the upper part of the circuit is open, the level on warm branch 1 becomes a little bit higher, in comparison with the cold one (Fig. 1 a).

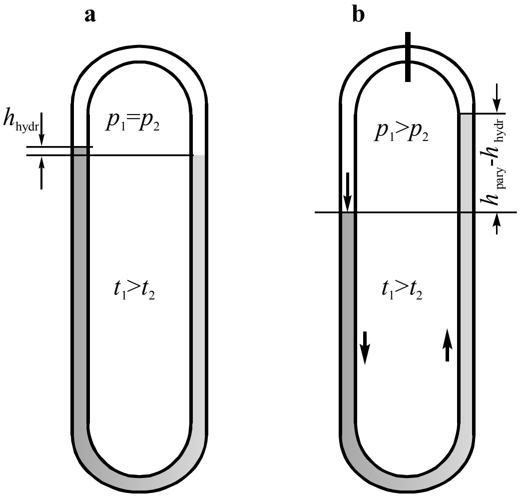

Fig. 1. Levels of liquid in circuit, which is filled by liquid incompletely: a – action of difference of density of liquid, when upper part of circuit is open, b – action of difference of saturated vapour pressure, when upper part of circuit is closed

If the upper part between branches is closed, the saturated vapour pressure is established in the branches according to their temperature. In this case, the difference in the levels between cold and warm branches is tens and hundreds times more in comparison with the difference of levels which can the forces of natural convection create.

When the level in the cold branch rises, there is a good opportunity to pour off any cold liquid surplus from the cold branch into the upper part of the warm branch gravity. This is possible when an additional intermediate canal is located between the cold and warm branches (Fig. 2 a), and the overhead pipe of flow circuit is open to equalise the vapour pressure in both branches. Such a device will operate cyclically. The overhead parts of each branch should be made wider to reduce the pumping cycles. Non-return valves can be used to maintain the required directions of liquid flow in the lower part of the circuit and in the intermediate canal. A special control valve has to be used for periodical opening and closing of the overhead pass of the flow circuit.

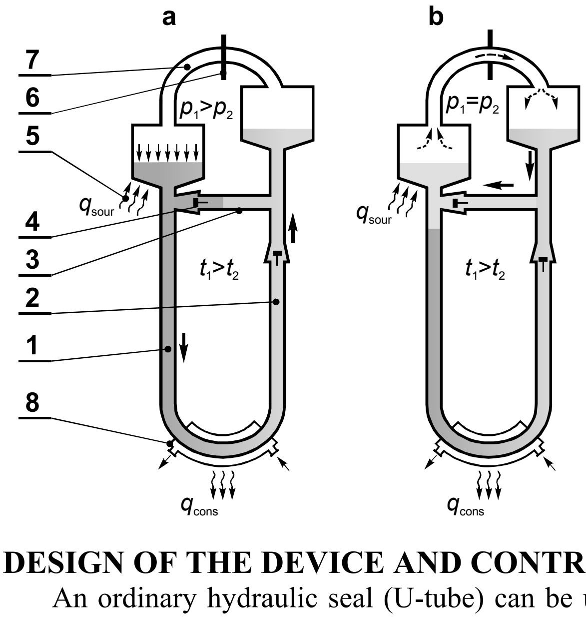

Fig. 2. Scheme and stages of action of the device: 1 – warm descending pipe, 2 – cold upflow pipe, 3 – intermediate canal, 4 – non-return valve, 5 –source of heat, 6 –control valve, 7 – upper way of the circuit, 8 – cooler, a) – stage of pushing warm liquid downward, b) – stage of pouring off cold liquid to the warm branch

DESIGN OF THE DEVICE AND CONTROL VALVE ACTION

An ordinary hydraulic seal (U-tube) can be used instead of non-return valves in the device. The lower part of the circuit and intermediate canal can be made with an appropriate form of U-tube, however the outlets and inlets of these tubes must be situated in the correct places to reach the desired aim. The upper end (outlet) of the circuit tube must be located above the maximum level of liquid in the cold branch vessel (Fig. 3). The upper end (outlet) of the intermediate canal must be situated above the maximum level of liquid in the vessel of the warm branch. Additionally, the height of the intermediate canal must be great enough: the bottom of the canal must be situated below the minimum level of liquid in the vessel of the warm branch [3].

The control valve can also be made as a hydraulic seal. The main requirements which the control valve should perform are:

– the overhead part of the circuit should open, when the difference in pressure between the warm and cold branches reaches a desired magnitude,
– the overhead part of the circuit must be opened for vapour flow, until surpluses of cold liquid have poured off from cold branch vessel to the warm branch vessel.

A scheme of such a control valve is shown in Fig. 3 (position 1 and 2). The valve will be opened, when a difference in pressure overcomes the pressure of a column of liquid heat-carrier in the crossover pipe of a control valve (Fig. 3). The valve will be closed, when the level of a liquid in the vessel of the warm branch rises up to the edge of a distribution vessel of the control valve (Fig. 4).

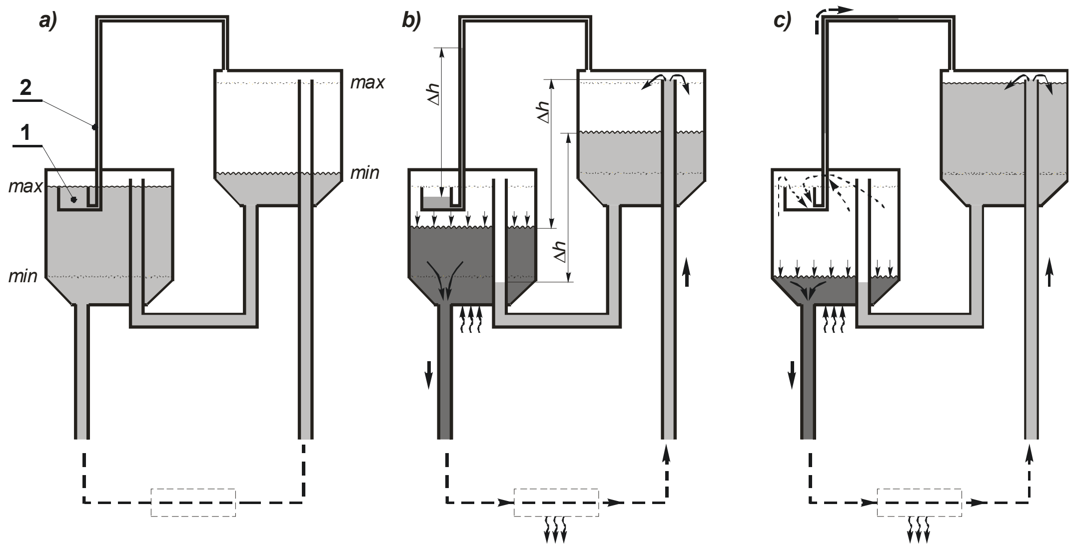

Fig. 3. Stage of pushing warm liquid downward: 1 – distributive vessel of control valve, 2 – crossover pipe of the control valve a) – initial state, b) – beginning of pumping warm liquid downward, c) completion of stage: moment of opening of control valve (liquid seal)

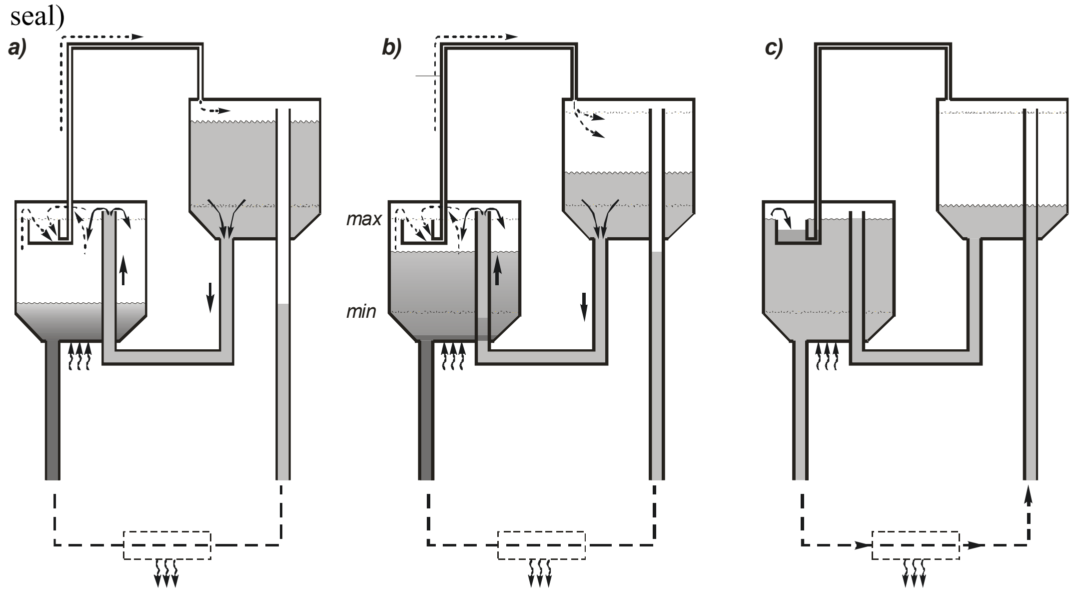

Figure 4. Stage of pouring off cold liquid to warm branch: a) initial state, b) pouring off cold liquid to warm branch, c) completion of stage: moment of closing of control valve (filling of distributive vessel of the control valve)

Scheme of action of the device at the stage of pushing warm liquid downward and the stage of pouring off cold liquid to the warm branch is shown in Fig. 3 and 4.

TESTING OF THE DEVICE

The action of the device was verified with the help of a laboratory model. A thermostatically controlled electric heating unit with a power of 300 W was used as a heat source. The tank-accumulator with a 10 litres capacity and with a coil was used as a cooler.

The following temperatures were measured: in the descending branch of a circuit with warm heat-carrier, in an upflow pipe with a cold heat-carrier, in the tank-accumulator. The initial temperature of the tank was 20 ºC. The temperature in the tank quickly increased in the first stage of action, and was then established at a level of 47 ºC. A similar change in temperature was found in the descending and lifting pipes (Fig. 5).

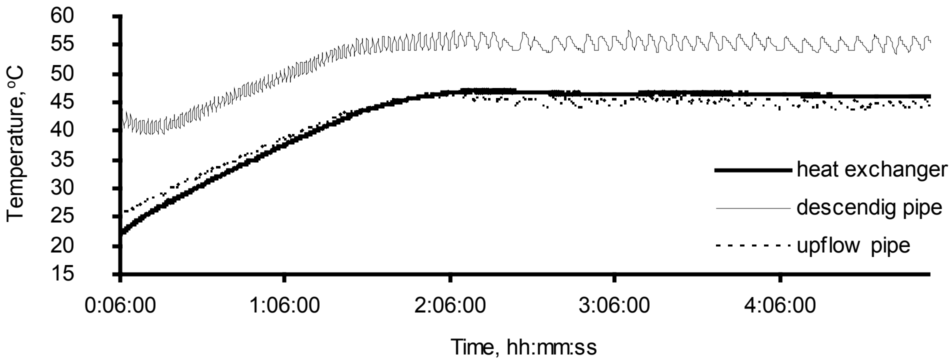

Fig. 5. Changing of temperature

Numerous extremes on the temperature line of the descending pipe is evidence of the cyclic operation of the device . The frequency of cycles was varied. The frequency was high in the first stage and it dropped when the temperature of the source achieved the target level.

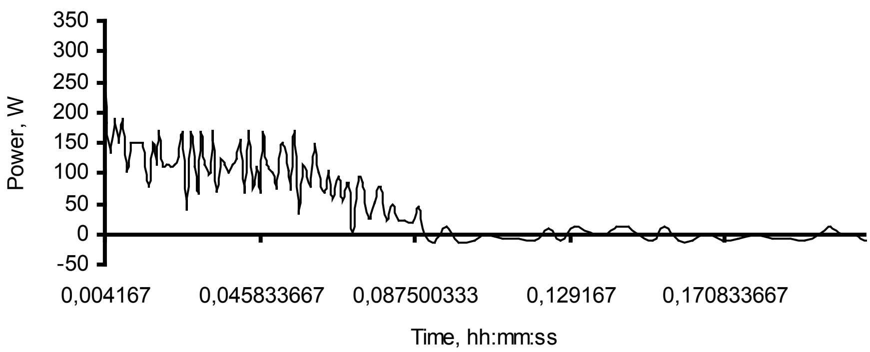

Fig. 6. Changing of capacity of heat transfer

Heat was transferred to the tank-accumulator with a power of 160 W in the first stage of action. Power fall to null, when the temperature in the tank reached 47 ºC (Fig. 6).

The device was stable throughout the experiment.

SUMMERY

The proposed device, which is named a cyclic reverse thermosiphon, is self-acting and self-controlling; it is powered by local heat, and can move warm a liquid heat-carrier downward in a closed circuit. The difference in saturated vapour pressure is used to pump the liquid. It was successfully tested in laboratory conditions, and it is expected that this device will be used instead of an electric circulating pump in solar installations as well as in other cases when passive heat transfer downward is needed.

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