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# The Effect of Multiplicity of Carrier Circulation on the Efficiency of Single-Contour Thermoisiphon Systems of Solar Hot-Water Supply

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**ABSTRACT:** The article deals with the optimization of circuit solutions and operational parameters in order to increase the efficiency of solar heat supply systems equipped with flat solar collectors.

**KEYWORDS:** solar collectors, solar water heating device, comparable costs, heat production, operating efficiency.

## I.INTRODUCTION

The heat cfrrier circulation multiplicity effect on one-contour thermosiphon systems of solar hot-water supply is investigated. It is shown that the number of circulation cycles in such systems has practically no influence on the daily productivity of a solar collector.

Notation

Cp - specific heat capacity, J/kg $^oC$;
E - density of solar radiation flux in the collector plane, W/m$^2$;
F\` - efficiency of solar collector,
$g_1$,$g_2$- water mass flov rates through the collector at single-and multiple-heating regimes, kg/m$^2$ s;
M - specific capacity of the accumulator tank, kg/m$^2$;
n - multiplicity of circulation (number of cycles);
Q - specific heat production of solar collector, J/m$^2$;
t - temperature, $^0C$;
$U_L$ - total coefficient of thermal losses in solar collector,W/m$^2$·$^oC$
($\tau$L) - optical efficiency.

One-contour thermosipon systems of solar hot-water supply can operate in two principally different regimes: with single and multiple heating of water in solar collectors (SC) [1]. Multiple heating is characterized by low temperature drop (about 10 C) on the solar collector. This circumstance essentially reduces the operational quality of the thermosiphon system due to the necessity to simultaneously heat the entire volume of water in the accumulator tank. Nonetheless, the method is widely used in practice because the circulation of the heat carrier in the solar contour under natural pressure is very reliable.

Under single heating the water from the accumulator tank passes through the SC once a day but at a large temperature drop (about 20-30 $^0C$). This regime is advantageous because of the low temperature of the water arriving at the solar collector while a flow with the required temperature is obtained at its outlet. This ensures higher serviceability and lover mean daily temperature of the collector and, all other conditions being equal, raises the available natural pressure in the solar contour, which makes it possible to raise the unit production of the installation [2]. The single heating operation mode is nevertheless seldom used because the estimates of its efficiency are rather contradictory [3,4].

The aim of this work is to define the influence of multiple circulation of the heat carrier on the efficiency of single-contaur thermosiphon systems.

Greater multiplicity of circulation in a thermosiphon system affects the daily efficiency in different ways. Thus, on one hand a greater number of cycles intensifies heat abstraction from the collector due to greater specific consumption of the heat carrier, and on the other hand it implies higher temperatures of the water feeding the collector.

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It is difficult to circulation multiplicity on the efficiency of thermosiphon system by comparing its daily production under the single- and multiple-heating regimes.

Suppose that the same amount of water with mass M and initial temperature $t_{in}$ is heated in the SC during a day which different mass flow rates $g_1$ and $g_2$ (Fig. 1), $g_1$ being the mass flow rate for which the entire mass M passes through the collector onece during the operation time $\Delta\tau$, while for $g_2$ it circulates n times. The finite temperature of the water in the tank $t_f$ is defined by the efficiency of SC operation in the compared variants. We assume that the SC works under stationary conditions and neglect the heat losses in the pipe lines and accumulator tank. We aslo suppose that for multiple heating the temperature separation in water layers is ideal.

For the thus stated problem the daily production of SC under a single-heating regime with mass flow rate $g_1$ is.

**a) b)**

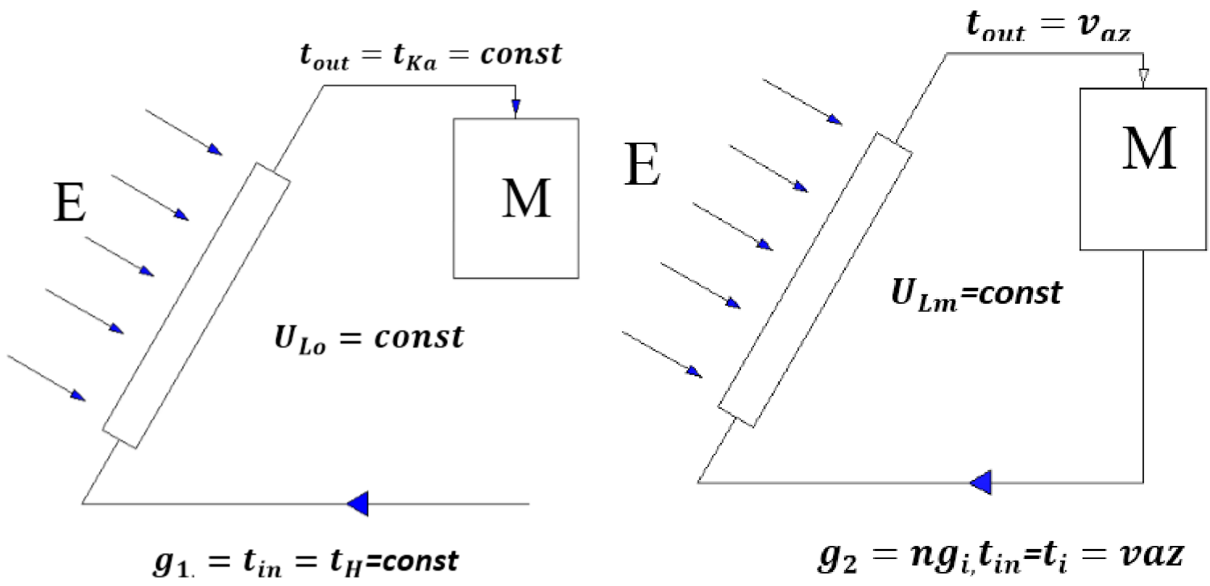


Fig. 1. Diagram of solar collector operation in (a) single –and (b) multiple-heating regimes.

$$Q_0=\frac{M_{cp}}{U_{Lo}}\left[1-exp\left(-\frac{U_{LO}\cdot F'}{g_1 C_p}\right)\right][E(\tau\alpha)-U_{LO}(t_{in}-t_F)], \qquad (1)$$

where $M=g_1\Delta\tau$ is the specific capacity of the accumulator tank in kg/m$^2$.

The daily production of heat in SC operating in a multiple-heating regime is defined as the sum of the the heats Q produced during n cycles of sigle heating with mass flow rate $g_2=ng_1$, i.e.

$$Q_m=\sum_{i=1}^{n} Qi=\frac{M_{cp}}{U_{Lo}}\left[1-exp\left(-\frac{U_{lm}\cdot F'}{ng_1 c_p}\right)\right]\sum_{i=l}^{n}[E(\tau\alpha)-U_{Lm}(t_{in}-t_{out})], \qquad (2)$$

or, taking into account

$$t_i=t_{in}+\frac{1}{U_{Lm}}\left[E(\tau\alpha)-U_{Lm}(t_{in}-t_{out})\left[1-exp[(i-L)]\left(-\frac{U_{Lm}\cdot F'}{ng_1 c_p}\right)\right]\right], \qquad (3)$$

we find

$$Q_m=\frac{M_{cp}}{U_{Lm}}\left[1-exp\left(-\frac{U_{Lm}\cdot F'}{g_1 c_p}\right)\right][E(\tau\alpha)-U_{Lm}(t_{in}-t_{out})].(4)$$

Dividing (1) by (4) we get

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$$\frac{Q_o}{Q_m} = \frac{U_{Lm[1-exp(-U_{Lo}\cdot F`)/g_1 C_p][E(\tau\alpha)-U_{Lo}(t_n-t_b)]}}{U_{lo}\left[1-\exp\left(-U_{Lm}\cdot F`\right)/g_1 C_p\right]\left[E(\tau\alpha)-U_{Lm}(t_{in}-t_{out)}\right]}. \quad (5)$$

It follows from (5) that the effect of the circulation multiplicity n on the efficiency of SC is only expressed in terms of the total loss coefficient $U_L$ which depends on the mean temperature of the absorption panel, and hence on n. For $U_{LO}=U_{LM}$ the number of cycles does not affect the daily production of heat in SC, $Q_0/Q_M=1$.

In order to find $U_{LO}$ and $U_{LM}$ we must knov the respective mean temperatures of the absorption panel $t_{no}$ and $t_{nm}$.The latter is dependent on the SC efficiency for single-and multiple-heating regimes, and hence the computation must be carried out by iterations [1]. To make our analysis simpler, we consider the limiting values of $U_L$ in the single- and multiple-heating regimes from 10 to 60 $^0$C using the data from [5]. We can assume that under a single heating with $g_1$-0 the mean temperature of the absorption panel is equal to that at the outlet of the collector, i.e.,$t_{no}=t_{out}=60$ $^0$C. Then for a common SC under the most unfavorable climatic conditions in the summer period (Wa=3.9-4.2m/s; $t_a$=12-20 $^0$C) $U_{LO}$=8.9 W/m$^2\cdot^0$C [5]. For multiple heating with $g_2 \rightarrow \infty$ *and* $n \rightarrow \infty$we can assume that $t_{nm}=0.5(t_{in}+t_{out})=35$ $^0$C, which means that for the same SC structure $U_{Lm}$=8.0 W/m$^2\cdot^0$C. Thus, for g and n the total loss coefficient $U_L$ for both heating regimes from 10 to 60 $^0$C differs by at most 10%.

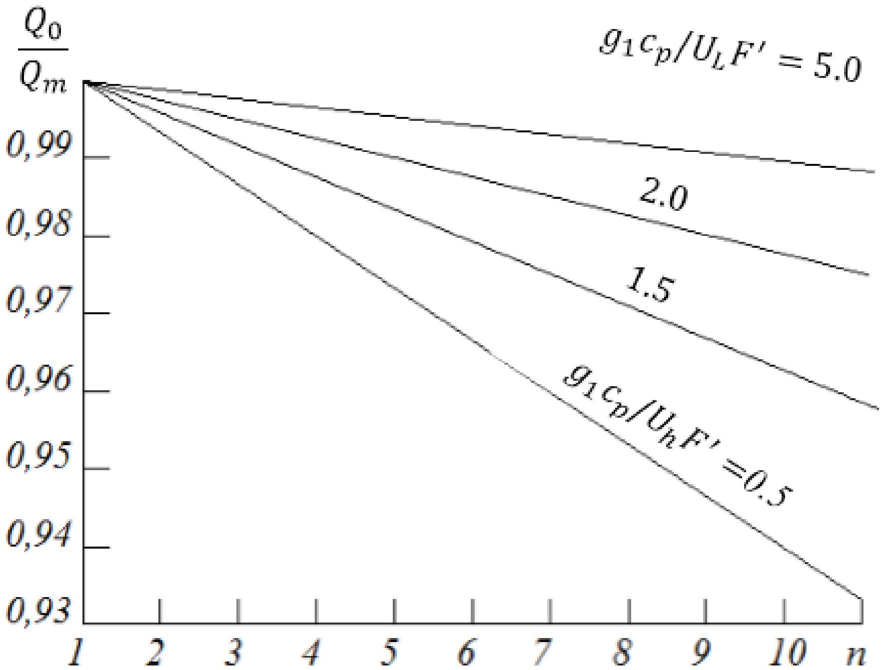


Fig.2.Daily productivity of the collector for signgle-and heating cycles as a function of circulation multiplicity for different values of the parameter $g_1c_p/U_LF`$.

We suppose that $U_L$ and $t_n$ are varying linearly and take into account that the first limiting case is valid for $g_1$=1-2kg/m$^2\cdot$hr and the second for $g_2 \geq$ 20kg/m$^2\cdot$hr [5], i.e., for $n \geq 10$., we can write.

$U_L=(1.01-0.01n)\, U_{Lo}$ for $1 \leq n \leq 11$ (6)

Substituting (6) into (5) and taking $t_{in}=t_{out}=10$ $^0$C,we find

$$\frac{Q_0}{Q_m} = (1.01-0.01n)\frac{1-\exp\left(-U_{LO*}F`/g_1C_P\right)}{1-\exp[-(1.01-0.01n)]U_{LO}F`/g_1C_P}(7)$$

It fllovs from Fig. 2 which plost the dependence (7) that the advantages of the multiple-heating regime decrease with the growth of $g_1$·For $g_1c_p>2U_{Lo}\cdot F'$ a heating with multiplicity n=10 raises the daily heat production of the SC only by 2% . We infer that further increase of $g_2$ will not essentially rise the heat production of the collector. This fast was also noted in [6, 7]. For small mass flow rates with the parameter $g_1c_P=0.5\, U_{Lo}\cdot F'$ ($g_1$ is approximately 3-4

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$kg/m_2 \cdot hr$) a considerable rise in the daily production of SC is observed for n>5, i.e., beyond the limiting circulation multiplicity (n=1.5-3) actual encountered in thermosiphon systems does not practically affect (the difference being no greater than 1.5%) the daily output of the solar collector.

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