

Solar collectors' operation methods effect on system efficiency

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Abstract

A control system has been designed for controlling the circulation pumps of a solar collector system depending on weather conditions.

To achieve the maximum efficiency of a solar collector system it is necessary to provide the optimum heat flow rate. Decrease in speed of heat flow leads to increasing heat losses in the pipes, especially between the solar collector and the accumulation tank. At the same time, increased flow rate reduces the efficiency of the heat exchanger, so the coolant flow will go at high temperatures thus causing increased energy losses.

The operation modes of solar collector systems were investigated at the Institute of Physical Energetics (IPE) solar energy testing polygon for different parameters. The most common types of solar collector operation modes were studied and compared: based on time, on the difference between the input and output temperatures of the heat carrier, on the solar radiation intensity, as well as control techniques in various combinations. The theoretical and practical advantages and disadvantages of using each control technique were analyzed and recommendations given as to the efficiency improvement.

Keywords: solar energy, solar collectors, operation modes/techniques.

1. Introduction

The operation modes of solar collectors and techniques for their control have been investigated at the IPE solar energy polygon for different parameters. The authors studied most common types of solar collectors and compared them. The theoretical and practical advantages and disadvantages of each control technique were analyzed.

Currently, a large number of companies offer solar collectors — about 1/3 of them offering a complete set fitted with all the necessary equipments for connection of a solar collector to the hot water supply or house heating systems. Only a few of trade companies make solar collectors operating in two or three control modes, with the main difference merely being the operation range of heat carrier pumps; and none of them offers solar collectors with control systems based on various parameters.

2. The operation modes of solar collectors

The control systems of solar collectors are designed for controlling the circulation pumps depending on the changing weather conditions. Solar collectors can be controlled manually or automatically. Automatic solar collectors can be operated: by the time; by the difference in temperatures at the input and the output; by the solar radiation intensity; using various combinations of the above mentioned techniques.

2.1. Operation by time

Except the manual operation mode, the weakest among the control techniques for solar collectors is the technique based on time. As a rule, equipment of such operation systems is primitive; it does not allow the use of an individual program for each day, so one and the same program is applied for all days of a solar collector's operation time.

Therefore, since the weekly average value of solar radiation varies and the sunshine hours differ, it is impossible to fully use the solar energy obtained in sunny days as well as the full time of a solar

collector's operation in the spring and autumn periods; the heat storage tank in such periods will be more cooled than heated.

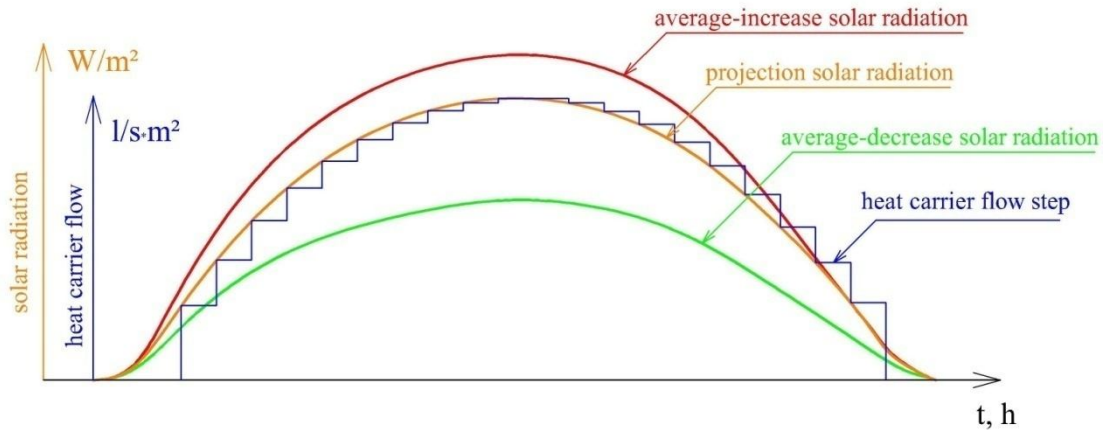


Figure 1 – Heat depending on the total daily average solar radiation value, and solar radiation deviations

Owing to the mentioned above flaws these solar collector operation types are not widely used anymore.

If the operation program could be determined for each day, still a serious disadvantage of these collectors would be the system's disability to take into account weather conditions and the energy amount that can be received from the collector workplace and respectively to adapt for all that. Therefore, in cloudy and rainy days such solar collectors would cool down the accumulation tank.

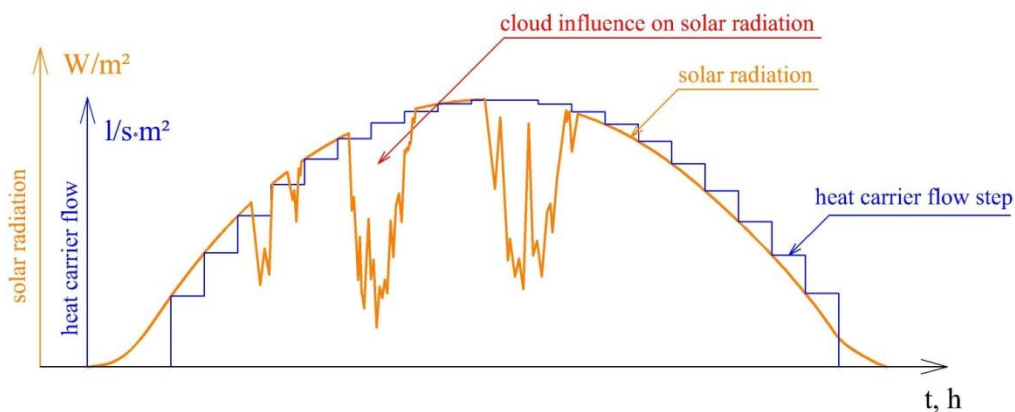


Figure 2 – Heat depending on the average solar radiation value of each day, and potential of solar radiation deviation of cloud activities

2.2. Operation by difference in the input and output temperatures

The operation of a solar collector based on the difference between the input and output temperatures two temperature sensors are required – one for measuring the input and another – the output temperature. The temperature difference is obtained if the heat sources are kept close to a solar collector, and, if we know the heat carrier flow value we can determine the energy produced by the solar collector. At the same time, if the heat source is located very close to the heat exchanger, to obtain the value energy produced by the solar collector the heat losses in pipes between the heat exchanger and solar collector should be taken into account. This technique is suitable for continuous heat carrier flows.

A system can operate by a temperature difference in the case when one heat temperature indicator is placed at the warmest point of the solar collector. If there is no such place, one of the heat temperature indicator is kept at the gate of the solar collector. This technique helps to determine the temperature of the heat carrier in solar collector even in the stationary phase. The second heat temperature indicator

should be placed in the water accumulation tank – the output pipe of the heat carrier. The pump is activated by a relay, which provides the necessary temperature difference. Unfortunately, this operation technique does not allow for account of the heat losses between the accumulating tank and the solar collector.

If this condition is not met, due to low temperature variations the heat pumps are often switched on and off, which leads to accelerated aging and measuring inaccuracies due to thermal inertia.

A third temperature sensor can be placed on top of the water heat accumulating tank; this sensor will send signal about the accumulation tank's overheating. In the case of overheating it is necessary to switch off the SC circulation pump, which will stop the temperature rise in the accumulation tank.

Nevertheless the temperature of a solar collector will rise sharply. The tests carried out at the IPE show that in the Baltic region during a stationary phase the temperature in some solar collectors in the sunniest days can climb up to 180 °C. Consequently, solar collectors in the Baltic Sea region are not at risk of overheating.

It is more profitable to use a temperature sensor with high thermal resistance even in our climate conditions when a short-term temperature rises above 140 °C (e.g. the PT100 or PT1000 platinum temperature sensors operating in the -200 °C to 850 °C range).

The task of the risk management is to determine the optimal temperature difference, reasoning from a compromise between the instantaneous system's performance benefits and the opportunity to adjust the solar collector operation; in fact, the system allows the maximum efficiency to be reached instantaneously.

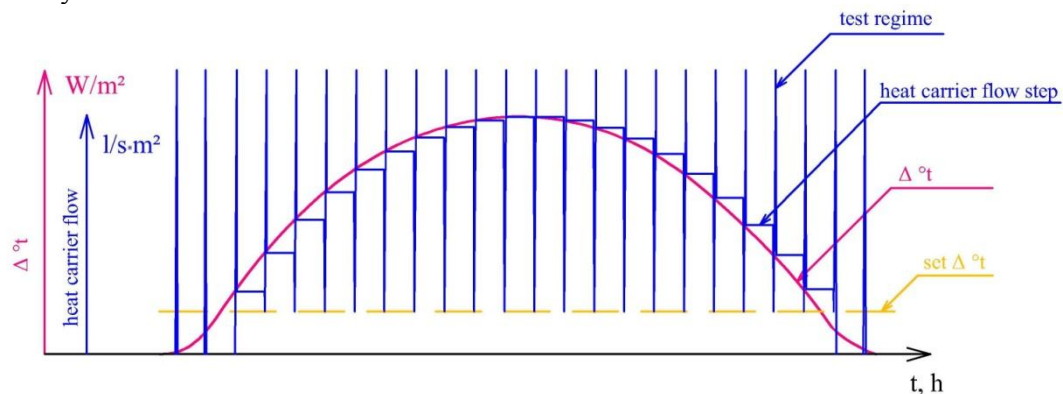


Figure 3 – Dependence of flow variations on the temperature difference at varying test conditions?.

For each step, the main energy losses and output were tested at different flow rates.

2.2.1. Operation by heat flow rate

To obtain the maximum efficiency it is necessary to provide the optimum heat flow rate. The heat flow rate fall increases the heat losses in pipes, especially in those between the solar collector and the accumulating tank. However, with increasing flow rate the efficiency of the heat exchanger decreases, and the coolant flow will be heated, which will lead to increased energy losses in all pipes.

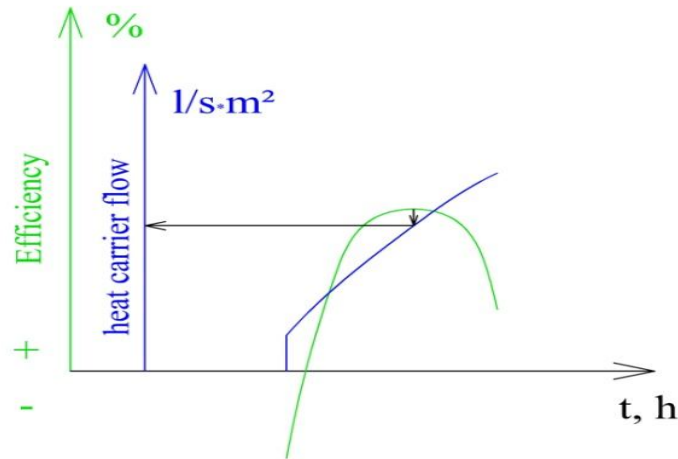


Figure 4 – The principle of automation control depending on the heating temperature difference

The heat losses may even be greater than the solar energy absorbed by a SC at too small or too large flow rates. Particularly large losses in the testing mode are associated with inappropriate weather parameters, when all the flow rates are under suitable for heat productivity. Therefore, the testing mode and the related heat losses, as well as deviations from the operational conditions of the system present the main weaknesses of this operation technique.

2.3. Operation by solar radiation intensity

Very seldom, only on a special order, the solar collectors are controlled by the heat source, i.e. by solar radiation intensity and the temperature of the accumulation tank bottom.

The operation by solar radiation intensity of a solar collector should be adjusted for the lowest boiler and outdoor air temperatures, with precisely determined its efficiency depending on the parameter variations. It is worthwhile to supply the system with the sensors of flow and return temperatures for precise calculation of the system size required for the flow, and for better accuracy and reliability of the estimates.

The amount of energy from the solar collectors can be described as:

$$q = c * m * \Delta t \quad (1)$$

where q is the amount of energy, c is the heat capacity of the substance, m is its mass, and Δt is the temperature difference;

as related to time, this formula will be:

$$\frac{q}{T} = \frac{c * m * \Delta t}{T}, \quad (2)$$

and the flow rate (i.e. quantity of the substance divided by time):

$$\frac{m}{T} = Q \quad (3)$$

In turn, the flow rate is:

$$Q = \frac{P}{c * \Delta t} \quad (4)$$

or

$$Q = \frac{P_s * \eta_c - P_{c.hl} - P_{p.hl}}{c * \Delta t}, \quad (5)$$

where P_s is the solar radiation intensity, η_c is the solar collector's absorption efficiency, $P_{c.hl}$ is the solar collector heat loss, and $P_{p.hl}$ denotes the piping heat losses;

hence:

$$P_{c,h-l} = (t_c - t_a) * K_c \quad (6)$$

where K_c is the solar collector heat loss coefficient, t_c is the temperature in the solar collector, t_a is the ambient temperature, and

$$P_{p,h-l} = \sum_{i=1}^n P_{p,h-l,n} = \sum_{i=1}^n (t_n - t_a) K_{p,n} \quad (7)$$

where t_n is the temperature in a given pipeline stage (e.g. at conditional or reversing flow), $K_{p,n}$ is the pipeline heat loss coefficient in a given stage [3].

Finally, we obtain the heat loss coefficient for single/one stage:

$$K_p = \frac{l}{\sum R} = l / \left(\frac{1}{\pi * d_1 * \alpha_1} + \sum_{i=1}^k \frac{1}{2 * \pi * \lambda_k * \ln \frac{d_{k+1}}{d_k}} + \frac{1}{\pi * d_2 * \alpha_2} \right) \quad (8)$$

Here l is the pipe length, $\sum R$ is the full thermal resistance of isolated pipeline, d_1 is the inner diameter of pipe, α_1 is the heat conductivity coefficient for inner surfaces, λ_k is the heat conductivity coefficient for a given pipe layer, d_k is the inner diameter of a pipe layer, d_{k+1} is the outer diameter of a pipe layer, d_2 is the design diameter of the insulation, α is the design thermal conductivity of the insulation surface.

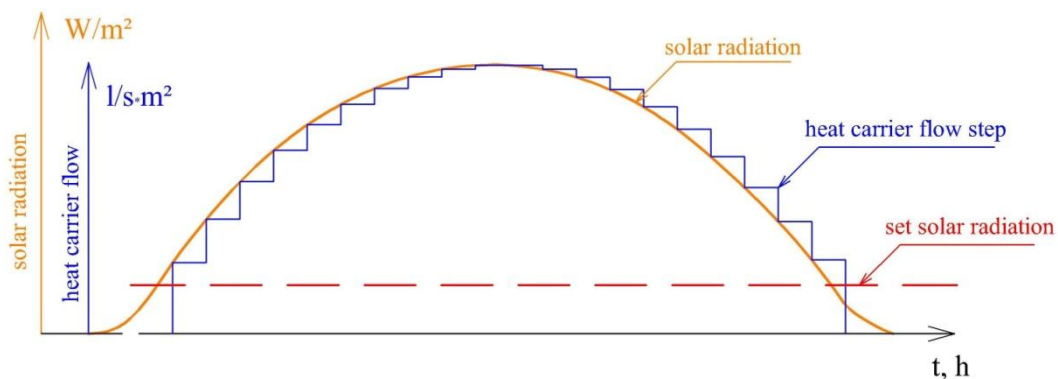


Figure 5 – Dependence of heat flow variations on solar radiation

The accuracy of solar collector operation (not taking into account the heat losses and the solar collector output calculation accuracy) depends on that for: the solar radiation metering, interval between the adjustment times, and, as before, the heat pump productivity.

The main weaknesses are: no data on the solar collector output for different values of solar radiation and solar collector heat losses. These are due to imprecise heat loss calculation, high cost of solar radiation measuring instruments, fast erosion processes, the necessity of regular calibration, etc.. At the IPE solar energy polygon also series of experiments have been carried out to determine the solar collector output for different values of the solar radiation intensity and solar collector heat losses.

3. Conclusions

To achieve the most possible efficiency of a solar collector system the automation is required that would regulate the capacity depending on weather conditions.

The more precise method of solar collector operation is combination of techniques by heat carrier temperature differences and by solar radiation intensity.

The automation accuracy depends on the complexity of a system. By contrast, the complexity of a system makes it less protected from damages and increases its cost. It is possible to get accurately determined the solar collector system activation time and the required capacity without energy use for the testing regimes if it is used the latest automated technology.

The automatically operating systems are especially important for the regions with low solar radiation.

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