Stagnation Behaviour of Thermal Solar Systems

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Abstract

The stagnation behaviour of thermal solar systems is now much better understood than in the past. On the basis of the measurements performed, the stagnation procedure generally can be divided into five typical phases, apart from differences arising from differences in the type of plant. In phases where steam occurs energy is transported very effectively from the collector to other system components and leads to high temperature loads.

Solar systems should be constructed in such a way that at the end of the phase where liquid is pushed out of the collector the residual content of liquid in the collector is as low as possible in order to minimise the thermal loads on system components and the heat transfer fluid.

In addition measures will be shown to minimise the volume of steam and the thermal load on the system components.

Introduction

In combi-systems in particular (domestic hot water and heating support) long periods of standstill occur in the summer with phenomena with regard to the standstill behaviour the causes of which have only recently been clarified to an increasing extent. The former include high temperature loads and the failure of system components as a result of these and leaks in the pilot plant, the opening of the pressure control valve although the design guidelines common with regard to the size of the expansion vessel and the pressure conditions were observed and the development of noise as a result of condensation pressure shocks in the primary and secondary circuit.

Within the framework of a project sponsored by the EU (the CRAFT-JOULE programme) in co-operation with AEE INTEC - Arbeitsgemeinschaft ERNEUERBARE ENERGIE, the Fraunhofer ISE and the companies Sonnenkraft, Solvis, Technische Alternative, Tyforop and Scherzinger Pumpen, measurements were carried out on problematic combi-systems the results of which have already been reported on /1/ /2/ /3/.

Stagnation procedure

The procedures during stagnation can in principle be divided into five different phases on the basis of a simplified collector model.

- **Phase 1** – the expansion of liquid.

- **Phase 2** – pushing the liquid out of the collector via the **first** formation of saturated steam. Liquid which is almost at the temperature of ebullition puts a strain on the system components.
- **Phase 3** – emptying of collector by boiling – phase with **saturated steam**. The residual liquid in the collector evaporated and transports the energy very effectively to other system components under steam which likewise reach the temperature of ebullition which is determined by the pressure and the local composition of the heat transfer medium. The steam expands in such a way that the energy transported out of the collector can be released to the environment respectively to components (e. g. heat exchanger) via the formation of condensate. At the end of phase 3 the plant pressure reaches its maximum value.
- **Phase 4** – emptying of collector by boiling – phase with **saturated steam and overheated steam**. The collector becomes increasingly dry, it overheats and this causes the rate of efficiency to drop. As a result the steam volume can fall even further and withdraws to the collector area despite the fact that solar irradiation continues. In this way the system is partly refilled. This condition can continue to be stable for a very long time. With corresponding collector designs (collector connection via which the collector is filled up again lies on the top) saw tooth like pressure fluctuations of a higher amplitude can occur.
- **Phase 5** – refilling of collector. This is done when the collector temperature is below the temperature of ebullition as a result of a reduction in the solar irradiation.

Critical phases

The course of phases 2 and 3 determines the maximum system load. Those liquid remains at the end of phase 2 (in which the collector is largely accessible to steam – the remaining liquid can then no longer be expressed by steam), determine the length and intensity of phase 3. The evaporation of the remaining liquid which now follows keeps the collector for the greater part at the temperature of ebullition with a comparatively high rate of efficiency. This leads to large streaming out amounts of steam which reach a maximum level at the end of phase 3. Once the evaporation of the remains has been completed the hole collector can reach its maximum stagnation temperature and thus no longer release any energy into the system (around the middle of phase 4).

The emptying properties of the collector during phase 2 are thus essential for the stagnation behaviour of the plant – figure 1.

Figure 2 shows the frequencies of temperatures during a half-year period measured at different points in the system with a collector which does not empty well. The maximum temperatures in the heating room equalled around 150°C in this period, around 210°C in the absorber strips and around 170°C in the collector header pipes.

These maximum values lasted for around 26 hours at the measuring point „collector outlet line - cellar“, and around 10 hours for the measuring point „collector inlet line - cellar“. The formation of steam, which occurs frequently, is also apparent on the secondary side of the heat exchanger („heat exchanger sec. outlet“). The maximum temperature which occurred in the inlet to the expansion vessel equalled around 150°C and the maximum temperature of the liquid in the expansion vessel around 105 °C.

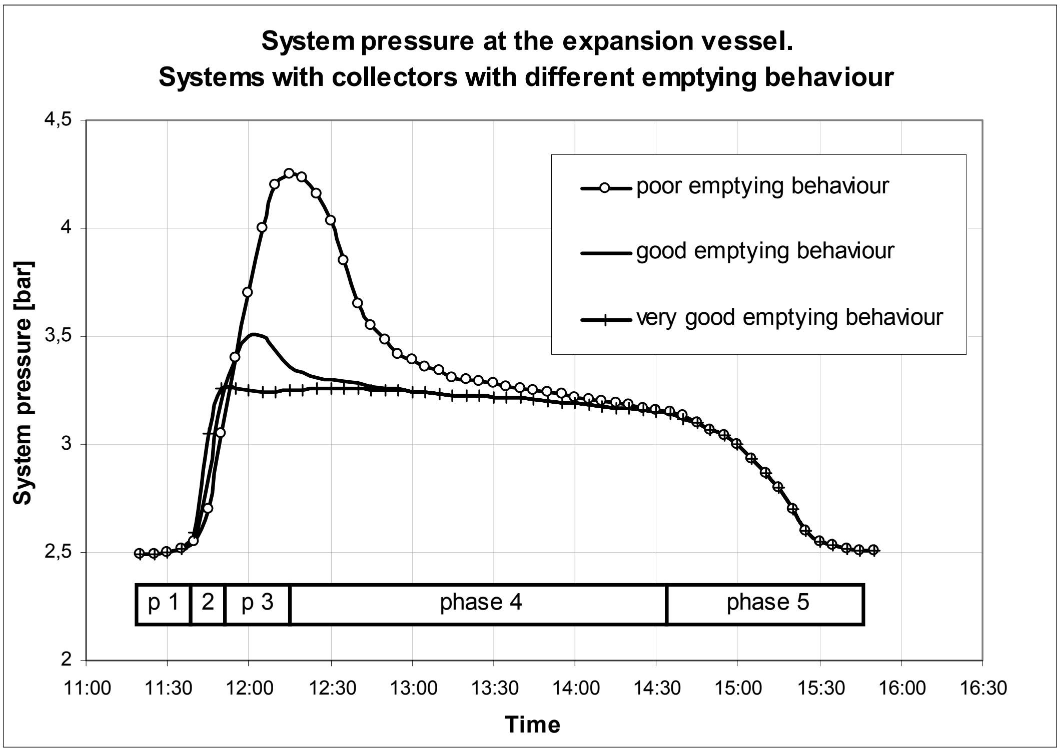


Figure 1: System pressure in the case of stagnation for collectors with a different emptying behaviour, depicted by way of example and in schematic terms. The systems and collectors are the same – with the exception of the emptying behaviour. A high pressure also means a high range of the steam and thus a high risk that system components will have to bear the strain of the temperature of ebullition. The stagnation phases are illustrated given the example of a collector which has not been emptied effectively. In this example a pressure of around 3.2 bar corresponds to a steam volume which only encompasses the collector area. In the event of pressures higher than this the steam also reaches more distant parts of the system.

These results show clearly that the real temperature loads in commonly available solar systems in the event of stagnation can lie above the limits recommended by the component manufacturers and this can lead in turn to damage to components respectively to a reduction in the service life of the plant and in turn to unsatisfied customers.

Emptying behaviour of collectors

Thus the emptying behaviour of collectors determines the frequency, range, height and duration of the maximum temperature load of the system and of its components.

Collector pipeworks should have a good emptying behaviour in terms of non-problematic stagnation behaviour. Collectors with a good emptying behaviour minimise the amount of residual liquid and thus reduce the period of time and extent of the critical stagnation phase 3.

A collector example with poor emptying behaviour is given in schematic terms in figure 3. The connection of the inlet and outlet lines takes place right at the top of the collector and the absorber pipes are laid „down and upwards“. This type of circuitry does not lead to good emptying behaviour as a result of the liquid sack which forms since large parts of the collector content cannot be expressed in liquid form but rather they have to evaporate. This leads to large amounts of energy which are transported through steam in the event of stagnation and thus to large areas with saturated steam in the system. In turn the pressure develops in the way shown in figure 1 which is described as „poor emptying behaviour“. In addition the probability of condensation pressure shocks increases /3/.

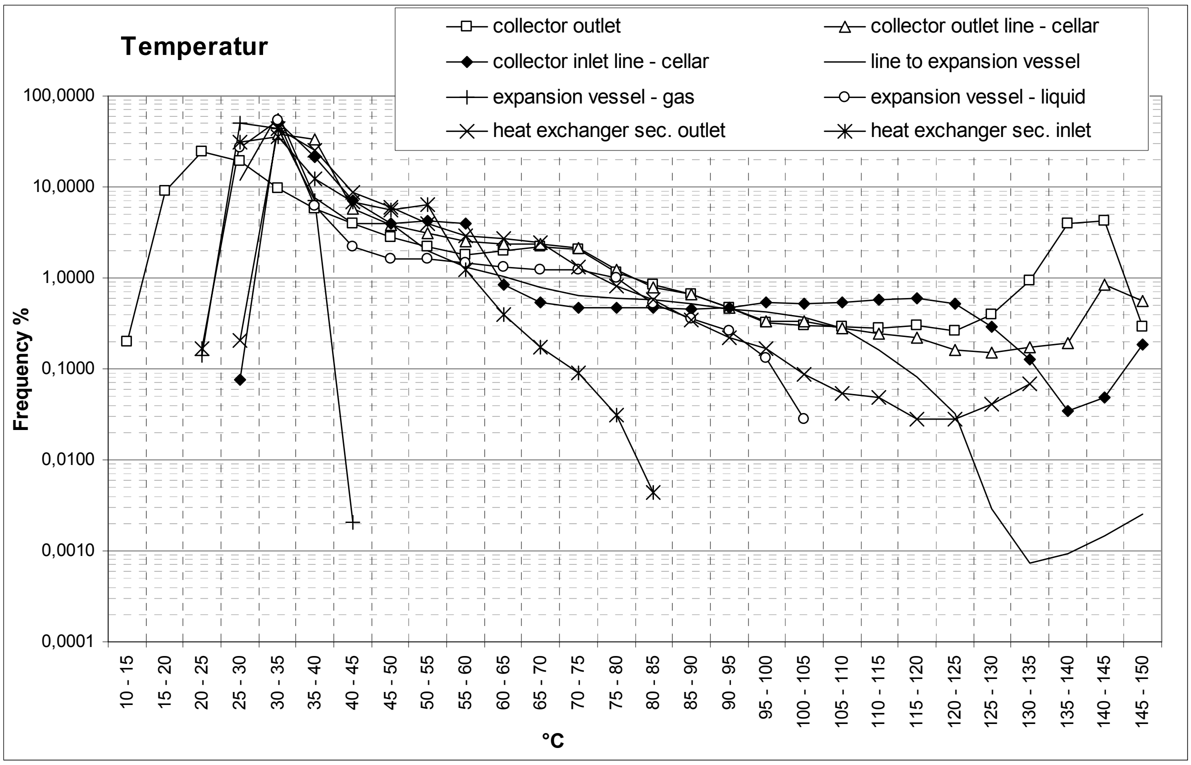


Figure 2: Frequencies of different system temperatures during a half-year period (May to September) of a combi-system with a collector with poor emptying behaviour. A frequency of 1% corresponds to 36.7 h, 0.01% corresponds to 22 min.

In the further course of phase 4 longer-lasting saw tooth like pressure fluctuations could occur when small amounts of liquid flow into the overheated absorber pipes and evaporate once again. The measurement did, however, show that the maximum pressures which occurred are smaller than the maximum value which occurs at the end of phase 3.

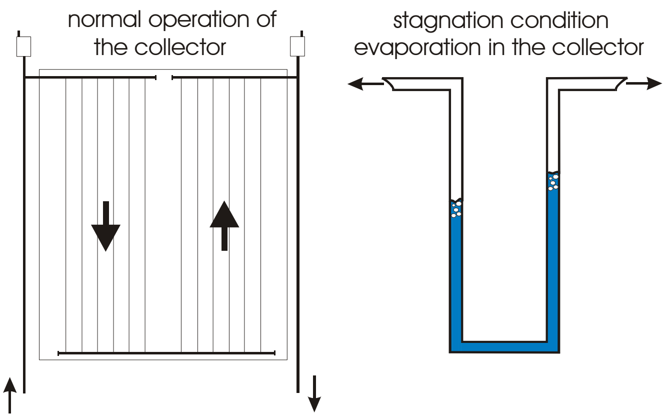


Figure 3: Schematic example of a common collector circuitry with poor emptying behaviour (on the left the normal function of the collector is shown, the right-hand shows in simplified terms the condition of steam formation in the collector).

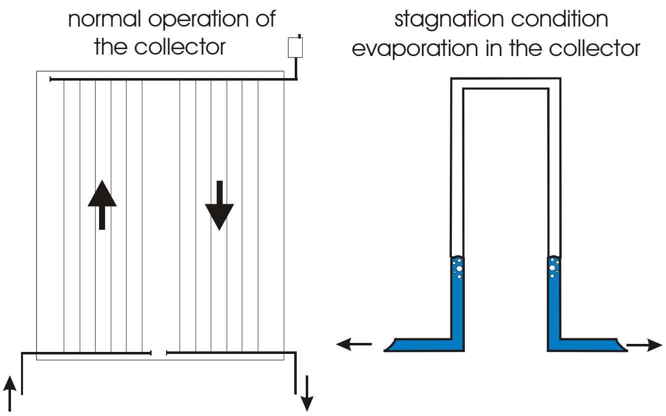


Figure 4: Schematic example of a collector circuitry with good emptying behaviour (on the left the normal function of the collector is shown, the right-hand shows in simplified terms the condition of steam formation in the collector).

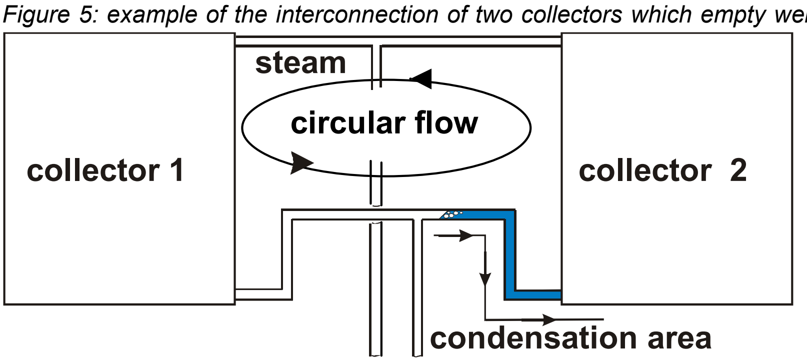
The collector circuitry shown schematically in figure 4 reveals a much more favourable emptying behaviour. The coupling of the inlet and outlet lines is performed at the bottom on the collector. Given a corresponding design this can help to make the driving out of the liquid medium in phase 2 better than was the case in the circuitry shown previously. With a persistent design the duration and extent of the critical stagnation phase 3 can be reduced even further so that the areas with saturated steam only reach to just below the collector level. This produces the pressure development described in figure 1 as “very good emptying behaviour”.

Emptying behaviour of collector fields

Good emptying behaviour in individual collectors does not yet guarantee a good emptying behaviour of fields of such collectors. Here the basic principles also have to be observed. If the connecting lines of the collectors are not laid in a favourable manner good emptying behaviour can become poor.

In the example given in figure 5 compared to figure 6 the inlet line connection is partially installed vertically. At the end of phase 2 this leads to one of the two collectors becoming accessible to steam as a result of slight individual differences, which is given preference. This results in a steam-liquid circuit which for a long time supplies liquid for the collector not yet fully emptied by condensing the steam in the condensation stretch of pipe. This also leads to a greater volume of steam in the remaining system.

Figure 5: example of the interconnection of two collectors which empty well with poor emptying behaviour of the overall collector circuitry. The circular flow which arises supplies liquid for a longer period of time which leads to the further formation of steam in one of the collectors.



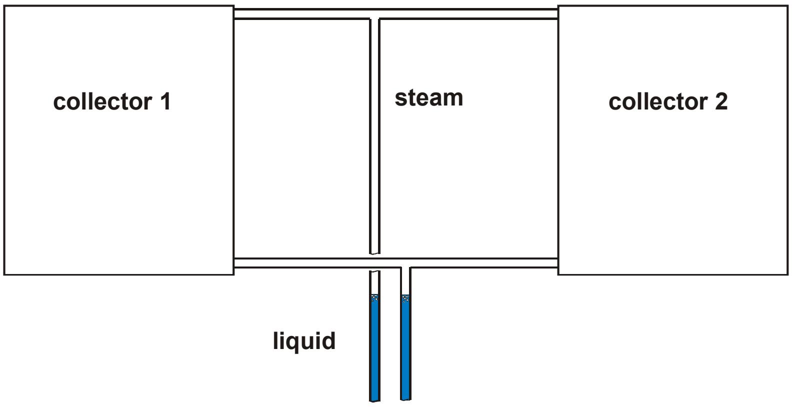


Figure 6: Example of the interconnection of two collectors which empty well with good emptying behaviour of the overall collector circuitry. Here the two collectors can empty nearly independently one of the other in phase 2.

Influence of system hydraulics on the emptying behaviour of collectors

The emptying behaviour of collectors is considerably influenced by the positioning of the return valve in relation to the arrangement of the membrane expansion vessel and the check valve. If the arrangement of the components in the return group is as in figure 7 (right-hand side) then emptying can only be performed via the collector outlet line in the stagnation condition. This results in a lot of residual liquid. The resulting large amount of steam has in addition only the collector outlet line at its service for the release of heat so that steam can penetrate very far into the system.

On the other hand the collector inlet line remains filled with liquid up to the entrance to the collector due to the position of the return valve.

The condition for the good emptying behaviour of collectors in the event of stagnation can be achieved via the arrangement of the check valve in relation to the connection to the expansion vessel as in figure 7 (left-hand side). In this arrangement the content of the collector in the event of stagnation can be driven out into the expansion vessel via both the collector inlet and outlet lines whereby much less residual liquid is left over. In addition the amount of steam streaming out is divided up between this both lines.

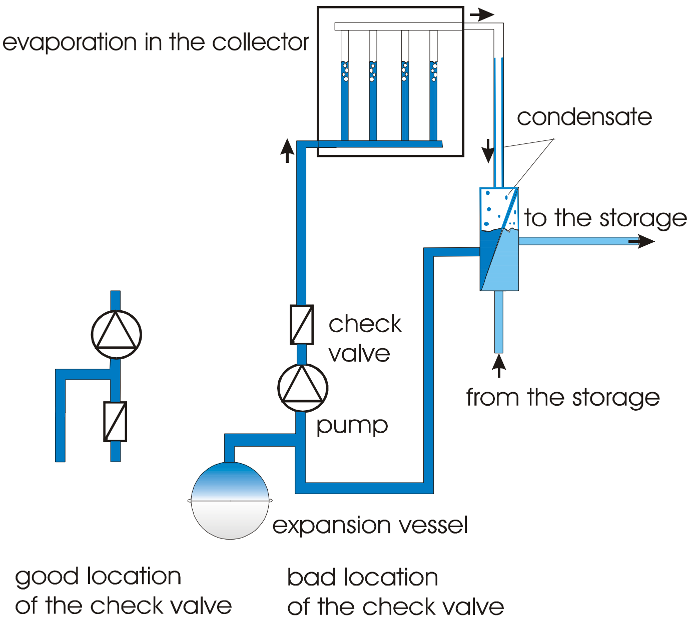


Figure 7: Arrangement of essential components of the primary solar circuit. If the collector inlet line is not available to empty the collector (right: check valve is arranged in the course of the collector inlet line in relation to the connection of the expansion vessel) this will lead to a drastic deterioration of the emptying behaviour of a collector which originally empties well.

Steam power

Measurements of the maximum power of the steam emerging from the collector at the end of phase 3 quantified the different emptying behaviour of different collector types: Whilst in collectors of the type schematically shown in figure 4 (e. g. a serpentine absorber with an entrance lying at the bottom and an exit lying at the top) short-lasting maximum steam performance values of around 20 W were observed for each m² of collector area, collectors of the type shown in figure 3 revealed (e. g. absorber with horizontal absorber pipes and header pipes leading upwards on both sides with an overhead entrance and exit point; vacuum collectors with u-shaped absorber pipes connected overhead were particularly unfavourable) long-lasting maximum steam performance values of up to 120 W for each m² of collector area; see also figure 1.

If one compares this with the specific heat losses of common insulated collector inlet and outlet lines at saturated steam temperature (e. g. for small domestic hot water plants around 20 - 25 W/m), then one can see that with collectors with good emptying behaviour in small plants the steam range (a few m) does not represent a problem. On the other hand collectors with poor emptying behaviour can even enter the critical range with small domestic hot water plants (e. g. 6 m² of collector area) since steam ranges of around 20 – 30 m pipe can be reached here and temperature-sensitive system components can be influenced. In combi-systems in particular with much larger collector areas these problems can increase.

Dimensioning of membrane expansion vessel

To make sure that in the case of stagnation the safety valve does not react, the overall steam volume (within the collector and the steam volume expected in the inlet and outlet pipes and components) is to be included in the calculations. By this way losses of heat transfer medium can be avoided.

Loads on heat transfer medium

The glycol component in the heat transfer medium and the inhibitor additives become unstable during high temperatures and can change (degradation, flocculation, formation of solid residues). The normal function of the plant represents no essential load for the heat transfer medium. However, longer lasting loads with higher temperatures which might occur in the event of stagnation are to be avoided as far as possible to prevent the premature ageing of the heat transfer medium.

Collectors with a good emptying behaviour largely comply with this requirement. With the system pressures common in solar plants of around 1.5 to 3.5 bar, ebullition temperatures of around 130 °C to a maximum of around 155 °C are reached which only have a short-term influence on a small amount of the liquid heat transfer content given good emptying behaviour.

With poor emptying behaviour the residual liquid is exposed to this temperature of ebullition for a longer period of time. This results in the preferred evaporation of water (fractional distillation) with corresponding increases in the concentration of glycol and inhibitor components in the residual liquid. This results in a local increase in the temperature of ebullition. This can go so far that the highly concentrated residual liquid then no longer evaporates and is exposed to extremely long high temperature loads (for the purely glycol components the ebullition point exceeds 210°C with the usual pressures in the case of stagnation) with corresponding significant ageing procedures.

The load on the steam phase within the collector with the standstill temperature should not represent any serious problem since this steam mainly contains water (fractional distillation) and only affects very small amounts of substance.

Measures to improve the stagnation behaviour given an unfavourable emptying behaviour

In the event that unfavourable framework conditions (e. g. unfavourable laying of pipes as a result of prescribed geometric conditions in the building) do not provide any opportunity to obtain optimum emptying behaviour different measures can bring about an improvement in the stagnation behaviour. More details were given about this in /3/. These are as follows:

- avoidance of stagnation condition using night cooling
- concerted removal of energy transported via the steam in the event of stagnation with
    - a small-volume heat sink with a large surface or
    - the controlled use of the external heat exchanger and the secondary circuit pump.

The last measures only protect system components prior to higher temperatures, the high load to the heat transfer medium is not reduced by this. With the first and last measure supplementary energy has to be used to lead off excess energy. This reduces the overall efficiency of the solar plant.

Examples of the use of a simple small-volume heat sink with a large surface which becomes effective automatically in the case of stagnation only and without the use of supplementary energy, are given in figure 8. In this respect the heat sink has to be arranged around 2 m or more above the level of the components to be protected.

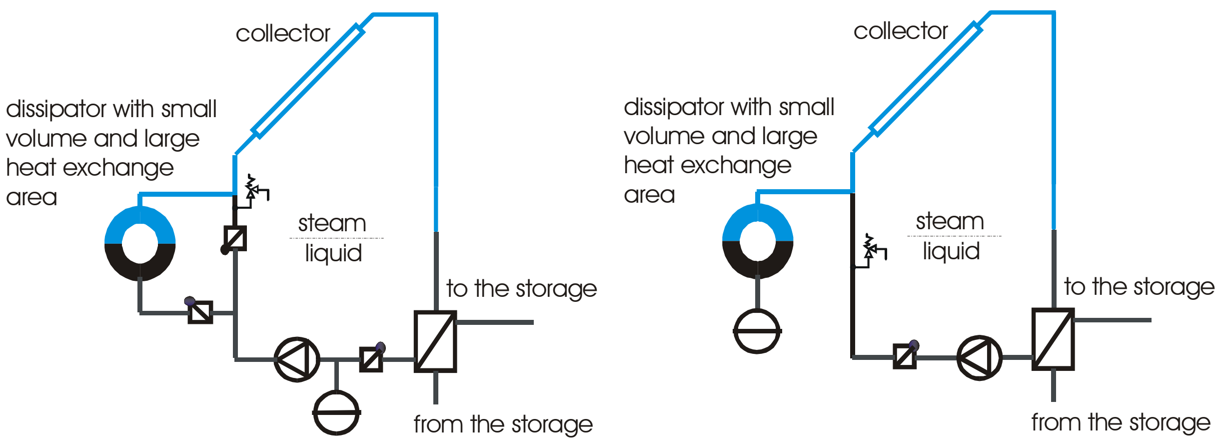


Figure 8: If the emptying behaviour of the collector cannot be improved, a simple automatically controlled air cooler in the primary solar circuit can limit the steam volume.

Literature

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