STAGNATION BEHAVIOR OF THERMAL SOLAR SYSTEMS

Robert Hausner and Christian Fink
AEE - Arbeitsgemeinschaft ERNEUERBARE ENERGIE, Feldgasse 19, Gleisdorf, A-8200, Austria,
Tel.: +43 3112 5886, Fax: +43 3112 5886 18, E-mail: r.hausner@aee.at, c.fink@aee.at

Abstract – The standstill behaviour of three thermal solar combi-systems was measured during a summer period. 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. These phases are: phase 1: liquid expansion, phase 2: pushing the collector empty, phase 3: emptying of collector by boiling - phase with saturated steam, phase 4: emptying of the collector by boiling - phase with saturated steam and superheated steam, phase 5: refilling the collector. At the end of phase 3 maximum temperature and pressure loads to the system components occur. In line with the principle of the heat pipe energy is hereby transported very effectively. Solar systems should be constructed in such a way that the liquid content of the collector at the end of phase 2 is as low as possible in order to minimize the thermal load to system components.

1. INTRODUCTION

The standstill behaviour is very important for the long-term, reliable and low-maintenance operation of thermal solar plants. Particularly when it comes to applications for the support of solar heating systems, the standstill behaviour becomes important for manufacturers and operators since these plants are very frequently shut down in the summer since their capacity cannot be fully utilised. This operating state places all the components in the collector circuit under considerable stress, a stress quite different to that encountered in normal operating conditions.
The behaviour of thermal collector systems in a shut-down state was, therefore, the subject of an examination within the framework of the project supported by the EU »Stagnation Technology for Thermal Solar Systems«" (CRAFT-JOULE programme) with the companies Sonnenkraft, Solvis, Technische Alternative, Tyforop and Scherzinger Pumpen in co-operation with Fraunhofer ISE and the AEE - Arbeitsgemeinschaft ERNEUERBARE ENERGIE. These tests aimed at finding out more precisely how temperatures and pressures develop in the system in standstill conditions. The aim was to support companies to further develop their plants and components in terms of unproblematic and reliable standstill behaviour. To this end, measurements were carried out by the Fraunhofer ISE on test systems and the AEE carried out „in-situ" measurements on three field plants covering two summer periods.
The following report gives the results and findings from the first measurement period from the measurement series conducted by the AEE on the three field plants.

2. MEASUREMENT CONCEPT

Three problematic combi-systems were selected in one-family homes of a representative size and with a representative plant hydraulic system, but with a different collector hydraulic system, and fitted with a measuring system. Initial measurements (first measurement period) were then carried out over a few months in the summer. In this respect the following were recorded:

- Solar radiation at the collector level and the ambient temperature
- The distribution of temperature in the collector field, numerous temperatures in the inlet and outlet lines, on the expansion vessel and on the heat exchanger in the secondary circuit
- The pressure in the inlet and outlet and on the expansion vessel
- The flow speeds in the inlet and outlet.

Figure 2 gives the example of a hydraulic circuit (correct scale geodetic heights) of a plant measured with a gross collector area of 44 m² (flat collectors) and a storage tank of 4,5 m³ with the measuring points sketched in. Figure 1 gives the Southern view of the building belonging to this.

Figure 1: Southern view of a measured system (one family home)

The goal of these measurements was to quantify respectively explain the standstill phenomena observed such as

- High temperature loads through to areas in the pilot plant area and any malfunctions of system components resulting from this as well as any possible leaks
- Opening of the pressure control valve although the usual design guide-lines have been adhered to with regard to the size of the expansion vessel and the pressure conditions (Eder, Fink, Streicher, Themeßl, Weiß, 1997)
- Condensation pressure shocks in the primary and secondary circuit of the solar plant

As well as to elaborate adjusted/adapted planning and design guide-lines.

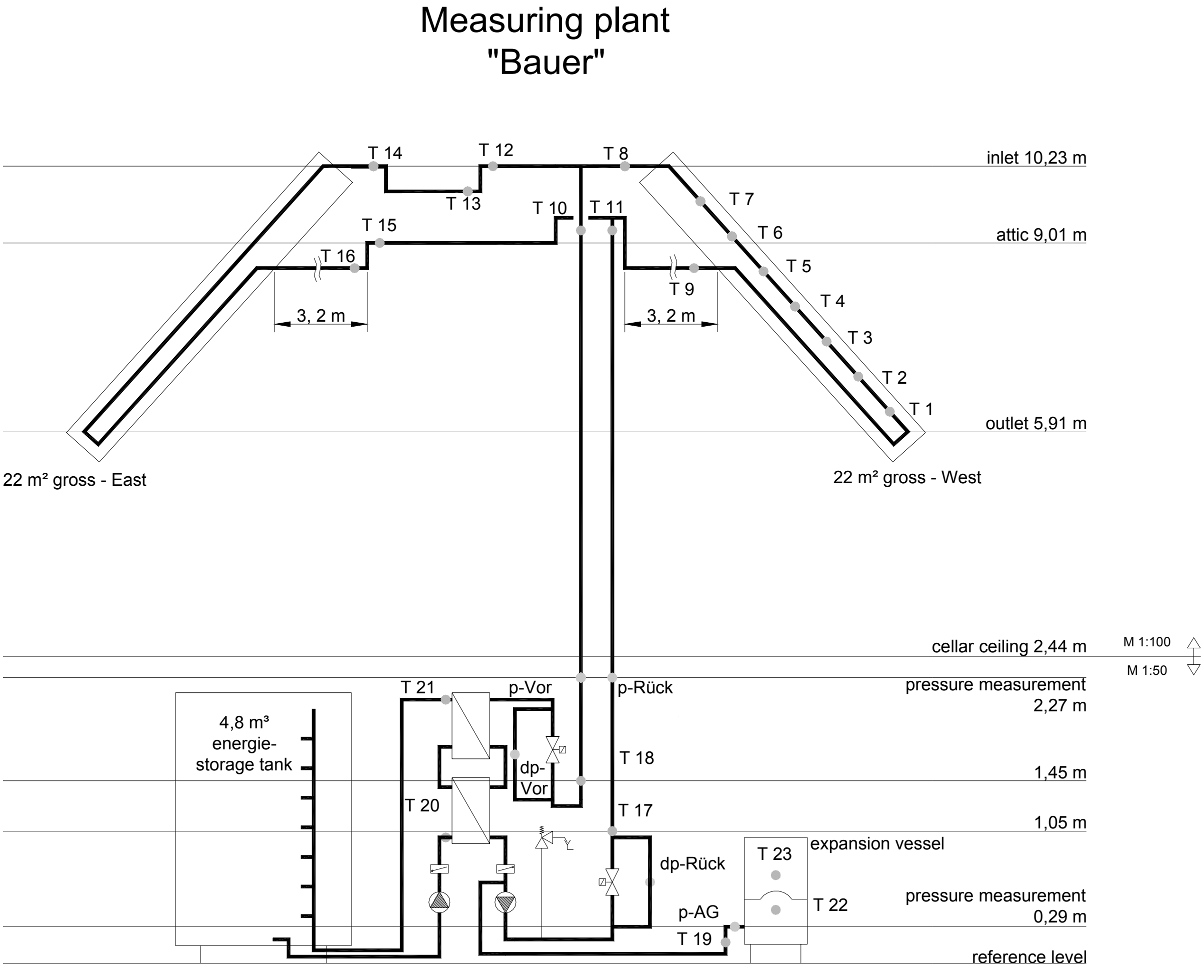

Figure 2: Hydraulic and measuring concept of a plant with a collector area of 44 m² and an energy storage tank volume of 4,5 m³.

3. PROCEDURES DURING STAGNATION

On the basis of the measurements performed (Fig.3), the stagnation procedure generally takes the form of the scheme which follows, divided into several phases, apart from differences arising from differences in the type of plant, that the arrangement of the flap trap in the evaporation process allows the expansion vessel to be filled with liquid both from the inlet as well as from the outlet line.

3.1. Phase 1: Liquid expansion

After disconnecting the collector circuit and the secondary circuit pumps from the normal operating condition, the collector temperatures rise again quickly in a regular manner until such time as the evaporation process begins in the upper area of the collector on one part of the absorber strip. Up to this point, the increase in the system pressure is only very slight.

3.2. Phase 2: Pushing the liquid out of the collector

The beginning of evaporation complies with the boiling point which results from the local pressure predominating at this point on the collector. Initially the boiling point is relatively low.

A small portion of the medium evaporates and pushes a larger share of the liquid content of the collector out until such time as the inlet and outlet lines are immersed in saturated steam. The pressure rises relatively quickly as a result of this since large amounts of liquid are pushed into the expansion vessel. With a simple collector hydraulic system with – in the direction of flow – only horizontal or rising pipe pieces, the larger share flows via the outlet line (return line) (content of collector) and the smaller share via the inlet line (communicating vessels). With more complex collector hydraulic systems – a mixture of rising, horizontal and falling pipe pieces – the emptying behaviour also becomes more complex.

The system pressure rises rapidly in this phase as does the boiling point in the area filled with saturated steam. These phase ends when there is a continuous path for steam from the collector inlet to the outlet. This phase lasts for only a few minutes.

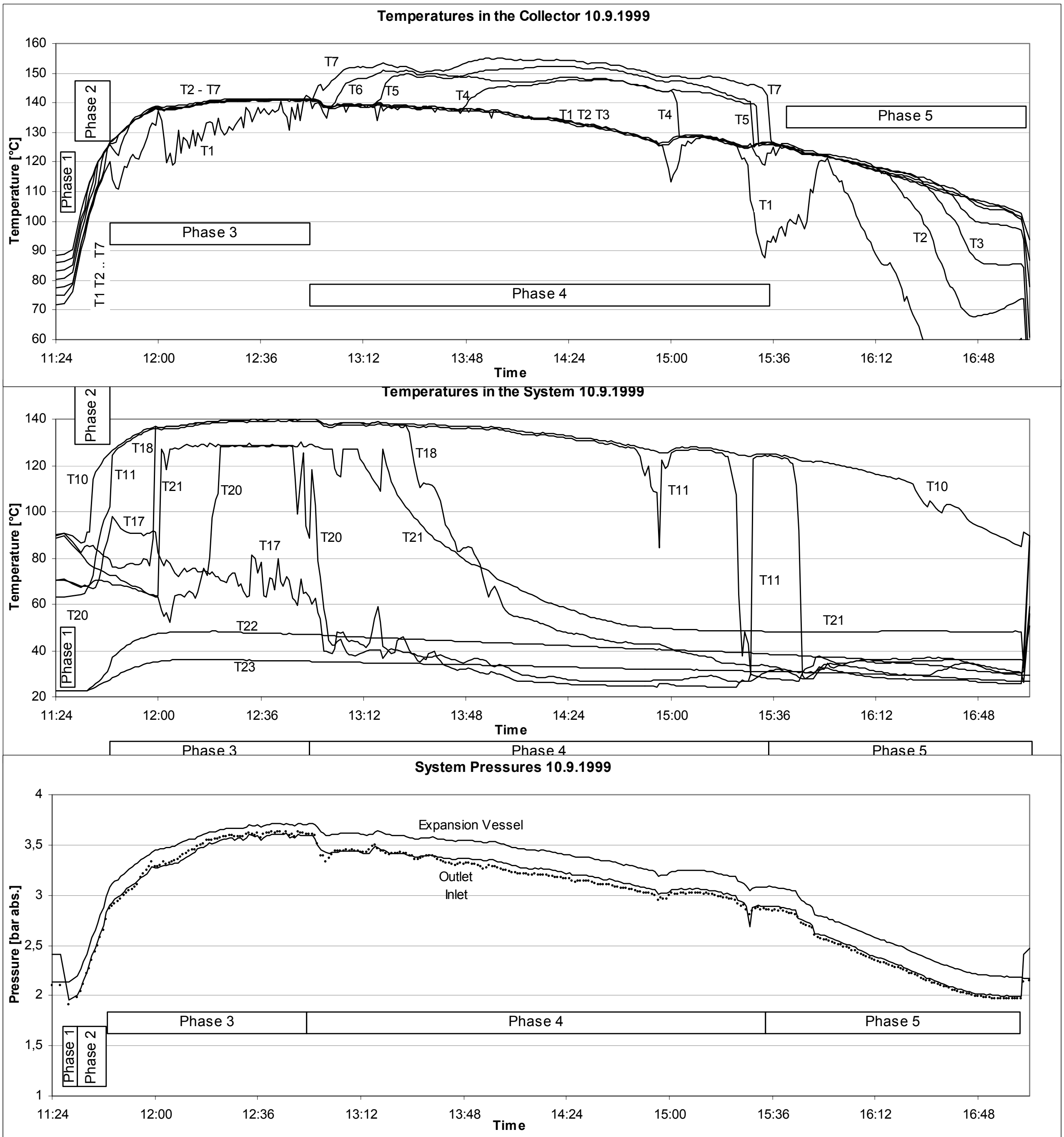

Figure 3: Example of measured temperatures and pressures for a cloudless day (measuring plant "Bauer"). Solar radiation at the collector level approx. 900 W/m² at maximum. Curve identifiers refer to Fig. 2. The system was initially filled with pure water. Therefore the temperatures of all components reached by saturated steam are very similar (±1K).

At the start the temperatures of the outlet and inlet lines in the heating room and the inlet line to the expansion vessel are low (cooled down following the pump standstill) and then later on they rise (hot collector content), however, they never reach the original high collector temperatures due to cooling down losses in the lines. If these lines are short and have low cooling down losses then non-permissible high temperature loads can occur in the expansion vessel and other system components particularly when with a highly selected system pressure evaporation does not start until the temperatures are higher. Long and non-insulated lines to the expansion vessel reduce the temperature load of the latter quite considerably.

3.3. Phase 3: Emptying of collector by boiling - phase with saturated steam

This is the phase when the rise in pressure slows down. A smaller but not insignificant share of the content of the collector is still present in the absorber and collecting pipes in liquid form. In this phase either a liquid medium, or saturated steam in equilibrium with liquid are observed at all measuring points. The inlet and outlet lines are increasingly pressed empty downwards in the direction of the heating room with about the same level of liquid (communicating vessels) and the heat exchanger can be reached by steam. This also causes steam to form on the secondary side of the heat exchanger. The pressure on the expansion vessel reaches its peak value and thus also the temperature of ebullition.

The energy led off from the collector by means of steam (this results from the collector efficiency rate at high temperatures and with due consideration to the stored energy) is always in equilibrium with the heat losses of the area under steam in the pipelines, fittings and on the heat exchanger. In line with the principle of the heat pipe energy is hereby transported very effectively at what is almost a constant temperature from the source of heat to all heat sinks whereby the steam condenses again here and runs off down the way in liquid form. The differences in temperature between the source of heat (collector) and the heat sink (e. g. heat exchanger) are small (on a scale of a few K) since there are only slight differences in pressure (flow pressure losses with regard to steam, but differences in concentration also exist in the system water-glycol – fractionated distillation). This means that the maximum pressure reached (on the phase border between steam - liquid) determines the maximum temperature load of the plant components reached by the steam in accordance with the relation of pressure – temperature of ebullition (Scheffler, Straub,, Grigull 1981) (Tyforop, 1999).

At the beginning of this phase the temperatures of the outlet and inlet lines in the heating room and the inlet pipe to the expansion vessel fall since the steam area now increases in size much more slowly and the lines filled with liquid cool down. A sudden rise in temperature up to the boiling point occurs only when steam occurs in these places.

3.4. Phase 4: Emptying of the collector by boiling - phase with saturated steam and superheated steam

The liquid begins to completely evaporate in the upper collector area. These areas superheat. As a result the collector efficiency rate decreases even further and the amount of energy to be transported away by steam decreases so that the energy amount also drops and so that the ”loss area” in the plant can also decrease. The steam volume decreases even if the solar radiation remains the same. The pressure in the plant drops (which also means the saturated steam temperature) and liquid is pushed slowly out of the expansion vessel into the outlet line (return line). The back flap prevents the latter on the inlet side. If the superheating areas in the collector continue to expand, the plant pressure falls even further and the liquid level of the outlet reaches the collector inlet. The inlet fills up slowly with condensate.

The superheating phase can take a few hours on cloudless days and ends when irradiation is on the decline.

3.5. Phase 5: Refilling the collector

The collector is refilled via the outlet lines whereby the temperatures drop quickly. The refilling of the inlet line takes place in a slightly delayed manner as a result of the condensate.

3.6. Additional comments

With more complex plant and collector hydraulic systems, more complex as well as periodic procedures overlap the behaviour described (sinus or saw tooth like pressure and flow fluctuations with periodical lengths of some seconds up to a few minutes) which are in part explained by the pipe guidance (up and down) within and outside the collector.

Maximum temperature and pressure loads occur in the plants on clear days with intermittent clouds rather than on cloudless days. The latter results in a very high diffuse share of the radiation and global radiation at the plain of the collector reaches extreme values in the short-term.

4. CONCLUSIONS

The stagnation behaviour of 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 minimize thermal loads to system components.

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