Reduction of Stagnation Load of Large-Scale Collector Arrays

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Abstract

The stagnation investigations at ISFH test arrays demonstrate a significant influence of the system pressure on the steam producing power (SPP) of the solar thermal flat-plate collector arrays. A higher system pressure reduces the SPP of these systems by 43%. On the other hand a high system pressure causes remarkable stress to the heat transfer fluid and the collector loop gaskets. The stagnation behaviour of the vacuum-tube collector array is nearly unaffected by the system pressure. In many cases the optimization of the external collector piping prevents the formation of liquid-bags inside the collector array. In the experiments the optimized piping led to a decreased SPP of approx. 50%. After one year of considerable stagnation load the heat transfer fluid of the investigated systems is still in a good condition. The in situ measurements of two large-scale combi-systems showed quite moderate maximum SPP of 25 and 37 W/m^2, although the steam in the collector loop reached the boiler room at both solar thermal systems.

Keywords: Solar Thermal, Stagnation, Steam producing power, SPP, Steam Spread, Evaporation, Heat Transfer Fluid, Combi-System

1. Introduction

The stagnation problem of solar thermal systems is moving increasingly into the focus of interest. Both the trend towards solar space heating and higher stagnation temperatures increase the risk of damage of the collector loop equipment. For the further development of solar thermal combi-systems with high solar fractions it is necessary to understand and control the stagnation process of large-scale collector arrays.

In the framework of a joint research project supported by the German Federal Ministry for Environment, Environmental Protection and Reactor Safety (BMU) large-scale solar combi-systems are being investigated. The research institutes SWT, ZfS, ISE and ISFH participate in this project, which is financially supported within the framework of the program Solarthermie2000plus [5]. In the sub-project of the ISFH the stagnation behaviour of large collector arrays is being investigated and recommendations for a non-critical stagnation process are to be devised.

In 2001/2002 the AEE INTEC (Gleisdorf, Austria) has investigated single collectors and collector arrays in regard to their stagnation behaviour [1]. The outdoor measured arrays consisted of flat-plate collectors with favourable evaporation behaviour. Due to optimized collector interconnections the formation of liquid-bags was prevented and the steam spread was quite moderate. Especially for large collector arrays the hydraulic interconnection is determined by limited installation options on the roof, whereby the implementation of an optimized collector connection without liquid-bags is often impossible. Continuing the investigations of AEE INTEC, at ISFH collector arrays with critical evaporation behaviour are measured in detail. In addition a vacuum-tube collector array is being investigated.

2. Stagnation Procedures

The term "stagnation" describes the state in which the collector loop pump is switched off although solar irradiance is heating up the collector. Consequently the evaporation of the heat transfer fluid in the collector may occur. In most cases a full storage tank is the reason for switching off the pump, sometimes it is a technical failure. Principally this situation is expected and not serious. Critical are two-phase flows occurring in some cases, which lead to a considerable spreading of hot steam into the solar circuit. The collector loop components (membrane expansion vessel, pump, valves and pipe insulation) and the heat transfer fluid are highly endangered.

The spread of steam which is produced by the collector array depends, among other things, on the draining behaviour of the collectors. Investigations have shown that the existence of liquid-bags in the collector pipes lead to a considerable spread of the steam and to prolonged evaporation. If there are no liquid-bags, a large amount of liquid will be pressed out of the collectors by the steam in an early phase of stagnation. So the steam producing power drops quickly and the steam spread is limited.

According to [2] the process of stagnation is divided into five separate sections:

- Phase 1 – expansion of liquid
- Phase 2 – pushing the liquid out of the collector
- Phase 3 – emptying of collector by boiling
- Phase 4 – emptying of collector by superheated steam
- Phase 5 – refilling of collector

The amount of remaining liquid after phase 2 determines the further course of the stagnation procedure quite considerably. It influences the range and duration of extreme loads.

3. Stagnation test arrays at ISFH

In spring 2004 three complete solar heating systems were assembled on the ISFH test stand and numerous stagnation experiments were carried out during summers 2004 and 2005 (Fig. 1). Array VTC1 with an aperture area of 12 m^2 consists of four vacuum-tube collectors, where the collectors and the single tubes are connected in parallel. The collector arrays FPC2 (20 m^2) and FPC3 (25 m^2) consist of flat-plate collectors, one with a harp-shaped (FPC2) and the other with a meander-shaped structure (FPC3). Test array FPC2 with a series connection of four collectors gives the opportunity to carry out experiments with supply and return connections on the top (FPC2a) and at the bottom (FPC2b) of the array. The option with pipe connection at the top of the collector array is often adopted in multi-occupation buildings and exhibits critical stagnation behaviour with considerable steam spreading, due to the formation of liquid-bags. Array FPC3 comprises a series connection of two sub-arrays each with a parallel connection of five collectors. In 2004 the return pipe showed a short upward section of 1.5 meters. As a consequence the produced steam of the stagnating collector flows only into the supply pipe while the liquid stays in the return pipe. This leads to a comparatively far steam spread. In spring 2005 the collector field was shifted 2.5 meters upward at the test roof and so the complete piping could be accomplished without any rising sections.

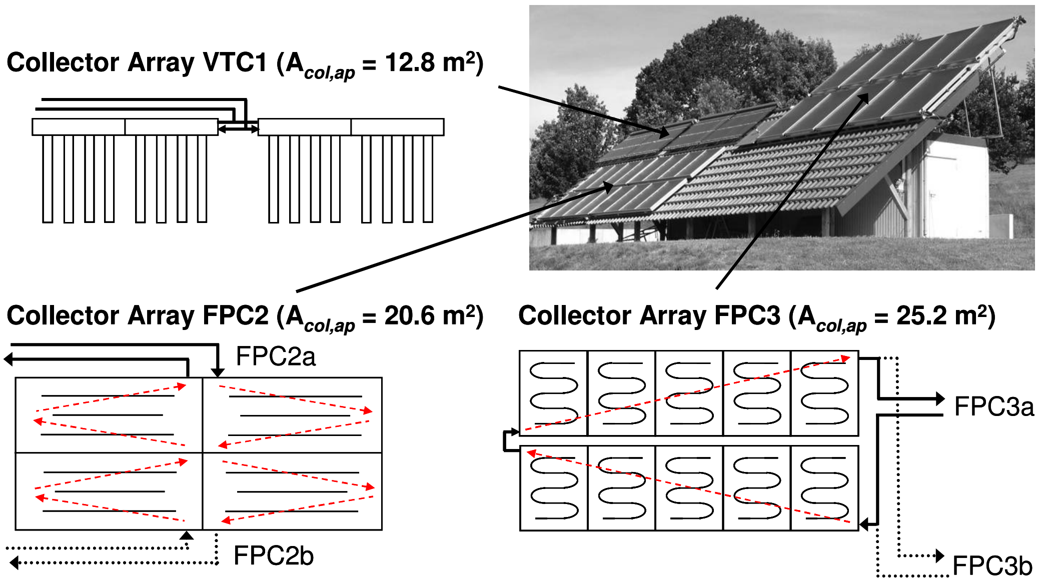

Fig. 1. Schematic sketch of the three investigated collector array hydraulics. At the flat-plate collectors experiments with unfavourable (FPCxa) and optimized external piping (FPCxb) were carried out.

In order to characterize the stagnation process, the maximum steam spread (StS) and the steam producing power (SPP) were measured during stagnation experiments. The StS is determined by numerous temperature sensors (PT100) on the collector loop pipes. In preliminary tests the thermal pipe losses were measured in order to calculate the SPP at the moment of maximum StS. It is assumed that the thermal losses of the insulated pipes and the SPP are in balance in the moment of maximum StS. So the SPP is calculated as follows:

$$SPP = \frac{StS \cdot \dot{Q}_{loss,pipe,stag}}{A_{col,ap}} \tag{1}$$

SPP	steam producing power [W/m²]
StS	steam spread [m]
$\dot{Q}_{loss,pipe,stag}$	thermal pipe losses per meter pipe length during stagnation [W/m]
$A_{col,ap}$	collector aperture area [m²]

During the experiments a maximum StS of between 41 meters (FPC2b) and 71 meters (VTC1) was recorded.

4. Influence of external collector piping and system pressure

More than 100 stagnation experiments were carried out under variable weather conditions (solar irradiance, ambient temperature, wind speed, etc.) in the years 2004 and 2005. 82 of these experiments led to evaluable results. The main focus laid on the influence of the external collector piping and the system pressure. A summary of the main results is given in Fig. 2.

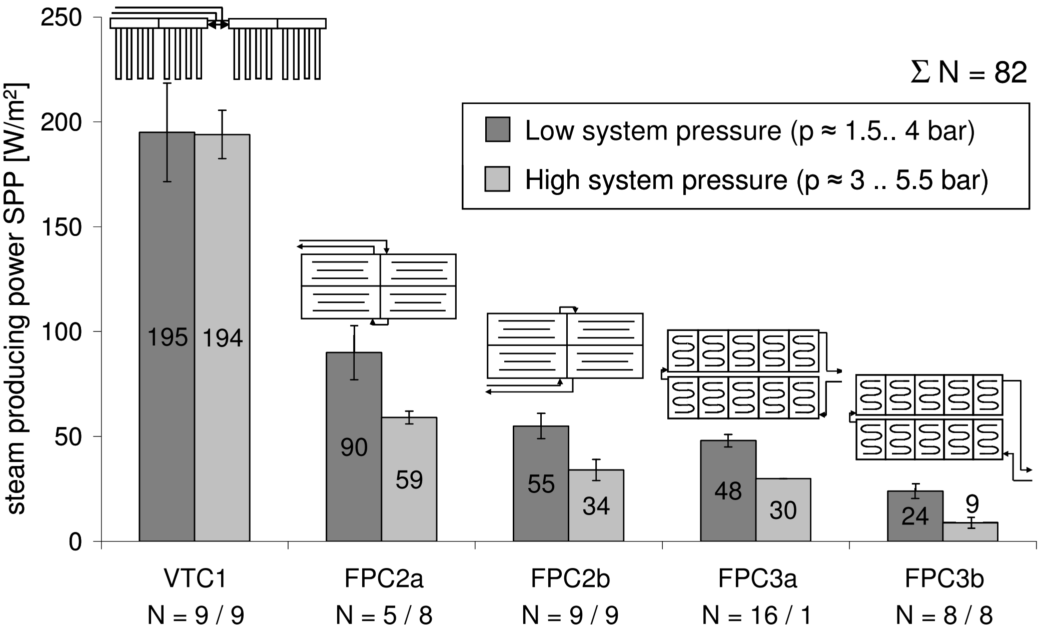

Fig. 2. Measured mean steam producing power (SPP) for different collector loop gage pressures and different external collector array piping. The values of system pressure refer to the static and maximum pressure. N termed the number of experiments for each bar. The error bar marks the standard deviation of the measured mean SPP.

Every bar in Fig. 2 characterises the mean steam producing power referring to the collector aperture area, for the stated system gage pressure and collector piping, averaged for all stagnation experiments. The vacuum-tube collector array (VTC1) shows the highest specific steam producing power of 195 W/m^2. Due to the flat efficiency curve no marked reduction of the steam producing power could be achieved at high system pressure. The higher pressure stage leads to an almost identical SPP.

Significant differences were displayed in the experiments with different pipe connection and different system pressure at the harp-shaped collector array (FPC2). At low system pressure and modified pipe connection from the top to the bottom of the array the mean SPP drops from 90 W/m^2 to 55 W/m^2, this is a decrease of approx. 40%. At high pressure stage the same SPP-reduction of 40% was recorded as well (FPC2a: 59 W/m^2; FPC2b: 34 W/m^2). A high system pressure leads to a 36% lower steam producing power for collector array FPC2.

The SPP of the meander-shaped collector array (FPC3) shows a marked dependence on the collector loop pressure and the external piping as well. The optimized external collector piping decreases the SPP by 40% (from 48 to 24 W/m^2 at low system pressure and from 30 to 9 W/m^2 at high system pressure). For this collector array the high system pressure leads to an averaged reduction in steam producing power of 50%.

The measured steam producing power for the different arrays shows a wide variation. The vacuum-tube array with its small heat losses at high fluid temperatures and the occurring liquid-bags shows the highest steam producing power of all tested systems. Depending on the type of collector construction, the external piping and the system pressure, the measured SPP of the flat-plate collector arrays differ about the factor 10. At high system pressure and optimized piping array FPC3b records a steam producing power of only 9 W/m^2, while array FPC2a shows a SPP of 90 W/m^2 at low system pressure and unfavourable external piping.

5. Investigations on the heat transfer fluid

In the framework of the test array experiments at ISFH the influence of frequent stagnation processes on the heat transfer fluid was investigated in cooperation with Tyforop Chemie GmbH (Hamburg, Germany). The stagnation process causes high stress to the heat transfer fluid. Propylene glycol/water based solar fluids are subject to premature ageing at temperatures above 160°C, indicated by darkening of the fluid and slowly decreasing pH value. The reserve alkalinity (RA) is an important parameter for the remaining corrosion protection of the heat transfer fluid [3]. If the RA drops below 10%, the substitution of the solar fluid is required.

Between 20 and 30 stagnation experiments were carried out during summer at each test system. In winter the solar thermal systems remained in permanent stagnation, whereby the stagnation load of the investigated systems exceeds the stress of common combi-systems. Weekly analyses of the heat transfer fluid were carried out by Tyforop Chemie GmbH during the summer measurement period. Fig. 3 shows the progression of the RA as a function of the operating time. Modifications at the test systems and leakages at the collector loops made it necessary to refill small amounts of new heat transfer fluid a couple of times which explains the temporary increase in the curve progression of the RA.

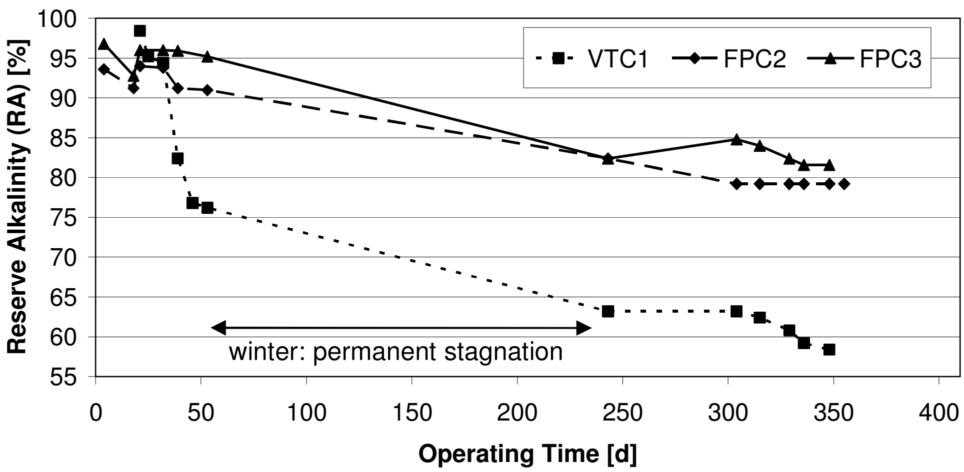

Fig. 3. Reserve alkalinity (RA) as a function of operating time of the three investigated test systems. Replenishment of new solar fluid leads to temporary increase of RA. Day 0 was 01.08.2004.

The permanent stagnation during winter leads to a significant reduction of the RA. As expected, the vacuum-tube collector system (VTC1) shows the fastest degradation of the heat transfer fluid. After one year the RA drops below 60%. The RA of the solar fluid in the flat-plate collector systems FPC2 and FPC3 shows a decrease to approx. 80%. In spite of the intense stagnation load of the investigated systems no heat transfer fluid reaches a critical RA of 10%.

6. Stagnation behaviour of two large-scale combi-systems

In the scope of the joint research project [1] six large-scale combi-systems were equipped with measurement technology. Two of these systems were investigated in respect to their stagnation behaviour. In order to measure the steam spread and the resulting steam producing power the pipes of the collector loop were equipped with temperature sensors (PT100), and two pressure sensors were installed at the collector array and the expansion vessel. The characteristics of these systems are presented in Table 1.

Table 1. Characteristics of the in situ measured combi-systems in Gelsenkirchen und Hamburg (Germany).

Combi-system	Collector area	Collector type	Pipe length	Flats	Storage
Gelsenkirchen	90 m^2	Harp-shaped flat-plate	supply/return: each 35 m	36	4.0 m^3
Hamburg	45 m^2	Harp-shaped flat-plate	return: 34 m; supply:19 m	15	2.2 m^3

At 16 days in 2005 the combi-system in Gelsenkirchen showed stagnation conditions with evaporation in the collector loop, in Hamburg 32 stagnation days were recorded. During stagnation process, the steam remains in the collectors and pipes for an average time period of two hours. The measured steam spread is shown in Table 2. In Gelsenkirchen an average steam spread of 31 meters (sum of the spread in the supply and return pipe) was recorded. The maximum steam spread achieved a value of 68 meters, when nearly the whole return and supply pipe were filled with steam. The average steam spread in Hamburg amounts to 16 meters, in maximum case a value of 26 meters was reached.

Due to the fact that the collector loop pipe losses of the investigated systems can only be estimated, the resulting steam producing powers (Table 2) show an increased uncertainty. In Gelsenkirchen and Hamburg a mean SPP of 19 accordingly 17 W/m^2 were measured, whereas maximum values of 37 (Gelsenkirchen) and 25 W/m^2 (Hamburg) were reached.

Table 2. Maximum and average steam spread and steam producing power (SPP) for the in situ measured combi-systems in Gelsenkirchen und Hamburg (Germany).

Combi-system	Max. steam spread	Avg. steam spread	SPP_{max}	SPP_{avg}
Gelsenkirchen	68 m	31 m	37 W/m^2	19 W/m^2
Hamburg	26 m	16 m	25 W/m^2	17 W/m^2

7. Conclusion

A high system pressure can considerably reduce the steam producing power, but causes high stress to the heat transfer fluid and the collector loop gaskets. A high system pressure has nearly no effect on the SPP of the vacuum-tube collector array. The great amount of influencing factors on the stagnation behaviour (type of collector construction, system pressure, internal and external collector piping, etc.) leads to a wide spread of measured SPP. Further investigations at ISFH showed that the collector slope has a remarkable influence on the stagnation behaviour as well [4]. Hence, especially for large-scale solar thermal systems the protection of the heat-sensitive collector loop components is required. A cooling device could protect temperature-sensitive components like expansion vessel and collector loop pump and limit and control the emerging steam volume during the stagnation process.

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