Solar heat for industrial processes in Germany – Market overview and detailed monitoring of selected systems

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Abstract

Since the start of the funding of solar thermal process heat systems in Germany, a growing market has begun to evolve. At the moment roughly 400 m² of collector area for solar process heat systems are submitted for approval each month; four times more than in 2012. All together about 14,000 m² were submitted since 2012 and more than half of the collector area is already in operation, delivering heat for commercial and industrial applications. Although many of these systems are within 20 m² to 40 m² and are used for very simple applications like rearing of piglets and hot water preparation for car washes, there are also bigger systems, up to 960 m², delivering heat for e.g. drying and cleaning applications of production sites and produced goods. Referring to the turnkey system costs, the average cost of nearly 800 €/m² is still quite high and differs significantly depending on the collector technology used and the application.

In addition to the funding of new solar process heat systems, a detailed monitoring of three newly installed systems is financed to gain in depth experience on solar process heat systems. These systems are a metal surface treatment facility, a bitumen production and a gas pressure regulation station. System descriptions and first results are presented.

Keywords: *industrial process heat, solar thermal, German market, monitoring*

1. Introduction

The supply of process heat has become one of the future key markets for solar thermal systems in Germany and Europe due to the significant technical potential for Germany of 130 TWh/a (Lauterbach et al. 2012). This is equivalent to more than 35 million m², with benefits such as year-long heat demand in commerce and industry, giving the opportunity to reach low solar heat generation costs. Since there were only very few systems installed in Germany until 2012, the Federal Ministry for Economic Affairs and Energy (BMWi) released a promotion for solar process heat systems within the Market Incentive Programme (MAP) in August 2012. Since then the supply of solar process heat is supported by an investment grant or subsidy on the loan redemption of up to 50 % according to the chargeable investment costs. With the latest amendment in April 2015, it was confirmed as an important component for the goal to provide 14 % of the German heat demand with renewable energies till 2020 (BMWi, 2015).

To increase the impact and quality of the new solar process heat funding, a scientific project was permitted and funded to be conducted by University of Kassel. The most important task of this scientific institution is to provide technical support and optimization measures to ensure the quality of newly installed systems. Within this scope of duties the detailed monitoring of three selected solar process heat systems is a very important issue. The aim is to gain information about the efficiency in the field of the specific applications, the effectiveness of the respective integration of solar heat, the long term reliability of the systems and possible malfunctions caused by the interaction of different heating systems.

2. Market overview and accompanying project

Since the start of the funding for solar process heat systems in August 2012 until the end of August 2015 more than 240 applications for solar thermal systems with a total gross collector area of 18,000 m² were submitted. Out of these applications only 7 % were rejected for formal reasons e.g. use of heat for domestic

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hot water or the use of unglazed collectors. Additional 6 % were cancelled by the applicants themselves for unknown reasons. Nearly 90 % reached the realization phase, equivalent to an area of 13.900 m^2_{gross}. Since there is usually a larger time gap between the application for the funding and the start-up of the realized solar process heat systems, there are currently only 134 systems in operation with a collective collector area of 7,241 m^2_{gross}. Figure 1 shows a yearly breakdown based on the collector area of the application forms that were handed in, the approved applications, the systems that started operation and the systems that are still under construction. In contrast to the other values the last bar also includes the collector area of approved but not yet realized systems of previous years. In this Figure it has to be considered that the funding of solar process heat systems started at the end of August 2012 and the values for the year 2015 only represent the period from January 1st to August 31st.

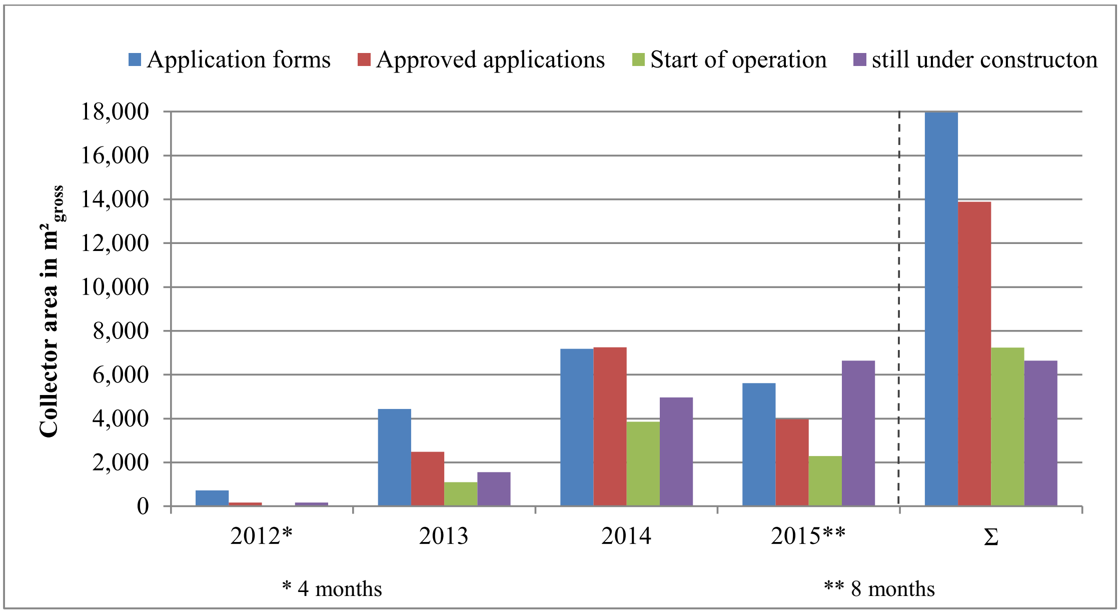

Figure 1: Overview on the German market for solar process heat

A more comparable illustration is an overview of the monthly approved applications according to the collector area as an average value for the particular year. This comparison, as it can be seen in Figure 2, shows a growth of the German market for solar process heat systems until the end of 2014. In 2015 there was a little decrease that can be explained by the restraint of applications caused by the amendment to the Market Incentive Program in April. Because of the weak start of the year 2015 and since there are still four months left, it would be too early to conclude that there is already a slowdown in growth of the German market for solar thermal process heat systems.

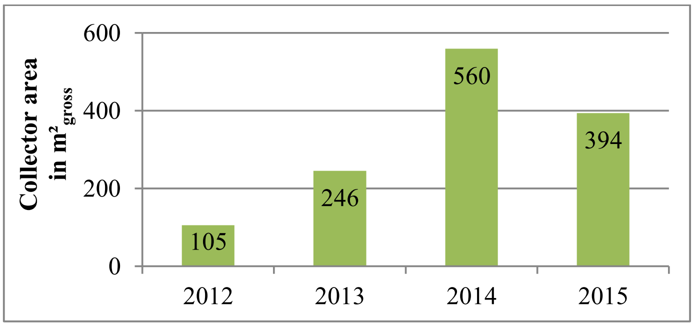

Figure 2: Average value of the monthly approved collector area in m²

At the early stage of the solar process heat funding program, the average collector field size was below 40 m^2_{gross}. Starting with the year 2013 small but constant growth of the average size was seen, reaching a peak in 2014, due to a system with 960 m^2_{gross}. However the average project size in 2015 is 66 m^2_{gross}. Although a large share of the installations is smaller than 40 m², already 22 process heat systems have a collector field size between 100 m^2_{gross} and 960 $m^2_{gross.}$ The three largest systems that are already in operation are a 297 m² system with CPC-collectors delivering solar heat to the different baths, drying chambers and the air washer of a metal treatment company, a 507 m² air collector system for drying of wood chips and a system with 960 m² with flat plate collectors that are used to deliver heat for the dehumidification and heating of greenhouses to prevent the fouling of vegetables and to extend the growing season.

Analyzing the end use of solar heat, it becomes obvious that over 50 % of all submitted solar process heat systems are used or will be used for only two applications: rearing of piglets and car washes. Beside these two often applied systems, there is a large variety of processes heated by solar thermal systems, especially in the field of drying and cleaning of products and production sites. Other uses of the solar heat are fish farming, production of pharmaceutical goods, heating of baths for plastics testing and surface treatment, hot water production for laundries as well as bitumen processing and others.

As solar thermal systems serve as fuel savers aside from a handful of applications, it is always interesting to refer to the costs of the systems which in combination with the solar yield determine the solar heat generation cost. The breakdown of the system costs including installation and integration into the respective process but independent of the used collector technology or the application down to 1 m^2_{gross} delivers specific system costs of 789 €/m² since the start of the funding in Germany. A deviation of the system costs between the different collector technologies can be observed also varying from year to year. As it can be seen in Figure 3, the costs for solar process heat systems using flat plate collectors are in some degree stable in a range between 760 €/m² and 860 €/m² nevertheless a slight but constant increase over the years can be recognized. According to the costs for systems using air collectors or evacuated tube collectors (ETC) - including CPC - it is very conspicuous, that they are clearly higher in 2012 compared to the other years. This is caused by three systems with very high specific costs in a range between 1.500 €/m² and 2.100 €/m² that could not be compensated by the other systems. But even such expensive systems are sometimes economical feasible depending on the reference price of the conventional heating system. If it is electrical heating, this reference price can exceed 0.20 €/kWh for smaller commercial electricity consumers. On the other hand considering the 50% investment grant, some systems even reach a heat price roughly 0.03 €/kWh, being competitive with modern gas boilers delivering heat for processes. The numbers in the bars in Figure 3 are the average system size for the particular collector type and year (BAFA, 2015 and KfW Group, 2015).

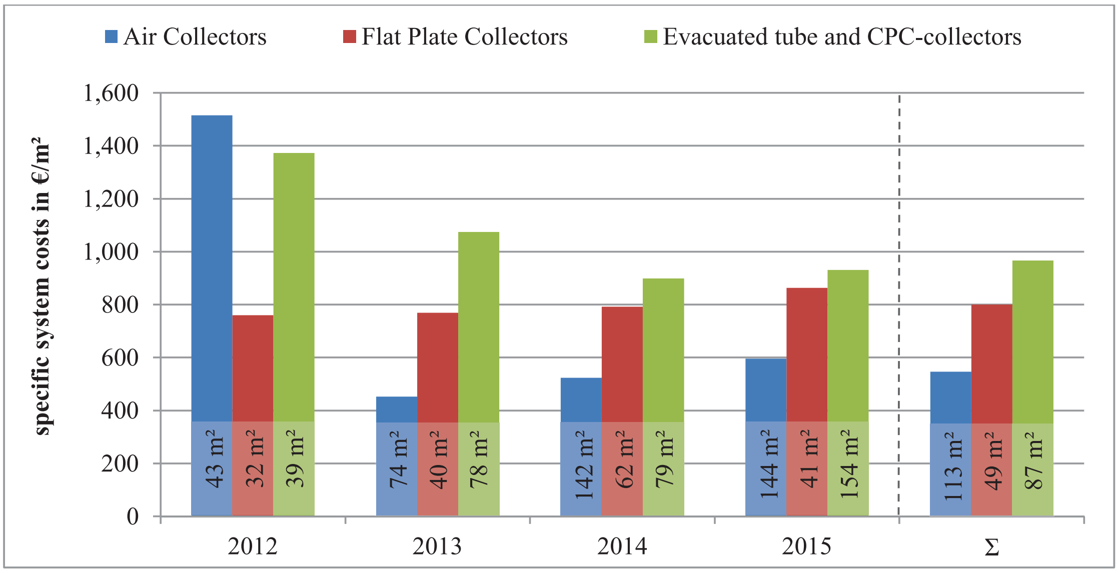

Figure 3: Average system costs for solar process heat systems in Germany according to the collector type

Since solar process heat is an emerging market in Germany and these systems are usually more complex compared to domestic applications, the BMWi is funding a scientific project to analyze and push the German market for solar process heat. As mentioned in the introduction, the University of Kassel has different tasks to ensure the quality of newly installed systems such as technical consultancy for planners, publication of technical recommendations, and identifying optimization measures. Beside this, it is also obligatory to spread the gained knowledge on the market by developing information materials and giving training courses as well as information sessions to selected target groups. One very important task is the detailed monitoring of three selected process heat systems that were funded within the Market Incentive Program to gain information about the efficiency in the field of the specific applications, the effectiveness of the respective integration of solar heat, the long term reliability of the systems and possible malfunctions caused by the interaction of different heating systems. The requirements according to the measurement devices, the description of the systems and some first results of the monitoring can be found in the following sections.

3. Selected solar process heat systems for the monitoring

For the detailed monitoring, three applications were selected: a metal treatment company, a bitumen production facility and a gas pressure regulation station. The selection of these systems for the detailed monitoring was done using several criteria such as temperature levels, the way of integrating solar heat, the financing model as well as innovative ways of dealing with stagnation or the combination with other heat supply technologies. Table 1 gives an overview on the similarities and differences of the named systems.

Table 1: Description of solar process heat systems for the detailed monitoring

	Metal treatment	Bitumen processing	Gas pressure regulation
Collector type	CPC evacuated tube collector	Flat plate collector	Large-scale flat plate collector
Collector field	300 m^2_{gross}, roof mounted	190 m^2_{gross}, roof mounted	500 m^2_{gross}, ground mounted
Buffer storage	15 m^3	20 m^3	25 m^3
Solar assisted process(es)	Heating of baths Drying of products Heating of air washer Maintain air temperature	Hot water for bitumen emulsion process Boiler make-up water Heating of bitumen tank Steam cleaning	Heating of natural gas pipeline before decompression
Temperature level for solar system	40...70°C	20...130°C	50...60°C
Integration concept	Supply level, all heat sinks are served	Process integration, several heat sinks	Process integration, one heat sink
Combination with other heat generators	Conventional oil burner as backup that is directly loading the upper part of the buffer tank	Hydraulically separated steam boiler as backup	Gas burners as backup. Additional gas-driven heat pumps to reduce natural gas consumption
Charge / discharge of storage	Storage is directly connected to solar heating system and heating network without hydraulic disconnections	External HX for storage charging. Combination of direct hot water use and external HX to discharge the storage	Charging with internal HX, discharging with external HX
Frost prevention	Active frost protection due to water as heat transfer medium	Water glycol mixture	Water glycol mixture
Load profile	More or less constant production over the year (order related production)	Very good match between energy demand for processes and solar radiation (road building)	Highest heat demand in winter (space heating), reduced base load in summer
Financing	Self-investment	Self-investment	ESCO
Planner	Holsmölle 2014	Aschoff 2014	Heinzen 2015

Since the metal treatment facility will be explained in more detail within the following two sections, some information of the bitumen processing and gas pressure regulation station are given below.

Bitumen processing

The produced bitumen emulsion is used for road construction. As these infrastructural projects normally aren't performed in winter, the production period of the company starts around April and ends the latest in November. In addition it is not unusual that weather forecasts are used in this business determining the production output. Therefore the available solar energy and the load profile of the production site have a very good congruence and a very high solar fraction of >70 % is planned. The main energy consumer is the preparation of hot water for the emulsion process where raw bitumen and emulsifiers have to be mixed to obtain a stable product. The second consumer is the pre-heating of boiler make-up water up to 90°C for the high-pressure steam cleaning of tanks and technical equipment. On days with high solar irradiation when the solar loop reaches temperatures of at least 120°C the third consumer, the heating of a raw bitumen tank, is driven by solar thermal energy to reduce the viscosity of the raw bitumen. The internal HX of this tank is directly connected to the solar loop, so this heat sink can also be used as an active stagnation prevention device (Aschoff, 2014).

Gas pressure regulation station

Gas pressure regulation stations are used to reduce the pressure of e.g. 90 bars of the natural gas in the cross-country high-pressure pipelines to a pressure of e.g. 12 bars for the local distribution networks for the final consumers. Caused by the decompression using expansion valves the temperature would decrease below 0°C. To prevent freezing of the regulation equipment and the piping of the local network, the natural gas has to be heated. Normally this heat is provided by gas burners located in the regulation stations but as the operator has to pay market-price for the burned gas, it is possible to compete against the natural gas with solar thermal energy. The highest natural gas consumption in the local grids is always in winter when there is a huge demand for space heating. Depending on how many commercial and industrial consumers with thermal energy demand are connected to the local grid, an appreciable base load is needed to prevent the gas from freezing also in summer. The selected system for the detailed monitoring has two specialties that should be named: First there will be an additional gas-driven heat pump to reduce the natural gas consumption additionally to the heat provided by the solar thermal system. Second the whole system will be financed and operated by an ESCO selling the heat to the gas provider for a lower price compared to the conventional heating using the installed gas burners (Heinzen, 2014).

4. Solar thermal process heat for metal treatment facility

The third named solar thermal process heat system chosen for the detailed monitoring delivers heat for the surface treatment of metallic materials in a medium sized enterprise. The main business of the company is the zinc coating in two automated production lines with a high output of specified mass products. Beside this automated production there is also a manufacturing area where smaller, more individualized charges are produced in small baths that are operated by hand. Beside the main surface treatment of zinc coatings, there are also various other coatings like copper, tin, chrome, nickel or cadmium.

Conventionally the required heat is supplied by two oil burners that worked with a small storage tank. For peak loads that cannot be handled by the oil burners, there is also the possibility to heat with electrical resistant heaters. In the past approximately 15 % of the heat demand was covered by electricity. During installation of the solar thermal system, the small buffer storage was removed and replaced by a 15 m³ buffer storage heated by both heat sources (oil and solar). As mentioned in Table 1 the whole system was planned and realized as an integrated heat network, so there are no hydraulic disconnections between the solar thermal system, the buffer storage and the oil burners. They all use the same heating circuit water.

For delivering the heat to the different processes named in Table 1, there are three circuits directly connected to the storage, taking the water out of three different heights at different temperature levels. The process with the highest temperature demand is drying of coated products within two drying chambers at the production lines. Here, water to air HXs are used, requiring ta temperature up to 70°C. The medium temperature loop is mainly used for heating of different production line baths and those operated by hand. Here the required temperature reaches up to 60°C and internal tube bundles are used as heat exchangers. Additionally the heat registers that are used for maintaining a specific temperature in the hall around the baths are supplied by the medium temperature loop as well as domestic hot water preparation and the space heating for offices and social rooms in winter. The third loop is supplying low temperature heat to an air washer that is necessary to wash pollutants out of the air. For this application a temperature around 40°C is needed. The return flows of the three heating loops are stratified into the buffer storage at different heights, depending on the temperature. Figure 4 gives an overview of the whole system of heat suppliers and heat consumers.

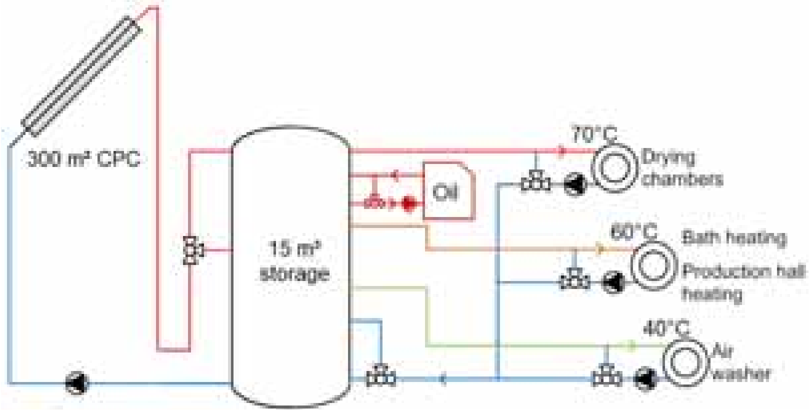

Figure 4: Hydraulic scheme of heating network supported by solar process heat system

The solar thermal process heat system consists of 63 CPC-Collectors with a total gross area of 297 m² and is installed on the roof of the production hall. The field is divided into two subfields each with an inclination of 12°, one north-east orientated with an area of 170 m^2_{gross} and the other one south-west orientated with 127 m^2_{gross}. A picture of the field can be seen in Figure 5: north-east orientated field on the left-hand side, south-west orientated field on the right-hand side.

Figure 5: CPC-collector field on metal treatment factory (Holsmölle 2015)

The control strategy is to feed the solar heat into the top of the storage at a set temperature of at least 65°C up to 100°C depending on the highest temperature of the buffer with the aim of reducing the pulsing of the oil burners. On the one hand this strategy reduces the yield of the solar loop caused by the higher temperatures, but due to the reduction of start-up times of the oil burners with poor efficiencies, a positive effect on the oil consumption can be expected. However, it was not possible so far to quantify this effect due to an increase of the production and a missing reference for the solar control strategy of pre-heating the buffer as soon as the solar flow exceeds the lowest temperature in the stratified storage (Holsmölle, 2014).

According to the detailed monitoring some important requirements were defined like the remote meter reading, the possibility to vary the interval of the data recording, the separate measurement of the heat production, heat consumption of the heat sinks connected to the solar assisted heating network, the flow distribution in every collector row, all done by the recording of the flow temperatures of each row as well as the measurement of the stratification of the storage using at least three temperature probes (top, middle, bottom). The solar radiation is measured in the collector plane(s) using first class pyranometer(s) to calculate the system efficiency. These requirements are the same for the three systems selected for the monitoring.

5. First measuring results of the described system

As there are still some calibrations necessary to obtain reliable measurement data for the whole system, it is reasonable to present only the solar loop and storage temperatures. As an example Figure 6 depicts a Monday after a sunny weekend in July, where the buffer was nearly completely loaded. On this Monday the solar process heat system is able to cover the whole thermal energy demand of the facility.

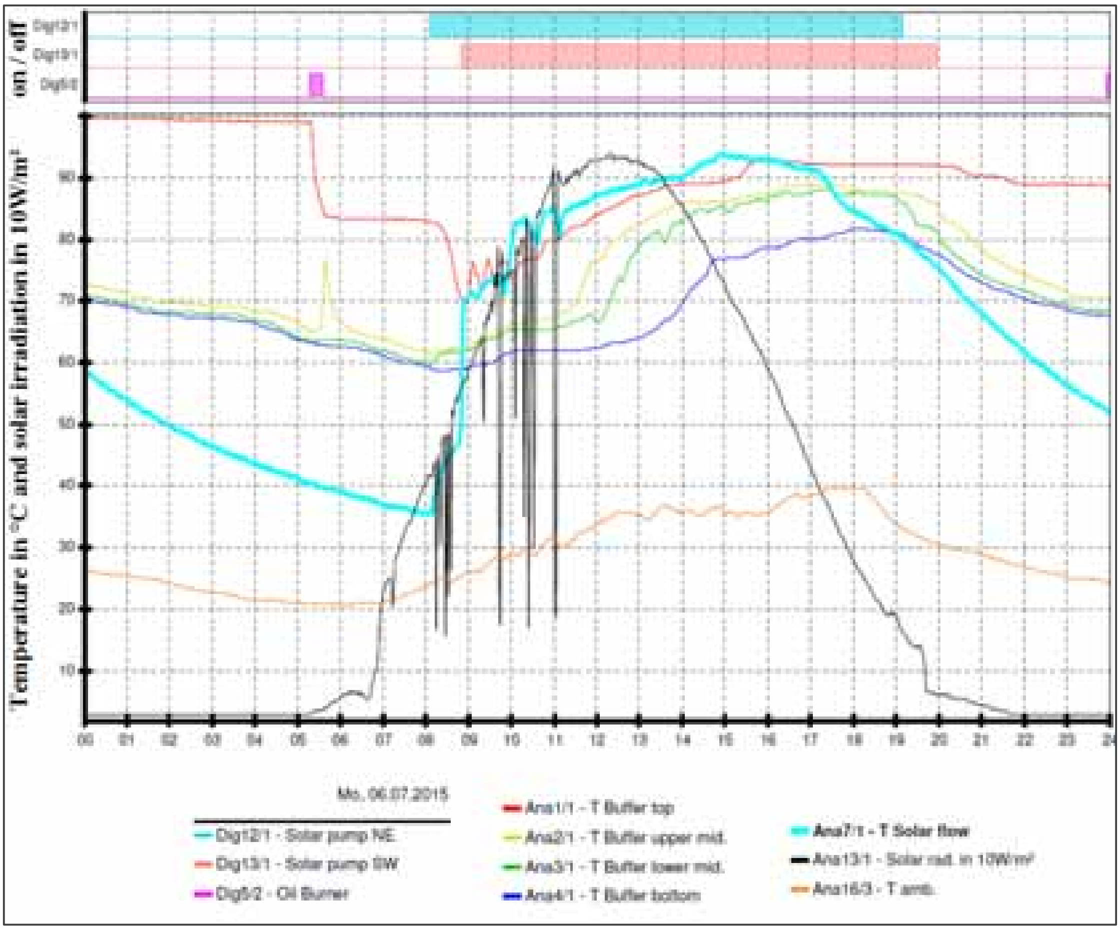

Figure 6: Temperature profiles and solar irradiation on Monday July 6th

This day, July 6th, the heating of the drying chambers and the baths started at 5:20 a.m. using solar heat from the buffer store. In Figure 6 this heating phase in the early morning can be seen with the help of the thin red line dropping from 98°C down to 83°C representing the temperature on the top of the buffer. Shortly before this temperature decrease in the storage caused by the withdrawal of the heat, the oil burners start operation because the temperature in the flow line of the higher temperature loop (not shown in Figure 6) dropped down below 65°C during the weekend.

At 8:05 a.m. the sun started to heat up the collectors and the pump driving the north-east field starts to circulate the solar loop until the temperature in the upper part of the buffer of 70°C was reached at 8:55 a.m. so the solar system started to feed in the heat. At the same time the pump for the south-west orientated field started to operate. This can be seen with the help of the turquoise line, the combined solar flow temperature, whose slope decreases immediately due to the thermal capacities of the south-west field. The maximum temperature of the combined solar flow was reached at 3 p.m. at 94°C. At this time the buffer has a temperature of 77°C at the button and 90°C at the top. After this time the solar system wasn't able to deliver

90°C anymore so it started to feed in the heat into the buffer at different heights and temperature levels until 7 p.m. As the temperature in the solar loop couldn't reach the temperature of the lower part of the storage by circulating the fluid in the collectors, the pumps for the north-east and south-west fields shut off at 7:15 p.m. resp. 8:00 p.m. The latest withdrawal of heat for the processes can be seen at 9:50 p.m. After that the temperature at the top of the storage is only slightly reduced by temperature losses over the next hours. In contrast the temperature in the middle and in the bottom of the tank decreases about 10K caused by the circulation of the medium temperature loop until 10:20 p.m. After that the temperature in the storage is nearly constant until 5:10 a.m. where the heating of the bathes started again.

Another part of the monitoring was the flow distribution in the different collector rows. This is important because if the flow in the rows is non-uniform, there is a risk of partial stagnation and for water based systems with active frost protection also a risk of freezing in single rows. Such poor flow distributions would lead to a reduced solar yield in summer and could cause damages on the collectors in winter. The described system in the metal surface treatment facility consists of 21 collector rows, each with three CPC-collectors. Figure 7 gives an overview on the two collector fields with its 12 collector rows on the north-eastern roof and 9 on the other. The piping was realized according to Tichelmann, so for each row the length of flow and return-flow pipes in sum is of equal length. This kind of piping is used to keep the pressure lost due to the piping the same for each row to ensure an evenly flow in the collectors and therefore a similar flow temperature of the rows.

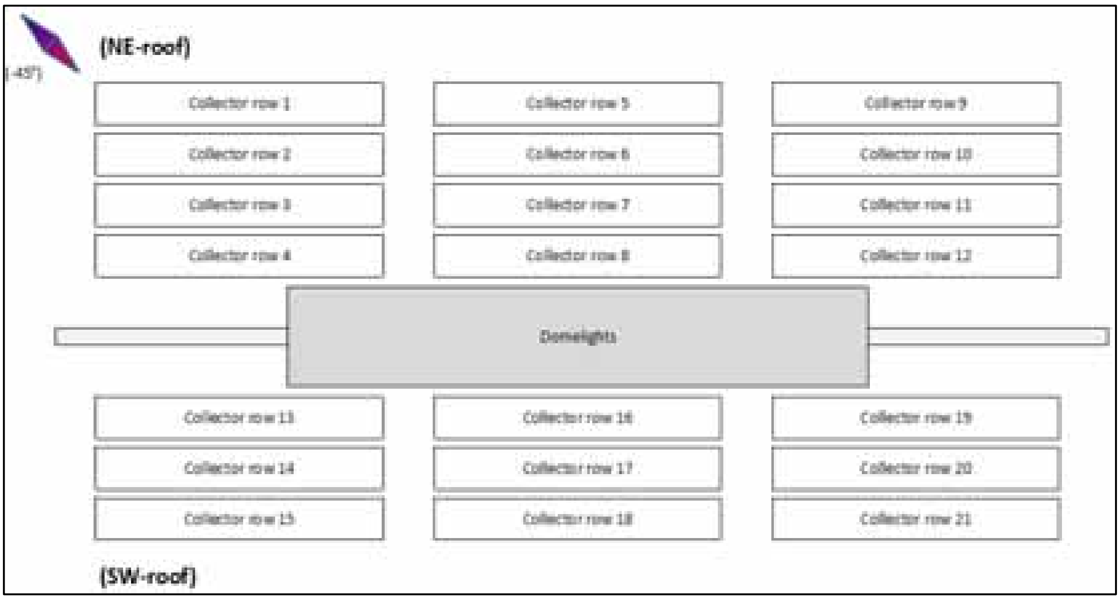

Figure 7: Scheme of the two collector fields with its 21 rows (Holsmölle 2015)

For the detailed monitoring at the end of each row a temperature probe was installed, measuring the flow temperature. In Figure 9 four temperature profiles recorded on September 21st can be seen representing four rows, two out of each field (NE, SW). They were selected because they represent the two collector rows each from the north-east and south-west field that show the largest flow temperature difference during the maximum irradiation on the collector field (760 W/m²) for the selected day.

It can be seen, that for the north-eastern field the largest temperature difference between the 12 rows is 8.2°C at 12:38 p.m. with a maximal flow temperature of 89°C for a single row and nearly half an hour later at 1:10 p.m. the largest difference in the south-west field with its 9 rows occurs with 5.6°C with a maximum temperature of 85°C. These values are reached without any additional valves. Since the working pressure is around 2.5 bars with water as heat transfer fluid, the boiling point amounts to 125...130°C. Since the maximum storage temperature is roughly 100°C and it is directly connected to the solar thermal system, there is only a small risk of stagnation due to this small temperature differences. Until now, stagnation only occurred on weekends or official holidays when the storage was fully charged with temperatures of 90...95°C at the bottom and 98...102°C at the top combined with high solar irradiation.

The breakdowns of the flow temperatures in Figure 9, for example at 12:45 p.m. and around 2:00 p.m., are caused by the controller for the solar pumps, trying to adapt the volume flow in the solar loop to meet the temperature at the top of the buffer. Therefore the volume flow at e.g. 12:45 p.m. is more than doubled from a specific volume flow of 11 l/m²h to 24 l/m²h. As this increase decreases the temperature too much, it must be reduced again. This overshooting according to the adaption of the pump speed could be optimized to obtain more constant flow temperatures.

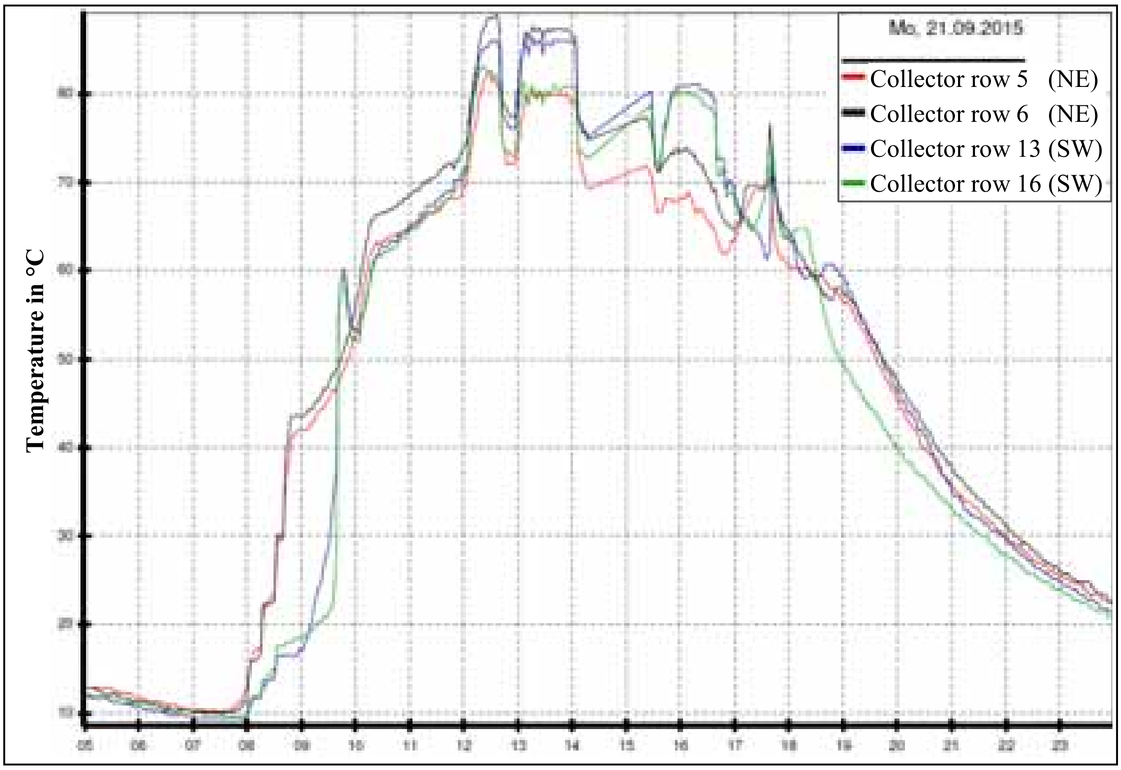

Figure 8: Comparison of the flow temperatures of the four selected collector rows

The first view on the measurement data shown in this section gives a promising first impression according the dimensioning of the solar process heat system avoiding stagnation in summer times and the flow distribution in the collector rows. Only two little optimization measures can be depicted so far: The short start-up of the oil burner shown in Figure 6 and the overshooting of the adaption of the pump speed that can be seen in Figure 9 could be optimized. As soon as the measurement data according the heat consumers and oil burners are validated, energy balances and system efficiencies will be calculated to give an overview on the whole system.

6. Conclusions and outlook

The German market for solar process heat systems is still small but with an increasing trend: Starting from a niche market for eco-minded companies, from August 2012 to August 2015 more than 7,000 m² of collector area are installed and in operation and another 7,000 m² are under construction. Meanwhile the average system size increased about 75% ending up at nearly 70 m² per installation. Although the number of new applications for approval decreased in the first half of 2015 it cannot be seen as a negative trend, because application forms were held back due to the pending novella of the German Market Incentive Programme that became effective in April. Since June the number of submitted application forms increased again, so it is still possible to achieve an increase in applied collector area compared to prior years and therefore another positive growth year for the German solar process heat market.

Although a growing market can be observed, there are still only very few planners and installers dealing with solar process heat systems, so the costs shown Figure 3 are still high due to a lack of competition and sometimes also because of missing expertise. Another fact that keeps the average costs high is the missing economy of scale due to relatively small systems. Nevertheless 14 systems with average system costs below 500 €/m² including the costs for installation and integration are approved representing a collector area of nearly 3,000 m². These numbers show that there is significant room for cost reduction that will hopefully be exploited with the further development of the German solar process heat market, making this technology more competitive and less funding dependent.

According to the detailed monitoring, three very interesting applications depicted in Table 1 were selected to obtain significant information regarding process integration points, load profiles and combinations of different heat suppliers under real conditions. In addition there is a chance to obtain reliable long term knowledge knowing the monitoring will last for seven years after the start-up of each system. Until now, little validated data from the monitoring of the described system at the metal surface treatment facility could be collected, which is not yet sufficient provide conclusions on the systems performance. Instead, only first impressions on the flow distribution in the collector rows and temperature profiles for a 100% solar fraction working day could be seen. Assessments like the usable solar yield and the overall systems efficiency will be done as soon as the recorded data according to the oil burners and heat consumers are validated.

7. Acknowledgement

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8. References

Aschoff, C., 2014. Documentation of system dimensioning and personal interviews regarding the 190 m² flat plate collector system for the bitumen factory. Aschoff Solar GmbH.

BAFA - Federal Office for Economic Affairs and Export Control, 2015. Documentation on solar thermal process heat funding. Provided within the scientific project for market analysis and development for solar thermal process heat systems. Used for statistical evaluations shown in section 2.

BMWi (Ed.): Guideline to support measures for the use of renewable energies in the heat sector (in German language), March 11th 2015.

Heinzen, R., 2015. Personal interviews regarding the 500 m² flat plate collector system for the gas pressure regulation station. Enertracting GmbH.

Holsmölle, G., 2014. Documentation of system dimensioning and personal interviews regarding the 300 m² CPC-collector system for the metal surface treatment facility. Energiebüro EGTEC.

Holsmölle, G., 2015. Pictures and scheme of collector field of the solar process heat system for the metal treatment facility. Energiebüro EGTEC.

KfW Group, 2015. Documentation on solar thermal process heat funding. Provided within the scientific project for market analysis and development for solar thermal process heat systems. Used for statistical evaluations shown in section 2.

Lauterbach, C., Schmitt, B., Jordan, U., Vajen, K., 2012. The potential of solar heat for industrial processes in Germany. Renewable and Sustainable Energy Reviews 16, 5121–5130.