Pilot Plant for Solar Process Steam Supply

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Abstract

An aluminium upgrading process will be supplied by steam directly generated in parabolic trough collectors. In this first of it's kind installation in an industrial environment, steam at 4 bar will be fed into the existing distribution lines of the production to heat anodizing baths and storage tanks. The integration of the solar steam through separate heat exchangers in parallel to the existing system was also considered. In principle, due to the low temperatures of the baths, solar hot water systems could be integrated in the same way. However, the additional heat exchangers and pipelines between the solar system and the consuming process generate significant investment cost on top of the solar system. The selected integration of the solar steam generator in parallel to the existing boiler reduces the complexity of the system, saves cost by avoiding duplication of piping and heat exchangers, and provides flexibility in the operation to ensure security of supply and maximum use of available solar energy.

Keywords: Renewable energy, solar process heat, process steam, direct steam generation

1. Introduction

Industrial process heat accounts for about 28% of the total primary energy consumption for final uses in EU25. More than half of that demand is required at temperatures below 400°, making it a promising and suitable application for solar thermal energy. Nevertheless, only an almost negligible fraction of the total solar thermal capacity presently installed is dedicated to this application [1]. The collaborative Task 33/IV of the Solar Heating and Cooling program and the SolarPACES program of the International Energy Agency (IEA) aimed to support a more wide spread application of solar heat for industrial processes by

- Assessing the potential and identifying most promising applications for solar technologies in industry
- Developing methods for the design and integration of solar systems for industrial applications
- Developing and testing of collectors for medium temperatures up to 250°C, and
- Initiating and monitoring of pilot plants.

In support of these efforts, the P3 project (Pilot plant for solar Process heat generation in Parabolic trough collectors) was started in February 2007 with the goal to demonstrate the direct steam generation in small parabolic trough collectors for industrial applications. The pilot plant will be installed at the production facilities of ALANOD in Ennepetal, Germany. One of the products of this aluminium anodizing plant is MiroSun™, an aluminium based mirror also used as reflector material in the SOLITEM PTC 1800 parabolic trough collector. Scientific support for the development of the solar system design, integration, operation and control concepts is provided by DLR. The future operation will be closely monitored and evaluated by Solar Institute Jülich and ZfS Rationelle Energietechnik GmbH. Although the site provides less than ideal solar radiation conditions, precedence was given to the relatively close neighbourhood of the project partners supporting the successful realization of this innovative application. To limit technical and financial risks, the solar field is restricted to a moderate size of 108 m² aperture area. An economic operation is not expected under these conditions. However, ALANOD regards the opportunity to demonstrate on site the utilization of their product in innovative applications as an additional benefit.

2. Background

2.1. Industrial process

The industrial steam system at the ALANOD is based on a gas fired steam boiler, a condensate tank and a feed water tank with chemical conditioning. For an average production year, the heat energy of 940 000 m³ gas is used to produce 2000 kg of steam per hour. An ongoing extension of the production facilities with a new aluminium anodizing line will not only increase the steam demand to 4000 kg per hour, but also open opportunities to consider different options for the integration of the solar system. The steam is distributed to the production facility by two steam lines, with 4 bara / 143 °C and 9 bara / 175 °C, respectively.

The 4 bara steam line feeds the heat exchangers of the anodizing bathes (degreasing, brightening, sealing) as well as a hot water storage tank which is used to periodically replace the water content of the sealing bath. The dryers for the aluminium strip drying in the anodizing process are fed from the 9 bara steam line. From the convective and evaporation losses of the different baths and storages their continuous heat demand was estimated (Table 1). In addition, heating of the total storage content after the periodic discharge requires about 8 hours with a thermal power of 390 kW for storage tank 1 and 195 kW for storage tank 2.

Table 1: Main heat consumers with continuous demand

Description	Temperature [°C]	Mean heat demand [kW]	Steam pressure [bara]	Distance to solar site [m]
Degreasing bath 1	75	1,9	4	30
Sealing bath 1	95	19,5	4	190
Storage tank 1	95	22,6	4	190
Degreasing bath 2	75	0,5	4	35
Sealing bath 2	95	3,1	4	20
Storage tank 2	95	11,3	4	20
Typical strip dryer		174	9	

Ground space for the solar field is not available at the site. Roof areas of production halls or office buildings could be considered but would require interference with the static of the existing structures. Therefore, in the context of the present extension, a dedicated platform for the solar field will be erected adjacent to the main production hall.

2.2. Collector technology

The SOLITEM PTC 1800 collector will be used in the pilot installation. This parabolic trough collector system is assembled from modules with an aperture width of 1,8 m and a length 5 m each. The concentrator consists of aluminium sheet kept in shape by specially manufactured aluminium profiles. ALANOD Mirosun reflector sheets are glued onto this structure. Additional stiffness is provided by a torsion tube mounted at the back of the concentrator. Up to 4 modules installed in series form a row, 6 rows can be connected to a single drive unit to be tracked via a rope and pulley arrangement. A sun position calculation gives the input for an approximate tracking of the collectors while sun sensors installed in several locations of the collectors provide data for a precise positioning (fine tuning). Mounted in the focal line is a stainless steel absorber tube with 40 mm diameter, which has been galvanically coated with a selective surface. A non-evacuated glass envelope reduces the convective heat losses from the absorber. Flexible hoses with thermal insulation and a metal fabric envelope connect the moving absorber tubes with the stationary field piping.

To obtain reliable performance data for design and performance calculations, a single row has been installed at the DLR test facilities in Cologne for a measurement campaign in summer 2008 (Figure 1). For the design considerations described in this paper, preliminary data from earlier measurements are used.

Fig. 1: SOLITEM PTC 1800 collector at DLR testfacility, Cologne

3. Design considerations

3.1. System integration

Following the procedure recommended as a result from IEA Task 33/IV, each potential application for solar process heat systems should initially be analysed to identify the potential for technological optimization of the production process and it's unit operations, including the potential for heat recovery [2]. Such analysis helps to avoid over-dimensioning of the solar system, and to identify the appropriate temperature level for the integration of solar heat into the process. Since collector efficiencies are strongly temperature dependent, this information is important for the selection of appropriate solar technology and operating temperature of the system. Other important factors are the daily, weekly and annual demand profiles. These, together with the related solar resource data are needed to determine heat storage requirements and the potential solar share. In any case, the design and integration of the solar system needs to take into account that the production has the absolute priority, and the processes must not be impaired by changes in insolation or any other influences from the solar system. On the other hand, it should be endeavoured to utilize as much as possible all energy collected by the solar field.

Since the purpose of this project is the demonstration of direct steam generation in parabolic trough collectors, the solar technology is already pre-determined. Under these conditions, there are three principal options for the integration of the solar steam:

- Solar augmentation of the drying process
- Direct solar steam supply to individual consumers in the new production line
- Solar steam integration into the existing distribution

Solar augentation of drying process

The strip dryers are operated with steam at 9 bar and have a capacity of 174 kW each. The advantage of this option is that all steam produced by the pilot plant can be utilized by a single consumer at all times, without the need to implement an additional storage. However, the 9 bar pressure level implies lower collector efficiencies and longer start-up times in comparison to the 4 bar applications. This drawback will be amplified by the solar radiation conditions at the given site, which will lead to significant proportion of part-load operation. Since the drying process is particularly sensitive for the product quality, this application was not considered appropriate for a first-of it's kind demonstration plant.

Direct solar steam supply to the new production line

The current extension of the production facilities provides favourable conditions for the implementation of additional piping and heat exchangers for the solar steam into the degreasing and sealing baths and storage tank. Such a dedicated solar heating system would allow more flexibility for optimized operation of the solar field. It could be operated at temperatures little above the desired bath temperatures, and allow, in principle, even the implementation of non-tracking medium temperature collectors like CPC, vacuum tube or double glazed flat plate collectors as described by Rommel et al. [3] with pressurized water as the heat transfer medium.

Figure 2 shows the hydraulic scheme for the direct supply of individual consumers by dedicated heat exchangers from the solar system. The solar field is operated in recirculation mode. Water from the bottom of the steam drum is pumped through the collectors, where a proportion depending on the solar input is evaporated. The water/steam mixture is returned to the drum where it is separated by gravitation. Saturated steam is extracted through a pressure control valve and directed to the consumers. To ensure appropriate temperature levels in the process at all times, the solar heat supply will be backed up by heat exchangers fed by the conventional steam system (not indicated in Fig. 2), connected in series to the solar heat exchangers. The condensate is collected and pumped back to the steam drum. An expansion vessel is integrated into the system to compensate for the different volumes of water and steam in the cold and operation conditions, respectively. Auxiliary heating for freeze protection could be integrated into the steam drum or the condensate vessel.

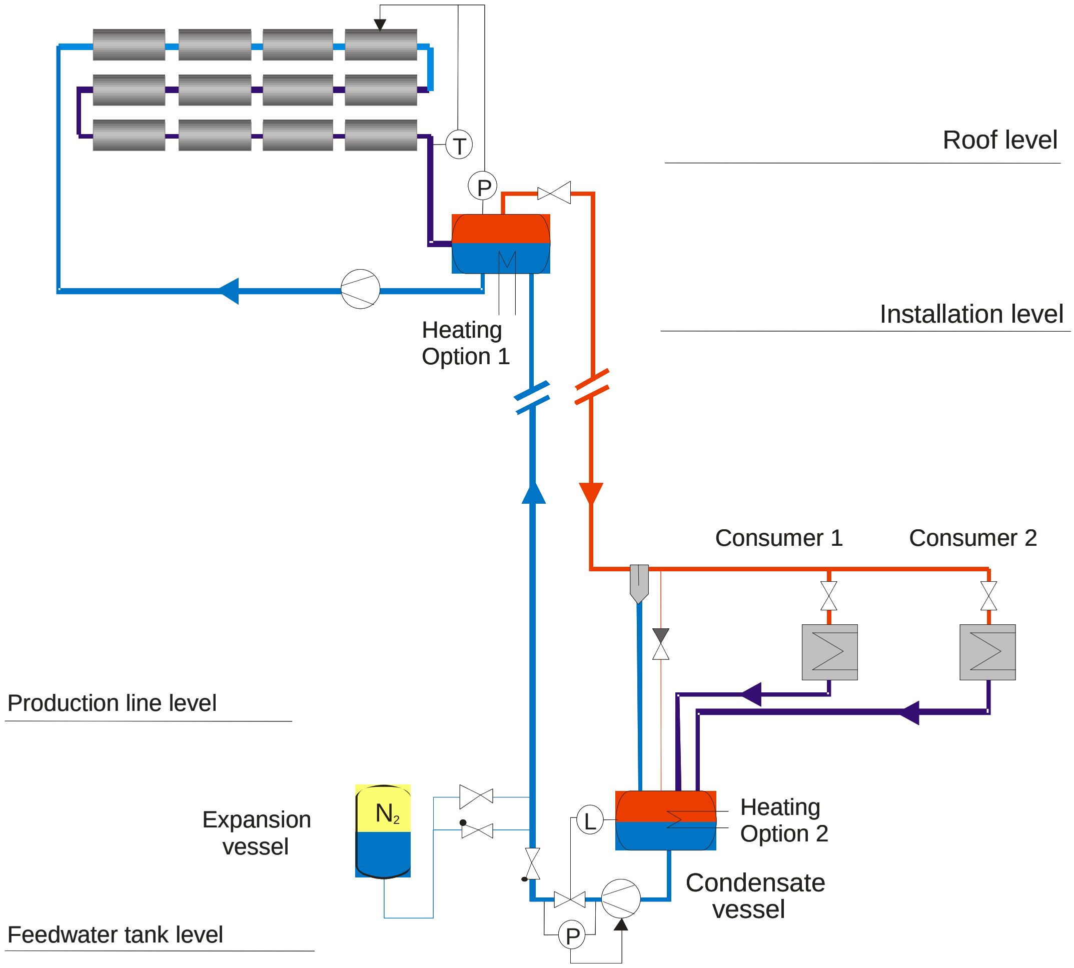


Fig. 2: Hydraulic scheme of direct solar steam supply to individual consumers

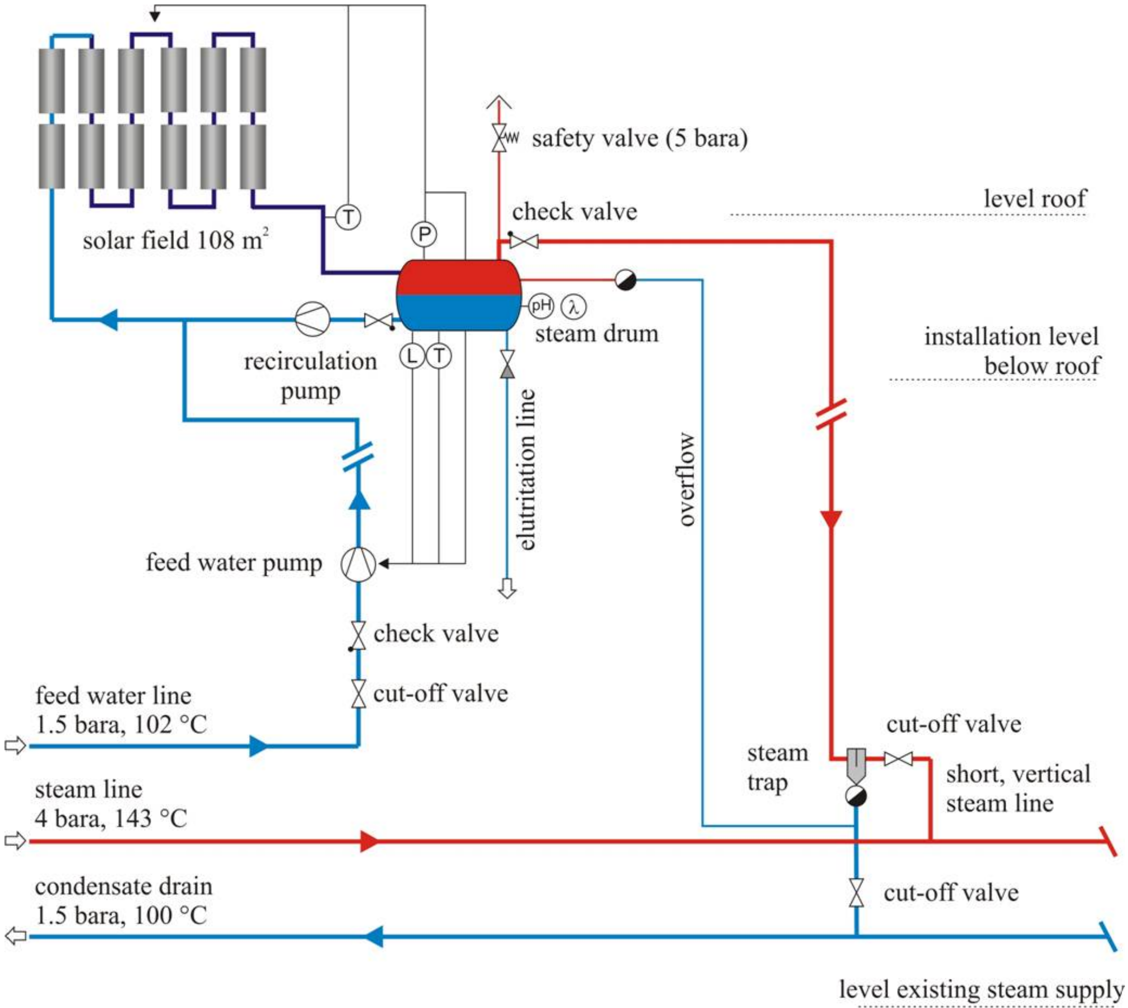
Operating the solar system as an independent closed loop has several benefits. The conventional steam system cannot be jeopardized by transient insolation, condensate quality or fluctuating pressure from the solar system. Reducing the pressure and temperature may increase the of the collector efficiency by several percent.

On the other hand, the base load consumption of the new production line is too low to guarantee direct utilization of the solar steam (compare table 1). Therefore, costly steam storage would have to be integrated, or additional consumers need to be connected. Steam and condensate piping to several more or less distant consumers will not only increase the necessary investment but also cause thermal losses which may partly compensate the potential benefits from the reduced temperature operation of the solar field. Parallel steam supply from solar and conventional boiler system to the various consumers does also imply duplication of controls, leakage detection and feedwater treatment, altogether leading to prohibitively high additional cost on top of the solar system.

Solar steam integration into existing distribution

Integrating the solar generated steam directly into the existing steam line is a more promising option. In order to fit the solar boiler into the system identical technical standards as for the production steam line should be applied. This means that, for example, the piping materials used in the solar field have to be the same as in the production line, the chemical properties of the condensate should be the same, etc. In any case, due to safety regulations, the solar field and all the steam devices (valves, flexible hoses, steam drum, etc.) should have the "CE" mark and all welding must be done by classified welder for pressure equipment to pass the performance and acceptance test of the technical inspection agency.

If these basic requirements are fulfilled, the solar steam could directly feed into the production line by means of an overpressure valve (>4 bara), with the feed water to the solar steam generator provided from the industrial steam system. Condensate from the solar system can be tracked back by the condensate line of the existing system. The feed water pump for the solar field will be controlled by a level measurement in the steam drum. Figure 3 shows the system layout for this configuration. The steam drum is operated at constant pressure of about 4.3 bara.



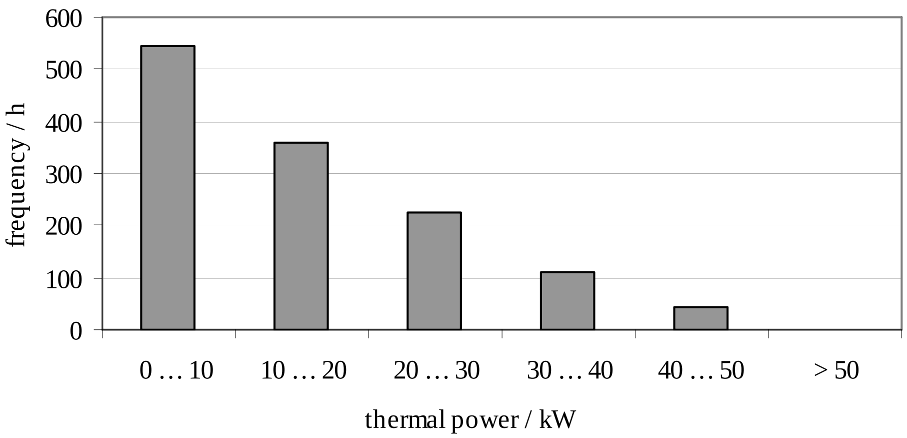
Fig, 3: Hydraulic scheme of solar steam integration into existing distribution

During strong transients, that might have negative impact on the stability of the steam line, the generated steam can be blown off through a waste steam line above the roof. In this case, the production line is not affected. If the solar field is out of operation for an extended period, all condensate will be removed into a waste reservoir and the plant refilled with fresh feed water to avoid condensate degradation by corrosion and aging.

This option allows a very simple and compact balance of plant for the solar steam generator, and avoids cost and losses associated with additional piping and controls for the distribution. The solar steam generator is simply treated like any conventional supplementary boiler which might be retrofitted to an existing system.

3.2. Solar field layout and expected performance

Length and orientation of the collector rows had to be adapted to meet the constraints given by existing infrastructure at the site. Performance calculations with different sets of meteorological data for the region confirmed that the highest annual energy yield could be achieved with the collector tracking axis oriented to NNW, perpendicular to the wall of the adjacent production hall [4]. Due to inconsistencies in the radiation data available for that region from different sources, there is still a great uncertainty about the expected annual thermal energy provided by the system, ranging from some 9.300 kWh/a to 19.200 kWh/a. Some 1250 productive operating hours may be expected per year, with major proportion in part load (Figure 4).



Fig, 4: Expected annual load distribution of the solar steam generator

3.3. Solar field freeze protection

At the given site, ambient temperatures fall below 2 °C at 20% of the year [4]. But even other regions for future applications of this technology may require freeze protection for the solar field. The intention to feed the solar steam directly into the existing distribution precludes the options to operate the solar field with refrigerants or antifreeze additives to the water. Another option is to decommission the plant during winter. Draining and refilling the system requires hardly any additional equipment installation. However, maintenance effort will be increased, and annual performance reduced. The latter could be avoided by an automatic draining and refilling system, at the expense of increased complexity and cost.

The proposed solution is circulation heating during times with danger of frost. First estimates indicate that the solar gain during winter will over-compensate the heating demand for freezing protection, subject to verification during the system operation and monitoring phase. Heat sources for the freeze protection could be either steam or condensate, but also waste heat utilization or electric heating may be considered.

4. Conclusions and outlook

The layout and integration of direct solar steam generation for a process heat application with parabolic trough collectors has been planned for a demonstration plant, which is under construction and will start operation late 2008. This will be the first installation which allows test and evaluation of direct steam generation in an industrial environment. A monitoring program will be performed to validate the design assumptions and simulation models. The integration of a solar steam generator into the steam distribution of existing conventional installations can be a cost effective alternative to the retrofit of solar steam or hot water systems supplying individual low to medium temperature processes.

5. Acknowledgements

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