Guideline for the utilization of solar heat in breweries

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Abstract

The large effort to identify suitable processes for the integration of a solar heating system and its planning is one of the main reasons for the small number of solar process heat plants in industry. Within the framework of the research project "Solar Process Heat and Energy Efficiency" (SOPREN), a guideline for the utilization of solar energy in breweries was developed at Kassel University. This guideline shall be used by planners to facilitate the fast feasibility assessment as well as the integration and planning of solar heating systems in breweries. Therefore, relevant background information is given to understand the production processes, mode of operation and energy consumption of breweries. Based on detailed process descriptions, suitable ways for the integration of solar heating systems in the existing processes are described. Relevant boundary conditions, such as required hardware, change in control strategies, or other special features, are considered.

1. Background

Within the scope of the project "Solar Process Heat and Energy Efficiency" (SOPREN), the Institute of Thermal Engineering (ITE) at Kassel University developed a concept that combines the improvement of energy efficiency, an optimized heat recovery and a solar heating system for process heat generation for a brewery. This concept has been implemented at the Hütt brewery in Kassel (Germany). The solar heating system that is integrated into the hot water buffer of the brewery is monitored by ITE.

A guideline for the utilization of solar process heat in breweries was developed based on the experiences of the extensive investigations at Hütt Brewery as well as results of various audits at other breweries of different sizes (40,000..1,800,000 hl per year), detailed literature study and the input of different plant manufacturers. This guideline includes all relevant information to analyze a brewery and find a suitable point of integration for a solar heating system for energy managers or planners.

Within the first section of the guideline, the beer production is explained. This includes all information that is necessary to get a brief overview of the production processes. Additionally, the distribution of heat consumption within the brewing sector is shown by benchmarks. Therefore, the specific heat demand for different company sizes, production facilities (brewhouse, bottle filling hall, etc.) and processes are listed and explained.

The second section of the guideline shows how to find a suitable point of integration for a solar heating system. Based on a distinction that is made between the integration on supply and process level, the most important criteria for the selection of a suitable point of integration are explained. These criteria are used for a ranking of nine promising processes that can be supplied with solar energy.

The third section of the guideline includes a fact sheet for every process that was ranked in section two. The header of the fact sheet shows the temperature range, operating time, effort for integration and share on the overall heat consumption. More detailed information is given regarding the purpose of the process and the required installations as well as the conventional way of heat supply. Based on the illustrated integration scheme, the integration of solar heat is explained.

Finally, the guideline includes a checklist for an approach how to find a suitable point of integration. This checklist shall guide a user through all relevant steps of data collection and investigation. The next chapters of this paper represent an extract of the guideline.

2. Overview of beer production

The production of beer in Germany takes place in a multitude of breweries. While micro-breweries with very low production volumes have the largest share of the total number of breweries (about 980 of 1,330), very large breweries with capacities over one million hectoliters per year produce nearly three-quarters of the total annual beer production of 95 million hectoliters [1]. According to the German purity law only water, malt, hops and yeast are allowed for the production of beer. In addition to these raw materials, further operating supplies such as CO_2, lye and other chemicals for cleaning as well as different containers for bottling the beer are required.

The production process in a brewery can be divided in three sections: the brewhouse, the fermentation and storage cellars and the bottling hall. In addition to these sections, utilities are necessary to maintain the production processes. These include the supply with all necessary media (heat, cold and compressed air) as well as cleaning equipment, water treatment, warehouse, and office buildings. While the production of wort within the brewhouse is responsible for a very large heat demand, the fermentation and storage cellars consume a lot of electricity to generate the required cold. The ratio of the required thermal and electrical energy is more balanced within the bottling hall. Typically, every brewery uses two installations to recover heat within the brewhouse. During wort boiling, the energy of evaporated water can be recovered and during wort cooling, cold brewing water is heated by hot wort.

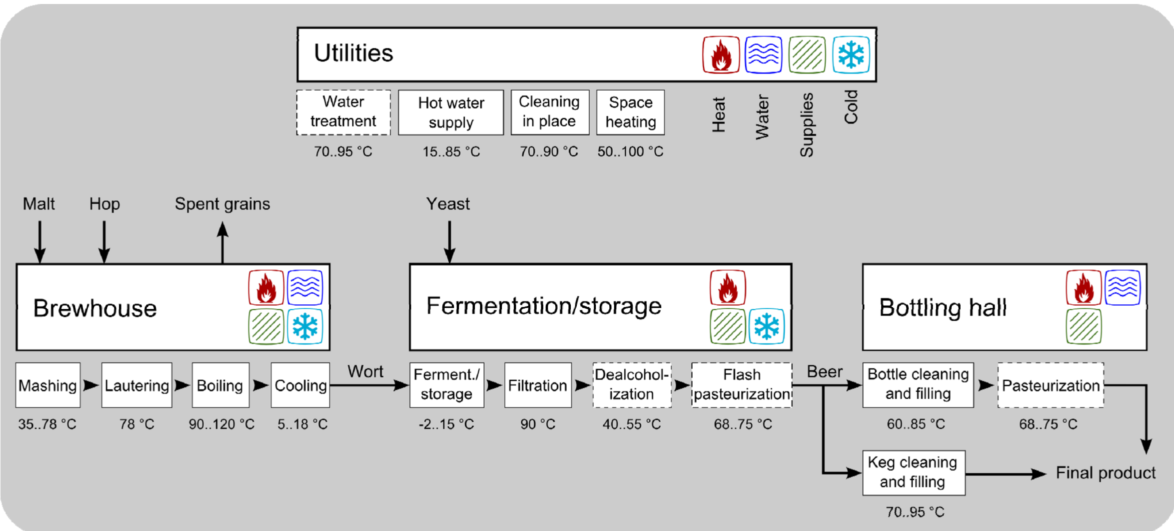

Fig. 1. Production sections of breweries with processes and respective temperature levels.

Approximately 75 % of the final energy demand is used to provide process heat and space heating. The rest is consumed as electricity, mainly for cold production and pressurized air. Benchmarks help to evaluate the efficiency of a certain brewery. These benchmarks, which are a quotient of the overall thermal or electrical energy consumption to the yearly production output, vary significantly with the size of a brewery. The average specific heat demand of a very small brewery (< 20,000 hl/a) is with 63 kWh_{th}/hl about twice as much as that of a large brewery (> 500,000 hl/a) consuming only 28 kWh_{th}/hl. Table 1 shows the specific heat demand of breweries by yearly production output.

Table 1. Specific heat demand of breweries by yearly production output [2]

Production output	< 20,000 hl	20,000..50,000 hl	50,000..100,000 hl	100,000..500,000 hl	> 500,000 hl
Heat demand	63 kWh_{th}/hl	59 kWh_{th}/hl	53 kWh_{th}/hl	43 kWh_{th}/hl	28 kWh_{th}/hl

The actual heat demand of a specific brewery can differ significantly from these values due to a large heat consumption of utilities or space heating. The typical distribution of the heat consumption of a brewery, as shown in Figure 2, can be used to identify inefficiencies in a certain section of the production process.

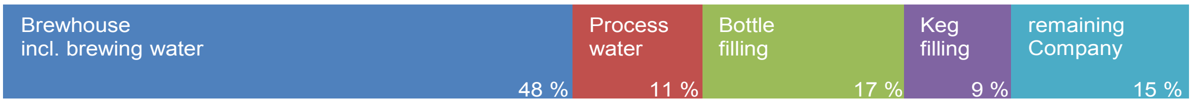

Fig. 2. Typical distribution of the heat consumption of different sections in a brewery [3]

As shown in Figure 2, about 50 % of the total heat consumption is needed in the brewhouse, mainly for mashing and boiling. About a quarter is consumed in the bottling hall. The 11 % for process water include the total hot water demand of a brewery that is not used for mashing and lautering but mainly for cleaning purposes. The remaining operations, which include space heating, cleaning-in-place and if applicable, dealcoholization, flash pasteurization and water treatment, consume approximately 15 % of the total heat demand. In very small and inefficient breweries this share can be as high as 50 %.

For the design of a solar thermal system in a brewery the heat demand of the chosen integration point and its demand profile have to be determined. Process benchmarks can be used to estimate the heat consumption of an individual process. Usually, these benchmarks indicate the specific heat demand of a process for one hectoliter of sold beer. The heat consumption for heating up the mash from 50 to 76 °C is e.g. in the range of 2.4 to 2.5 kWh per hl sold beer. Values for other processes can be found in technical literature for breweries, see e.g. [4].

3. Identification of suitable integration points

There are different possibilities for the integration of solar heating systems to provide process heat. Basically, the integration on supply level can be distinguished from integration on process level. Typically, breweries have a central boiler house, which supplies thermal energy for the different processes. Mainly natural gas and heating oil are used within the boiler house to generate hot water or steam. Sometimes other fuels such as biomass or organic residues are used. The heat generated by a boiler is usually fed into a central heat distribution network. Mostly steam networks are used that supply all processes with the required thermal energy. Therefore, heat exchangers are connected to the steam network (see Figure 3).

The integration on supply level comes along with high set temperatures that have to be provided by the solar heating system. This is based on the fact that solar heating systems are mainly installed in parallel to the boiler and have to provide the set temperature of the heating network. Based on the boundary conditions of the respective heat generation and supply system, the minimum set temperature for the solar heating system is approximately 100 °C, and can easily exceed 200 °C. By integrating solar heating systems on process level, solar energy can be used directly for one or more processes, at temperatures below the return temperature of the heat distribution network. Therefore, the supply of solar heat on process level generally comes along with lower temperatures compared to integration on supply level [5]

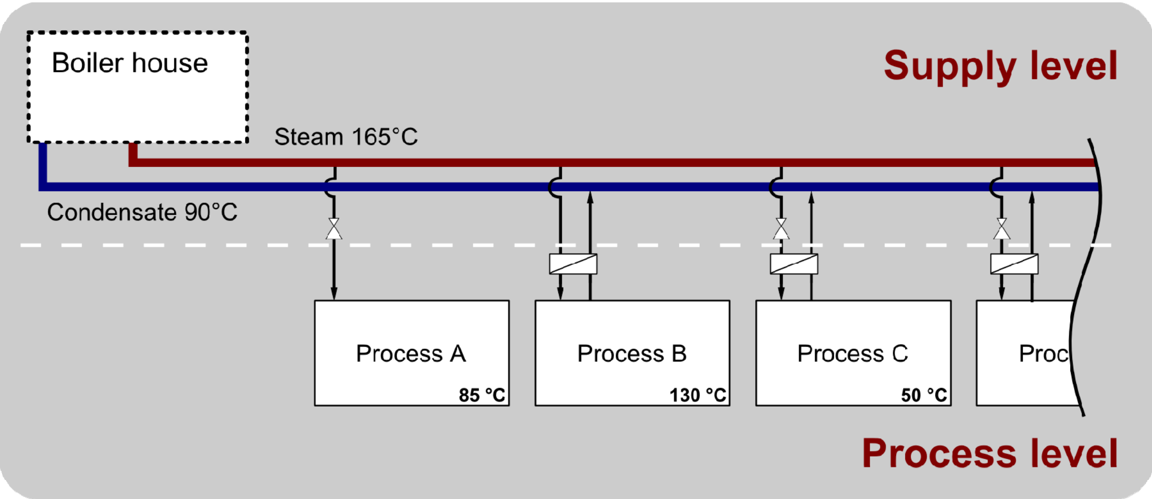

Fig. 3. Distinction between supply and process level.

The following criteria are relevant for the selection of a suitable point of integration of solar heat:

- In Germany and other countries with similar climatic conditions, the **process temperature** is the most sensitive parameter. In general, the solar yield decreases with increasing set temperature. Therefore, processes that have a low set temperature or that allow a solar pre-heating should be favored.
- Another parameter of great importance is the **load profile** of the process. In principle, processes with long operating hours within a week should be preferred. However, a minimum operating time is difficult to specify. A process that runs every second day is for example more suitable for the supply of solar heat than a process that has the same operating time on consecutive days. The utilization of solar heat for multiple processes can lead to a more constant load profile.
- The **effort to integrate** the solar heat into the existing process is the third important criteria. The effort can vary widely according to the respective process. While the solar assisted heating of brewing water only requires an additional heat exchanger (and some peripheral equipment) that is connected to the existing hot water buffer of the brewery, the utilization of solar heat for mashing requires either the replacement of the existing mash tun or a costly retrofit with sufficient heat exchange surface at the inside of the tun.

Finally, all three criteria have to be considered for the decision regarding the optimal point of integration. If a process with high set temperature and long operational hours is compared with a process with a low set temperature and shorter operational hours, the disadvantages of the poorer load profile may be compensated by the advantages of lower set temperature. Other criteria that can influence the feasibility of integrating solar heat are the share of the process heat demand on the overall heat consumption of the company, available and unused waste heat and the distance between a suitable area for the solar heating systems and the process where the heat is required.

Table 2. Suitable processes for the integration of solar heat in breweries.

Process	**Temperature**	**Criteria**			**Comments**
		Operat. time	Integration	Heat demand	
Hot water supply	15..85 °C				Additional hot water demand strongly depends on heat recovery at wort boiling.
Water treatment	70..95 °C				Necessity of water treatment depends on quality of available water.
Tunnel pasteurization	68..75 °C				Not in every brewery, influenced by product range (non-returnable, mixed beer, etc.).
Dealcoholization	40..55 °C				Not in every brewery.
Cleaning in place	70..90 °C				Heat demand depends on production profile and cleaning cycles.
Flash pasteurization	68..75 °C				Heat demand depends on amount of beer that has to be pasteurized.
Bottle washing	60..85 °C				In smaller breweries sometimes alternating with Keg cleaning.
Mashing	35..78 °C				Solar heat only in case of modernization or new installation.
Keg cleaning	70..95 °C				Compare bottle washing

The listing is the result of a quantitative ranking. Scores were awarded for temperature (low T = high score), operating time (long time = high score) and effort for integration (large effort = low score). The placement results from the total score. The share of the heat demand strongly depends on the boundary conditions of a brewery. In this case the numbers are exemplary calculated for a brewery with 250.000 hl/a.

4. Integration schemes for selected processes

Within this chapter, integration schemes for two processes listed in Table 2 are shown and explained. To understand the ranking and influence of the criteria set temperature and effort for integration, the solar assisted hot water supply and solar assisted mashing were chosen.

4.1. Hot water supply

In addition to hot brewing water that is required for mashing and lautering (this amount is usually covered by heat recovery from wort cooling), breweries need additional hot water for cleaning and sterilization purposes. The amount of this hot process water can range between 0.2..1.5 hl per hectoliter of cast wort.

Depending on the quality of the available water, breweries have separate hot water buffers for brewing and process water or a central brewing water buffer, which supplies all consumers. Based on the required volume that has to be stored, the hot water buffer can consist of several storages that are connected in series or parallel.

Usually, the hot water buffer is connected to an auxiliary heating system (mostly external heat exchanger fed by steam) to ensure a supply temperature of at least 85 °C. The buffer is fed with hot water from wort cooling, sometimes also with hot water from heat recovery at boiling. Additionally, the buffer can have a cold water inlet.

Prior to the integration of solar heat, the amount of cold water that is fed into the hot water buffer has to be determined. If a significant amount of cold water enters the buffer a solar preheating can be realized (left scheme). Besides the possibility to operate the solar heat exchanger purely as a flow heater, it can additionally be used to heat the buffer. However, in this case the solar heating system has to provide significantly higher temperatures, since the buffer is usually fed with hot water from the heat recovery. Due to the very high flow rates of fluid that leave or enter the buffer, there is usually no or only little stratification. Based on the mixing of hot and cold water within the buffer, a solar heating of the buffer without preheating of cold water will result in lower solar yields.

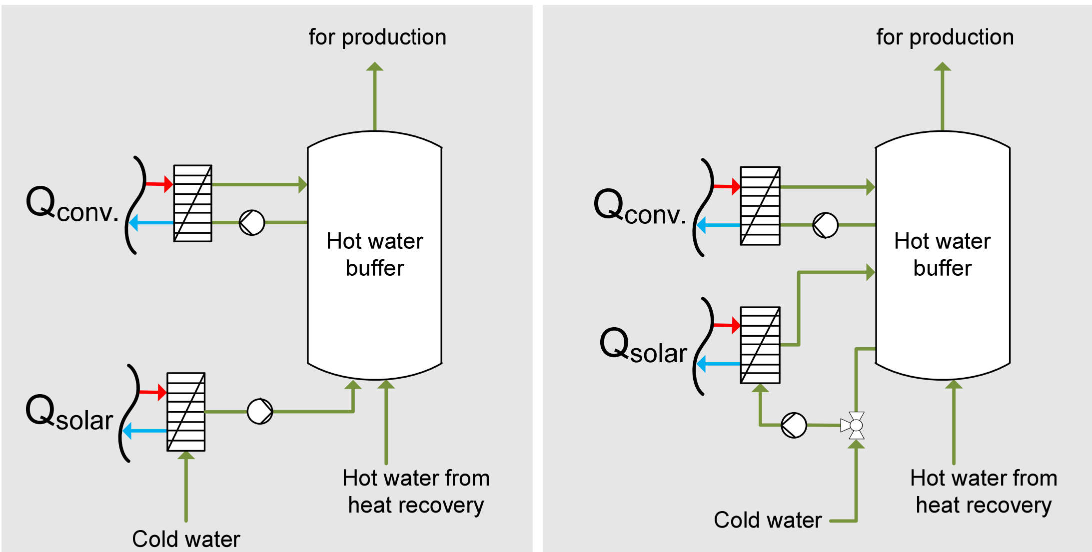

Fig. 4. Integration scheme for solar assisted hot water supply.

The requirement for additional hot water can vary strongly from brewery to brewery. It is mainly affected by the heat recovery during wort boiling. If the waste heat from wort boiling is used for hot water generation, the integration of a solar heating system into the hot water buffer of a brewery can usually be excluded from the list of suitable integration points.

4.2. Mashing

During mashing, malt is mixed with brewing water (35..63 °C) and heated to convert the contents of the malt into soluble compounds. The respective start temperature and the following time-temperature profile depend on the mashing process and type of beer that is produced.

Mash tuns are equipped with a heating and stirring device. Based on the respective mashing process, either the content of the entire tun is heated (infusion method) or a part of the mash is drawn off, boiled and mixed with the rest (decoction).

Usually, mash tuns are heated by steam that passes welded half pipes or pockets at the side and bottom part of the tun. Another possibility, but rarely used is direct injection of suitable steam. If mash tuns are heated with hot water, the entire shell is usually a structured heating surface (so-called dimple plates).

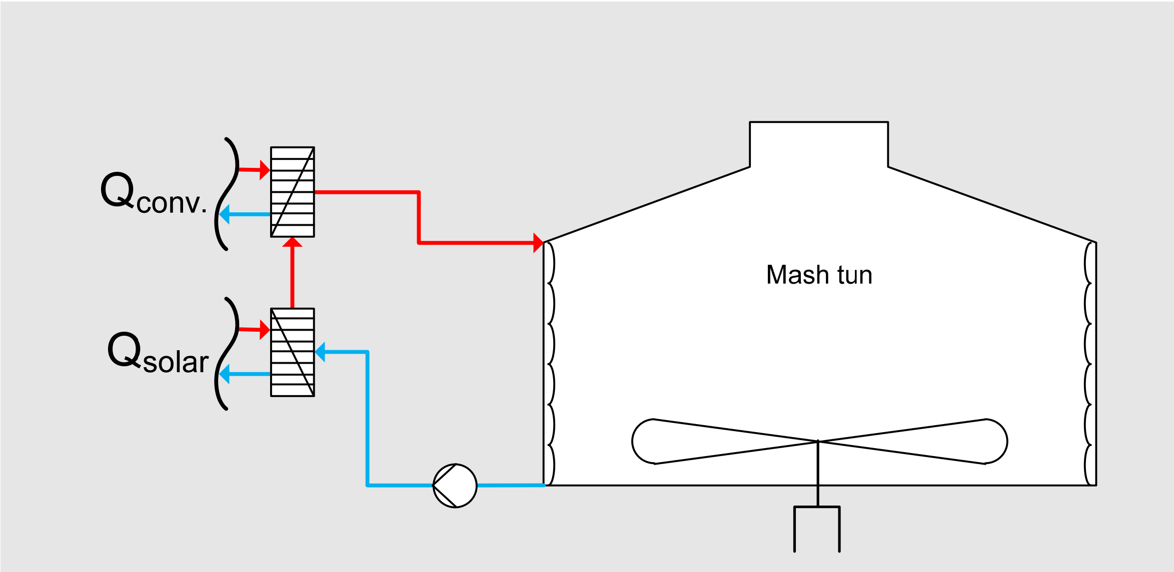

Fig. 5. Integration scheme for solar assisted mashing.

The integration of solar heat for the mashing process should only be considered if the mash tun already has a sufficient heat transfer area for heating with hot water or if the mash tun has to be replaced. The modification of an existing steam heated mash tun is generally too complex and expensive. The required flow temperature of the heating medium for mash tuns with dimple plates is about 95 °C. Since the maximum temperature of the mash is around 78 °C, return temperatures of approximately 85 °C can be reached. At the beginning of the mashing process lower return temperatures are possible. The heating system has to ensure heating rates of 1 K/min. The integration of the solar heat takes place in the return flow, prior to the conventional heat exchanger. This serial connection guarantees the required set temperature.

4. Summary

Industry is one of the most promising sectors for solar heating systems within the near future, though the total number of installations worldwide is still rather small. To accelerate the further development of this technology, tools are needed to simplify the feasibility assessment and preliminary design of solar heating systems. This can be achieved by different strategies such as the development of guidelines for the design of process heat systems, the development of suitable computer programs or the creation of so-called sector concepts. Within the project SOPREN a sector concept for the brewing industry was developed by Kassel University that includes in detail all relevant information on the structure of the brewing industry, applied production processes and energy consumption. Based on detailed process descriptions with information regarding temperature levels, load profiles, equipment and heat supply and considering possible measures for heat recovery, the sector concept includes integration schemes for solar heat for all relevant processes. The presented guideline for the utilization of solar heat in breweries is an extract of the sector concept and can be used by solar planners and energy managers to perform feasibility assessments and to identify a suitable point for the integration of solar heat. The complete sector concept as well as the guideline for utilization of solar heat in breweries will be published in German on the website of Kassel University by the Institute of Thermal Engineering (www.solar.uni-kassel.de/downloads).

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