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# 388 - Integration of Solar Heating Systems for Process Heat Generation in Breweries

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**Abstract**

The generation of process heat for industrial applications seems to be a promising market for solar thermal systems. Processes in several industrial sectors consume high amounts of thermal energy at a low to medium temperature level. These boundary conditions are given in the food and beverage industry, especially in breweries. In this paper, basic information are given for the implementation of solar heating systems in breweries.

Using the Hütt brewery in Kassel (Germany) as example, the diversity in brewing processes is shown. Although all breweries consume large amounts of thermal energy for the wort production, every single brewery has to be analysed relatively detailed. To estimate a reasonable integration of a solar heating system, a detailed water and energy balance has to be drawn. The strong influence of the existing or available installations on a solar heating system is shown by two different concepts for the Hütt brewery. Therefore, it will be difficult to develop general guidelines for a suitable implementation of solar heating systems in breweries.

Keywords: solar process heat, industrial processes, brewery, energy efficiency

## 1. Introduction

By the year 2006, approximately 128 $GW_{th}$ of solar thermal collectors had been installed worldwide. Most of the installed systems were used for domestic hot water preparation, space heating or swimming pool heating [1]. So far approximately 90 solar heating plants with a total capacity of 25 $MW_{th}$ were used for industrial applications, which is a nearly negligible share of 0.02%. Within the framework of IEA SHC Task 33/IV, the potential for industrial applications within the EU 25 was estimated to be between 100 and 125 $GW_{th}$. This huge potential is based on two facts: Firstly, the industry sector consumes nearly 30% of the total primary energy consumption in the EU25 and secondly, a significant share of the heat consumed in this sector is in the low and medium temperature range [2]. Approximately one third of the total industrial heat demand is required at temperatures below 100°C and nearly 60% at temperatures below 400°C. In some of the industrial sectors, such as food, wine and beverage, transport equipment, textile, pulp and paper, the share of heat demand below 250°C can be as large as 60% [3].

The food and beverage industry is one of the key sectors for solar heating, since processes such as cleaning, drying, pasteurisation, sterilisation or boiling take place at a low temperature range and the overall energy consumption is large [4]. To realise a significant implementation of solar heating systems within this industry sector, it has to be analysed which part of the high heat demand at a low and medium temperature level could be provided by solar heating systems, how to integrate these systems in already existing processes and finally, how to transfer this knowledge to similar processes or other sectors.

Within the food and beverage sector, breweries show a large heat demand at relatively low temperature levels, but also a large potential for heat recovery. The brewing sector is furthermore interesting because of the large amount of breweries in Europe and especially Germany. All over Europe, there are more than 2,800 breweries, nearly half of them is located in Germany. Almost 85% of all German breweries are small and medium sized companies (SME) with an annual beer production of 50,000 hl or less [5]. In 2006, about 4.3 TWh (15.5 PJ) of energy was consumed in almost 1,300 German breweries, only one fourth of the consumed energy was electricity [6].

## 2. The Hütt brewery

Within a research project that started in 2005, four case studies for medium sized companies located around Kassel (Germany) were carried out to analyse the suitability of implementing solar heating systems for process heat generation. Specific and overall heat consumption and temperature ranges were estimated or measured and transient needs of the heat supply systems were analysed, with focus on existing stores and hydraulics, used fluids (e.g. steam cycles) and possibilities for heat recovery installations [7]. The Hütt brewery in Kassel is one of the investigated companies. It was founded in the 1750's and has a current staff of about 60 employees today. The brewery produces approximately 80,000 hl of beer per year and has an annual final energy consumption of 6.5 GWh. More than 80% of the energy is supplied by natural gas and used to provide process heat, hot water and space heating. All heat consumers are connected to a steam network that is fed by a boiler ($P = 2.6\ MW_{th}$). The production process is operated in one shift on five days per week. During summer, the amount of produced beer increases by a factor of 1.3 compared to the winter period. Based on their production capacity, technical installations and energy consumption, the Hütt brewery is a representative example for a typical SME in the brewing sector. The continuous development over the last decades with structural alterations and technological changes led to a non-optimised combination of production sites, installations and energy supply. Thus, energy efficiency measures of different complexity can be realised within several sections of the production process.

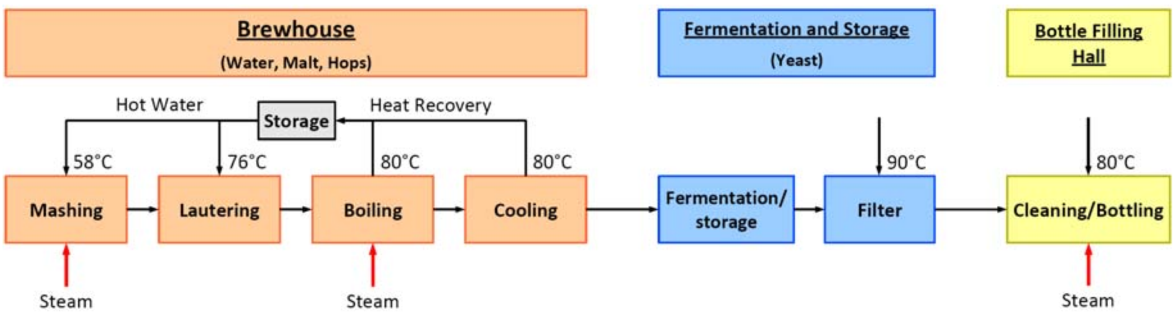


Fig. 1. Schematic of the brewing process at the Hütt brewery.
The respective temperatures are similar to other breweries.

Independent from the specific characteristic of a brewery, the production of beer can be divided into three parts: brewing, fermentation/storage and filling of bottles, kegs or cans. Figure 1 shows the simplified scheme of the production process at the Hütt brewery. In the beginning, the wort is produced within the brewhouse by mashing, lautering and boiling. After cooling the wort, it is stored in the fermenting cellar. Once fermented, the beer is filled into bottles and kegs. Within the production process, the brewhouse has a share of 40..50% of the overall heat consumption. The bottle and keg filling hall, with the bottle washing machine as biggest consumer, requires about 20..30% of total heat demand [8]. Besides a small amount of hot water for filtration, there is no significant heat demand within the process step fermentation and storage. However, this part is characterised by high electricity demand for cooling.

## 3. Diversity in brewing

As can be seen from the huge amount of breweries, there is a big variety of beers and every beer has more or less its individual recipe. One can hardly find two identical brewing processes in two different breweries, which is also influenced by the personal preferences of the respective brewer. Besides variations in used raw materials such as grains, hops and yeast, there are differences in time periods and temperature ranges during the wort production. Additionally, there are various technical installations available for mashing, lautering and boiling as well as heating or cooling the wort. This leads to the fact that the detailed knowledge of the brewing process in Brewery “A” might not result in a similar knowledge of any other brewery “B”. Within the brewhouse, there is a great difference in existing mashing and boiling systems.

At the Hütt brewery, the brewing process starts with mashing by mixing crushed malt with 58°C hot water in the mash tun. Within the next two hours, the mash follows a defined time-temperature profile with various temperature rests. Therefore, the shell of the mash tun is heated by steam. The principle of mashing (heating a mixture of water and grains) is more or less the same in all breweries. The diversity is based on the starting temperature, heating rate, way of heating the mash, set temperature and time for mashing as well as the used number and types of the mash tuns.

In the next process step called ‘lautering’, the resulting liquid is separated from the grains. Besides straining the mixture, the resulting draff is washed with hot water (around 80°C), to extract additional sugars. The variety of lautering processes in terms of consumed thermal energy is relatively small compared to mashing or boiling. Main differences can be found by the used lauter tun units. The temperature and proportion of hot water for this process step are more or less in a similar range.

Afterwards, the wort boiling takes place, which is the most energy intensive process step within the brewhouse. Before the wort is boiled, it has to be pre-heated from lautering temperature (around 75°C) to boiling temperature. This can be done by different methods, such as using the boiling copper or an external heat exchanger that is fed by steam, by high pressurised hot water or by recovered heat. After pre-heating, the wort is boiled for a fixed period, while hops are added to the wort. The respective boiling time and temperature is directly linked to the desired amount of evaporated water and the installed boiling system. This leads to different boiling times for different beer recipes or breweries. Another variation during wort boiling is given by the installed heat recovery system. At the Hütt brewery, the occurring vapours are condensed to heat brewing water that is temporarily stored in a hot water tank. Based on the respective installation, the recovered heat can also be used for pre-heating of lauter wort or boiling itself. For pre-heating of lauter wort, the evaporated water is condensed and heats water in a closed heat recovery cycle to a preferably high temperature level. This water is used to heat the lauter wort with a special heat exchanger from 75°C close to boiling temperature. The second possibility, using the recovered heat for wort boiling, is realised by using a special vapour compressor (thermally or mechanically driven). The compressed vapour can be used to heat the wort during boiling with a special heat exchanger.

After boiling, the so called ‘hot trub’ (remaining solid particles) is separated from the wort within a whirlpool. The wort is pumped tangential into the whirlpool, which causes a sedimentation process. After leaving the whirlpool, the wort is cooled by a double-stage heat exchanger. At first, the wort is cooled to approximately 15°C while cold brewing water is heated to 80°C and fed to a hot water storage tank. In a second step, ice water is used to cool the wort to a temperature below 10°C. The separation within the whirlpool is rather similar in all breweries. Solely the temperature level of hot wort can vary, which is based on the respective boiling process. The heat recovery installations for wort cooling are also comparable within different breweries. Usually, the amount of produced wort is similar to the amount of brewing water, heated within wort cooling, and sufficient to cover the demand for mashing and lautering. After wort cooling, the wort production is finished and the wort leaves the brewhouse.

## 4. Wort boiling – initial state and energy efficient alternatives

The wort boiling is the key process within a brewery. Because of the high thermal energy consumption and the high temperature level, two heat recovery systems that can cover the hot water demand of the whole brewhouse or even the whole brewery are usually installed.

Within the last 100 years, there has been a continuous development of the wort boiling process by the brewing industry. The main objective was to reduce the amount of water that has to be evaporated, which results in shorter boiling time and reduced energy demand. So it was possible to reduce the amount of evaporated water from more than 16% (equals a boiling time of more than 120 min) to 3..5% (35..50 min), while increasing the quality of the produced wort. At present, there are lots of boiling systems available that are offered by different companies. These systems differ mainly in the used boiling copper, its position within the brewhouse, the process control (continuous or batch), heat exchangers, pressure and temperature profiles as well as used heat recovery installations [9].

The wort boiling at the Hütt brewery takes place by so called classical internal boilers at atmospheric pressure. In the beginning, the wort is heated from 74°C to boiling temperature by indirect heating of the outer surface of the wort copper. After reaching the boiling temperature, the wort flows several times through an internal boiler that is placed directly in the copper. While passing the tube bundles of this boiler, the wort is heated under pressure to about 101..105°C. While leaving these tubes, the wort starts to evaporate. Compared to the state of the art within wort boiling, this boiling system is relatively simple and old. It consumes a high amount of thermal energy, due to the required time and temperature for atmospheric boiling, the relatively high amount of water that has to be evaporated and the missing insulation of the boiling copper [10].

To clarify the operating mode of heat recovery installations within a brewery, figure 2 displays the initial state of the wort production at the Hütt brewery in a simplified way. Two hot water storage tanks, each 50 m³, are installed to cover the hot water demand of the whole production process, including filtration and bottle filling hall. These tanks are connected in serial and charged by two heat recovery installations. The first storage tank is fed by the heat exchanger within the process step of wort cooling and has a temperature level of maximally 80°C. The second store is fed by a tube bundle heat exchanger that condenses the vapours which occur during wort boiling. Two modes of operation can be chosen: heating cold brewing water to 80°C, or increasing the temperature of the already stored hot water. All consumers of the brewery are fed by the second storage tank with the higher temperature level. The main hot water load is caused by mashing (58°C) and lautering (78°C). Other consumers with lower hot water consumption are cleaning processes, sterilisation and keg filling. If process steps require lower temperatures than the storage tank temperature, the stored water is mixed with cold water. The consumed amount of water from store number two is settled by the first storage tank. An additional heating device that runs with steam ensures a set temperature of minimum 80°C in the upper part of storage tank number two during weekends or longer periods with no heat recovery.

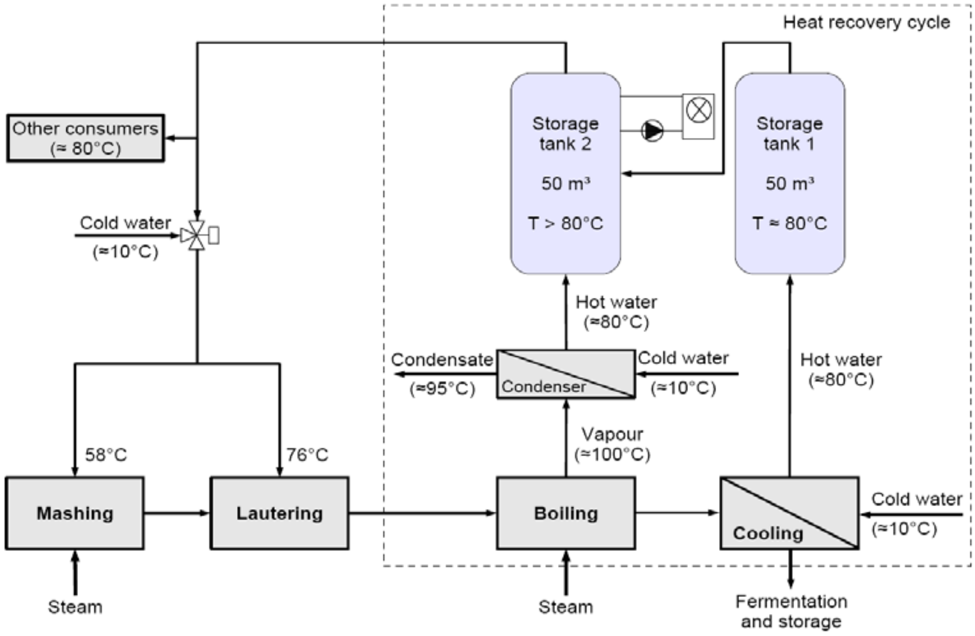


Fig. 2. Initial state in the brewhouse at Hütt brewery.

As mentioned before, there are multitude wort boiling systems available. These systems differ in the way of heating lauter wort and the used boiler. The overall objectives for this process step are to assure a gentle and rapid heating of lauter wort and gentle wort boiling with low shear forces. Further on, large evaporator surfaces, good circulation and mixing of wort and a limited but sufficient boiling time is requested [11]. Based on these and even more requirements, every brewhouse manufacturer has its own solution for the ideal wort boiling system. These can be classical internal or external boilers, thin-film evaporators, dynamic low-pressure boiling, high-temperature wort boiling, secondary evaporation under vacuum or downstream thin-film evaporation [10]. All of these systems vary a lot in the overall energy consumption, due to the boiling process as well as the heat recovery installations, which influences the water balance of the whole brewery.

Based on the relatively old and inefficient atmospheric wort boiling at the Hütt brewery, the technical management planned to implement one of these new boiling systems. During the planning phase, two different boiling systems were under consideration: a vacuum boiling system and dynamic low-pressure boiling. The vacuum boiling is characterised by a special geometry of installations and two boiling phases (atmospheric and vacuum) that are adjustable at will and cause a reduced evaporation. The whole boiling procedure takes place in a cycle consisting of a storage vessel, an external boiler (calandria) and an expansion evaporator in which a vacuum can be applied depending on the respective boiling mode. A tube bundle heat exchanger will be used to condense the vapours and pre-heat cold water. The main advantage of this boiling technology is the reduced effort for implement all installations in the existing brewing process. Besides savings of thermal energy, this boiling system shows an increased electricity demand for generation of vacuum. The dynamic low-pressure boiling represents boiling at slight positive pressure with periodically increased and subsequently reduced pressure. An internal boiler is mostly used for heating and boiling. This boiling system is combined with a special heat recovery system that uses the condensation enthalpy of vapours to pre-heat the lauter wort. This heat recovery system consists of a common tube bundle condenser, special high temperature storage and an additional heat exchanger for the lauter wort [12].

## 5. Integration of Solar Heating System

Although breweries show a high heat demand at a low temperature level, it is relatively difficult to estimate in the first instance, if a solar heating system can be reasonable integrated into the existing processes. This is based on the diversity and complexity of the brewing process, as explained before. The basis for this decision is the detailed knowledge of the water- and energy balance of the overall production process. Some breweries don't have any noteworthy hot water consumers beside the brewhouse, which can even lead to a surplus of hot water gained by heat recovery. In this case, the hot water is drained to the sewer and a non-concentrating solar heating system cannot be installed reasonably. Some breweries have several other hot water consumers beside the brewhouse, and need to produce the missing amount of hot water via conventional ways. And finally, hot water consumption and hot water generation can be balanced. If a change in the boiling system is planned, a new water- and energy balance has to be drawn, because of the interaction of boiling system and heat recovery. This might be difficult, since not all details are clarified before the new process is running. The link between boiling system, heat recovery and solar heating system and the associated changes in water- and energy balance shall be clarified in the following by the two considered boiling system at Hütt brewery.

The dynamic low-pressure boiling affects the water balance in a significant way. The energy of evaporated water during boiling is directly used for the closed heat recovery cycle with a high temperature level and no longer to generate hot water. The only remaining source of hot water is wort cooling, which can supply the amount for mashing and lautering. In this case, the missing hot water demand can be suitable met with a solar heating system. Together with the recovered heat from boiling that is used to heat the lauter wort, high energy savings can be achieved.

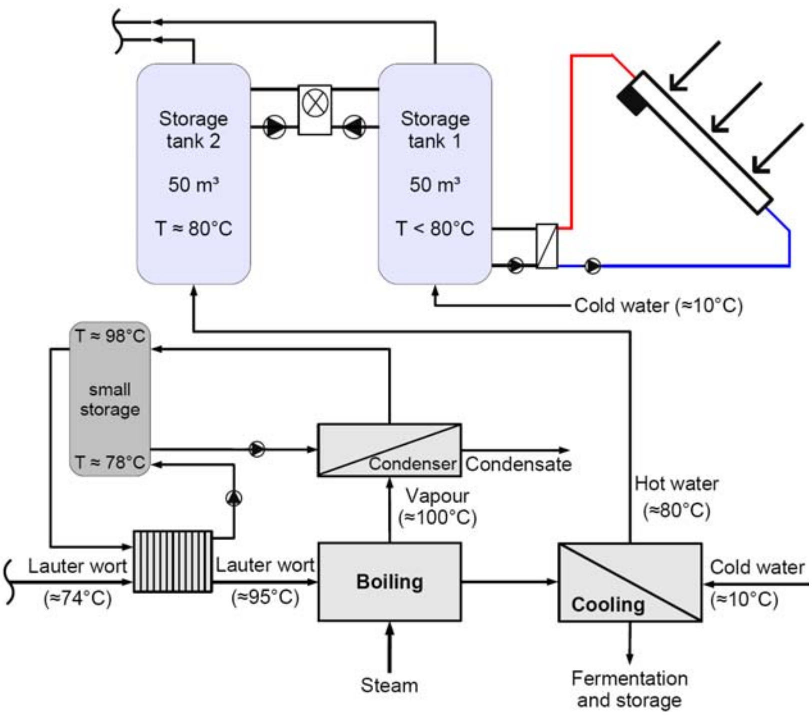


Fig. 3. Possible integration of solar heating system in combination with dynamic low-pressure boiling.

The vacuum boiling system affects the heat recovery during wort boiling and wort cooling, but with lower effect. In case of wort boiling, the amount of recovered heat decreases by two reasons: the amount of evaporated water is reduced by at least 25% and approximately two third of overall evaporation is realised under vacuum. Beside the reduced amount of evaporated water, the boiling temperature during the vacuum evaporation phase is decreased successively from 100°C to 85°C. This leads to a reduced amount of energy that can be recovered. As a result of the lower temperature during vacuum boiling phase, the wort temperature prior to wort cooling is also lower compared to the old reference boiling system. However, a detailed knowledge of all process parameters in prior is not possible, since the brewer has to adjust the new boiling system to the specific requirements, which influence the final boiling temperature and ratio of atmospheric to vacuum boiling phase. Nevertheless, both heat recovery installations are here used to heat water, which leads to an amount that should be adequate to cover the overall hot water demand of the brewery. If the actual water balance in a brewery is already balanced, an implementation of a solar heating system is rather difficult after this retrofit. To find a suitable way for the implementation in combination with this vacuum boiling system, a change in the heat recovery during wort boiling is required. In this case the condensation enthalpy should not be used to generate hot water, but to increase the temperature of the already stored water. Likewise, the storage concept should consider the separation of high and low temperature level as shown in figure 3.

The integration of the solar heating system into the brewing process after implementation of the vacuum boiling system is displayed in figure 4. In this case, the storage tank with higher temperature level would be fed by the heat recovery installation for wort cooling and the one with lower temperature level by the solar heating system. To ensure the required temperature for all process steps, the auxiliary heating system should be connected to both tanks. Additionally, the heat recovery during boiling can be used to increase the temperature level of both storage tanks.

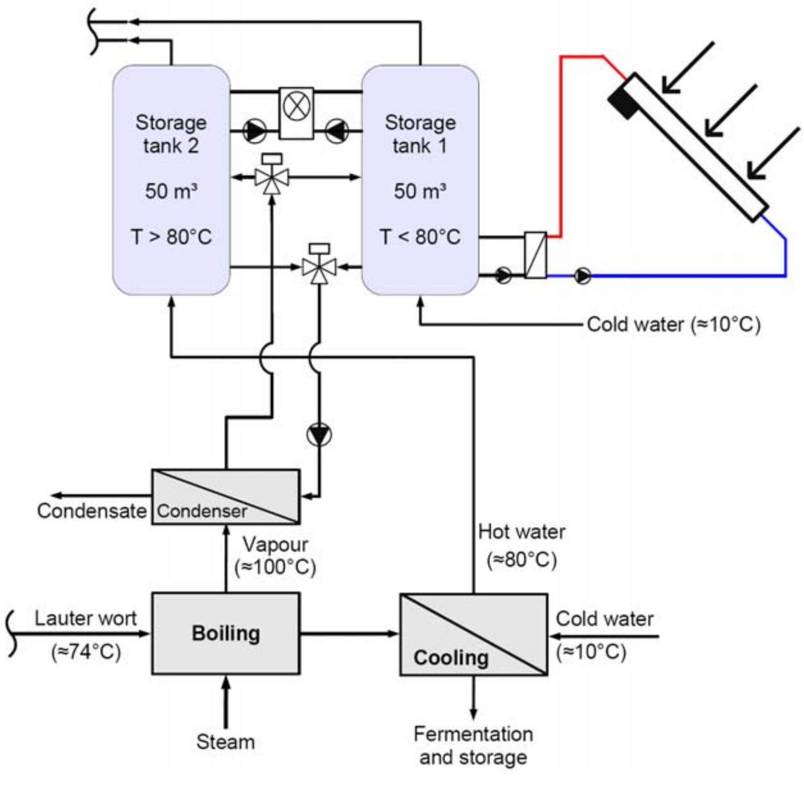


Fig. 4. Possible integration of solar heating system in combination with a vacuum boiling system.

## 6. Conclusion

This paper showed the large diversity in the brewing sector, especially within the process steps of wort production. Although breweries generally show a high thermal energy demand at a relatively low temperature level, a reasonable integration of solar heating systems can be rather difficult. This is based on various technical installations that are available and a high rate of heat recovery, which can also vary a lot by means of temperature level and used installations. There is no general approach to implement a solar heating system in breweries so far. It will probably always be essential to draw a detailed water and energy balance of the overall production process for every single brewery. This balance should include all accumulating hot water streams with the respective temperature level. If there will be a change in the technical installations that influences the produced and/or consumed hot water, a new balance has to be drawn. Based on this balance it has to be proven, if a solar heating system can be integrated in the existing process or not. Furthermore, the integration can be difficult, if the complete heat recovery runs at lower temperature levels to produce hot water.

## 7. Acknowledgements

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