Sustainable Beer Production by Combining Solar Process Heat and Energy Efficiency - Holistic System Concept and Preliminary Operational Experiences

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Abstract

Recent research projects in the field of solar process heat have shown that, besides the ambitious economic targets, the integration of solar heating systems in industrial processes is a main barrier for the widespread of this technology. Therefore, a sufficiently deep understanding of industrial processes is necessary, which currently does not exist among solar engineers. In a current research project, Kassel University developed a concept for solar process heat generation in a brewery that combines energy efficiency measures and the application of solar thermal energy. This paper gives an overview of the developed concept including the applied approach and will present experiences of planning and installation of the solar heating system. Furthermore, first operational results are presented.

1. Introduction

While the utilisation of solar thermal energy for domestic hot water and space heating applications is common today, solar heating systems in industry are limited to few examples so far. This is based on differing boundary conditions compared to domestic applications. Besides the ambitious economical expectations of industrial companies, the integration of solar heating systems in existing processes is often the main barrier to overcome. Therefore, a sufficiently deep understanding of industrial processes is necessary, which currently does not exist among solar engineers. In return, industrial- or process engineers usually have a lack of knowledge regarding the requirements for an efficient and economical operation of solar heating systems. To overcome this barrier, Kassel University carries out a project in cooperation with the midsized Hütt brewery in Kassel to implement a solar heating system.

This paper presents the approach to realize the holistic concept, starting from data collection and ending with the installation of the solar heating system. Important experiences of planning and installation of the solar heating system will be explained as well as first operational results.

2. Holistic System Concept

The applied approach for the realization of a project to supply solar process heat includes five steps that are built upon each other. At the beginning, a detailed data collection has to be carried out, which is the basis for the second step - analysis and description of the current situation. The outcome of this analysis is an overview of the energy situation of the production site, which allows the detection and evaluation of energy efficiency measures. This is the basis to develop a concept for the integration of a solar heating system in the forth step. The last step is the detailed planning and implementation of all measures. This approach enables a comprehensive concept that takes into account all relevant factors instead of planning a solar heating system without having a closer look to the production processes. In the following, the developed and realized concept for the utilization of solar process heat at the Hütt brewery is presented.

2.1. Current State

The current state of the wort production and hot water supply of the Hütt brewery is shown in Figure 1. Wort is produced in the brewhouse by four process steps: mashing, lautering, boiling and cooling. While the process steps mashing and lautering require large quantities of hot water at 60 °C and 80 °C, wort boiling consumes plenty of energy for heating the wort and evaporating water. Due to this high energy consumption, two heat recovery systems are installed. During the process steps wort boiling and wort cooling, brewing water at 10..15 °C is heated up to 80 °C and fed into the hot water buffer. This buffer consists of a variable volume tank which is serial connected to a fixed volume tank. All processes are supplied with hot water by the fixed volume tank. The variable volume tank that is fed with hot water from heat recovery provides water to the fixed volume tank to keep it filled. The amount of hot water generated by the heat recovery is sufficient to cover the hot water demand of the brewhouse (mashing and lautering) as well as other processes such as cleaning or sterilization.

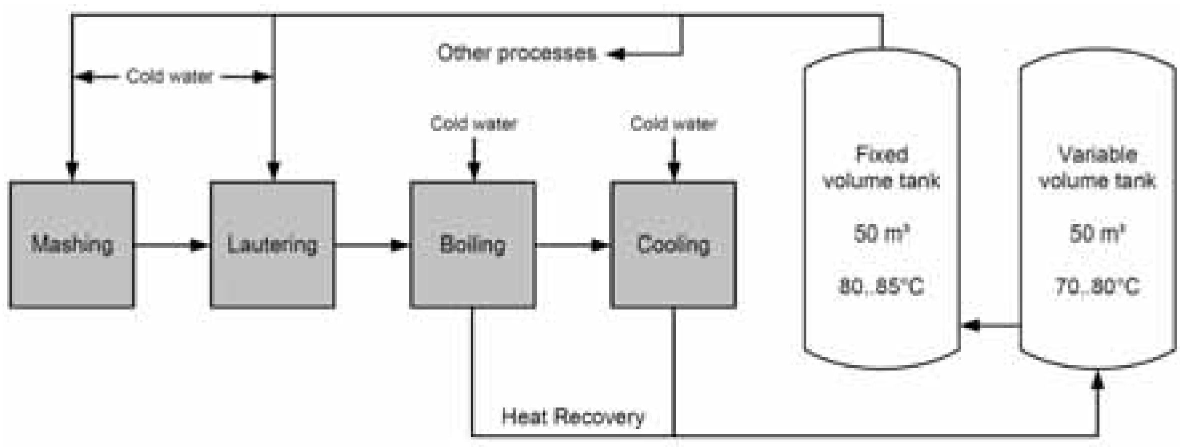

Fig. 1. Current state at the brewhouse of the Hütt brewery

Step one and two of the presented approach (data collection and detailed analysis of current situation) showed that the most important boundary conditions for the utilization of solar energy in a brewery are determined by the wort boiling, since this process step has a major influence on the heat recovery and therefore on the water- and energy balance of the brewery. At the moment, different technologies are available to recover and utilize waste heat during wort boiling such as hot water generation, mechanical/thermal vapour compression or heating of lauter wort by an additional heat exchanger. Besides the systems engineering, the main difference between those installations is the temperature level at which the recovered heat is used [1]. The installed heat recovery system at Hütt brewery is used to generate hot water.

2.2 Energy Efficiency Measures

Based on the analysis and description of the current situation, step three was carried out - detection and evaluation of energy efficiency measures. The detected measures were evaluated regarding their combination with a solar heating system. Based on these considerations, the first energy efficiency measure was the implementation of a new boiling technology. The existing wort boiling at atmospheric pressure was replaced by a vacuum boiling process which led to energy savings of approximately 30 % for this process step.

In the following, the heat recovery system has been optimized. The tube bundle heat exchanger which is used to condensate vapours during wort boiling was overhauled. Instead of generating hot water with this tube bundle heat exchanger the recovered heat from wort boiling will be used to heat the wort after lautering by an additional heat exchanger close to boiling temperature. Thus, steam can be saved which is required for wort heating before boiling. To operate the wort heating with recovered heat, the tube bundle heat exchanger is used to heat up the fixed volume tank. Therefore, water of the lower part of the tank at 75 °C is heated by the tube bundle heat exchanger up to 95 °C and stored in the upper part of the tank. The hot water from the upper part of the fixed volume tank is then taken to heat the wort and fed into the variable volume tank afterwards.

To maintain the high temperature level in the upper part of the fixed volume tank it seemed useful to supply the process with the lowest temperature level, mashing at 58 °C, out of the variable volume tank. Since the variable volume tank has a lower temperature level, less cold water is needed to ensure a mashing temperature of 58 °C. Therefore, an additional piping has to be installed at the variable volume tank and the existing process control has to be expanded. All changes of the heat recovery system that are shown in Figure 2 are explained in detail in [2].

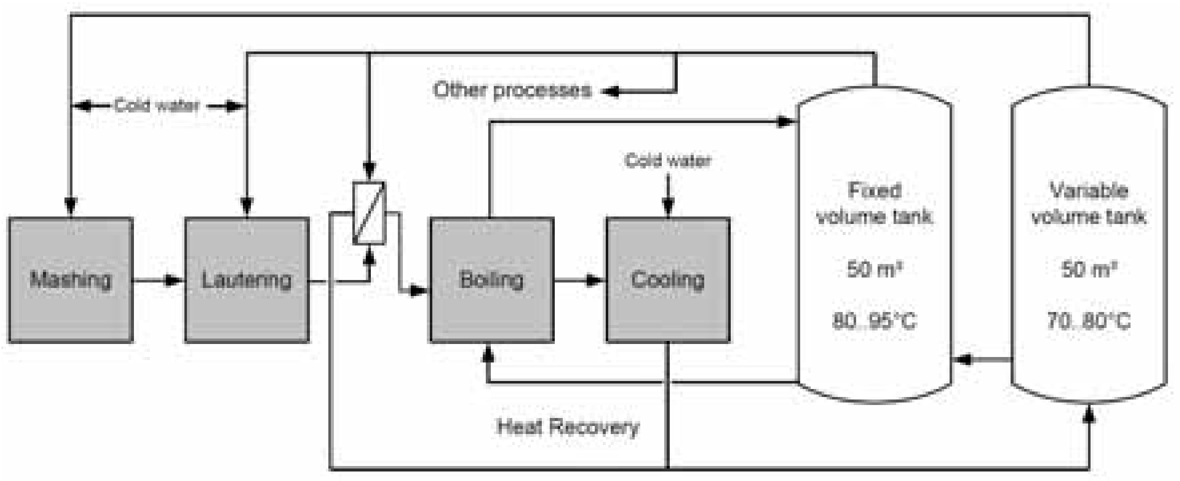

Fig. 2. Change of heat recovery after implementing new wort boiling technology

2.3 Implementation of Solar Heating System

Step three (detection and evaluation of energy efficiency measures) resulted in a more efficient heat recovery since the waste heat is utilized at a higher temperature level. This has three consequences: Firstly, steam for heating up the wort before boiling is saved. Secondly, the available amount of hot water from heat recovery is reduced. Thirdly, less cold water is used to provide the mashing process with 58 °C since it is supplied by the variable volume tank which has a lower temperature level. All these changes led to the fact that the cold water streams that are used for heat recovery and to mix hot water were reduced. This amount can be heated by a solar heating system and fed into the variable volume tank. Thereby, the solar heating system always heats cold water at 10..15 °C, which results in high solar gains. However, this optimal integration of the solar heating system was only possible due to the analysis and optimization of heat recovery. For the dimensioning of all solar components, TRNSYS simulations with detailed load profiles of the hot water streams were carried out by determining the maximum amount of energy, which can be delivered by the solar heating system to the variable volume tank while avoiding stagnation in summer. The simulation with these load profiles showed that a large amount of hot water is required at night time and during morning hours. Therefore, the variable volume tank has to be fed with solar heated water mostly during the early morning hours. Due to this fact, the decision was made to install an additional solar buffer tank for the solar heating system, as shown in Figure 3. The simulations resulted in a collector array of A_{coll} = 150 m² and a volume for the solar buffer tank of V_{sol} = 10 m³. Both shall ensure a high specific collector yield of more than 400 kWh/m²a.

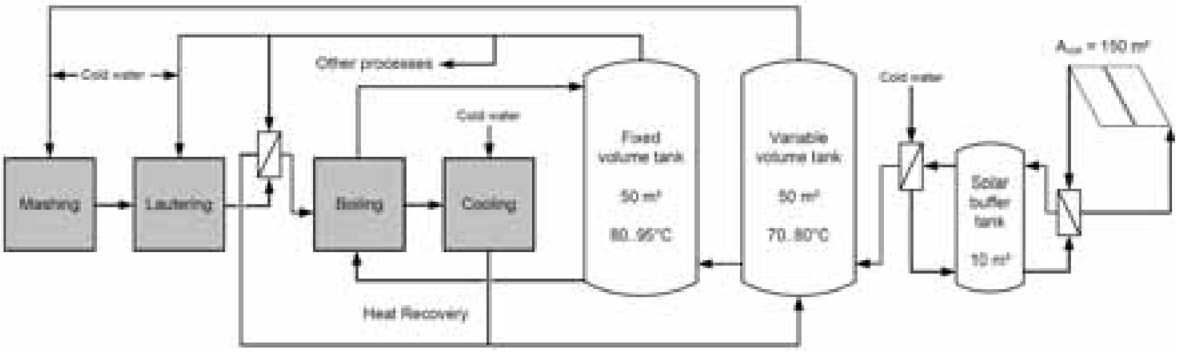

Fig. 3. Integration of solar heating system

To monitor and optimize the interaction of solar heating system and hot water supply of the brewery as well as the operating mode of the modified heat recovery, additional measuring equipment has to be installed in the brewhouse. Henceforth, stratification of the fixed and variable volume tank, flow and return temperatures of the heat recovery and heating of lauter wort will be monitored as well as volume flow and temperature of hot water that is consumed by different processes. The installation of the measurement equipment will be finished by the end of the third quarter of 2010. Similarly, all activities to supply the mashing process with hot water from the variable volume tank will be finished at this time.

3. Experiences of Planning and Installation

Step five of the presented approach (detailed planning and implementation of all measures) was very time consuming since more questions occurred while the detailed planning was carried out. The realization of the holistic system concept started in the second quarter of 2009 with the implementation of the new boiling technology, the solar heating system started its operation in May 2010. The implementation of all presented measures will be finished within the third quarter of 2010 with the installation of additional measurement equipment. The relatively long period between the installation of boiling technology and solar heating system is based on two reasons. Due to the ongoing production, the brewery was not able to install the required equipment for the connection of the solar heating system before the beginning of 2010. Additionally, it was not possible to start the installation of the solar heating system before April due to the long and harsh winter.

3.1 Planning

The most important experiences of planning are related to the required TRNSYS simulations and questions that occurred during planning of the installation of the solar heating system. The simulations for the dimensioning of collector area and the solar buffer tank require detailed load profiles which include all relevant heat sources and -sinks that are in interaction with the fixed and variable volume tank of the brewery. The load profiles were created based on the production protocols provided by the brewery staff and measured data. It included all charge and discharge flows of the fixed- and variable volume tank in a time resolution of three minutes. However, the creation of the required load profiles was very difficult and time consuming.

During the detailed planning of the solar heating system and its connection to the variable volume tank some constructional problems had to be solved. These were related to the installation site of the solar buffer tank (sufficient space and static), the most suitable way of connection (distance between solar buffer tank and variable volume tank, dimension of hauling and pump, safety installations) and the control for feeding-in solar heated water (communication between variable volume tank and solar heating system).

3.2 Installation

The major experiences gained within the period of installation refer to the connection of solar heating system and variable volume tank. Due to the brewery’s directive, no external company should execute the connection of the solar heating system with the variable volume tank, as only internal staff is allowed to change the existing installations. Therefore, the entire work for the integration of the solar heating system had to be done by the brewery staff itself. This included the hauling of additional pipes for cold respectively solar heated brewing water as well as the necessary preparation of the control. Since the cold brewing water that is heated by the solar buffer tank is a preliminary stage of a beverage, all installations that are in contact with brewing water have to be food save. Hence, the piping had to be made of stainless steel. Additionally, the pressure within the brewing water circuit has to be higher than the pressure of the solar buffer circuit to avoid contamination of the brewing water in case of leakage of the discharge heat exchanger of the solar buffer tank. Therefore, a relatively powerful pump had to be installed in the brewing water circuit. Due to these facts, the connection of solar heating system and variable volume tank became time consuming and expensive.

The overall specific investment costs of the solar heating system are approximately 600 €/m² collector area. The largest share of investment had the solar heating system itself with 74%. The costs for the connection to the variable volume tank were with a share of 14% slightly higher than the costs for planning. Including the required measuring equipment, 50 % of the total investment was funded by the German Federal Ministry for the Environment.

4. Preliminary Operational Results

The hot water supply by the solar heating system is controlled by the fill level of the variable volume tank. During regular production periods, solar heated brewing water is fed into the variable volume tank if its fill level is below 60 % and stops when the fill level exceeds 70 %. During the production period the upper limit of 70 % for filling has to be kept, since sufficient volume for hot water from heat recovery has to be available in the variable volume tank. Between Friday afternoon and Sunday evening, the variable volume tank can be filled up to a level of 92 % with solar heated water, since there are no input streams from heat recovery during this time.

Simulations showed that the fill level of the variable volume tank is relatively often below 60 % if the heat recovery during wort boiling is operated to heat up the wort instead of heating up cold water as explained in Chapter 2.2. At present, the brewhouse staff has still the option and remains to utilize the heat recovery during wort boiling for hot water generation. In this case, the fill level of the variable volume tank does not fall below the limit of 60 % very often. As a result, the wort cannot be heated up efficiently before the boiling process and the feed-in of solar heated brewing water is reduced to a minimum. Since the volume of the solar buffer tank is dimensioned to store the amount of energy of only one or two days, stagnation times increase while solar gain decreases. The correlation between fill level of variable volume tank and feed-in of solar heated brewing water is shown in Figure 4. The upper graph of this Figure shows the fill level of the variable volume tank over one week. Only three times the fill level is below 60 % for a short time. During these times, solar heated brewing water is fed into the variable volume tank which is displayed by the lower graph.

The traditional, but from solar point of view wrong, operational mode of heat recovery is still preferred by the brewhouse staff, since the greatest fear is that the fill level of the variable volume tank is not sufficient to cover the hot water demand of the production process. Therefore, it is preferred to keep the fill level of the variable volume tank as high as possible. The brewhouse staff is used to this operational mode of the heat recovery for decades for which reason it is very difficult to convince them to change the operational mode of heat recovery. Different to the management, the brewhouse staff is still not aware of the background and purpose of the holistic system concept and that it is possible to use solar heated brewing water to keep the variable volume tank at an adequate fill level. Since the economic operation of the solar heating system is strongly influenced by the operational mode of the heat recovery and therefore by the brewhouse staff, there is still a backlog in this field. In case that this problem cannot be solved by an instruction to the staff, other possibilities have to be identified. Possibly the overall control of the fixed and variable volume tank including the heat recovery has to be automated to prevent negative interventions of the staff. However, this option is not fully supported by the brewery management since the production process is partially unsteady and hardly predictable. So far, the effort to change to a fully automated control is not predictable. Thus, additional training and convincing of the staff seems to be the best option.

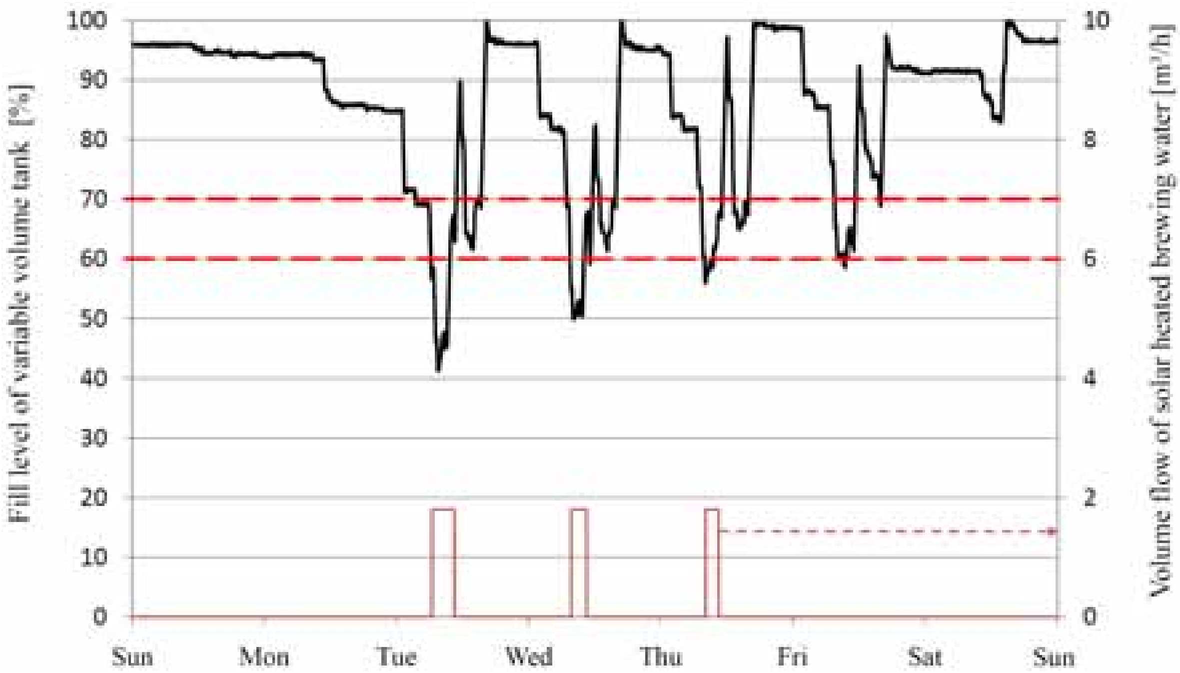

Fig. 4. Fill level of variable volume tank (upper graph) and feed-in of solar heated brewing water

Between 10th of June and 6th of July, the solar heating of brewing water was limited to ten times with an average duration of three hours and a volume flow of approximately 1.8 m³/h. According to this, the solar heating system provided about 350 kWh. The insulation on the collector field during this period was in the range of 23,500 kWh. After analysis of measurement data, the wrong operational mode of heat recovery and its impact on the solar heating system was discussed with the brewery management. It was agreed to instruct the brewhouse staff to change the operational mode of the heat recovery during one of the three daily brews. The monitoring results were used to show the brewhouse staff that the variable volume tank can be kept at a sufficient fill level with solar heated brewing water. Based on this awareness, the brewhouse staff will be instructed to operate the heat recovery during all daily brews in the desired mode.

5. Summary and Outlook

The supply of solar process heat for industrial applications is limited to few examples due to ambitious economical expectations and the complicated integration of solar heating systems in existing processes. To overcome the barrier of ‘system integration’, Kassel University carries out a project in cooperation with the midsized Hütt brewery to implement a solar heating system in a feasible way. The developed holistic system concept combines energy efficiency measures within the brewhouse, optimization of heat recovery and integration of a solar heating system. After applying energy efficiency measures, a solar heating system with 155 m² flat plate collectors and a 10 m³ solar buffer tank was installed. Cold brewing water is heated up by the solar buffer tank and fed into the variable volume tank that supplies hot water to all consumers in the brewery.

There are three important experiences gained during the realization of the concept. The dimensioning of all relevant components as well as assessments of operational performance and expected gains are strongly dependent on load profiles which are necessary for simulations. The creation of these profiles is very time consuming and difficult. The installation of the solar heating system showed that the connection of solar heating system and process was very time consuming and cost intensive as well. This is based on special boundary conditions for companies of the food sector. Finally, the start-up showed that the interaction of solar heating system and variable volume tank is not satisfying yet, because the heat recovery is not operated by the brewhouse staff as planned. To enable an economic operation of the solar heating system, an improved in-house training of the staff is necessary. To monitor the interaction of solar heating system and variable volume tank, additional measuring equipment will be installed within the brewhouse. This includes all relevant charge- and discharge streams of the fixed and variable volume tank with temperatures and volume flows.

References

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