METHODOLOGICAL ANALYSIS OF INDUSTRIAL PROCESSES REGARDING THE IMPLEMENTATION OF A SOLAR-THERMAL PROCESS HEATING SYSTEM

Holger Müller[1], Sebastian Brandmayr[1], Christoph Trinkl[1], Wilfried Zörner[1] and Vic Hanby[2]

[1] *CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH*, *Ingolstadt University of Applied Sciences*, Esplanade 10, D-85049 Ingolstadt (Germany), Phone +49 841 9348 736,
E-Mail: holger.mueller@haw-ingolstadt.de

[2] Institute of Energy and Sustainable Development at De Montfort University, LE 1 9BH, United Kingdom

Abstract

One third of the European primary energy consumption is used for industrial applications. A huge amount of this energy consumption is needed for heating processes. Today's process heating systems are normally fossil fired. Not only the increase in fuel cost in recent years requires the industry to reconsider their approach regarding process heat supply but at the same time the finite nature of fossil fuels and the negative impact of CO_2 emissions on the climate.

A very promising option is the implementation of solar-thermal power into the process heat systems. However, standardised procedures for system implementation are generally not available. Much more complex than the design of common solar heat supply technologies is the integration of solar heat in industrial processes. So, the use of solar-thermal systems for process heat supply requires extensive research concerning the processes occurring in several applications. The exact knowledge of process data is of essential significance. Temperature level, heat requirement, and periods of heat demand are collected by a comprehensive monitoring of each process. Based on these data, optimisation measures are defined and simulation models for the process structure are developed in order to identify appropriate processes for solar heat supply.

1. Introduction and Background

Several studies, carried out within the framework of IEA TASK 33/IV – Solar heat for industrial processes (SHIP), identified a high potential of solar-thermal process heating systems. Of course, a lot of industrial processes work at temperature levels that cannot be covered by solar heat. Technically practicable for solar-thermal supply, however, are process applications up to 250 °C. Therefore, specific solar-thermal equipment, e.g. parabolic trough collectors, is needed. With today's state-of-the-art technologies (e.g. flat-plate or evacuated tube collectors) processes up to 100 °C can be supplied by solar-thermal heat. Despite convenient conditions, only few solar-thermal process heating installation exist today.

For that reason, the *CENTRE OF EXCELLENCE FOR RENEWABLE ENERGY RESEARCH* of *Ingolstadt University of Applied Sciences* carries out a research project with two industrial partners. A previous study identified a few companies out of the promising food industry. This sector offers very favourable conditions concerning their processes. Many of these processes as shown in 'Fig. 1', e.g. washing or pasteurisation, only require temperature levels of up to 100 °C in conjunction with a continuous heat demand.

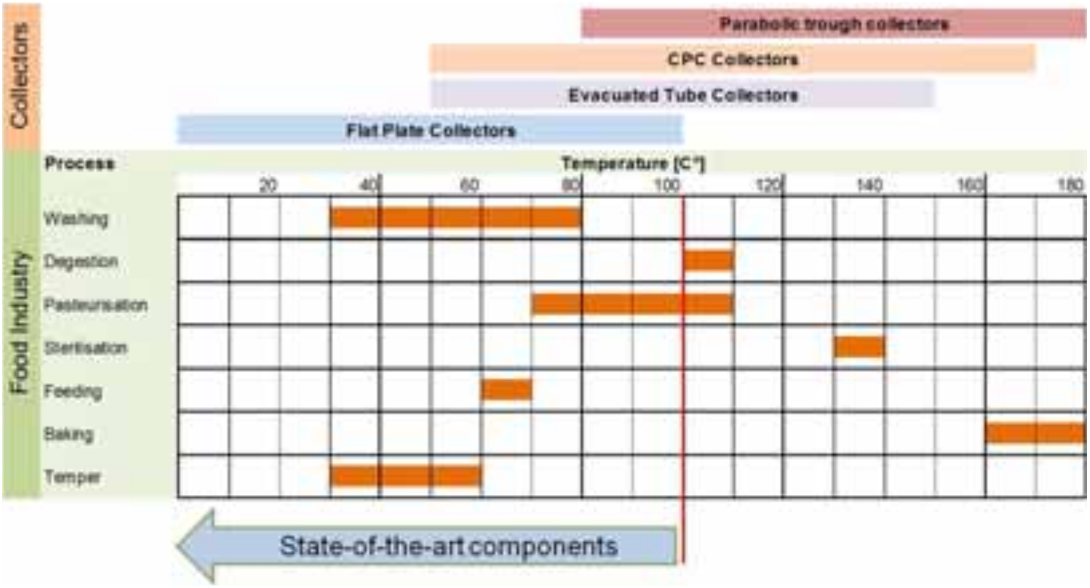

Fig. 1. Typical Processes and Relevant Temperature Levels in the Food Industry.

Additionally, the heat demand in some production sectors, e.g. breweries, seasonally follows the solar radiation. This means a higher heat demand in summer than in winter and additionally favours the use of a solar-thermal process heating system.

The research project highlighted in this paper is funded by the *Bavarian State Ministry of Science, Research and Art* and is accomplished in cooperation with a brewery and a dairy. Standardised solutions for the process analysis, system development and the implementation of solar-thermal process heat systems will be defined to increase the market share of this technology, not only in the food industry.

Herrnbräu GmbH & Co. KG

Herrnbräu is a medium-sized brewery in Ingolstadt (Germany). 90 employees at *Herrnbräu* produce approximately 150,000 bbl/a of several kinds of beer and non-alcoholic beverages. The energy supply of the *Herrnbräu* production plant is based on fossil fuels and electricity.

Zott GmbH & Co KG

Zott is a large-scale dairy with its head office in Mertingen (Germany). 1,800 employees process approximately 2 million litres of milk daily. Considering this, the *Zott* dairy belongs to the ten biggest dairies in Germany. The energy supply of the *Zott* production plant is based on biomass and electricity.

2. Process Analysis

An extensive process analysis is the first work package of the project, providing the basis for all further activities.

The use of solar-thermal systems for process heat supply requires extensive research concerning the processes occurring in the several applications. Focus of the process analysis is to establish an energy efficiency process and energy supply structure. This is essential in preparation of the further process simulation and the identification of adequate access points for linking solar heat into the existing system.

2.1 Procedure and Methodology

Documentation of state-of-the-art production processes is the first step. This includes the analysis of heating and cooling units, energy distribution networks as well as the production facilities and processing of the several products. This stable data base supported by existing inventory records, energy balances and an up-to-date data collection provide the basis for all the further steps. Differences between the inventory records and the current conditions have to be noted as well.

One of the central tasks is to record energy flows according to size and temperature level as well as single day and periodic course of the energy consumption of the occurring processes. Based on these data, it is possible to compare the collected amounts of energy generation and energy consumption with the quantities of used primary energy. With this energy balance, problems such as transport losses due to leaks or deficiencies of insulation of the piping can be identified.

The energetic optimisation potential is determined by a targeted system monitoring. A key point in this respect is to determine the potential of heat integration by using scientific methods. Using the so-called pinch method, waste heat potentials can identified. The reuse of waste heat is one of the essential requirements to reduce the overall heat demand.

2.2 State-of-the-Art of Processes

Energy Supply – Heating, Cooling and Compressed-Air

The main heat supply at *Herrnbräu* and *Zott* production plant is based on steam. The steam generated in fossil fuelled steam boiler on the one hand and in a biomass fuelled combined heat and power plant on the other hand and is supplied directly (steam ➘ process) or indirectly (steam ➘ hot water ➘ process) to all the processes and applications. The energy distribution is realised through several steam and hot water networks at different temperature levels. This kind of heat supply is regarded as state-of-the-art in today's production plants, not only in the liquid food industry.

Cooling energy is a very important form of energy in the industry sector of food processing because a lot of the foodstuff is highly perishable in fact of too high temperatures. For both, storing and processing, therefore, a high amount of cooling energy is necessary. This is even more the case for milk products than for beer. The proportion of used fossil fuels for heating and electricity for cooling in 'Table 1' shows this fact.

Table 1. Proportion of Energy use for Heating and Cooling Generation.

	***Herrnbräu* Brewery**	***Zott* Dairy**
Fuels for Heating [-]	4.5	1.4
Electricity for Cooling [-]	1	1

For cooling at *Herrnbräu* and *Zott*, electrically driven compression chillers are used. These chillers supply the two forms of cooling energy needed to processes and applications. On the one hand, cold air for cooling storage rooms or fermenting cellars and on the other hand ice water for cooling processes and storage tanks is needed. The difference between cold air and ice water is that cold air is generated and directly used (direct evaporator) whereas ice water is generated and stored in latent storages during the night. Using low-price electricity during the night and reducing the installed cooling capacity are advantages of ice water. Compression chillers generally provide a high waste heat potential, which, however is only used by *Zott* to a small proportion.

In addition to the heating and cooling units, the compressed-air compressors consume a considerable amount of energy. The share of the total electrical energy consumption is not as significant as that of the cooling units at *Herrnbräu* and *Zott*. But for further considerations concerning the energy efficiency of the whole plants they got more importance because of high waste heat integration potentials.

'Fig. 2' shows the two forms of energy supplied to the production plants and the connected users.

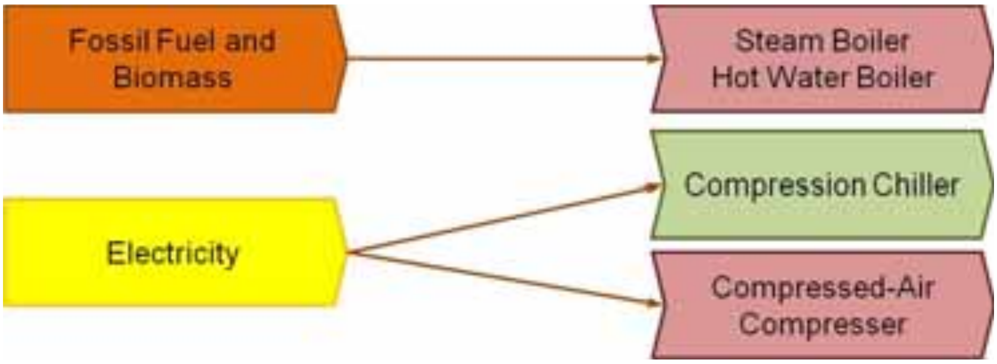

Fig. 2. Sources of Energy and their Use.

Processing

As a simplification and for better a comprehension the production processes at *Herrnbräu* and *Zott* are separated into five main steps each. The focus in this consideration is an energetic approach, so that the five production steps are classified in hot and cold sections ('Fig. 3'). A hot section is where the main energy use is heating energy and a cold section is where the main energy use is cooling energy.

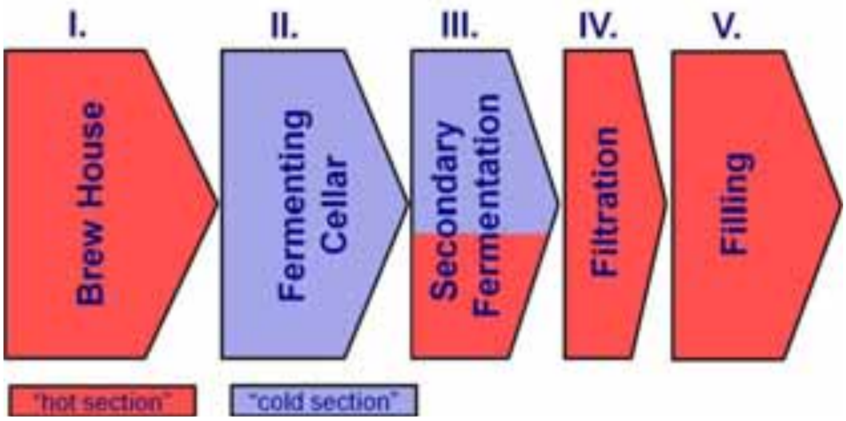

Fig. 3. Main Steps of Beer Processing at *Herrnbräu*.

Most processes in the brew house are cooking processes, e.g. wort cooking, and take place at temperature levels between 50 °C and 100 °C. Therefore, about 50 % of the total heating energy needed in the brewery is used within the brew house.

The next section following the brew house is the so-called fermenting cellar where the beer matures. The fermentation takes place at temperatures between 3 °C and 20 °C depending on the kind of beer; it actually radiates heat. To ensure the temperature required, cooling energy is necessary.

The so-called secondary fermentation also depends on the kind of beer. Bottom fermented beer is stored at 2 °C in cold stores while top fermented beer is stored at 20 °C in storage rooms. Most energy required is cooling energy. Heating energy is only required in the storage rooms in winter.

The final two steps are the filtration and filling sections. The filling section is the second largest consumer of heating energy after the brew house. This is due to the bottle washer which cleans the deposit bottles before refilling. The cleaning process takes place at 82 °C.

The processing of milk is much more difficult than that of beer ('Fig. 4'). One reason for that is the sensitivity of milk. It requires specific treatment. Many different milk products with their individual processing are another reason.

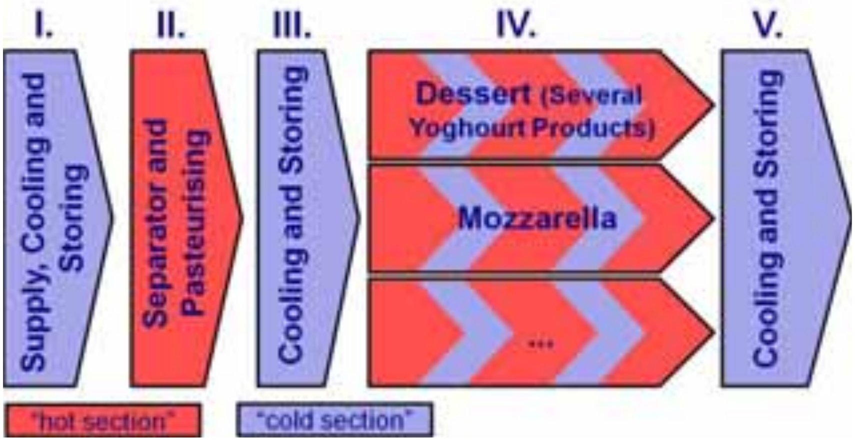

Fig. 4. Milk Processing at the *Zott* Dairy.

When the raw milk is supplied to the dairy it is initially cooled and stored at 4 °C before further processing takes place. So the supply, cooling and storing sections need only cooling energy.

During the separator and pasteurising section the milk is first standardised to get a specific fat content. This is a standard process in today's industrial dairies. Further on, the milk is heat treated to extent shelf life of the milk products. Mainly heat energy is needed for these processes.

After that, the milk passes again a cooling and storing section before the actual processing starts. Again only cooling energy is necessary here.

With the actual processing of milk into the several milk products a continuous process of recurring heating and cooling starts. Depending on the product, e.g. dessert, mozzarella, and its specific manufacturing processes temperature levels with less than 10 °C up to more than 150 °C are required.

After finishing the several products a cooling and storing section is the final step before distribution.

<u>Energy Distribution</u>

The energy distribution at the *Herrnbräu* brewery as well as at the *Zott* dairy is divided into two energy networks. These networks can be generally classified into heating and cooling networks at several temperature levels as shown in 'Table 2'.

Table 2. Classification and Temperature Levels of Heating and Cooling Networks.

Energy Network	***Herrnbräu* Brewery**	***Zott* Dairy**
Steam 1	170 °C	198 °
Steam 2	134 °C	--
Hot Water	85 °C	65 °C
Ice Water	1 °C	1 °C
Air-Conditioning	< 10 °C	< 10 °C

The analysis of the energy distribution generally provides promising conditions concerning the use of solar-thermal heat. These are the hot water networks at *Herrnbräu* and *Zott*, whereas the temperature level at the *Herrnbräu* is considerably high regarding solar-thermal heat integration.

2.3 Process Optimisation

The optimisation at itself is a multi-level process. The first stage was described before within the state-of-the-art of energy generation, energy distribution and processing. Furthermore, a comparison between the energy use and energy supply of processes concerning their temperature levels as well as energy losses shows technical inadequacies such as deficiencies in insulation. The central task within the optimisation, however, is the detection of waste heat integration potentials and its use.

A comparison of the temperature levels of heating networks and heat supplied to processes has shown that some processes fit only partially to the energy supplying network, e.g. when steam is used for low-temperature space heating. ‘Table 3’ shows, for example, an energy demand for space heating.

Table 3. Energy Supply and Process Conditions

Energy Network Conditions		**Process**	
Steam	134 °C	Space Heating	20 °C

Such differences between the energy network conditions and the process temperature are often caused by the structures of production plants evolving over longer periods of time. Energy efficiency was at the implementation of the energy systems not necessary and appears only gradually. It is therefore essential to improve and adapt the energy network structures. This means to define several groups of processes and adequate energy networks as exemplary shown in ‘Table 4’. The development of heat exchanger networks for the integration of waste heat is the central task of the optimisation and one of the most important options achieving energy efficiency of production plants. The method used within the project is the so-called pinch analysis. Using this method it is possible to define the minimum heat requirement, the maximum cooling requirement and the waste heat integration potential by contrasting hot and cold processes.

Table 4. Exemplary Definition of Heat Networks.

Energy Network Conditions		Process
High Temperature	> 85 °C	Cooking, Thermisation, …
Medium Temperature	≤ 85 °C	Washing
Low-Temperature	≤ 45 °C	Space Heating

Whereas continuous hot processes start at a high temperature level, finish at a low temperature and require cooling energy, continuous cold processes start at a low temperature level, finish at a high temperature and require heating energy [1]. 'Fig. 5' shows a illustration of the Pinch Method.

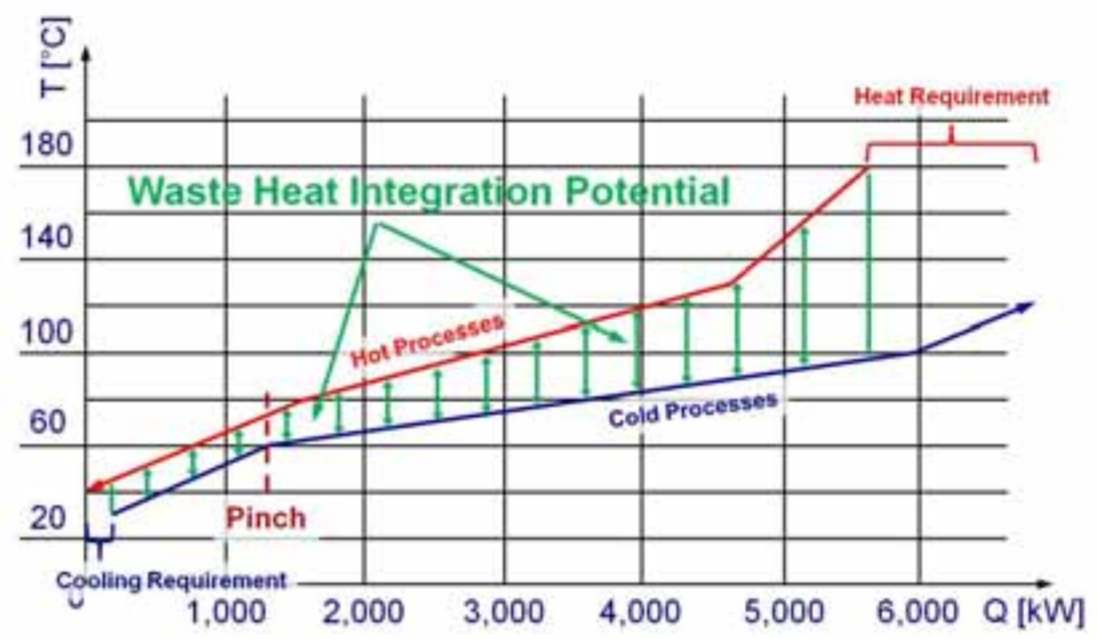

Fig. 5. Illustration of the Pinch Method

In preparation of the pinch analysis, load profiles of all the relevant processes must be recorded. 'Fig. 6' shows the necessary data of an exemplary CIP plant (Cleaning in Process), where temperatures and flow rate are of major importance being the input data for the further pinch analysis.

The challenge accomplishing the pinch analysis within this project is that most of the processes in breweries and dairies are batch processes and take place delayed. Batch processes are dependent on time in contrast to continuous processes as described before. Relating to that, Krimmenacher (2002) analysed several variations of batch pinch methods [2]. The most promising methods are the time pinch analysis and the time slice model.

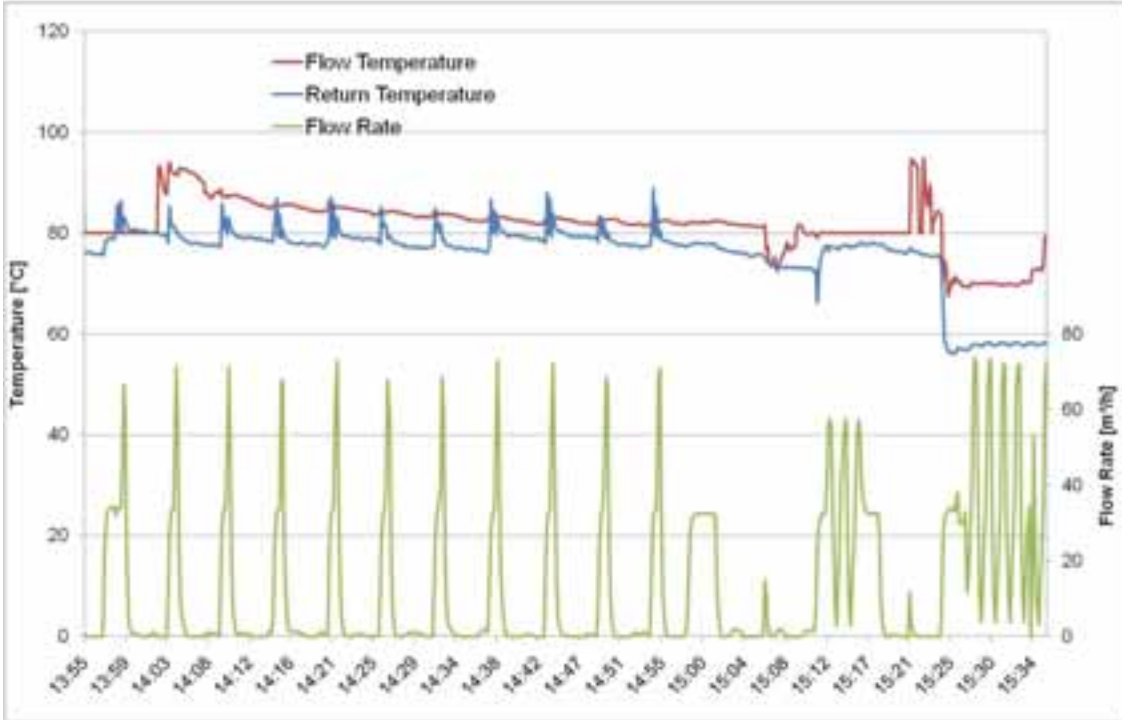

Fig. 6. Energy Data of a CIP plant at the *Herrnbräu* Brewery

3. Conclusions

The previous data acquisition and the analysis of the state-of-the-art process situation have shown, that energy efficiency concerning process energy requirement and energy supplement is effected very different at the industrial partners. A considerable potential of waste heat integration could already be identified. High investments in connection with long amortisation periods or technical expenditure often prevent efficiency measures.

Furthermore, the availability of process data for the plants is not in any case sufficient for a detailed analysis. A more extensive data acquisition as planned is therefore required. However, this makes the accomplishment of the pinch analysis as well as the development of detailed energy balances more difficult.

With finishing the pinch analysis, the process analysis will be completed. The following project steps are the definition of appropriate access points for linking solar heat in the existing heating systems and the development of a process simulation model on the basis of the optimised process structure.

References

[1] I. C. Cemp (2007). Pinch Analysis and Process Integration, Butterworth-Heineman, Burlington.

[2] P. Krimmenacher (2002) Contribution to the heat integration of batch processes, Ecole Polytechnique Federale de Lausanne, Lausanne.