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The Green Brewery Concept - Energy Efficiency and the Use of Renewable Energy Sources in Breweries

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Within the project "Green Brewery" the emissions of fossil and climate-relevant CO_2 from the production of beer could be significantly reduced and even set to Zero, by development and implementation of a methodological optimisation approach.
In one brewery the total fossil gas demand can be substituted by efficiency measures and the integration of renewable energy sources. This corresponds to saving of 1,200,000 Nm³/y fossil gas (basis 2007) and a reduction of fossil CO_2 emissions of 2,670 t/y. The results and experience gained is brought together in a "Concept for Green Breweries", a calculation tool for guiding breweries towards CO_2 neutral energy supply.

1. Introduction

The agro food industry encompasses a wide variety of processes and operations with a large supply chain. With the quest for sustainability and combat of climate change as major driving forces new developments in the food industry focus on multiple possibilities of introducing energy efficiency and the use of renewable resources as energy sources. For industry, the main possibilities for the reduction of GHGs will embrace 1) increased efficiency in the conversion processes with an emphasis on cogeneration, 2) Process intensification and heat integration, 3) Zero-energy design for factory and administrative buildings, 4) a shift in energy resources from fossil to renewable and 5) the use of industrial waste heat for general heating purposes outside the company (regional heating systems).
A number of studies so far have dealt with the optimization possibilities of food processing, applying process integration and the use of renewable energy sources. Process Integration for the food industry requires the consideration of batch processes. For breweries where rescheduling is a delicate issue due to the biological processes the adaptation of existing storage tanks or the integration of new storage tanks into the hot water management is a favorable option. Approaches for heat integration for batch processes including heat storage systems have been reported by several authors, however still not extensively studied (Chen and Ciou, 2008; Foo et al., 2008; Atkins et al., 2010a; Majozi, 2009). The integration of renewable energy into industrial utility systems has been studied based on thermodynamic optimization methods or Total Site

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targeting (Varbanov et al., 2005). For the integration of solar thermal process heat a method has been established within the IEA Task 33 Solar Heat for Industrial Processes. Its integration ideally takes place after heat integration of the production site (Schnitzer et al, 2007; Atkins et al, 2010b).
In this paper the thermal energy supply optimization has been studied for breweries via heat integration taking into account all thermally relevant processes of the production site. The integration of renewable energy supply is considered subsequently to ensure that no additional systems are installed if waste heat can serve the heating purpose.
For breweries much effort has been done lately in research and plant development to reduce the energy demand of the processes, visible through a large number of papers and publications. Typical energy demand figures, such as 24-54 MJ/hl for wort boiling, can be found in literature for different processes (Priest, 2006; Kunze, 2007). However, in some breweries the real specific energy demand per area is unknown and improvements can therefore be hardly identified even if benchmarks are known. The project "Green Brewery" was conducted as a cooperation between industry and research to identify possible solutions to reduce the fossil CO_2 emissions in the thermal energy generation for breweries, based on a detailed analysis of real case studies.

2. Methodology

The aim of a Green Brewery concept is to demonstrate the potential for reducing energy consumption and fossil CO_2 emissions. Although undergoing radical changes in production equipment (Kunze, 2007) the brewing process itself is a quite standardized process and to a large extent similar technologies are used in different breweries. However small technological changes and/or the ratio of brewing and packaging capacity influence the energy management of breweries already to such an extent that optimization measures such as heat integration strategies cannot be generalized. Therefore, it was decisive to develop a tool instead of a simple guideline where a pathway to a CO_2 neutral thermal energy supply is shown for different circumstances. The development of the Green Brewery concept was based upon the experiences drawn from the real plants and vice versa the concept was tested with the data of the companies. The concept that aims to be used for a specific brewing site leads the companies from their own energy balances to guidelines for efficiency measures. The elaboration of the case studies as well as the concept itself follows the steps necessary in an auditing methodology for thermal energy optimization (Brunner et al., 2008).

2.1 Data acquisition and energy balancing

In many industrial companies the allocation of energy to processes is only known on the level of accounts. A network of a few decisive measurements was elaborated to develop optimization strategies and to have reliable benchmarks.
The calculation of the energy demand is done on a process level based on the production data and technologies. This minimal energy demand is decisive, to know the final target value for each process step based on the currently used technology (see Figure 1). The overall minimum energy demand can be compared to the useful supply heat converted over the boiler and distribution losses can be identified.

2.2 Process optimization and heat integration

From recent studies in Process Intensification it is known that the change of currently applied production technologies can reduce energy requirements substantially (Reay, 2008). These offer new opportunities for heat integration, however might change the composite curves of breweries considerably. Thus, these changes need to be considered prior to heat integration. For optimizing existing production sites which are the focus of the Green Brewery concept a review of possible measures for enhancing energy efficiency (from simple cleaner production measure to technological improvements) was done.

Pinch analysis was applied taking into account all processes within the brewery. The calculation of the minimal heating and cooling demand was based on a time average approach (Kemp, 2007). First a heat exchanger network was calculated based on a developed design algorithm. It is based on an adapted time slice model selecting heat exchangers with hot water buffers and aiming for maximum energy savings. The results were then taken as basis for applying practical constraints and developing a practical network on site, including available storages. Resulting storage levels and temperatures were calculated and the experiences incorporated in the Green Brewery concept.

2.3 Integration of renewable energy

Integration of different renewable energy supply technologies was not considered via the Total Site targeting methodology as shown by other authors (Varbanov et al., 2005). The remaining energy demand after heat integration measures was analyzed with annual load curves – well known to technicians on site from boiler design - on different temperature levels. In this way the possibilities for integrating renewable energy (solar thermal, biogas, biomass, geothermal) can be identified depending on demand temperature and load changes without constraints of existing distribution systems.

Batch fermentation tests were conducted to analyze the biogas production of residues from the brewing process (incl. spent grain). For solar thermal integration simulations applying T-Sol were elaborated for different scenarios.

3. Results

3.1 The Green Brewery concept – the tool

The Green Brewery Concept is an Excel based expert tool that guides breweries towards a production without fossil CO_2 emissions for covering the thermal energy demand.

Energy balance of the specific brewery

In the first section of the concept the main compartments in a brewery such as brew house, fermentation and storage cellars, packaging and energy utilities (boiler, compressors) are covered. For each process the energy demand can be calculated based on the production and plant figures entered. With this detailed balancing of each process, intensive energy steps and/or improvement targets can be promptly identified (see Figure 1). The comparison of useful supply heat generated over the boiler and the energy demand of the different processes shows system and distribution losses. A generic list of heat sources and heat sinks of a brewery is shown and the potential for process integration is stated. The results of the energy balances are brought together in a list of benchmarks and compared with aim-targets.

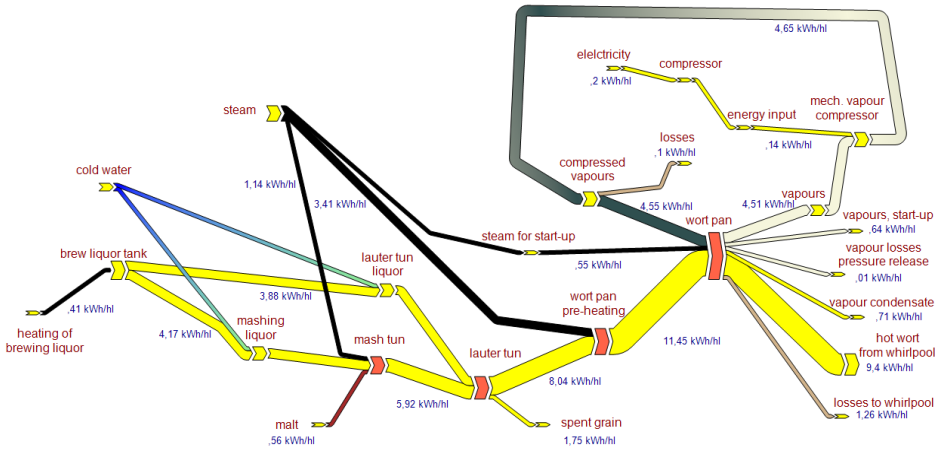

Figure 1: Energy balance of wort boiling with mechanical vapour compression

Databases for area specific optimization measures
This part of the concept includes a list of energy efficient technologies for breweries. An overview of new technologies is provided with brief descriptions and references. The information listed is based on real data, several handbooks, books and articles.
Information sources for new energy supply technologies
This section is a core part of the Green Brewery concept and deals with the potential of different renewable energy supply for breweries. For different energy sources (biogas, biomass, PV, solar thermal, district heat, geothermal energy, heat pumps (low temperature waste heat)) a general description, conversion technologies and the application potential for breweries under different framework conditions is shown. Especially the hot water management is considered and decision trees according to key figures (such as the technology applied in the brew house) were elaborated for different supply technologies. The combination of real process data from the specific brewery (from section 1) and key data known from studies allow the calculation of the potential of energy generation from different biogenic residues and offer necessary basic information to choose the best energy supplies to be used onwards.

3.2 The Green Brewery concept – practical results

The minimal thermal energy demand that can be reached in the considered breweries with 1,000,000 hl production capacity is as low as 37 MJ/hl. The possibilities for reaching this target depend on the production cycles and on the balance between hot water demand in brewing and packaging. It could be shown that even for breweries with existing vapour recovery systems (mechanical vapour compression) 25% of the energy can additionally be recovered over intelligent heat integration systems. The batch fermentation tests showed that for a brewery with this production capacity the energy yield from biogas out of spent grain can be as high as 36 MJ/hl. Biogas from waste water can additionally increase this figure. The combustion of spent grain with 40% humidity on the other hand can produce 46.5 MJ/hl (basis 15,000 t/a spent grain and 900,000 hl produced beer). Here an advanced drying technology is necessary, as fresh spent grain with 80% humidity has a heating value of 24.7 MJ/hl. For the Austrian

breweries that were considered within the case studies the production of biogas for supplying the existing steam network is favoured due to the framework conditions: 1) The boiler needs to cover peak loads efficiently and respond easily to load changes. 2) The infrastructure is available (biogas from waste water is already integrated in the gas boiler). 3) Cooperation possibilities with existing biogas plants, treatment systems and the local gas net are possible.
Overall, the project „Green Brewery“ has shown a saving potential of over 5,000 t/y fossil CO_2 emissions from thermal energy supply for the 3 breweries that were closely considered. For one brewery it could be shown that the total fossil gas demand can be substituted saving 2,760 t/y fossil CO_2 emissions.

4. Conclusions

The Green Brewery concept has been developed as a tool to reduce emissions and to give guidance for decisive actions in order to improve thermal energy efficiency. It is aimed as a living tool that can be extended and updated according to the best engineering practices. The following conclusions can be drawn based on the concept:
The hot water management of a brewery is the key factor for integrating waste heat or new energy supply technologies. It is highly influenced by production capacities (brewing vs. packaging) and the technology applied in the brewhouse. The result of the pinch analysis for breweries shows that heat integration over direct storages need to be integrated in an intelligent way, as often hot water that is generated from waste heat can later be directly applied in processes. The heat available at high temperatures needs to be re-used at similar temperatures and the exergy should not be destroyed over mixing with cold water. An example of such an intelligent “energy swing” is the use of the hot brewing water for preheating the wort and the consequent use as brew water. Ideal storage sizing and management based on heat integration and renewable energy integration is seen as an important target for future simulation studies. This has been shown similarly for indirect storage tanks in other industries (Atkins et al., 2010a).
According to the criteria of the pinch analysis the use of waste heat sources at 65-70 °C (e.g. from vapour condensate or desuperheater of the cooling machines) for preparing the hot water for mashing is more sensible than the use of 85 °C hot brewing liquor. The energy of the hot brewing liquor could instead be used in CIP systems/packaging or other processes where it is required at this temperature level.
Based on the vast possibilities of heat recovery in the low temperature range, solar thermal energy has to be sensibly placed within the energy supply system. In principle hot water distribution systems can be recommended for breweries, especially for the packaging areas. Distribution losses that make up 10 to 20 % in breweries -because of the batch processes and long piping- can be minimized and solar thermal process heat can be well integrated. Especially in new plants the use of solar thermal process heat needs to be considered for processes such as mashing and packaging.
The use of CHP system in breweries is a sensible choice if there is a heat demand below 90°C that cannot be covered via heat recovery. At production sites with a surplus of hot water and a high potential for recovering heat from cooling compressors, the application of CHP system will only be favourable when the generated heat can be used for absorption cooling of certain areas (yeast rooms, brewing liquor).

A brewery with optimized heat recovery and comparable production capacities in brewing and packaging can supply its thermal energy demand over own resources (excluding space heating). The energy produced over biogas from biogenic residues of breweries and waste water exceeds the minimal thermal energy demand of 37 MJ/hl.
Based on the results of the Green Brewery concept, the development of a Green Food Industry Concept, including process optimization and intensification possibilities next to heat integration and renewable energy is seen as an important step for the future.

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