ECOS 2026: Heat Recovery and Cogeneration in Cheese Production: A Practical Case Analysis

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Abstract:
Over the course of one year, energy consumption was measured in refrigeration and heating systems as well as some dominant energy consumers of a medium-sized cheese factory. During the measuring campaign, a heat recovery system in a CO_2 refrigeration system was installed. Balancing primary energy consumption under the “German Strom-mix” considers heat recovery as a better solution than the operation of fossil-based combined heat and power systems. Sometimes the operation of cogeneration systems is feasible only by electricity production for onsite consumption, which highlights a no-go criterion for the implementation of more exhaustive energy recovery discovered in the case study.

Keywords:
Phase change materials, Heat from waste water, carbon dioxide as refrigerant.

1. Introduction

The food industry of Germany is a growing sector, making up more than 200 billion euros [1].

Food processing mostly demands energy for heating and cooling besides electricity consumption. Cheese production is therefore a good example. However, historically, cheese was a form of milk conservation without a cold chain. EU sanitary guidelines provide a pathway for the cold chain from factory to consuming [2]. In the case of cheese maturing occurs at refrigeration temperature during transport, sale and home storage to consume it according to personal preferences.

Energy savings in industry are part of the energy transition strategy of the EU. Such an impact is evidenced by the fact that in Germany the consumption of electrical energy is decreasing slightly, despite a growing population and a progressive electrification of the society by promotion of heat pumps and electric vehicles. The latter in 2025 accounted for close to 20% of new vehicle registrations. Energy analysts are experienced in the evaluation of industrial processes to discover the potential for energy savings, which can be exploited from economic point of view. Combined heat and power systems (CHP) are a good example of more efficient production. However, when they use fossil energy-based carriers, under certain conditions the use of heat pumps is a better solution, as reported in the literature recently [3,4].

The practical case analysis focuses on a cheese production facility, which uses acid-cured cheese in bags as feedstock and produces about 60 tons per week of flat fermented cheese with a cylindrical shape.

A previous energy audit in 2018 highlighted some energy efficiency suggestions, which were partially implemented. The new PV system with an additional capacity of 74.25 kW peak is running at 70% on own requirements. Since these suggestions lacked a deeper thermal analysis the motivation for this study arose.

2. Methodology

The study starts from an energy audit, which was carried out according to DIN EN 16247-1 by the company Eco-Win in 2018. In this analysis, the boundary was defined as the production facility and was maintained in the present study. Inputs of the facility were acid-cured cheese, packaging materials, water, gas and electricity. As outputs were balanced the cheese, wastewater and contamination of exhaust gases. Further interactions with the environment were the heat flows over the building envelope and harvested solar energy from the PV system. Since the factory uses only one electric vehicle this output in form of stored electric energy is neglected.

The data acquisition is based on billing from providers and manual reading of gas and water meters. The latter task was carried out daily, or when considered as useful in hourly defined time steps. In the case of electricity, a load curve from the provider is available upon special request. For the electricity generation of the PV system also load curves are available. In the case of the cogeneration units some information about performance could be read out from the display in the form of accumulated and daily production.

Most demanding equipment in the facility were the CO_2 cooling system, air pressure supply equipment, acid-cured cheese transporter, the cheese forming machine, the shower for cheese washing and the washing units for Euro pallets made of plastic and the cheese racks. The specific consumption of those important electricity and thermal energy consumers was inspected with a power current clamp meter CM12 from Benning Company Germany, with simultaneous detection of current and voltage for effective power and data logger function. A time step of 20 seconds was normally selected. When the data logger was connected to equipment over a couple of days the phase was alternated in order to detect imbalances in phases. Flow and heatflow of heating and cooling systems were measured with a ultrasonic analyzer DeltawaveC XUC-P, from Systec Controls Company, Germany. In the case of constant flow of fluids, once detected further consumption could be monitored by measuring only temperature differences between in and outputs. Therefore, a data logger Almemo 2590 from Ahlborn Company, Germany was employed.

Since the thermal energy balances depend highly on outside temperature results were balanced on monthly and seasonal basis (summer and winter seasons). Based on this analysis some innovations in heat management arose from this study and are part of the following section.

3. Results and Discussion

3.1. Historical Review

Regionally the production of the flat fermented cheese was driven due to the demand of the growing urban areas in the Rhein-Main metropolitan area, the economic opportunities for populations in the north of Frankfurt and climatic conditions, which originally supported fermentation and maturing in a close relationship. Within the last century, logistic infrastructure changed and promoted the establishment of various smaller production facilities in the mentioned region. Among them also the cheese factory H. Birkenstock, which was founded in 1959. This boom of small-scale cheese manufacturing facilities declined in the early 2000s, so that only a few survived. H. Birkenstock is considered to be third largest producer of the “Handkäse” in Germany. The case study focuses on the production facility, which has been in operation since 1992 and has been extended in 2010. Under the present conditions the factory manufactures close to its production capacity of about 60 tons per week.

3.2. Results from first energy audit

The first energy audit from 2018 suggested five energy efficiency measures from which a new central chilling unit and an additional PV system were implemented. As a refrigerant for the central chilling unit carbon dioxide was chosen due to be ambiently friendly and due to its environmentally friendly and safe properties. Indeed, investment and amortization time was highest for that action, but the reduction of CO_2 emissions was highest, since refrigerant considerable leaks of the 25 old chillers (about 75 kg of the refrigerants R417a, R413a and R404a). The facility already had a PV system installed, however, it was operated privately by the owner under a fixed energy contract for 20 years [5]. Therefore, still available space on the facility roof was exploited to a maximum for a PV system under a net metering scheme.

The share of energy carriers sold to the company for the years 2017 and 2022 maintained a coverage of 75% with natural gas and 25% of electricity. The natural gas balance showed an increase of about 12% and electricity from grid was reduced by 60%. This reduction was originated by on-site production with PV system and also may also be caused by the more efficient centralized CO_2 chiller even by the fact that average monthly temperatures in the summer months were higher in 2022 than in 2017. Since four CHP units were running in the facility it has to be considered that about 1 of 3.6 kWh of natural gas consumed in these CHP Units is converted into electricity onsite. Also, the electricity produced from the PV system must be taken into account for the total electricity consumption in the factory, which was with 499 000 kWh about 12% lower than in 2017. Figure 1 shows such a corrected energy balance. Noteworthy is that 94.6% of the electricity produced by CHP is consumed on-site and 70% of PV electricity is consumed on-site.

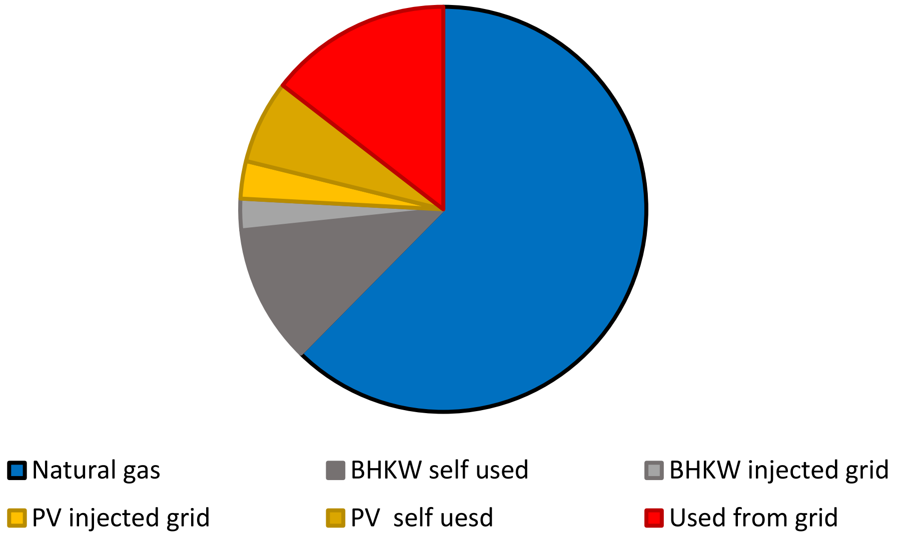

Figure. 1. *Overview of final energies prosumed in the factory.*

Such a high share is unusual, even when industries combine their PV system with battery storage solutions. Since more than 30% of electricity is employed for cooling purposes the need for thermal energy is highlighted. Some other consumers with high energy demand are described in the following subsection.

3.3. Share of specific users on total electricity demand

The measurement of electricity consumption with the clamp power meter on specific components allowed their classification according to total energy use. These eight mayor consumers comprised a total share of 68.4%. After the CO_2 chilling system were ranked the air compressor and the acid-cured cheese transporter. This latter technology was not the most efficient for transporting such a material, however, it has to be acknowledged that additional mixing is realized in this equipment and guarantees better integration of the starter culture.

Electric resistance radiators used for heating fermenting rooms were chosen due to having the best control mechanism, but they are real exergy destroyers and contribute to a total share of 2.9% of the electricity demand. There were detected other resistance-based heating systems for which alternative heating systems were suggested. One is installed in the cheese forming machine and demands about one third one third of the total equipment consumption. This equipment accounts for about 2.6% of the total energy demand in the company. Another one is the washing machine for the pallets. The consumption of this equipment was not measured.

3.4. Heat generation in the facility

The heat generation was realized with four CHP units, the heat recovery from the CO_2-chilling unit, the backup boiler and the heat recovery from the air compressor. They had for a typical winter day shares of 84.3%, 8.4%, 6.8% and 0.6% respectively. For a summer day the heat recovery takes a considerable share from the CHP-units and backup boiler. There the latter is not running in summer time. A comparison of the years 2022 without operation and 2023 with operation of heat recovery from CO_2-chilling system showed that for the months

January to June electricity injected to the grid was reduced by 20% and the demand from the grid increased by 9%. In June demand from the grid reduced for about 6%. A economic analysis showed that the heat recovery performed better than running CHP-units when electricity is self-consumed, but performed worse when the CHP units injected electricity into the grid. Since consumption from grid is about 10 times higher than injection the economic benefit is evidenced. In addition, it has to be mentioned that instead of CHP-units running the heat recovery is free of maintenance. In addition, the energy demand of the CHP unit is reduced since the heat dissipation over the air/fluid heat exchanger can be realized more efficient by the heat recovery of the water/fluid heat exchanger in the heat recovery mode. The argument that CHP units can contribute to reducing the power demand of the company is limited, since limiting the capacity of the CO_2 chiller by employing a load management system would have a greater impact.

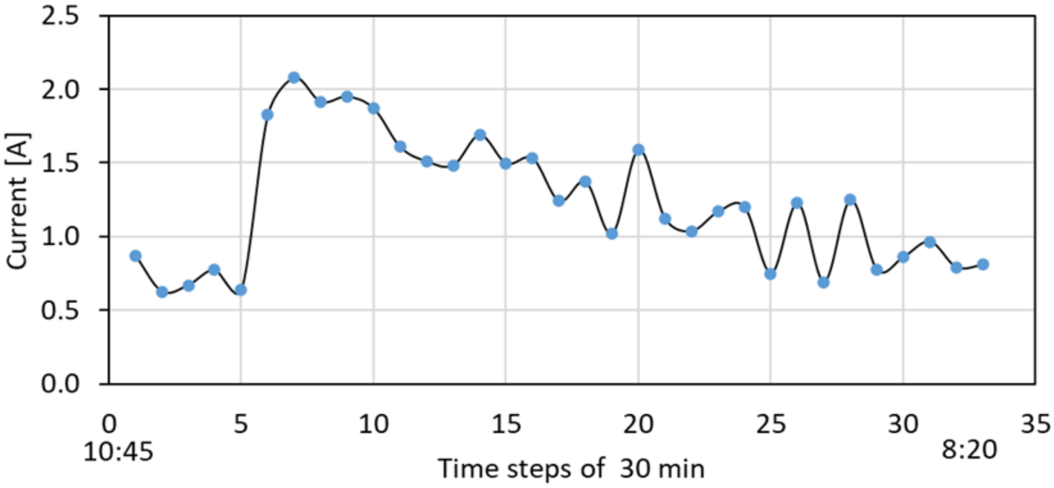

Figure. 2. *Current measured on the fan of the heat dissipater of the CO_2 chiller for the 18.04.2023.*

3.5. Heat consumption in the facility

For winter days about 80% of the thermal energy demand was used to replace heat losses over the building envelope. About 13% of the thermal energy could not be assessed and was therefore considered as thermal energy losses from envelope heating distribution. The rest was needed for warm water preparation. As equipment, the washing machine for cleaning the metallic grids used to support the cheese during winter days demands about 10% of the thermal energy of the facility. Here a heat recovery from the wastewater generated by this equipment would be an innovative solution. However, structural change in the building would be necessary for implementation. Therefore, such a solution would be only considered for new constructions.

The heat recovery in the CO_2 chiller could be optimized by dispatch thermal energy also to the heating system instead of the solution implemented, where thermal energy is only dispatched into the hot water tanks. Such a implementation could be realized by a smaller inversion, while changes in the heating systems having different thermal circuits one operating at (90/70) °C and (40/30) °C for floor heating only could be realized in the case of a new construction. It is worth mentioning that for cheese production days during winter days the dispatch of thermal energy for covering heat losses of the envelope only by heat recovery is feasible.

3.6. Heat management during the fermentation and maturation of cheese

The acid-cured cheese used as feedstock undergoes the following steps during manufacture. This feedstock was received refrigerated at the facility maintained for a few days in the cooling chambers for feedstock storage in the interval of 2 °C to 5 °C. A few hours before processing by mixing and cheese forming the feedstock was relocated to this area and underwent a slow temperature increase to room temperature. However, still far from thermal equilibrium, the feedstock was processed by mixing, where water and salt were added, transporting and cheese forming. The cylindrically shaped cheese was then relocated to the fermentation chambers with a temperature between 15 °C and 20 °C. In the fermentation chambers the cheese was heated and maintained within an interval of 26 °C to 28 °C. For good temperature control electric resistance heating was preferred by the company. Temperature control was automated but also monitored visually, to ensure that maximum temperature was not exceeded, at wich cheese began to flow. At a certain time, the cheese fermenting heat of fermentation was sufficient to maintain temperature and a cooling phase began. This task was carried out by replacing the air inside the camber with air from inside the facility. Thereby, the exhaust gas was blown out.

After two days, the cheese is washed down with cold water to remove undesired dairy mold from its surface. This process consumed about 400 Liters of water per ton of cheese.

Then the cheese entered in the cooling phase staying one to two days in the fermentation chamber. In this phase post fermenting (maturing) was ongoing and demanded additional cooling loads. The last processing stage consisted in packaging into different sales options. Obviously in this form they were stored under refrigeration before transportation. The company's strategy is to maintain minimum allowed temperature to secure temperature during transport. Cheese maturing is still ongoing and therefore the packages had small holes to facilitate gas exchange with the ambient. Understandably, part of the cooling energy is still needed for the dissipation of the heat of fermentation.

Maintaing the feedstock and product at the desired temperature shared a considerable part of thermal energy for heating and cooling purposes in the plant and revealed some undiscovered energy efficiency potentials, which are described as follows. While the cheese has to be heated and cooled during fermentation, the use of phase change materials (with a phase change temperature near to 28 °C) integrated into the surroundings of the chamber can contribute to this task in a reversible way. Such a solution is outlined in Figure 3 for the heating and cooling tasks. According to a personal communication with Seidel [6] the implementation of a heat recovery solution based on phase change materials could be realized.

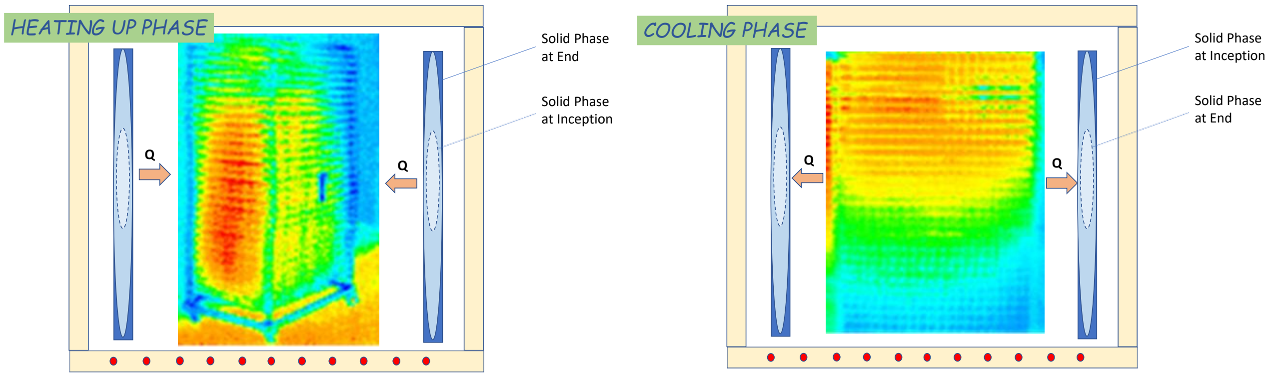

Figure. 3. *Employment of phase change materials in the fermentation chamber.*

The heat of fermentation was derived from the metabolizing of lactose, fats and also proteins (caseins) in cheese. Its aerobic fermentation released a heat of reaction of about 17.7 kJ, 39.2 kJ oder 27.2 kJ per gram, respectively. Reaction products were water and carbon dioxide. This water prevented drying of cheese. A mass loss of 1% during this step taking into account an average calorific value (28.03 kJ g^{-1}) a heat of fermentation in the chamber of about 38.9 kW would result. This value is not far from the measured gas exchange in the chamber, which was determined to be 28.7 kW. The gas exchange during a winter day caused considerable energy losses since the exhausted gas had to be replaced with outside air preheated inside the envelope. Notwithstanding this each cubic meter of CO_2 was extracted with about 50 m^3 of air. The use of phase change materials would reduce the air exchange considerably. Heat recovery of the exhaust gas is also feasible.

The biological activity did not stop after the washing down step. This effect was observed during the subsequent cooling phase. Figure 4 shows the current of CO_2 chiller starting on a Saturday after washing down the dairy mold. While current didn´t reduce in an exponential way as it is characteristic for the cooling down of a product, the prolonged stationary cooling demand is assumed to be caused by maturing metabolism. For a 20 °C temperature reduction of 10 tons of cheese about 1200 kWh was needed. However, the cooling energy balance was about 7400 kWh and subtracting the cooling energy originated from the base load (3000 kWh) a difference of about 3200 kWh may be caused of mentioned maturing metabolisms. The effect cannot be suppressed, but phase change materials can ameliorate it.

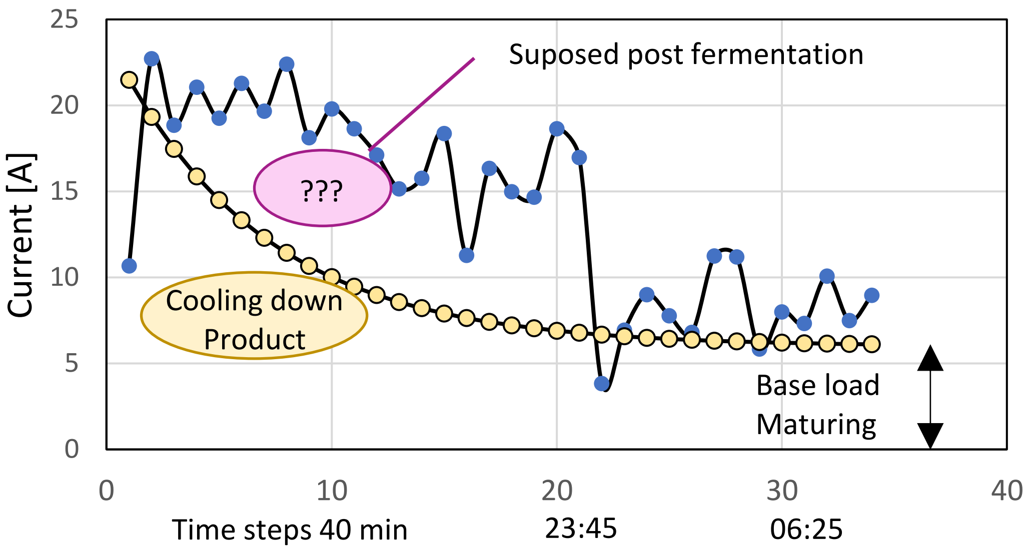

Figure. 4. *Cooling load in the plant starting Saturdays after washing down of dairy mold.*

3.7. Cooling potential of cold water discharged during washing down of dairy mold.

The cold water discharged during washing down of dairy mold had a temperature near to 10 °C. A passive cooling of office with this cold water, which balanced about 20 m³ to 30 m³ per week, is suggested, since integration into central CO_2 cooling didn´t make much sense due to cause only a negligible effect to the much higher cooling demand.

3. Conclusions

From an economic point of view the operation of cogeneration systems is feasible only through electricity production for onsite consumption, therefore it does not matter from where the waste heat is taken, whether from the CHP system or central refrigerant system. Heat recovery from the latter undoubtedly show a better performance. In addition, the carbon footprint is also better since more than 20% of electricity consumption is covered by the own PV system and the electric energy taken from the grid were 100% renewable. There is even a higher potential for heat recovery from the central refrigerator, demanding more extensive changes in the hydraulic system. Also heat recovery from the wastewater of the pallet washing machine represents a significant potential for the facility. Heat recovery from fermentation processes has also not yet been explored. The heat release from the fermentation of about 8 tons of cheese was estimated to be 28.7 kW. Since fermentation process is split into a heating phase and a self-heating phase the use of phase change materials in the surroundings of the fermentation chamber can be an innovative solution

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