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Energy Efficiency Measures for Batch Retort Sterilization in the Food Processing Industry

Ron-H. Peesel*[a], Matthias Philipp[a], Gregor Schumm[a], Jens Hesselbach[a], Timothy G. Walmsley[b]

[a]Universität Kassel, Dep. Umweltgerechte Produkte und Prozesse, Kurt-Wolters-Strasse 3, 34125 Kassel, Germany
[b]Energy Research Centre, School of Engineering, University of Waikato, Private Bag 3105, Hamilton, New Zealand
peesel@upp-kassel.de

The purpose of this study is to highlight the energy saving potentials of a batch retort sterilization process operated by steam and to develop concepts for improving its energy efficiency. By using the methodical approach of the Onion Diagram and the recovery of low grade heat sources, four comprehensive improved energy efficiency concepts have been developed. Two concepts increase the initial product temperature resulting in lower transient steam consumption rates and a decreased energy demand. The other two options transform the waste heat and the energy for product cooling into heat streams for supplying nearby heat sinks or other processes in the plant. Results show that the total energy demand can be reduced by more than 23 % and 42 % of the energy injected into the system can be recovered. The scope of the study focused on a single, independent retort to ensure the transferability of the concepts. This study also shows, using a practical example, the importance of a comprehensive process understanding and analysis prior to application of Pinch Analysis, which is needed to ensure that the correct waste heat stream temperatures are defined, necessary processing constraints are appreciated, and all possible heat sinks in the process are considered.

1. Introduction

In 2010, the global industry sector consumed around 58 PWh. This energy consumption will steadily increase up to 88 PWh in the year 2040, which is around 37 % of the global energy consumption (EIA, 2013). Facing climate change and increasing energy costs, energy efficiency has to be increased at all stages of the energy chain from generation to final consumption. Simultaneously, the advantages of energy efficiency measures have to outweigh their investment costs. For the food processing industry in Germany, the energy costs are already the third biggest impact on the total production costs (Federation of German Food and Drink Industries, 2015). Strong commitment to reduce carbon dioxide equivalent emissions by the industry is required to ensure the achievement of the two-degree-target and to avoid dangerous climate change. One practical example for this commitment is the ambitious goal of the company Mars Petcare, which aims to become a carbon neutral company by 2040.
In food processing plants with thermal treatment processes, the sterilization process is the one of the main energy consumers. Therefore, the focus of this work is to increase the energy efficiency of a single batch retort sterilization process. This is done by developing energy efficiency concepts. All concepts are applied to a representative industrial case study. The related energy savings contribute to the energy and environmental goals of the industry.

2. Batch Sterilisation in Food Processing Industry

For production of canned foods, retortable pouches, aluminum trays and bowls thermal processing is one of the main methods of food conservation. Providing long-term preservation and a commercial sterility via inactivation of pathogenic and food spoiling microorganisms is the basic function of the sterilization process in a batch retort. In order to achieve the commercial sterility, the heat processing temperature is well above

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100 °C and pressurized steam retorts, so called autoclaves, are used (Simpson et al., 2006). In many food processing plants, a battery of individual batch retorts is operated with steam in order to destroy all forms of microorganisms, including spores (Berk, 2013).
The process steps of Heating (Come-Up-Time or CUT), Holding, Pre-Cooling (PC) and Cooling determine the energy demand for a batch retort sterilization cycle. The highest heating demand occurs during the CUT process. The product and all components need to be heated from ambient temperature to the designed sterilization temperature. In order to satisfy the need of the high energy demand, steam is injected. Maintaining the sterilization temperature during the holding process requires significantly less energy compared to the prior step. Only the heat losses to the environment need to be counterbalanced. The PC and Cooling steps have a cooling demand. The energy for the cooling is necessary to reduce the product temperature from the sterilization temperature to less than 40 °C. Figure 1 shows a qualitative temperature and energy distribution of the required heating and cooling demand of the different processing steps. The curve in figure 1 is the design process temperature. The area on the left side of the figure displays the heating demand, whereas the grey area on the right shows the cooling energy demand for PC and Cooling. This figure underlines the fact that most steam consumption takes place during CUT and only minor steam use is required during the holding phase. Therefore, the focus of the energy efficiency measures is on reducing the steam demand during CUT. The energy demand for cooling is a high potential for energy recovery. This energy is transferred to cooling water during the PC and Cooling process. The by-product of the two cooling processes is warm water (~80 °C), which can be a heat source for other heat sinks. Because of this energy recovery potential, the cooling process is the second focus of this analysis.

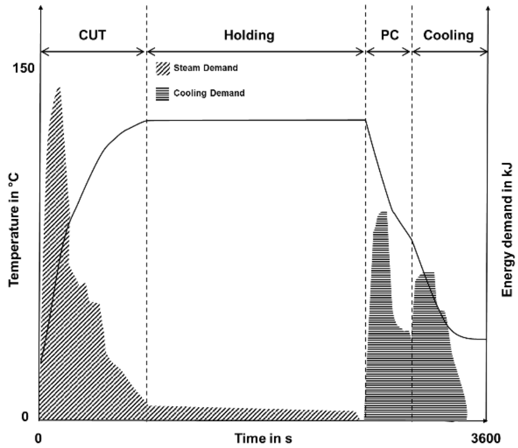

Figure 1: Energy demand distribution for heating and cooling

3. Method and Concepts

Since there are a variety of options and actions to transform the energy efficiency potentials into effective energy savings, a methodical approach is the key to develop an optimal energy efficient solution. To develop an energy optimization concept for an existing batch process, a strictly hierarchical approach is essential. This hierarchy is well illustrated by the Onion Diagram and the developed energy efficiency concepts follow this method.

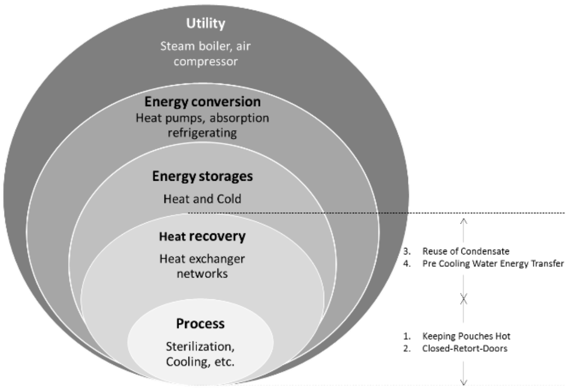

Figure 2: Onion Diagram with concepts (Own figure based on Kemp, 2007)

The recovery of waste heat for heating a nearby process stream is often the most economical solution after reducing the energy demand of the process. Recovering waste heat for sinks in other processes that are some distance away and/or may operate on different schedules, or as a heat source for heat pumps, absorption refrigeration, or electricity generation using organic rankine cycle, significantly increases the financial investment of these options (Law et al., 2013). Therefore, the developed concepts focus on waste heat sinks in the same or nearby processes.

3.1 Concept 1 – Keeping Pouches Hot

Before the product is loaded into the retort, two other process steps – filling and stacking – have to be carried out. During the filling process, the meat chunks and the gravy are filled together into the packaging (e.g. cans, trays and pouches). In this work, only retortable pouches are analyzed. However, the qualitative results can be transferred to other forms of packaging, too. After filling, it can be assumed that the product (meat chunks and gravy in the pouch) has a uniform temperature, because the heat capacity of the meat chunks is very low compared to the heat capacity of the gravy. An initial analysis measured that adding the meat chunks reduces the overall temperature by around 2 °C. No further investigations into the temperature change were carried out. Due to the lower specific heat capacity, the effect of cooling gravy by the meat chunks is neglected in this work. The gravy temperature may vary from 25 °C up to 60 °C depending on the recipe. When the filling process is finished, the pouches are transported via conveyor belts to a so called stacker. At the stacker, the pouches are put on aluminum trays. Multiple trays are piled up until a pre-defined number of layers is reached. The stack is then transported to a holding point where it waits until the defined number of stacks are ready to be loaded into the retort. During the entire time between filling and loading, the inserted heat energy is transferred to the environment. The result of this idle time is a product temperature equal close to ambient temperature. These losses can be avoided by putting insulation housing around the conveyor belt and the stacker. These heat losses have a significant impact on the transient and total steam consumption (Simpson et al., 2006). According to the work of Simpson et al. (2006), one degree Celsius higher initial product temperature reduces the total steam consumption by around 0.78 %. Also, filling a pouch with a gravy temperature above 30 °C is referred to as a hot-fill. Fills with lower gravy temperatures are the so called cold-fills. The idea of a higher initial temperature of concept 1 raises the question whether a hot- or cold-fill should be preferred for further recipes.

For this question there is no trivial answer, since it depends on how the gravy is heated. In case of heating the gravy water with steam from a boiler, it is recommended to use cold-fills. The transferred heat from the steam to the gravy's water gets lost during the idle time and this effect is only preventable to a certain amount. There are also implementation costs for insulation housing or other solutions for minimizing the heat losses. Moreover, the heat transfer coefficient of the steam in the retort is very high and optimized by the integrated fan in the retort.

A different case is the heating with waste heat streams. If there are no other suitable heat sinks in the plant other than the gravy water, it is reasonable to perform hot-fills with this energy. The waste heat is recovered and the heat losses on the conveyor belt can be accepted due to the reduced heating demand in the retort and the fact that there is no extra utility needed to heat the gravy water. In addition to this papers, carried out chilling curve analysis also show that for short idle times, heat loss is insignificant. Another argument for the hot-fills using recovered heat is that besides the total steam consumption, the transient steam consumption is also reduced. Since the high steam peaks during the CUT are a common limiting factor of starting more than one sterilization process at a time, it is a good concept to use waste heat for the hot fills and gain more flexibility regarding the process starting times of each retort.

3.2 Concept 2 – Closed-Retort-Doors

At the end of the process step "Cooling", the pouches reach a target output temperature which is commonly higher than ambient temperature. Since the retort is a closed system, both the inner retort shell and the air in the retort have the same temperature as the pouches. While unloading the stacks, the retort door is opened and kept open until the stacks for the next sterilization process are loaded. During this time, the hot air in the retort escapes through the open retort door. The result is that the inner retort shell and the air in the retort cool down to ambient temperature by natural convection. This energy loss is avoidable with changes to operating procedures. A possible solution for avoiding the escaping of some hot air is to close the door between two sterilization cycles. This implies that a change in the control closes the door immediately after the unloading process is finished. Subsequently, the door is not re-opened until the loader is ready to start the loading process. This control strategy reduces the time when the door is open to a minimum. The results are lower heat losses through the door. Subsequently, the initial temperature of the retort shell and the air in the retort is higher compared to the status quo process. The influence of a higher initial temperature is also applicable to the aluminum trays and the base frame. The following thermal energy balance on a stationary retort underscores this concept (Barreiro et al., 1984).

$$Q_{steam} = Q_{condensate} + Q_{retort} + Q_{product} + Q_{trays} + Q_{convection} + Q_{radiation} \quad (1)$$

The thermal energy required to heat the retort shell, the product, the packaging, aluminum tray and base frame is defined as:

$$Q_j = m_j \cdot c_j \cdot (T_{target} - T_{input}) \quad (2)$$

The equations show that the higher the initial temperature of all the materials, the lower is the required thermal energy.

3.3 Concept 3 – Reuse of Condensate

During the CUT and Holding steps, the injected steam transfers its latent heat to the product. The product temperature rises while the releasing of the latent heat leads to condensation of the steam. The condensate temperature eventually becomes saturated at the pressure of the system. In the heating process of the product, it is also likely that more than the latent heat is transferred to the product, the crates, and the retort material. This results in a sub-cooling of the condensate. The temperature of the sub-cooled condensate is very important for any heat recovery calculation since the enthalpy of sub-cooled condensate can be significantly lower than the enthalpy of saturated water. The lower enthalpy results in less flash steam and determines the technical and economical feasibility of using flash steam. Currently, the condensate is collected at the bottom of the retort and is mixed with the cooling water in order to maximize the recycling rate of water. To reach the designed cooling water temperature the water is cooled down by cooling towers. Recovering hot condensate has great impact on the energy savings, amount of boiler chemical treatment and make-up water use.

The following list shows some examples for reusing condensate.

- As heated feedwater for the steam boiler
- For pre-heating any suitable heating system
- As steam, by reusing flash steam
- For cleaning equipment or other cleaning applications

Figure 3a shows a scheme for a condensate recovery system including a steam trap, a condensate collector tank and a condensate pump. Figure 3b shows concept 4, which is explained in chapter 3.4.

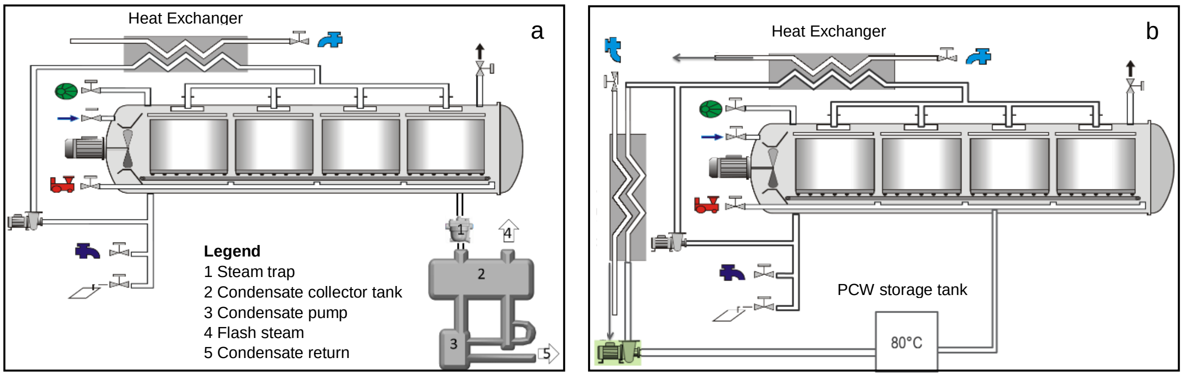

Figure 3: Scheme of retort with condensate collector system and scheme of concept 4

3.4 Concept 4 – Pre Cooling Water Energy Transfer

In the process "Pre-Cooling", fresh water with a temperature of 20 °C - 30 °C is sprayed over the hot stacks that have reached the target process temperature. Pre-Cooling is continued until the product temperature is around 80 °C. During this process the hot materials of the stack transfer their heat by forced convection to the Pre-Cooling Water (PCW). The result is both a cooled down stack and as a by-product, heated fresh water. It can be assumed that the total mass of PCW has the same temperature as the system at the end of the Pre-Cooling process, since the mass stays in the closed system. As explained, in the status quo process this heated PCW is mixed with the condensate and extra fresh water. This water mixture is recirculated and cooled down by a cooling tower in order to reuse the water for the "Cooling" process. The result of the flow through the cooling tower is a cooled down water mass flow and significant heat loss to the environment. This energy loss caused by the cooling tower can be avoided by implementing an additional water cycle for heat recovery. The purpose of this extra cycle is to heat fresh water via a heat exchanger by the hot PCW. Figure *3*b shows that the PCW is collected in a storage tank during the complete Pre-Cooling process. Subsequently, the PCW is pumped through a heat exchanger and transfers its heat to a mass flow of cold fresh water. The result is a cooled down mass flow of the PCW that can be used for further cooling of processes, as well as heated fresh water which can be used for other heat sinks.

4. Application of Concepts to a Representative Use Case

To demonstrate the application of the energy efficiency concepts, pet food packed in 100 g pouches thermally processed in a standard batch sterilization retort with an internal fan operating with steam was selected. For the comparison, the framework conditions of the case study are a steam demand of 320 kg per batch and a cold stream referencing temperature of 40 °C. In addition, the specific energy consumption (per produced ton of product), SEC, is determined, which is the key indicator for the energy efficiency of a product. For determining the SEC, a total product mass of 1,114 kg per batch process is applied to the calculation. The heating medium, materials, process time and temperature in this case study are already optimized to a maximum extent or limited by external factors such as safety issues, product quality standards or product recipes. This high technical level of the case study's sterilization process emphasises its representability and allows application to a state of the art process.

5. Results

The most energy savings can be achieved by implementing concepts 3 and 4. This is underlined with the waterfall chart in Figure 4. The percentage energy saving of the individual concepts is shown neglecting feedback effects. The diagram shows that with concept 4 more than one third of the energy can be recovered resulting in an equivalent reduction in the SEC. By implementing all four concepts, the status quo SEC reduces by 65 % for the batch sterilization process. Heat recovery contributes 42 % of the reduction in SEC while process optimisation provides the remaining 23 %. To sum up the results of the comparison, the highest priority implementation is concept 4. It is recommended carrying out the required actions in line with implementing concept 3 in order to prevent the intermixing of hot condensate and PCW. Another benefit of implementing both at once is that both may require a Pinch Analysis and a heat exchanger network design. Furthermore, the hot-filling of concept 1 should be put into practice by using some of the recoverable heat loads from concepts 3 and 4 as the heat source for the gravy water. The following Sankey diagram in Figure 5 shows the enthalpy streams of the sterilization process after implementing concept 1, 3 and 4. The transfer of the waste heat of the PCW to the cold gravy water is done via a heat exchanger. As it can be obtained from Figure 5, the heat of the PCW can only be transferred to the cold water for the gravy to a limited extent. However, this combination of the concepts reduces the initial energy demand of the process, transfers the waste heat to a nearby heat sink and provides recoverable heat for other heat sinks.
Besides concept 4, all concepts can be independently put into practice. Hence, all four concepts should be considered in any case of process changing, installing new retorts or creating new recipes. Inter-divisional work is the key to realize the described concepts successfully.
The next steps for optimizing the energy efficiency of batch retort sterilization is performing comprehensive field tests on a pilot retort in order to verify the results of the simulated energy savings of the concepts. Positive field test results enable the opportunity of a technological rollout of the concepts on a wider scale. Further technical issues in the field of energy efficiency and steam sterilization is the technical design of a pre-heating system for the retort shell.

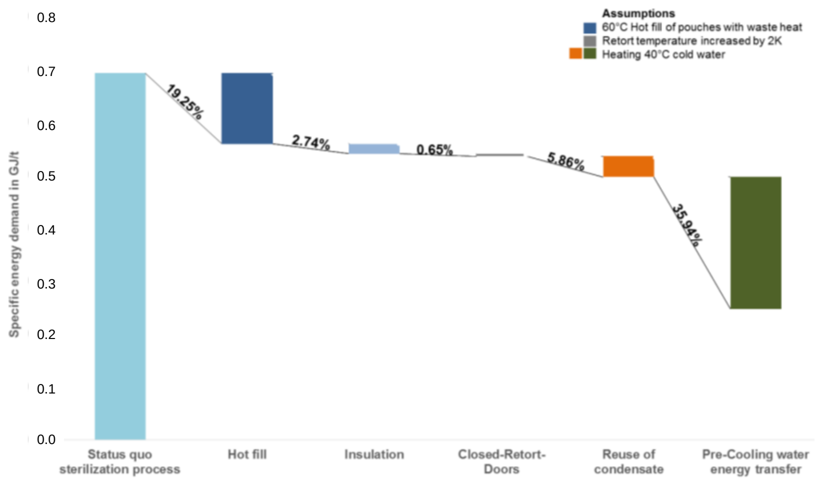

Figure 4: Waterfall chart specific energy demand of overall process and savings

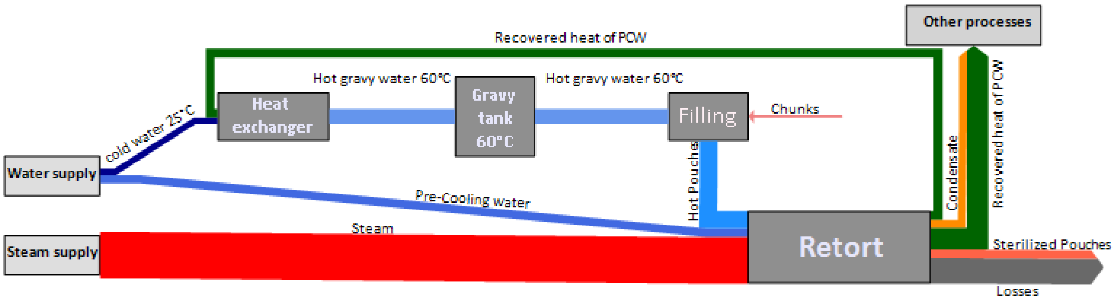

Figure 5: Enthalpy streams of sterilisation process

6. Conclusion

The analysis of the retort batch sterilization process shows that the present process has been optimized to almost a maximum in terms of sterilization temperature, sterilization time, material properties, heating medium and heat transfer coefficient. But, all these optimization actions neglect the energy saving potential of higher initial temperatures of all components included in the process. Also, optimization measures for the cooling process have focused on water recovery. The hot condensate and the hot Pre-Cooling water are cooled down by a cooling tower and the energy of the hot pouches is lost to the environment. These two neglected areas are the starting point for the four concepts. By using the methodical approach of the Onion Diagram and the recovery of low grade heat sources, four comprehensive energy efficiency measures have been developed. In total around 65 % of the energy injected into the system by steam, can be reduced or recovered. The energy demand can be reduced by more than 23 % and 42 % of the energy can be recovered, respectively.
A detailed process analysis is the key to identify the correct temperature and mass of a waste heat stream, which can change due to process optimization actions. In the sterilization process, for example, not splitting up the Pre-Cooling and the Cooling water lowers the temperature of the waste heat stream significantly. Implementing a heat recovery system requires a comprehensive analysis of heat sinks and sources across processes. The Pinch Analysis ensures that all options for a heat recovery system are considered. Possible heat sinks are the feed water tank and gravy water tank. Another suitable heat sink is the retort shell. The Pre-Cooling water could be used to increase the initial retort shell temperature in order to reduce its heating demand. At the moment there is no feasible concept for heating the retort shell with waste heat streams. A detailed evaluation of feasible solutions is necessary because of safety regulations and material limitations. The retort shell is a heat sink in the same process and a higher initial shell temperature reduces the energy demand.
Since the scope of the work is limited to a single, independent retort, the transferability of the concepts and the results to other food processing plants is assured. Any of the four concepts is applicable to a batch retort sterilization process which is operated by steam. Promising areas of application are all packaged products such as meats and sausages, baby foods, ready-to-serve dishes, fruits and vegetables.

References

Barreiro J.A., Perez C.R., Guariguata, C., 1984, Optimization of energy consumption during the heat processing of canned foods, Journal of Food Engineering 3, 27–37, DOI: 10.1016/0260-8774(84)90005-0.

Berk Z., 2013, Food process engineering and technology, vol. 2, Academic Press, Amsterdam, the Netherlands.

Federation of German Food and Drink Industries BVE, 2015, Annual Report 2014_2015, Berlin (in German).

Kemp I.C., 2007, Pinch analysis and process integration: A user guide on process integration for the efficient use of energy, vol. 2. Butterworth-Heinemann, Oxford, UK.

Law R., Harvey A., Reay D., 2013, Opportunities for low-grade heat recovery in the UK food processing industry, Applied Thermal Engineering, 53, 188–196, DOI: 10.1016/j.applthermaleng.2012.03.024.

Simpson R., Cortés C., Teixeira A., 2006, Energy consumption in batch thermal processing: model development and validation, Journal of Food Engineering, 73, 217–224, DOI:10.1016/j.jfoodeng.2005.01.040.

U.S. Energy Information Administration EIA, 2013, International Energy Outlook 2013, Washington DC, USA.