CHEMICAL ENGINEERING TRANSACTIONS Volume 18, 2009
Editor Jiří Klemeš

DOI: 10.3303/CET0918067

Optimisation of the cooling systems in industry in CHP production

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Cooling systems play an important role on the energy efficiency of process industry. Typically these systems have not been integrated efficiently as they have been designed process by process. As a result, significant improvement of industrial energy efficiency can be reached by systematic evaluation.
Optimisation of the cooling systems in industry in CHP (combined heat and power) production has been a three year research project between Helsinki University of Technology, Tampere University of Technology, Åbo Akademi University and VTT. Four case studies have been carried out representing different branches of industry: mechanical pulp and paper mill, steel mill, copper and nickel production and food processing. Different process integration methods and simulation tools were used in the case studies and were developed further based on the experiences, including pinch analysis, mixed integer linear programming and process simulations.
The results show a significant potential for improvement. These include the retrofits of heat-exchanger networks, utilisation of secondary heat in absorption chillers and combined heat, cooling and power production in industrial power plants.

1. Introduction

Optimisation of the cooling systems in industry in CHP production has been a three year research project between Helsinki University of Technology, Tampere University of Technology, Åbo Akademi University and VTT.
The focus of the study has been the rationalisation of the use and production of cooling and heating in industry by integrating cooling and heating systems inside the mill as

Please cite this article as: Hippinen I., Ruohonen P., Nousiainen , Hakala , Manninen , Soderman , Aittomaki , Makinen and Ahtila P., (2009), Optimisation of the cooling systems in industry in chp production, Chemical Engineering Transactions, 18, 415-420 DOI: 10.3303/CET0918067

well as between the mill and community. The study has included: (A) the selection, integration and optimisation of cooling systems, (B) the utilisation of secondary heat from industry in cooling systems (absorption heat pumps), (C) the combined heat, cooling and power production (trigeneration), (D) the energy integration between industry and community and (E) the optimisation of the systems mentioned above.

2. Case results

2.1 Pulp and Paper

In this project a heat exchanger network of a pulp and paper mill has been retrofitted by pinch analysis (Ruohonen & al., 2007). Later the study was expanded to a comparison between the heat exchanger network and the possibilities to use the secondary heat to dry bark or sludge (Ruohonen & al., 2008).

Heat load model for pulp and paper (HLMPP), developed by Hakala & al. (2008) is a generic tool for screening energy reduction potential in pulp and paper industry (Figure 1). The goal is to convert the mill data into heating and cooling requirements of the process, and thus a lot of the process details have been left out. In the model, several sources for wood fibre and several paper machines for different paper products and drying section setups can be applied. The model parameters can be adjusted to the mill in question. Energy targeting is carried out by Pinch analysis (Linnhoff & al., 1982).

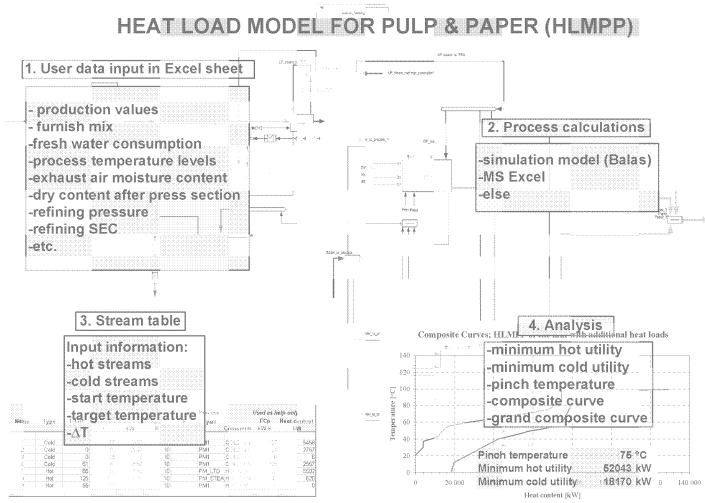

Figure 2. Visualization of the HLMPP (Heat Load Model for Pulp and Paper) tool (Hakala & al. 2008).

The tool has been proven to work well with a pressurized ground wood (PGW) mill in previous studies (Hakala & al., 2008). In the project the model has been developed further to cover thermo mechanical pulping (TMP) and de-inked pulp (DIP). The model is tested using two different cases and the results will be published by Ruohonen & al (2009a). One is a simulated case containing one TMP line and one paper machine and the other is an existing European mill containing one TMP line, one DIP line and two paper machines. The results show that the model works with a suitable accuracy level and provides valuable information of the energy system of the mill.

2.2 Absorption heat pump in steel industry

The main advantage of the absorption cooling in comparison with the compressor cooling is the use of excess heat instead of electricity as the source of energy. In absorption cooling machines an absorption/generation process step is used instead of a compressor. A solution of two compounds is circulated between the absorber and the generator. The more volatile compound is evaporated at the generator, condensed in the condenser, evaporated again at a lower pressure in the evaporator and absorbed back to the solution at the absorber. Of the two most common working pairs, water/ammonia pair is often applied in processes with temperatures below 0 °C, while lithium bromide/water pair is widely used at temperatures above 0 °C. In Fig.2 $LiBr/H_2O$ pair is utilised for cooling of district cooling water from 16 to 6 °C. A hot water stream at 95 °C is utilised as the heat source.

The steel industry is highly energy intensive. Heat that is dissipated from its processes is conventionally cooled off and discharged to atmosphere or to waterways. In colder climates the heat can be used for example for district heating during cold seasons. During warm seasons, the heat becomes excessive also in the Nordic countries.

The steel mill has cooling demands at low temperature levels, such as air conditioning of operator rooms, electricity rooms etc. Conventionally, these cooling demands have been carried out with compressor driven chillers with considerable electricity costs. The electricity costs can be avoided by installing absorption cooling machines for the cooling tasks. The operational costs of such systems are very low. A hot utility at around 100 °C and a cooling water circulation at a middle temperature range of 20 to 40 °C are needed. The excess heat can normally be considered as free of charge.

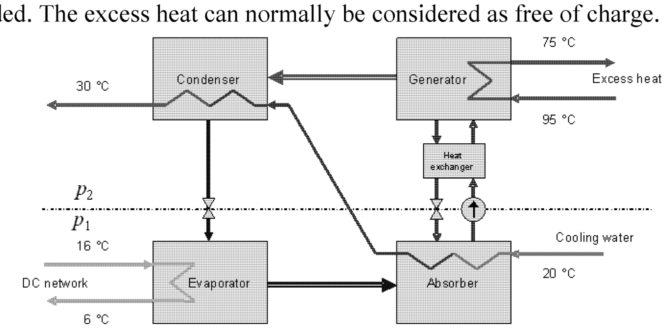

Figure 2. Absorption cooling machine.

When looking at the investment costs, an absorption chiller prices are about the same as the prices of compressor-driven cooling machines. The hot water and cooling water pipelines and potential cooling towers or secondary heat exchangers for the middle temperature water circulation are additional costs that have to be covered by the savings in the electricity costs. When comparing compressor-driven cooling machines with absorption chillers the difference in the coefficient of performance (COP) have to be taken into account: COP for a compressor machine is around 3, for an absorption cooling machine usually around 1.

The above described considerations of the technical and economical potentials of an absorption cooling system were carried out at a steel mill. At the site the sea water cooling of the middle temperature water circulation seemed to become too costly, whereas an evaporative air cooler with moistening spray system was more economically viable. The absorption cooling system in consideration had 4 MW cooling effect.

2.3 MILP in process industry

Mixed Integer Linear Programming (MILP) model for the integration of industrial cooling and heating systems was developed and applied for a large site comprising a number of different plants. The model, described in (Söderman et al., 2008) combines a heat exchanger network synthesis and the pipeline routing optimisation model. The model integrates hot and cold streams at different temperature levels and in different locations at the site, applying suitable temperature intervals, so that a global economical optimum solution for the energy system is found.

Applying the model and solving the formulated problem by e.g. branch and bound method the optimal cooling system structure is obtained, i.e. which optional heat exchangers, distribution pipelines and energy storages shall be built. The objective function of the optimisation problem is to minimise the overall cost of the system, i.e. the sum of the annualised investment costs and the operational costs.

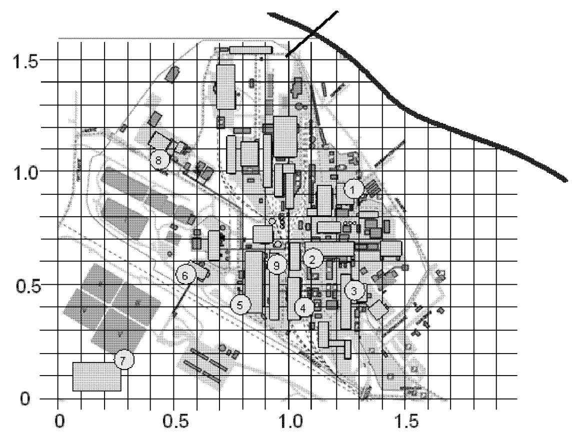

Figure 3. Industrial site as an illustrative case. The coordinates are given in kilometers.

The site that was chosen as an illustrative example for the application of the developed optimisation model has a very complex energy system. In Fig. 3 the plants that were included in the consideration are marked with numbers, having physical coordinates for their locations. Ten hot streams with a total cooling demand of about 150 MW and ten cold streams with a total heating demand of about 135 MW were chosen for the illustrative case. The optimal solution comprised 5 hot utility heat exchangers with about 35 MW effect and 18 heat transfer matches with about 100 MW of heat recovery.

2.4 Heat recovery of cooling systems in the food industry

The special features of the food industry are a high demand of refrigeration at various temperature levels and the varying demand of heating at temperatures of air conditioning until to temperatures of food processing. To day, a normal way of combined production is a heat recovery from condensing heat of the refrigeration system. However, because of a limited temperature level, only a part of this heat has been utilized. Therefore, a study on possibilities to boost the heat recovery and combine energy production was justified.

The goals of this part were to find out the special features of the energy systems of the sector and to develop methods and tools for analyzing the energy balances. These tasks were carried out on the basis of a case plant located in southern Finland. The simulation was based on solving the describing equations by a general Engineering Equation Solver (EES). The component models or unit operations of the refrigeration/heating system were implemented in the program as modules, which can be "combined" to form different systems as shown in Figure. 4.

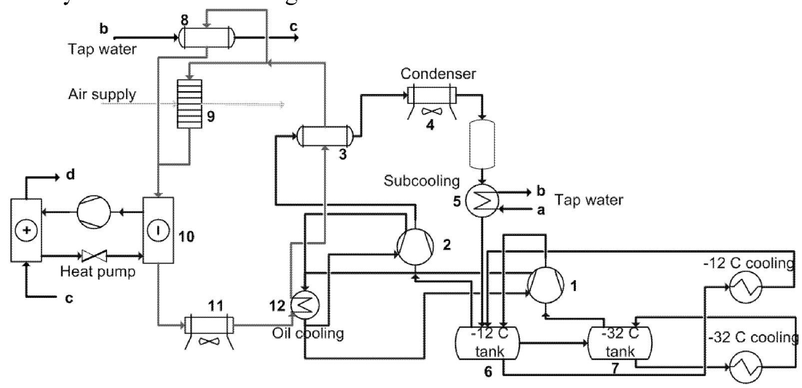

Figure 4. The schematic of the studied case-system.

For the simulation purposes of the case studied, a simplified system was defined (Figure. 4). The refrigeration system is an open two-stage ammonia pump-circulation system extracting heat from two temperature levels: -32 °C for freezing and -12 °C for cooling duties. From the low-temperature stage, the vapour is compressed by the low pressure compressor (1) to the intermediate receiver (6) at temperature level -12 °C. From here, the high pressure compressor (2) compresses the vapour to the condensing pressure level. The superheating of the hot vapour (and possibly also a part of condensation) is recovered to the brine loop in the heat exchanger (3). The rest of the condensation heat is removed to outdoor air in the condenser (4). The brine loop utilizes heat for preheating of hot water (tap water) (8) and supply air (9). An option is further to use heat in the evaporator of the heat pump (10) which supplies peak heating to the hot water. The water can also be preheated using subcooling of the refrigerant liquid (5). The path a-b-c-d describes these optional heating stages.

The simulation results show that the main options to increase heat recovery in the case plant are a heat pump and the effective subcooling of refrigerant liquid after the condenser. The combined production of electricity, heat and refrigeration by a gas motor and absorption refrigerator can get a pay-back time 3…4 years.

2.5 Trigeneration

Trigeneration is defined as the combined production of electricity, heating and cooling in the same plant. Usually, this is done by adding an absorption chiller to a combined heat and power plant (CHP). The CHP plant can be based on a boiler, a gas turbine or a motor. In the project trigeneration and CHP are compared with compression chillers in terms of primary energy consumption and CO_2 emissions. The study in this project focuses on the process industry, and two cases from different industrial sectors are presented. These sectors are food processing and mechanical pulp and paper. The results will be published by Ruohonen & al. (2009b).

An important advantage of a trigeneration plant, compared with traditional CHP, arises from the different load curve for heating and cooling needs; the heating demands peak in the winter and the cooling demands in the summer. The power plant is usually dimensioned to cover all the heating demands over the winter. This means, especially in Finland where the temperature differences between winter and summer are substantial, that there is idle capacity in the power plant during the summer. This capacity can be used to drive the absorption chiller in a trigeneration plant. This results a more stable load curve for the power plant, which improves the average power-to-heat ratio. An Excel-based tool has been developed to take these effects into account on annual basis.

3. Conclusions

The case studies have shown that there are improvement potentials in energy efficiency of cooling systems. When analysing the systems it is essential to consider them as a part of the whole utility system to avoid partial optimisation. Further studies will present the synthesis of these results as well as the potentials for energy savings in various industrial sectors.

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