Heat Recovery in a Pasta Factory

Pinch Analysis Leads to Optimal Heat Pump Usage

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In the previous issue of the IEA Heat Pump Centre Newsletter (Vol, 12, No.3, pp. 29-31), an article by these authors described the use of pinch analysis (also known as pinch technology) in a buildings application. This article describes a similar procedure for integrating a heat pump into a pasta production process.

Many industrial processes, and particularly those dealing with drying, are characterized by an overabundance of low-grade heat which often cannot be efficiently recovered by means of simple heat exchangers. Heat pumps thus represent the primary means of upgrading the energy of moisture loaded streams into useful process energy. Powerful process integration tools based on pinch analysis allow the assessment of the heat recovery options and will lead to the optimal use of heat pump technology.

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Pinch analysis works on the general principle that for the optimum process, heat pumps should ideally only be used to upgrade energy across the pinch temperature of the process or site considered.

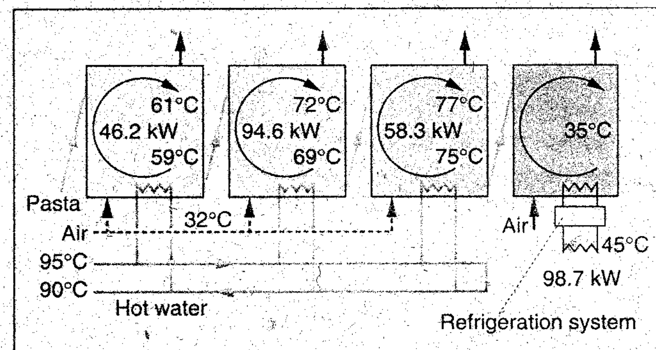


Figure 1: Simplified flowsheet of the pasta drying line.

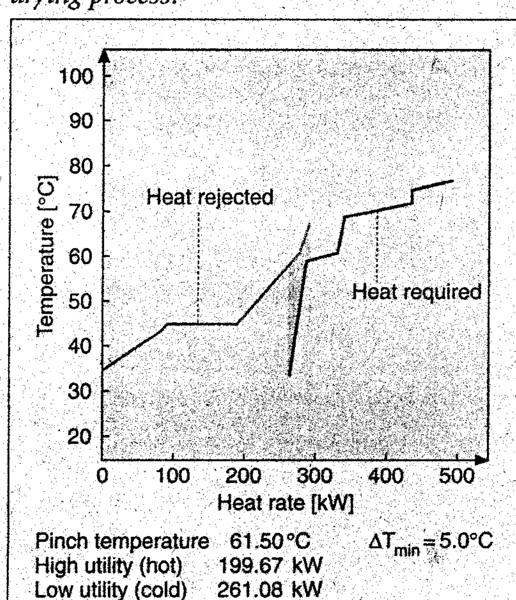
However, this requires that several parameters, such as the heat pump evaporation and condensation temperature levels and heat rates, should be optimized with respect to the drying process. At the Swiss Federal Institute of Lausanne, a dedicated heat pump optimizer included in the process integration computer program PinchLENI, has been applied to one of the drying lines of a pasta production factory.

Pasta Production

Figure 1 is a simplified flowsheet of the pasta drying line. After kneading and wire-drawing, the pasta is dried in three drying zones with controlled temperature and humidity. Afterwards, the pasta passes through a cooler before packaging. Presently, the air used for drying is heated by hot water (95/90°C) from an oil or natural gas boiler. The cooling water is supplied by a refrigeration system. The essential economic data for the drying line are:

- operating time: 5600 h/y;
- heat cost: CHF 0.06/kWh (US$ 0.04/kWh);
- electricity cost: CHF 0.11/kWh (US$ 0.07/kWh).

Figure 2: Composite curves of the existing drying process.



Pinch Analysis

Pinch analysis involves two graphical tools, namely the composite curves and the grand composite curve. An important step in pinch analysis is the collection of data on the heating needs and recovery opportunities. This phase of the analysis of the pasta production process results in the composite curves of Figure 2. The right curve summarizes the heating needs of the drying air of the three successive sections of the drying line. The left curve represents the energy recovery opportunities, with the "plateau" at 45°C

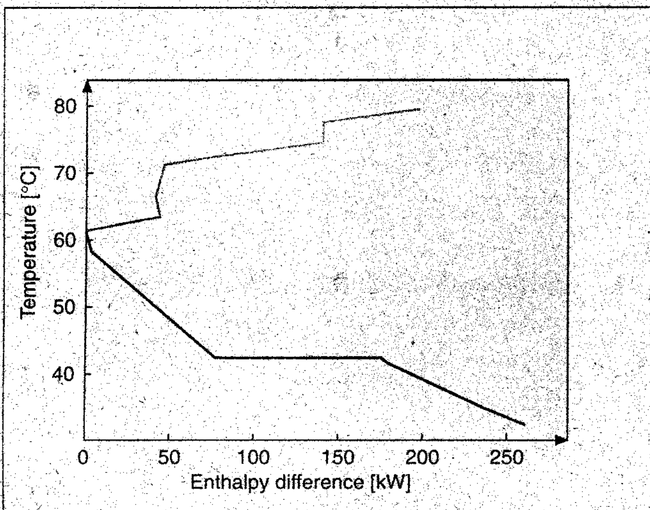


Figure 3: Grand composite curve of the drying process.

characterizing the heat released from the condenser of the refrigeration system. It is obvious from this representation that, without a heat pump, there is little margin for internal heat recovery.

The grand composite curve is useful for determining the temperatures and capacities of the evaporator and the condenser [1,2]. Note that the capacities depend directly on the temperatures and on the analyzed process. Figure 3 shows the grand composite curve for the pasta production process. For this process, the evaporator of the heat pump can exchange heat with the exhaust air only, or with the exhaust air and refrigeration system condenser. The condenser of the heat pump can heat one, two or three drying zones. The latter proposition has been analyzed using the process integration program PinchLENI.

Using PinchLENI

The PinchLENI software includes a heat pump optimizer module which is applicable to closed cycle compression heat pumps.

The evaporator or condenser capacity can be chosen by the user or can be calculated from the grand composite curve at the corresponding temperature. For a fixed value of the condenser or evaporator capacity, the module can, for instance, scan the evaporator and/or condenser temperatures to find the minimum payback time. The derived investment cost includes the cost of all heat exchangers and the cost of the heat pump compressor. The new operating cost includes the cost of electricity and back-up heating. The heat pump optimizer module of PinchLENI offers 12 possible heat pump calculation and optimization scenarios. The heat pump module also provides a graphical representation of how the various parameters (temperature, capacity, electric power, payback time, COP, investment cost, operating cost, etc.) vary with the temperature or with the capacity of the evaporator or condenser.

Results

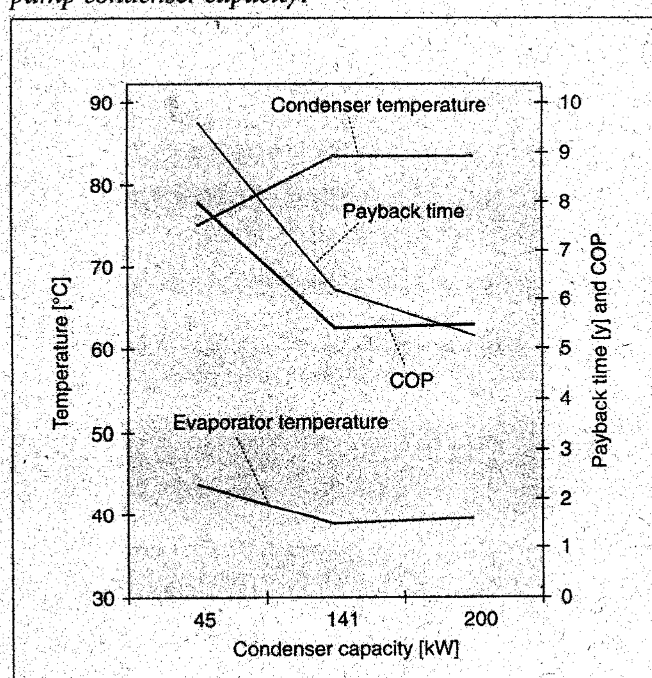
Figure 4 plots the evaporation and condensation temperatures, and the corresponding payback times, against the capacity of the condenser. The COP of the heat pump cycle is also shown. This illustrates that the optimal solution (for a minimum payback time) is with a fixed evaporator capacity of 200 kW. The results of optimization with PinchLENI indicate that this solution corresponds to a heat pump with a condenser covering all the dryer needs (three zones), and with an evaporator heated by the exhaust air and the heat from the refrigeration system condenser. The boiler is only used for the start-up of the process or for back-up. The composite curves relative to the pasta production process with the heat pump are shown in Figure 5.

The calculations presented here are based on refrigerant HFC-245ca, a potential substitute refrigerant for CFC-11, that would be well adapted to the working domain. HCFC-123 is another possible refrigerant (with final results similar to HFC-245ca) but with an ozone depletion potential and a higher toxicity level than the CFC.

Considering the economic criteria, heat pump integration is always a tradeoff between the following:

- lowering the temperature lift to minimize the electric power consumption of the compressor;
- increasing the temperature differences in the heat exchangers (higher pinches) to allow the use of lower-cost heat exchangers with small exchange areas.

Figure 4: Variation of different parameters with heat pump condenser capacity.



This tradeoff is very sensitive to the economic parameters (energy cost and equipment cost). In the analyzed case, the value of the payback time indicates that on the basis of typical industrial economic requirements, the integration of a heat pump at the pasta factory is not profitable enough. However, it would become more attractive if a new pasta drying line were envisaged, or if the operating time of the process were extended, or if the costs of energy were increased.

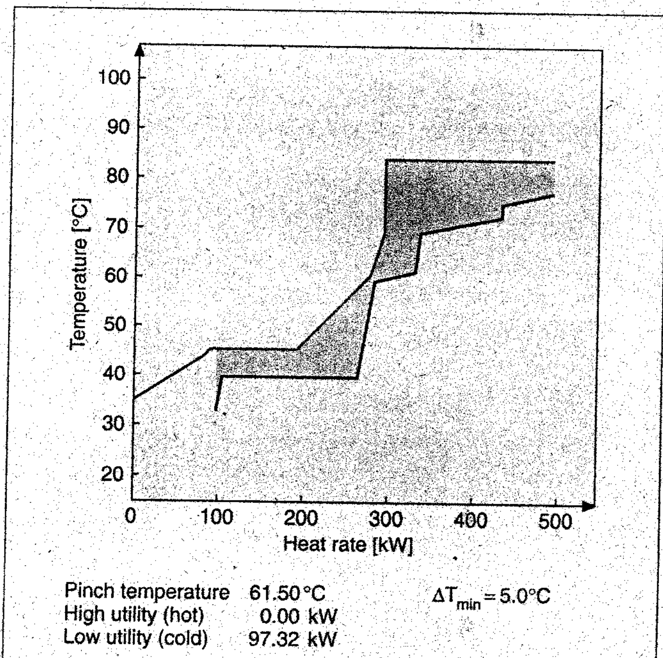
Exergy Losses

When introducing heat pumps, the classical representation of the original pinch method does not graphically highlight the resulting exergy losses in the system. Figure 6 shows the extended composite curve in which the heat flows are plotted against Carnot Factor instead of temperature. The dimension less Carnot Factor is calculated from the absolute process temperature T_1 and an absolute reference temperature T_0 via:

$$\text{Carnot Factor} = 1 - \frac{T_0}{T_1}$$

If T_0 is the ambient temperature, the Carnot Factor represents the fraction of a process heat flow that can be theoretically converted into work - i.e. its exergy. Thus the pink area in figure 6 represents the exergy losses in the heat exchangers. Using the same scales, it is also possible to show the exergy loss in the compressor. This loss is represented by the blue area bounded by the electric power and the compressor efficiency factor (1 - exergetic efficiency). These extended composite curves thus portray all exergy losses and provide a useful tool for comparing different systems [3].

Figure 5: Composite curves of the process with the optimal heat pump.



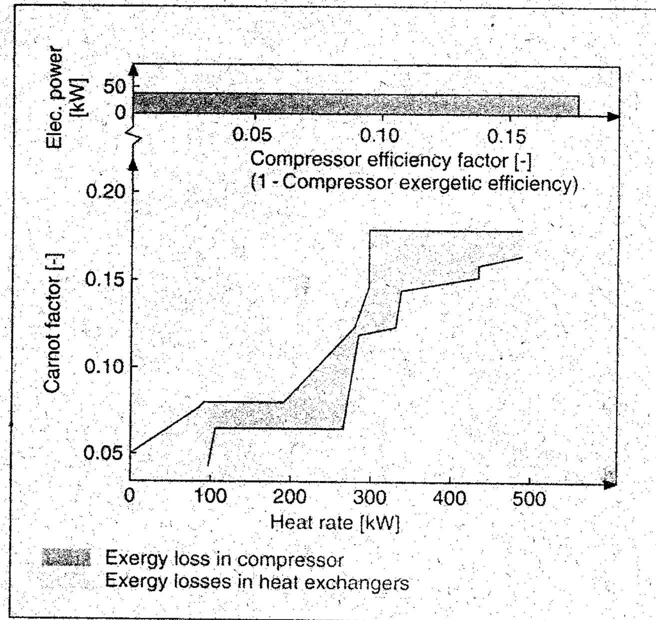


Figure 6: Extended composite curves of the process with the optimal heat pump.

Overcoming Obstacles

Predesign of industrial processes with optimal placement of heat pumps can be significantly accelerated by using process integration tools with dedicated heat pump optimizers. In the particular case of pasta drying, pinch analysis shows how significant energy savings can be made. However, several major obstacles must be overcome before such technology will be put into practice. These include the current low price of energy, the present uncertainty regarding refrigerants condensing in the 80 to 100°C range and, to some extent, the present trend towards higher drying rates and higher temperature, which is, unfortunately, favoured by present low energy prices.

References:

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[2] Wallin E. and Berntsson T., "Integration of Heat Pumps in Industrial Processes", Heat Recovery Systems & CHP, vol. 14, No.3, pp. 287-296, 1994.

[3] Staine F. and Favrat D., 1993, "Energy Integration of Industrial Processes Based on a Graphic Representation of Exergy Factors", Proceedings of the International Conference Energy Systems and Ecology, Cracow, Poland, pp. 427-437.

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