EXERGY ANALYSIS VERSUS PINCH TECHNOLOGY

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ABSTRACT

A comparison between exergy analysis and pinch technology is performed by studying systems where threshold problems occur and heat pumps are available. Pinch technology is shown to be a poor method in these cases. Instead exergy analysis is recommended. Methods such as energy utility diagrams and thermoeconomic optimization are recommended to improve the structure and to optimize the operation of systems, i.e. design of systems.

INTRODUCTION

This paper is an elaboration of earlier work (Wall, 1995). From an increasing misapplication of the pinch technology there is a strong need to explain the differences between exergy (second law) analysis and pinch technology. Pinch technology is a method to improve heat exchanger networks (HEN) by matching excess of heat and cold streams in a system through composite curves in a *T–H* diagram (Temperature – Enthalpy), Fig. 1 (Townsend and Linnhoff, 1983).

This method reduces heat losses by indicating how to rearrange the heat exchangers in a given HEN. A limit temperature difference at the pinch $\Delta T_{\min}$ is assumed. Above the pinch we have a heat sink; and below a heat source. The area between the composite curve for the hot and for the cold stream represents an exergy loss. However, in a *T–H* diagram, it is important to notice that the area is not equal to the exergy loss. If the composite curves are close, the exergy loss is less, and vice versa. For large temperature differences apart from the pinch, which implies large exergy losses, further improvements might be justified.

Unfortunately, many people today uses the pinch technology as a method of optimizing systems other than HEN. However, pinch technology is only a method to improve structure of a HEN under specific conditions. We should also notice that there is a fundamental difference between optimization and improvement. Optimization in a general sense involves the determination of a highest or lowest value over some range. For the mathematician optimization is to find the maximum or minimum value of a given function in a region. Certain conditions must be met, e.g. the function must be continuous at the point in question, and the optimum is a well defined concept. In engineering we usually consider economic optimization, which usually means minimizing the cost of a given process or product, i.e. we need a well defined objective function. It is also important not to be mislead by a local optimum, which may occur for strongly non linear relations. In pinch technique there is no objective function. Thus, pinch technology is just a method to improve the design of HEN under specified restrictions discussed below.

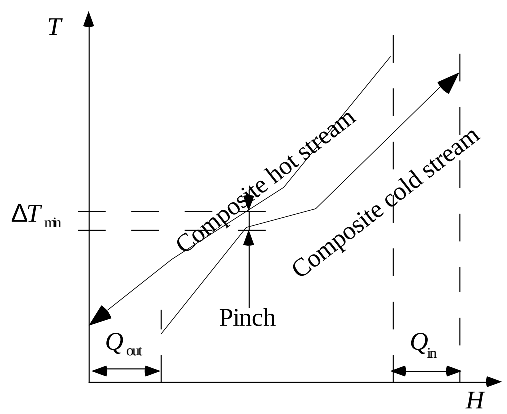

Fig. 1. Composite curves and the pinch in a *T–H* diagram.

The power of using second law insights to prescribe improved designs, whether in HEN or processes in general, and the advantage of this approach over pinch technology has been well demonstrated by many authors. In two comparative studies exergy analysis and pinch technology were applied to a proposed, new nitric acid plant to be integrated into an existing facility (Linnhoff and Alanis, 1991 and Gaggioli et al., 1991). The result, in millions of dollars saved per year, was that from an exergy analysis the savings are several times better than the savings from pinch technology. The final conclusion is that "exergy analysis is a more powerful tool, which brings to light opportunities that go undetected by pinch technology" (Gaggioli et al., 1991). This conclusion has been further developed and substantiated by Sama (1995a & b). Recent studies, based on work by Hohmann in 1971, also indicate important results in opposite direction from pinch technology (Sama 1996).

When it comes to improving the structure of a system, the engineering skill based on common sense second law guidelines proposed by Sama et al. (1989) and Sama (1993, 1995c), together with the technique of Energy Utility Diagrams (EUD) proposed by Ishida (1982) and applied by many others, e.g. Wall (1989), insight, creativity, and experience are the most powerful tools. As far as we know now, this can not be replaced by a simple methodology. Obviously, there is no optimization technique to optimize the structure of a system, this is left to the engineers' imagination and intuition to just improve, e.g. through technical inventions.

However, the operation of a given system or process may be optimized by techniques such as thermoeconomic optimization introduced and developed by Tribus, Evans, Gaggioli and El-Sayed (1983, Gaggioli et al., 1987). Thermoeconomic optimization is an economic optimization subject to the physical constrains of the system. This is a well documented optimization method which has been successfully applied even to strongly non linear systems (Wall, 1986 and Kenney, 1989).

The object of this paper is to clarify the principal differences between exergy analysis and pinch technology from studying simple common problems. One of the well known disadvantage of the pinch technique is that, it can not solve threshold problems, which are quite common in practice. Also when we have systems of not only heat exchangers, the pinch technique is not applicable. Let us see why pinch technology is a poor method in these cases and why exergy analysis is a much more powerful tool. Hopefully, this will also bring a better understanding to why pinch technology sometimes fails, whereas exergy analysis never does.

THRESHOLD PROBLEMS

When the external heat input Q_{in} or the heat output Q_{out} disappears, i.e. $Q_{in} = 0$ or $Q_{out} = 0$, then we reach a threshold situation $\Delta T_{min} = \Delta T_{thr}$, see Fig. 2. When $\Delta T_{min} \leq \Delta T_{thr}$ we have a situation where the energy need is not effected by the position of the composite curves, $Q_{in} = Q_{in,1} + Q_{in,2}$. However, the exergy need is strongly effected, because of the different temperature levels, see Fig. 3. The exergy need in the upper diagram of Fig. 3 is larger than in the lower diagram, $E_{in} > E_{in,1} + E_{in,2}$. Thus, exergy diagrams add important insight, which is lost in the pinch technique. Thus, this is also a good example to point out the loss of information, which is one result of applying pinch technology (Sama, 1995a). Let us now see what happens if we introduce heat pumps into a HEN system.

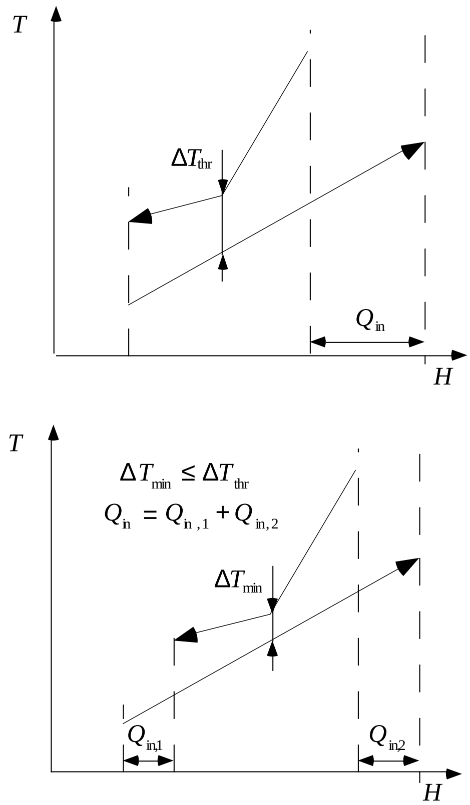

Fig. 2. Threshold problems – when $\Delta T_{min} \leq \Delta T_{thr}$, the energy need is sometimes not effected by change of the composite curves $Q_{in} = Q_{in,1} + Q_{in,2}$.

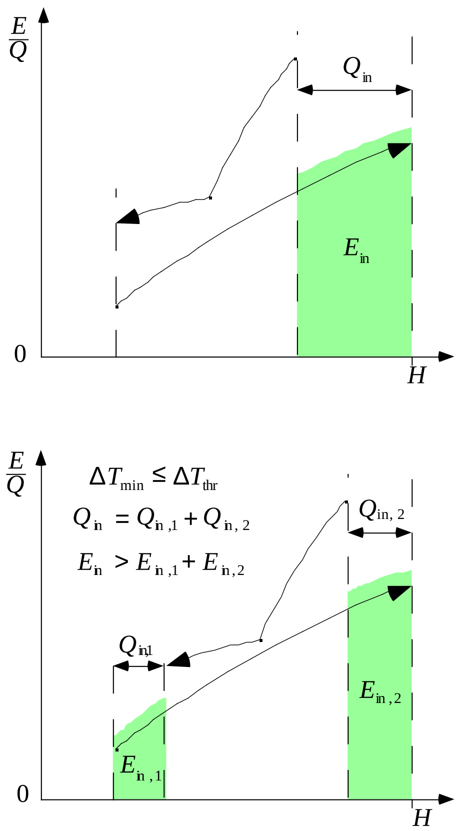

Fig. 3. Threshold problems – when $\Delta T_{\min} \le \Delta T_{\text{thr}}$, the exergy need is always effected by the positions of the composite curves $E_{\text{in}} > E_{\text{in},1} + E_{\text{in},2}$.

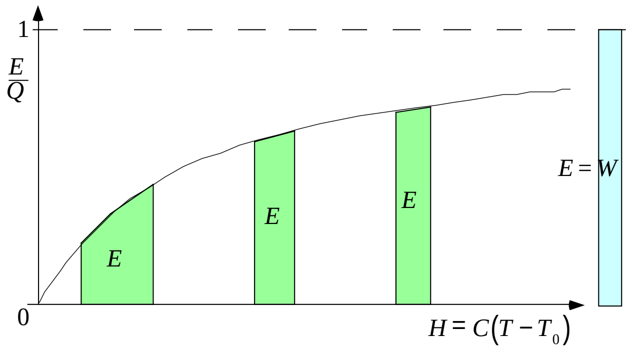

Fig. 4. The exergy E is conserved when the temperature T of the heat changes, but the enthalpy ΔH decreases with increasing temperature. The amount of enthalpy as work is indicated by the far right rectangle.

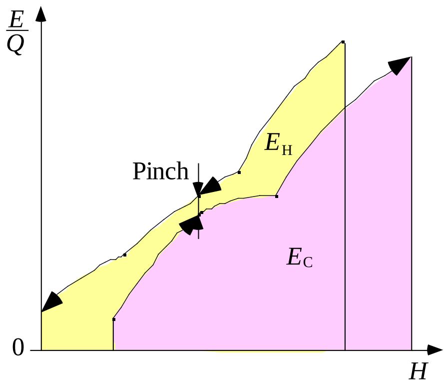

Fig. 5. The exergy available from the hot stream E_H can support the exergy need to the cold stream E_C. Note, that the E_H is partly covered by E_C in the Figure.

HEN WITH HEAT PUMPS

By introducing heat pumps we introduce the possibility for heat to go from lower to higher temperature. However, from Fig. 4 we see that the heat content ΔH changes when we move heat along the temperature scale, i.e. the enthalpy is effected by the exergy factor E/Q. The exergy E is conserved, but the energy or the heat content ΔH is not. This is a consequence of the second law of thermodynamics stated by Carnot in 1824. We have also indicated the equivalent amount of work, as a rectangle limited by the exergy factors 0 and 1.

Exergy input might be external work or exergy extracted from the system through heat transfer from higher to lower temperatures. In practice the exergy use is the driving force. All kinds of heat pumps as compression heat pumps, absorption heat pumps and vapor ejection heat pumps and heat transformers are applicable. However, we need to consider that exergy is conserved in the system, not enthalpy, H as described by Fig. 4. The situation can be described by Fig. 5.

The exergy available from the hot stream E_H can be used to support the exergy need to the cold stream E_C, also by introducing heat pumps. If $E_H > E_C$, then theoretically, heat exchangers and heat pumps can support all heating needs in the system, also above the pinch. So even though there is a lack of heat, i.e. enthalpy at higher temperature in the system, this will be produced by lifting heat from ambient temperature by using exergy at lower temperature. So in this case, no exergy input is necessary, instead there will be a net exergy output. When $E_H < E_C$, we need an exergy input to the system. However, heat pumps can still support the needs of heat, also above the pinch.

In pure HEN systems, heat can only go from a higher to a lower temperature, but heat pumps transport heat from a lower to a higher temperature. Thus, by introducing heat pumps pinch technology can not show us how to improve the system. It is also impossible to illustrate work in the T–H diagram. Let us return to the original situation illustrated in Fig. 1. Since we are no longer restricted by a limit temperature difference at the pinch, $\Delta T_{\min}$, we may move the composite curves as in Fig. 6. This gives us a situation where $T_H < T_C$, i.e. heat would spontaneously go in the wrong direction. However, this is easily eliminated by heat pumps. Let us illustrate the situation in an exergy diagram, see Fig. 7.

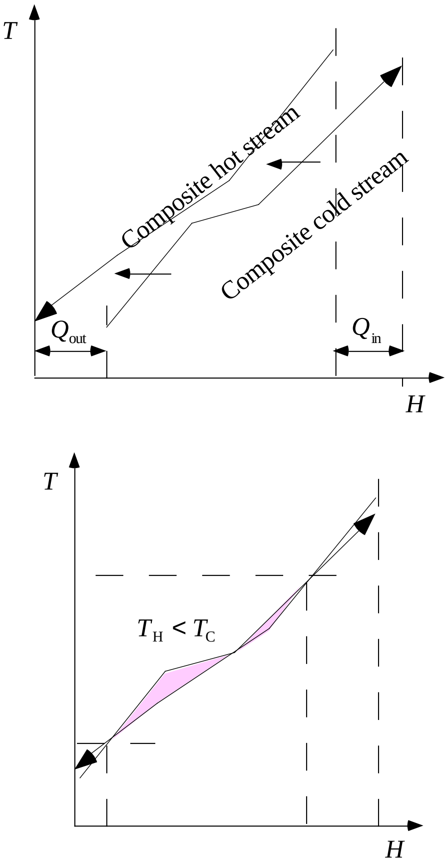

Fig. 6. Now the composite curves may cross, and we may get an area were $T_H < T_C$.

In Fig. 7 the different regions of excess of or need for exergy is indicated, and we can see that the need for exergy now has been moved to a lower temperature region, cf. Fig. 5. The curves are also very close. The advantage is obvious. We have replaced a heating need at high temperature with a need at low temperature, thus making heat pumps more appropriate. In this case we would only need to separate the curves very little by applying a heat pump in a suitable place operating on the two flows. This simple example gives us a better understanding of the limitations and danger of applying pinch technology to systems not limited to heat exchangers.

The situation can also be illustrated by Fig. 8. Heat engines and heat pumps make it possible to freely exchange heat and work according to the 1st and 2nd law, i.e. conservation of energy and exergy, since we assume reversible processes.

$$Q_H = Q_L + W \tag{1}$$

$$E_H = E_L + W \tag{2}$$

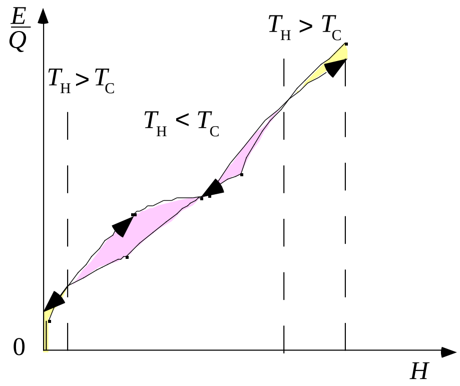

Fig. 7. Areas with excess $(T_H > T_C)$ and need $(T_H < T_C)$ of exergy.

From Fig. 8 we see how both the exergy factor and the enthalpy of the heat is effected when work is introduced as an available form of energy.

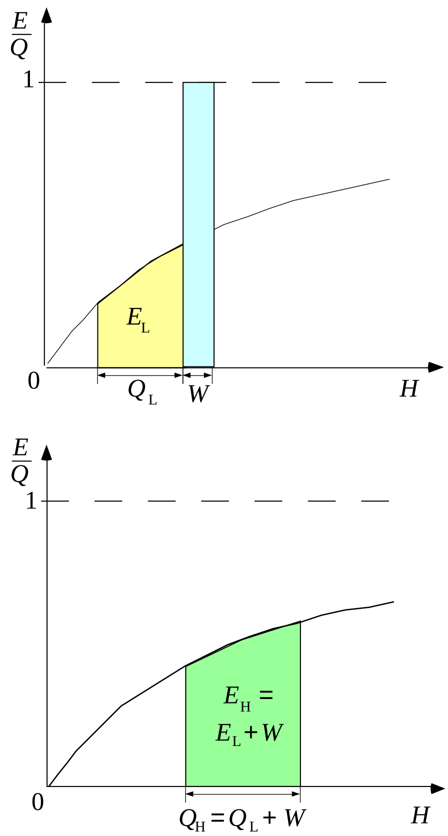

Fig. 8. With heat pumps exergy as heat can be moved in temperature according to the 1st and 2nd law.

Thus, when we introduce heat pumps to a HEN, pinch technology is no longer useful as a design tool, since it is only applicable to improve pure HEN systems without threshold problems. Instead we must use exergy methods, e.g. the EUD technique (Ishida, 1986). This technique is based on the exergy factor or the availability factor as it is named by Ishida (1982). Among other processes the EUD technique has been used to describe the high efficiency of the Kalina cycle and to indicate further improvements with good results (Wall, 1989).

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CONCLUSIONS

The pinch technology is a method restricted to pure HEN systems without threshold problems. Methods based on exergy are advantageous to the pinch technology.

When heat pumps are available, pinch technology can not be used to improve the system. It is only through exergy based methods, e.g. the EUD technique that the structural design of the system may be improved.

To optimize the operation of a system techniques like thermoeconomic optimization is recommended.

We also strongly recommend to differ between the concepts of optimization and improvement.

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