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A Novel Approach for Including Multi Phase Flows into Pinch Analysis – The Heat Exchange Limits Estimated by the Advanced Composite Curves

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Traditionally, pinch analysis assumes a complete freedom of design when it comes to connecting different stream with each other. However, if the hot flows have a composition of different components, of which some have a condensation temperature on the range in question, the assumption of constant heat capacity flow does not always hold. For streams like this, the end temperature and the total enthalpy given by the stream are dependent on the stream on the other side and a simple temperature difference is not sufficient to describe the situation. Typical examples of streams of this kind are moist air and other mixtures of several gases.

1. Introduction

The basic idea of pinch analysis is to investigate what is the theoretical minimum for utility consumption on a chosen minimum temperature difference (ΔT_{min}) when all the heating and cooling demands of the plant are taken into consideration (Linnhoff et al., 1994). However, if the hot flows taken into the analysis have a composition of different components, of which some have a saturation temperature within the same range, the basic assumption of freedom to choose matches in the pinch analysis does not always hold. For streams like this, the end temperature and the total enthalpy given by the stream are dependent on the stream on the other side and a simple temperature difference is not sufficient to describe the situation. Typical examples of streams of this kind are moist air and other mixtures of several gases. In this paper we define a novel pinch-based approach for estimation of heat recovery possibilities based on the use of advanced composite curves in combination with thermodynamic simulation.

1.1 Advanced composite curves

Advanced composite curves (Nordman and Berntsson, 2009a) are a pinch-based method that is developed especially for retrofit situations. The advanced curves take into account the existing heat exchanger network at the mill. Therefore, it is possible to estimate with good precision how costly it will be to improve the heat exchanger network. There are four curves above pinch and four curves below. The curves above are: Hot Utility Curve (HUC), Actual Heat Load Curve (AHLC), Extreme Heat Load

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Curve (EHLC), and Theoretical Heat Load Curve (THLC). The corresponding curves below pinch are: Cold Utility Curve (CUC), Actual Cooling load Curve (ACLC), Extreme Cooling Load Curve (ECLC), and Theoretical Cooling Load Curve (TCLC)
The EHLC and THLC show the limits for temperature levels of possible heat exchange in the heat exchanger network. Therefore AHLC should always be between them. If AHLC is close to THLC, it means that the design is originally poor, heaters are placed on low temperature levels and thus more heat exchanger area is installed than would be necessary. In a retrofit case this is usually beneficial because this area might be useful when located somewhere else, and replacing heaters placed low usually requires a smaller number of matches to be changed. Therefore AHLC lying close to THLC is an indication of a relatively cost-effective retrofit and AHLC lying close to EHLC is an indication of a relatively expensive retrofit. A more comprehensive description of the method can be found in (Nordman and Berntsson, 2009a). The methodology has been used in two case studies considering chemical pulping (Nordman and Berntsson 2009b) and in three articles considering mechanical pulping (Ruohonen and Ahtila, 2009; Ruohonen and Ahtila, 2010; Ruohonen et al., 2010).

2. Methodology

The advanced composite curves can be used to define an upper and lower limit for the possibility of recovering heat from soft streams. This is achieved by combining the advanced composite curves with sophisticated humid air heat exchange simulation. The novel methodology can be defined as follows:

1. Analysis of the plant using the advanced composite curves
2. Calculation of heat recovery possibilities in two cases:
    a. The heat is taken to the streams that compose the Extreme Heat Load Curve
    b. The heat is taken into the streams that compose the Theoretical Heat Load Curve
3. Presentation of the results in graphical way using two new curves

The current heat recovery of the mill is between the two extreme cases and can be shown in the AHLC. The heat recovery possibilities are calculated using a thermodynamic simulation program presented by Sivill et al. (2005). The program calculates heat transfer rate for any given heat recovery system that may include condensing streams and for which the state of the incoming streams (temperature, humidity and flow rate), structure and heat transfer surface area are known (validation in (Sivill et al., 2010)). The program is used to examine the impacts of retrofitting and changing the operation point of the studied heat exchanger network in cases 2a and 2b.

3. Results from a case study

The mill used as an example in this study is a mechanical pulp and paper mill with one paper machine and one TMP line with annual production of 400,000 ADt (air-dry t) of paper per year. The data does not represent a specific mill, but can be seen as an example using typical values and a simplified structure. The streams taken into the analysis are presented in Table 1.

Table 1: The streams taken into the analysis

Type of stream	Start temperature (°C)	Target temperature (°C)	Heat content (kW)	Description
Cold	15	45	19100	Chem. Water
Cold	0	20	22900	Ventilation air
Cold	28	95	3600	Supply air
Cold	95	120	2600	Preheating of TMP condensate
Cold	60	72	18400	PM clear filtrate
Cold	30	55	8000	Chem. Water for coating kitchen
Hot	67	60	6800	Cooling of TMP dull filtrate
Hot	74	45	6000	Cooling of TMP waste water
Hot	20	15	10000	Drives cooling
Hot	50	40	4200	Waste water from TMP
Hot	48	40	1700	Waste water from PM
Hot	91	90	500	Dryer section condenser
Hot	142	78	7000	TMP condensate
Hot	111	110	10900	TMP heat recovery condenser
Hot	70	45	300	Exhaust from dryers
Hot	100	45	1400	Exhaust from IR
Soft	80	51	19700	PM Exhaust air

The soft stream in this case is the paper machine exhaust air. There is no need to cool the air down. Traditionally it could be taken into the analysis as a hot stream, but then the streams where the heat is taken must be locked. Otherwise the target temperature and the heat content would not be known. The GCC of the process with ΔT_{min} = 5 K is shown in Figure 1.

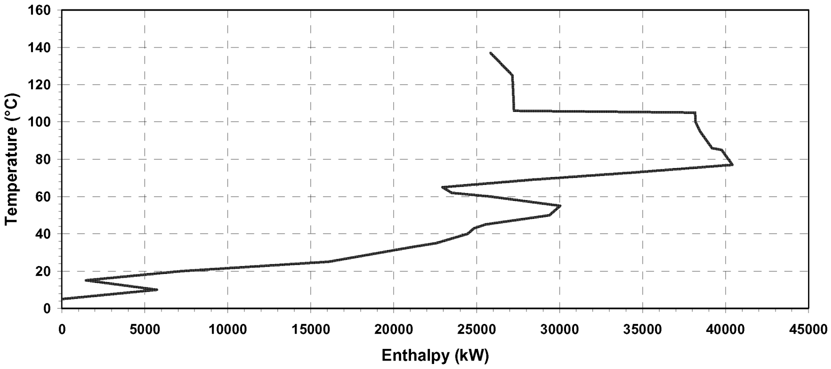

Figure 1: The Grand Composite Curve.

The Grand composite curve shows a minimum hot utility consumption of 25.8 MW. Currently, 19.7 MW of this demand is covered by paper machine heat recovery and 11.6 MW is covered by steam. The theoretical saving potential is 5.4 MW. The ΔT_{min} that corresponds to the current utility consumption is 16 K. The advanced composite curves drawn using this ΔT_{min} are shown in Figure 2.

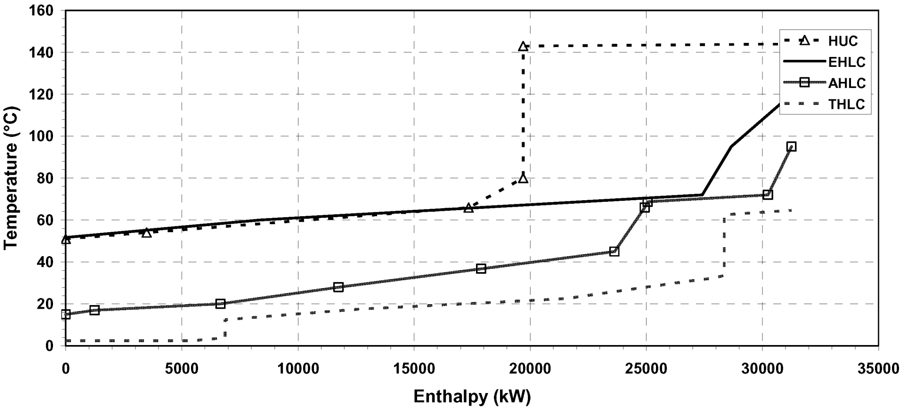

Figure 2. The Advanced Composite Curves.

In Figure 2 the heat recovery is treated as a utility. However, there is no need to take just this much heat out of the stream. The upper and lower limits for heat recovery have been calculated by assuming that the heat is taken either to the EHLC or the THLC.
The results are shown in Figure 3.

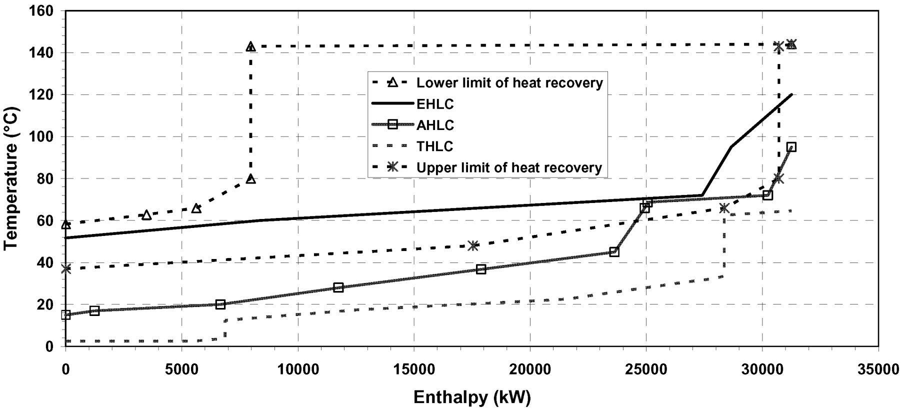

Figure 3: The new approach.

For practical reasons, the heat can not be taken to the system in as low temperature as the THLC shows. This is due to the need of a glycol circulation between the exhaust air and the incoming ventilation air. This practical limitation cause a 7.1 MW decrease in the amount of heat that can be taken out of the paper machine heat recovery using the current system.

Two different practical options for retrofit of the PM heat recovery are considered. In both options, it is assumed, that the heat exchanger network of the mill will first be retrofitted according to the pinch principles. This gives savings of 5.4 MW.

Retrofitting the network also allows the heat to be taken into the system on a lower temperature level, as shown by the THLC. This gives possibilities to take more heat out of the PM heat recovery. The two options considered here can be defined as follows:

1. The area of the PM heat recovery system is kept constant, but the heat exchangers are rearranged.
2. The heat exchangers are rearranged and additional area is installed.

The original arrangement and the two new options are shown in Figure 4.

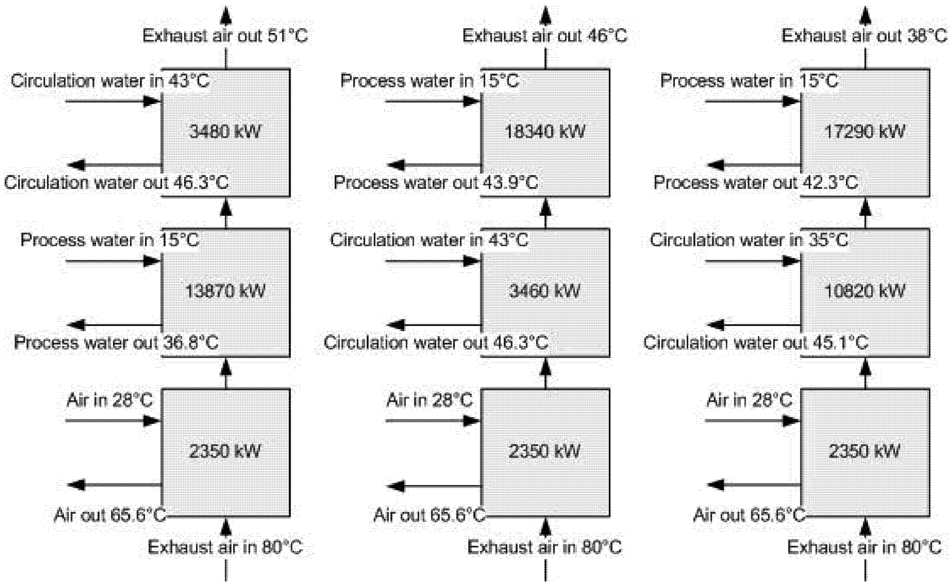

Figure 4: Construction of the heat recovery network in the different options. Left: the original system, centre: Option 1, and right: Option 2.

The calculation shows that in addition to the 5.4 MW saving that can be achieved by the retrofit of the heat exchanger network, 4.5 MW extra can be saved in Option 1 by rearrangements in the PM heat recovery system. Then the temperature of the exhaust air after the heat recovery is 46 °C instead of the original 51 °C. Option 2 would allow 10.8 MW more to be taken out of the PM heat recovery and the temperature of the air after the heat recovery would be 38 °C. This result is very close to the theoretical upper limit shown in Figure 3.

4. Conclusions

The advanced composite curves can be used to show the upper and lower limits for heat recovery. However, technical limitations have to be taken into account either manually or by using individual minimum temperature differences when calculating the THLC. The case study presented in this paper shows that in addition to the 5.4 MW that could be saved by modifications of the heat exchanger network, more can be saved (4.5 MW in Option 1 and 10.8 MW in Option 2), because the changes made in the heat exchanger network also lower the temperature level where the heat must be taken into the process. This makes it possible to get more heat out of the paper machine heat recovery system. It should also be noted, that an approach where the larger amount of heat recovery would be locked in advance and treated as a hot stream, is not feasible when discussing multi phase flows and condensation. In this case, the amount of heat that is available is *dependent* of the network structure, and can not be known beforehand.

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