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Capital Cost Targeting of Total Site Heat Recovery

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A single uniform ΔT_{min} specification had been mostly considered for the evaluation of the trade-off between the heat recovery and the capital cost for individual processes. However, exploiting heat recovery on Total Site level offers additional potential for energy saving (Klemeš et al., 1997). The current work deals with the evaluation of the capital cost for the generation and use of site utilities (e.g. steam, hot water, cooling water), which enables the evaluation of the trade-off between heat recovery and capital cost targets for Total Sites. The procedure involves the construction of Total Site Profiles and Site Utility Composite Curves and the further identification of the various utility generation and use regions at the profile-utility interfaces. This is followed by the identification of the relevant Enthalpy Intervals. The lower bound of the required heat transfer area can be then estimated which enables its further use in optimisation procedures.

1. Introduction

Methods for targeting capital and total cost of Heat Exchanger Networks (HENs) were initially developed by Townsend and Linnhoff (1984) and further elaborated (Ahmad et al., 1990). A trade–off between the rate of heat recovery and the involved capital cost for an individual process, accepting a single ΔT_{min} specification has been described (Serna-González et al., 2007). However, it still receives considerable attention (Serna-González and Ponce-Ortega, 2011). In a recent work (Varbanov et al., 2012) Total Site heat recovery targeting using multiple ΔT_{min} specifications for the site processes and process-utility interfaces has been explored. It is also possible to define and use the ΔT_{min} contributions of individual process streams in a process (Kravanja et al., 1997). The aim of this work has been to determine the lower bound on the heat transfer area for meeting the targeted heat recovery on the Total Site. This can be used in further work for finding the optimal configuration of ΔT_{min} specifications for heat recovery inside the processes and between them through the utility system.

2. Methodology

Total Site is a set of processes linked with a central utility system (Figure 1). The first step for Total Site targeting is to maximise the heat recovery within the processes. Total Site Profiles (TSPs) are then constructed to evaluate the heat recovery potential between the processes through the utility system. The procedure is described next and illustrated in Figure 2.

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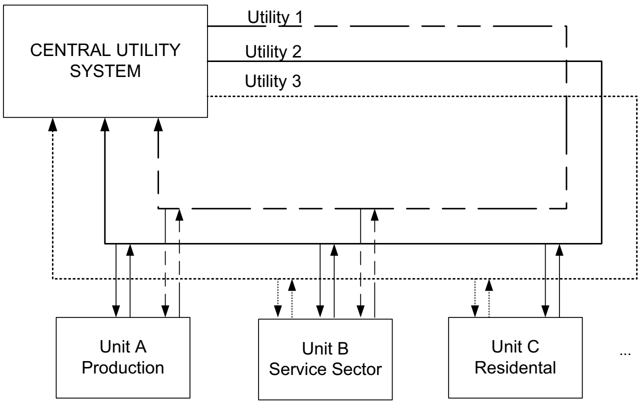


Figure 1: A Total Site (after Perry et al, 2008)

Step 1. Process heat recovery (Figure 2). The process-level utility targets and Grand Composite Curves (GCCs) are obtained using the Problem Table Algorithm (PTA). The heat exchanger area depends, besides others, on the heat transfer coefficients. However, the GCC segments generally represent several streams. To be able to determine the area of heat exchangers without resorting to detailed HEN design, a representative heat transfer coefficient should be selected. The aim of the current method is to set the lower bound of the heat exchange area required. According to this, a representative stream with the highest heat transfer coefficient should be selected. By this selection the lower bound is ensured – the heat exchanger area of any network cannot be smaller.

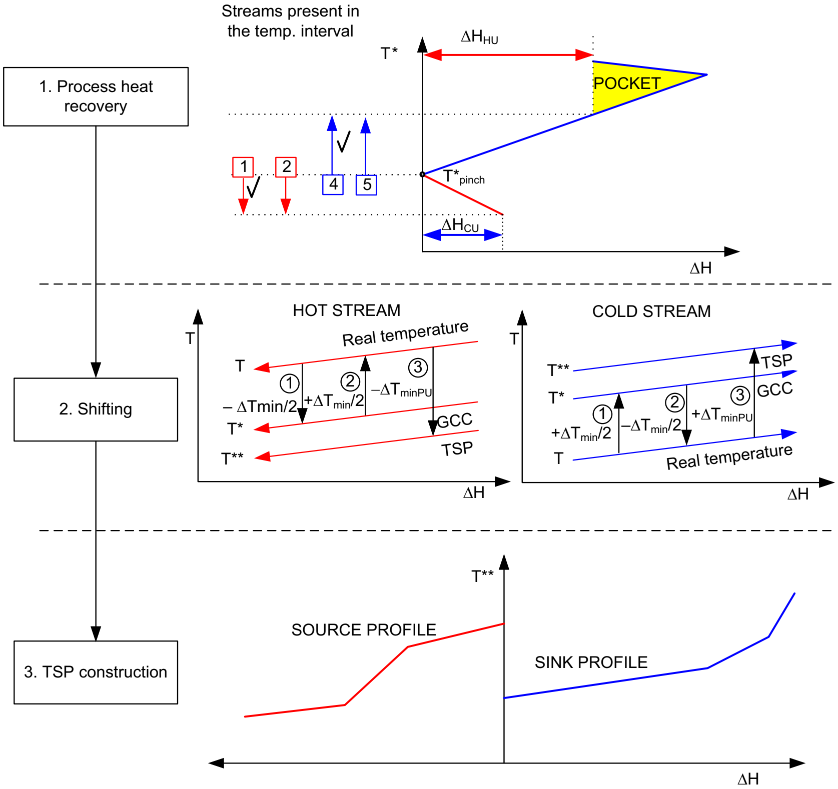


Figure 2: Constructing TSPs

Step 2. Shifting (Figure 2). In this step the segments identified at the previous step are shifted using the procedure by Varbanov et al. (2012), using individual ΔT_{min} specifications for heat exchange between process streams as well as between process streams and utility – for each of the site processes. Two shifts are performed for each GCC segment: (i) Back to the process stream real temperatures and after (ii) Forward by ΔT_{minPU}, which is the minimum temperature difference required for a feasible heat exchange between process streams and the utility.

Step 3. TSP construction (Figure 2). The GCC heat source segments are combined on the left hand side of the Y–axis. The heat sink segments are combined on the right hand side of the Y-axis. The construction of each profile (heat sources and sinks) is performed using the technique for building process CC, but in this case using the segments extracted from the GCC for each process.
As a result, the constructed plot consists of two parts. On the left-hand side is the Heat Source Profile and on the right-hand part is the Sink Profile. In this way the problem is partitioned into utility generation (Site Source Composite Curve) and utility use (Site Sink Composite Curve). Heat recovery can be performed through intermediate utilities/media (Figure 3).The Site Utility Composite Curves are constructed to evaluate the maximum site heat recovery. The Enthalpy Intervals (EIs) are identified, as illustrated in Figure 3, by selecting the enthalpies corresponding to the changes in the slopes of the Site Profiles and the Site Composite Curves.

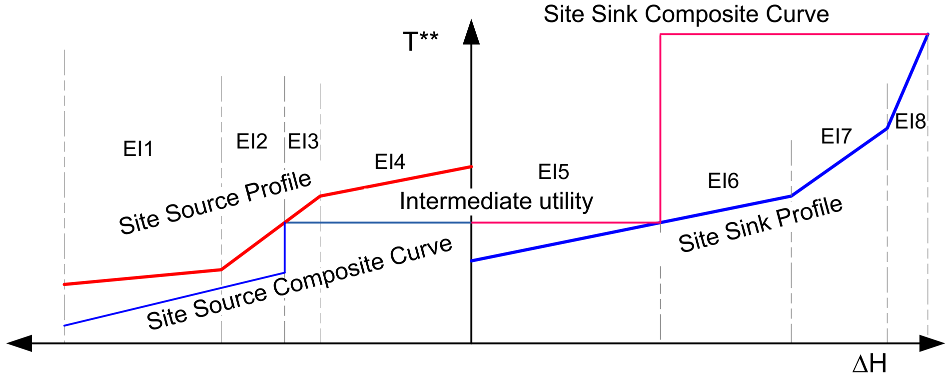
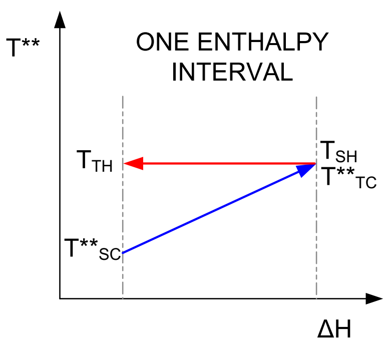


Figure 3: TSP with EI

The heat exchange areas are determined in each EI separately using the general equation for heat transfer area evaluation (Figure 4). In the TSP plot, the utilities are represented at their real temperatures while the Site Profiles are at temperatures shifted by whole ΔT_{minPU} with respect to the initial process streams.



$$A = \frac{Q}{U \cdot \Delta T_{LM}}$$

$$\frac{1}{U} = \frac{1}{h_U} + \frac{1}{h_{PR}}$$

$$\Delta T_{LM} = \frac{(T_{SH} - T_{TC}) - (T_{TH} - T_{SC})}{\ln\frac{(T_{SH} - T_{TC})}{(T_{TH} - T_{SC})}}$$

Figure 4: Determining the heat transfer area in one EI

When the profiles for the process heat source and the hot water generation in Figure 4 touch each other they still have sufficient temperature difference equal to ΔT_{min}. When determining the heat exchanger area the temperatures of the process stream should be shifted back to their real temperatures. To determine the overall area for heat transfer between utility and process stream the areas from each EIs are summed up.

3. Case study

The input data for the case study are listed in Table 1. They are considered two processes A and B.

Table 1: Input data for case study

Process	Stream	Supply temperature °C	Target temperature °C	CP MW/°C	ΔH MW	Type of medium	H W/(m^2 °C)
Process A	A1, cold	50	110	0.05	3.0	Liquid	800
	A2, hot	100	30	0.06	4.2	Liquid	800
	A3, cold	100	140	0.02	0.8	Gas	350
Process B	B1, hot	190	120	0.06	4.2	Gas	350
	B2, cold	100	240	0.04	5.6	Gas	350
	B3, hot	80	60	0.02	0.4	Liquid	800

They are three utilities available: cooling water with the input 30 °C and output 20 °C, h (water) = 800 W/(m^2 °C). The intermediate utility is steam at 120 °C, h (intermediate utility) = 10,000 W/(m^2 °C) and the utility with the highest temperature is available at 250 °C, h (steam) = 11,000 W/(m^2 °C).

3.1 Results

The GCCs of the processes and the TSPs are shown in Figure 5. The next step is to determine the area of heat exchangers between utility and process streams by constructing the TSPs (Figure 5).

Table 2: Calculation of the heat exchanger area

Enthalpy Interval	Hot stream	Cold stream	Q MW	U W/(m^2 °C)	ΔT_{LM} °C	A m^2
EI1	A2	CW	1.8	400	19.3	233.2
EI2	A2+B3*	CW	0.6	400	41.3	36.3
EI3	A2	CW	2.0	400	59.9	8.4
EI4	B1	IU	1.0	338.2	39.9	74.1
EI5	IU	A1	0.5	740.7	24.7	27.4
EI6	IU	A1	0.5	740.7	16.2	41.8
EI7	ST	A1	0.2	745.8	141.4	1.9
EI8	ST	A3	0.06	339.2	124.4	1.4
EI9	ST	B3	24	339.2	30.8	229.5
					TOTAL	**653.8**

**Both streams A2 and B3 media are liquid and as a consequence the overall heat transfer coefficients are assumed equal, and in the area calculation it is not important which one is the representative stream.*

From Table 2 is visible that by heat recovery 1 MW occurring in EI4, EI5 and EI6 (Figure 5) can be recovered through the intermediate utility. Required heat transfer area is143.3 m^2. This is determined by summation of areas required in those EIs. If the intermediate steam level (at 120 °C) is removed then the same part of the profiles would require larger heat transfer area amounting to 171.6 m^2.

By applying the heat recovery via the intermediate steam level both the utility targets and the capital cost targets are reduced.

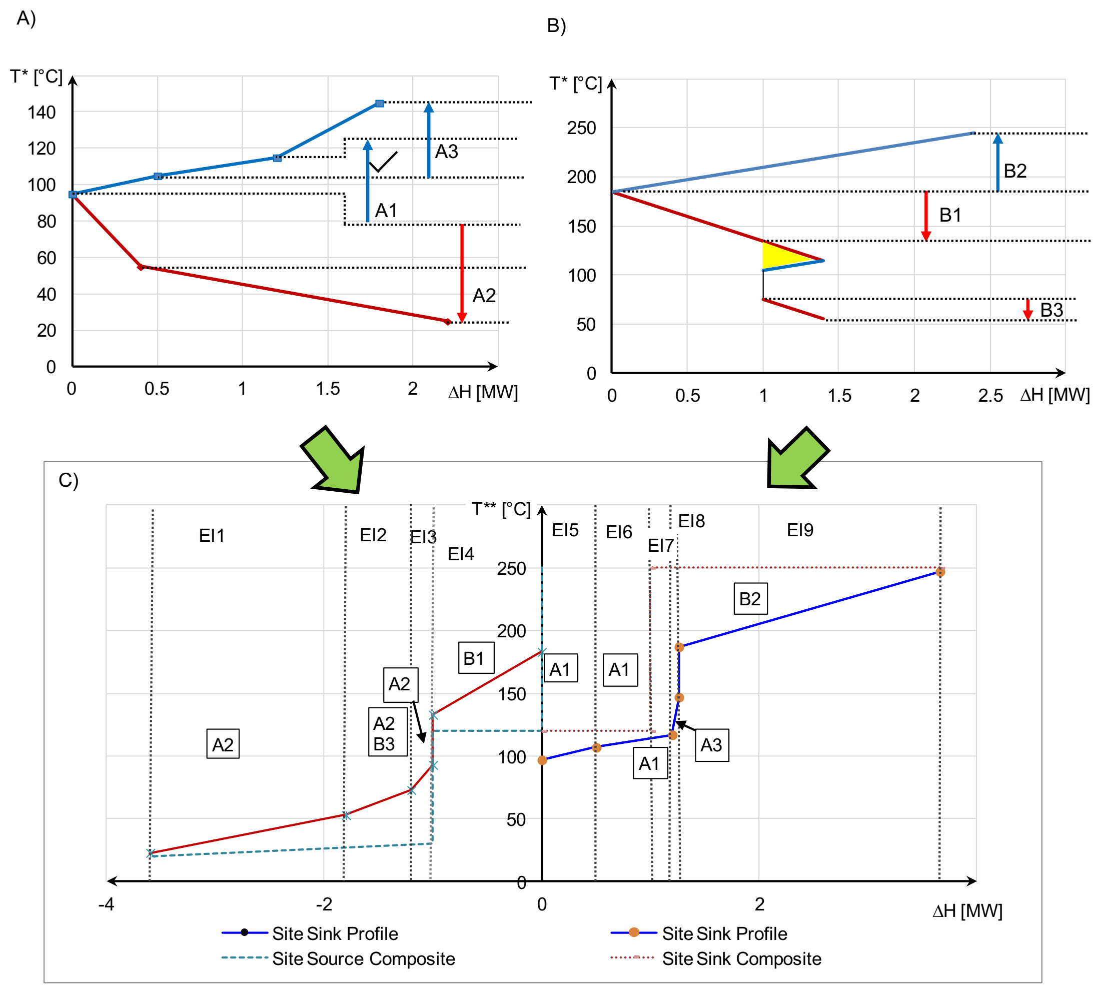


Figure 5: GCC of A) Process A and B) Process B and the c) TSPs

4. Conclusions

A procedure for evaluating the lower bound of the heat transfer area for a heat exchange between utility and process streams on a Total Sites has been developed and demonstrated. This methodology enables a preliminary analysis of the trade-off between the amount of recovered heat and the needed investment cost. In the case study presented 1 MW of heat can be recovered through the central utility system for which 143.3 m^2 heat exchanger area is required. In comparison if just a high pressure steam and cooling water are used the heat exchanger area is increased by 28.3 m^2. It indicates that the additional investment can be economically viable.

The developed model and the obtained results lay out the ground for a procedure evaluating the capital cost targets for all heat transfer units on a Total Site in a future work – also including the heat recovery at the process level. Based on this, the fundamental capital energy trade-off can be evaluated and an optimisation of the minimum allowed temperature difference specifications for whole Total Sites can be performed.

Acknowledgement

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Nomenclature

ΔT_{min}	minimal temperature difference between two process streams, °C
ΔT_{minPU}	minimal temperature difference between process stream and utility, °C
EI	enthalpy interval, MW
PTA	Problem Table Algorithm
CP	heat capacity flowrate, MW/°C
A	area of heat exchanger, m^2
ΔT_{LM}	Logarithmic mean temperature, °C
Q	heat, MW
Q_k	heat exchanged in enthalpy interval k, MW
h	heat transfer coefficient, W/(m^2 °C)
h_U	heat transfer coefficient of the utility stream, W/(m^2 °C)
h_{jPR}	heat transfer coefficient of process stream, W/(m^2 °C)
ΔH	enthalpy, MW
T	temperature, °C
T*	shifted temperature, °C
T**	twice shifted temperature, °C
U	overall heat transfer coefficient, W/(m^2 °C)

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