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Total Site Targeting Accounting for Individual Process Heat Transfer Characteristics

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This contribution presents an extended approach to Total Site targeting. Total Site integration offers the opportunity of maximising energy recovery between processes by reducing unnecessary fuel consumption and greenhouse gas emissions. Despite the methodology developments, how to deal with the minimum temperature differences is still an open question. This includes the overall selection of the ΔT_{min} values for Total Site Utility systems and how ΔT_{min} affects the design of the heat recovery networks of the individual processes. Specifying a single uniform ΔT_{min} for all processes integrated in the Total Site is not always optimum and could be too simplistic. This can lead to the underestimation of the overall site-wide heat recovery targets. The procedure proposed in this paper allows for estimating the heat recovery potential of Total Sites, which is closer to the reality. It is illustrated by a demonstration case study.

1. Introduction

In most cases heat recovery between various site processes is performed by indirect integration using steam as the energy carrier. The Total Site concept of integrating site process energy demands, and specifically heat demands was introduced by Dhole and Linnhoff (1993). Klemeš et al. (1997) made further advances in the field by adding targets for power co-generation. More recently the Total Site concept has been further extended by adding residential and service-building processes (hospitals, hotels, offices), low-grade industrial heat, waste to heat, and renewables (Perry et al., 2008) as well as integrating renewables with varying availability (Varbanov and Klemeš, 2010). This indicated that significant further energy savings can be achieved.

Placing steam levels has affects significantly the site utility demand and its cogeneration potential. Any heat excess in one process after internal recovery may be reused in another via the steam system. To achieve this, each steam pressure level has to allow both the generation and use in sufficient amounts. Any steam raised from process cooling should be utilized as much as possible to maximize the site-wide heat recovery.

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2. Heat recovery through utility systems

The Total Site Integration of energy systems, based on the concept of the site heat source and heat sink profiles, was first introduced by Dhole and Linnhoff (1993). The method allows a target to be set for the total site heat recovery. Data for process heat recovery are converted to Grand Composite Curves (GCCs). The pockets of the GCCs that represent the scope for process to process heat recovery are removed, if the process to process heat recuperation is carried out in each plant separately. Another option is to allow wider integration amongst processes. However the extra cost should be monitored if the total site is not sufficiently compact. The resulting GCCs are combined to form a Site Heat Source Profile and Site Seat Sink Profile. From the resulting plots, the Total Site Composite Curves are constructed, using the temperatures of the steam levels, as well as the hot water and cooling water utilities.

3. Problem statement

Transferring and recovering heat requires heat exchangers of reasonable size. This is ensured by keeping the temperature differences between the hot and the cold streams in each heat exchanger (Towler and Sinnott, 2008) larger than the specified ΔT_{min}. The previous studies on Total Site Integration assumed (Dhole and Linnhoff, 1993; Hui and Ahmad, 1994; Klemeš et al., 1997) that the ΔT_{min} for the integrated processes and for exchanging heat with the utilities are the same. This is can be rather limiting for real problems. Some important limitations are:

- Processes with different heat transfer characteristics require differing values for process to process heat exchange. E.g. ΔT_{min} values for 2007 prices (Towler and Sinnott, 2008) were 10 to 30 °C for refinery and chemical processes, 50 to 80 °C for furnaces, and 3 to 5 °C for plate-fin heat exchangers in the food industry. For heat exchange between the processes and the utilities the ΔT_{min} can be rather different.
- If different types of plants are integrated on a site as e.g. oil refinery, food processing plant, brewery, hospital, football ground and stadium, rather different ΔT_{min} values could be the optimum for each plant.

Introducing individual ΔT_{min} values may provide more realistic evaluation of the capital-energy trade-offs since the complete heat recovery potential of the considered site would be revealed.

4. Novel total site methodology for flexible ΔT_{min}

Transferring To tackle the above limitations, a novel methodology for constructing the Total Site Profiles (TSP) is proposed. Compared with the original methodology, there are changes in the TSP construction, using different ΔT_{min} values for heat exchange within each process and also between each process and utilities. The procedure is as follows:

Step 1: Parameter specification. For each process an individual ΔT_{min} is specified for heat exchange between the process streams **Error! Reference source not found.**(Figure 1). Separate ΔT_{min} values are specified for heat transfer from the hot utilities to the processes and from the processes to the cold utilities.

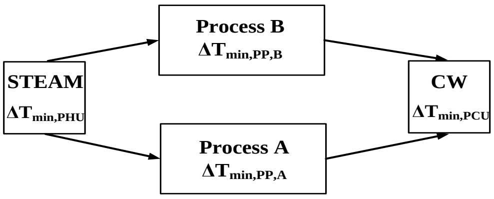


Figure 1: ΔTmin Values accounting for different heat transfer types

Step 2: Pinch Analysis of the processes. For each site process, the heat recovery targets are obtained using Pinch Analysis (Linnhoff and Hindmarsh, 1983). The required results are the Grand Composite Curve (GCC), the Pinch location and the overall minimum utility heating and minimum utility cooling demands of each process.

Step 3: Extraction of the heat source and heat sink segments from the GCCs for all processes. This is performed in the same way as in the original methodology (Klemeš et al., 1997). It is assumed that the GCC pockets are removed before the heat source and sink segments are extracted.

Step 4: Shift the extracted segments to the temperature scale of the utilities. This is an aggregated step, implementing the novel idea of applying individual ΔT_{min} values to different heat exchange types. First the GCC segments are shifted back to the scale of the real stream temperatures by $\Delta T_{min,PP}/2$ and then they are shifted forward by the corresponding ΔT_{min} values for heat exchange, with the relevant utilities to the temperature scale of the utilities T^{**}. Similarly to the original methodology the heat source segments are shifted to be colder and heat sink segments are shifted to be hotter.

Step 5: Combination of the shifted heat source segments into a **Heat Source Profile** and of the shifted heat sink segments into a **Heat Sink Profile**. This step is performed in a way similar to the construction of a Composite Curve.

Step 6: Identification of the utility use and generation. Because of the shifting, the resulting temperature scale is that of the real utilities, so the utility identification is similar to the original methodology.

5. Case study

The described procedure is illustrated on a case study. The considered site consists of two processes – A and B. Initially, applying the original procedure, the same ΔT_{min} = 20°C is used for both processes and their interaction with the utilities. In the second analysis, individual ΔT_{min} values are used for process to process heat exchange: $\Delta T_{min,PP,A}$ = 20 °C, $\Delta T_{min,PP,B}$ = 10 °C, and for both processes heat exchange with utilities $\Delta T_{min,PHU}$= $\Delta T_{min,PCU}$= 5 °C. The extracted hot and cold process streams from the process data are shown in Table 1. They are common for both analyses.

Table 1 Data for process A and process B

Process Stream	Temperature [°C]		CP [kW/°C]
	Supply	Target	
A1	30	210	6.5
A2	150	35	1.5
B1	140	180	1.3
B2	50	220	1.5
B3	140	80	7
B4	200	110	4

The GCC for process A is the same for both the original and the novel methodology and it is shown in Figure 2. The GCCs for process B resulting from the original methodology and from the novel methodology are presented in Figure 3. In the figures the minimum hot and cold utility requirements are given. Following the original methodology, the heat source segments are extracted in Figure 4 for processes A and B to construct the Heat Source Profiles. In the figure, all heat source segments, intersecting each temperature interval, are lumped together by summing up their CP values. After that, the heat duty (ΔH_i) in each interval is obtained by multiplying the CP sums by the interval temperature differences (T^{**}_{start}–T^{**}_{end}). The same procedure is applied to combine the sink segments and construct the Heat Sink Profiles.

For the novel flexible ΔT_{min} the source segments are obtained applying the calculation procedure described in section 4. In figure 5 are shown the resulting heat sources.

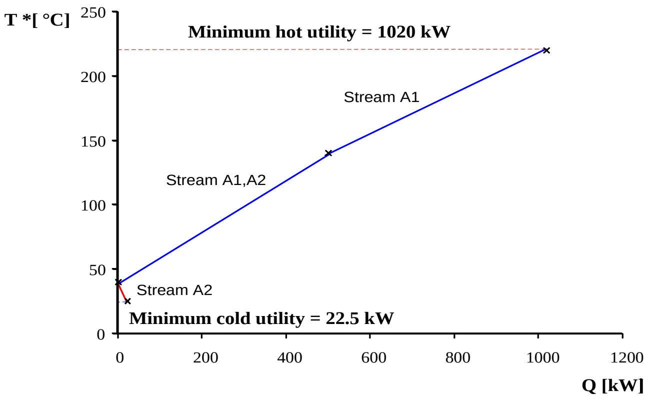


Figure 2: GCC for process A following both methodologies

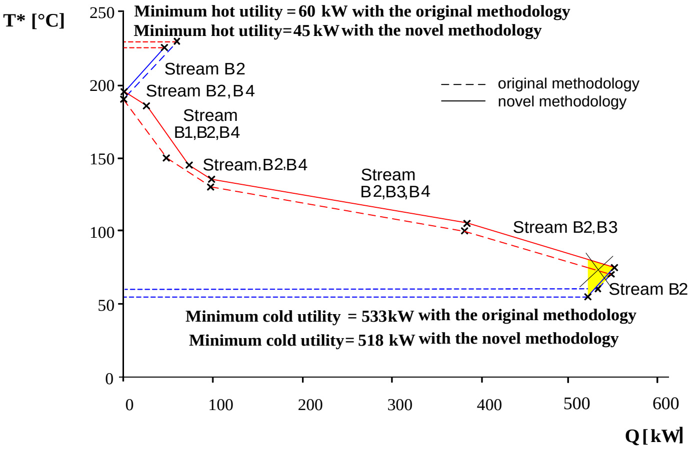
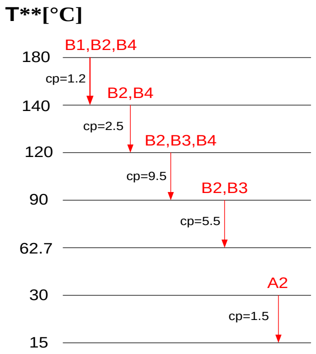
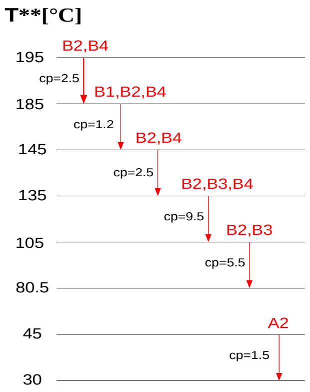


Figure 3: GCC for process B following the original and novel methodology



Source Interval	T^{**}_{start}	T^{**}_{end}	∑CP	ΔH_i
1	180	140	1.2	48
2	140	120	2.5	50
3	120	90	9.5	285
4	90	62,7	5.5	150.15
5	62,7	30	0	0
6	30	15	1.5	22.5

Figure 4: Heat Source Profile Composition for Process A and B with original methodology



Source Interval	T^{**}_{start}	T^{**}_{end}	∑cp	ΔH_i
1	195	185	2.5	25
2	185	145	1.2	48
3	145	135	2.5	25
4	135	105	9.5	285
5	105	80.5	5.5	135
6	80.5	45	0	0
7	45	30	1.5	22.5

Figure 5: Heat Source Profile Composition for Process A and B with novel flexible ΔT_{min} methodology

Further, the Total Site Profiles are constructed together the utility generation and use. The plot for the original methodology is shown in Figure 6 and the plot for the novel methodology – in Figure 7.

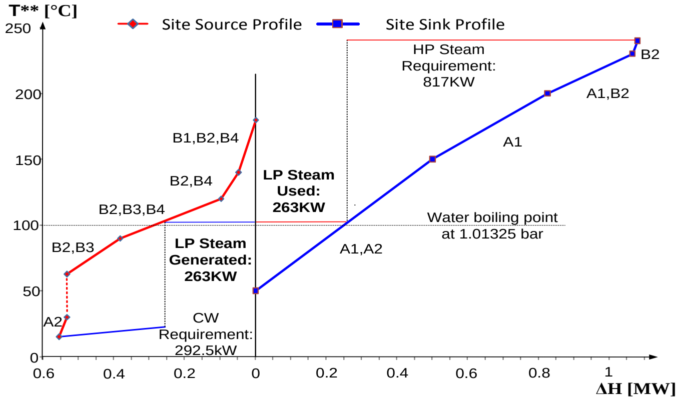


Figure 6: Total Site Profile for the original methodology

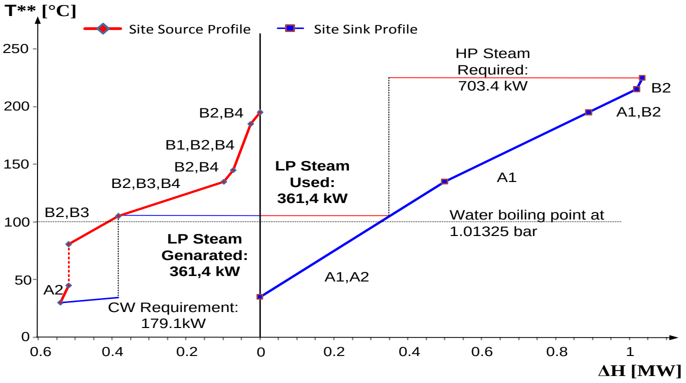


Figure 7: Total Site Profile for novel flexible ΔT_{min} *methodology*

6. Conclusions

The presented work is a step toward developing a novel procedure for evaluating the Total Site targets for heat recovery accounting for the individual heat transfer properties inside the various processes, as well as between the processes and the heating/cooling utilities. The main point of the novel procedure comes from the realisation, that the temperature shifting in the original methodology positions the source and sink profiles exactly on the temperature scale of the utilities. The novel procedure uses the same principle, but allows flexible specifications of individual ΔT_{min} values. This procedure has been illustrated with a case study and the comparison of the results between the original and the novel methodology shows potential for improvement of the heat LP steam recovery by about 37%. The HP steam demand decreases by 14% and the cooling water by 39%. Allowing the flexible specification of ΔT_{min} values also allows for a more realistic estimate of the site-wide energy recovery by revealing the full site heat recovery potential.

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