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Total Site Targeting with Stream Specific Minimum Temperature Difference

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The paper focuses on extending traditional Total Site Integration methodology to produce more meaningful utility and heat recovery targets for the process design. The traditional methodology leads to inadequate results due to inaccurate estimation of the overall Total Site heat recovery targets. The new methodology is a further development of a recently extended traditional pinch methodology. The previous extension was on the introduction of using an individual minimum temperature difference (ΔT_{min}) for different processes so that the ΔT_{min} is more representative of the specific process. Further this paper deals with stream specific ΔT_{min} inside each process by setting different ΔT contribution (ΔT_{cont}) and also using different ΔT_{cont} between the process streams and the utility systems. The paper describes the further extended methodology called stream specific targeting methodology. A case study applying data from a real diary factory is used to show the differences between the traditional, process specific and stream specific total site targeting methodologies. The extended methodology gives more meaningful results at the end of the targeting with this avoiding the over or under estimated heat exchanger areas in the process design.

1. Introduction

Traditional pinch analysis (Linnhoff et al., 1983) can be used to set the minimum utility targets, to inform thermo-economic analysis of potential recovery and process integration, and to identify heat exchanger network design and synthesis opportunities. Total Site analysis can be conducted to establish the overall energy targets for a site (Klemeš et al., 2010). The targets generated from the traditional total site approach can be misleading because it assumes that the whole site operates with the same minimum allowed temperature difference (ΔT_{min}) for both direct and indirect integration. The traditional pinch methodology assumes the same values for ΔT_{min} also inside the process and between different sites through the utility system.

The paper deals with an extension of Total Site Integration producing more meaningful utility and heat recovery targets. A single global ΔT_{min} for all processes cannot be generally optimal as it is far from realistic and may lead to inadequate results due to inaccurate estimation of the overall Total Site heat recovery targets. Currently the extended methodology was defined individual ΔT_{min} for the different process (Fodor et al., 2011, 2012) for direct heat integration and heat transfer between processes to utility system for indirect heat integration. The modified Total Site targeting procedure still does not account for the individuality of the streams inside the process, such as its phase. The paper presents a further improved method that assigns a ΔT contribution (ΔT_{cont}) (Sinnott et al., 2005) for each individual stream, which allows for more explicit calculation of the basic energy and heat exchanger area targets.

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Typically a ΔT_{cont} for individual streams is used where it is known that streams have a significantly higher or lower heat transfer coefficient. Non-condensing gaseous streams typically have very poor heat transfer coefficients, which may be one order of magnitude less than liquid streams found in most processes. By including a ΔT_{cont} for relevant streams both energy and heat exchanger area targets become more meaningful, allowing for more accurate economic assessment. An industrial case study is given to illustrate the differences between each methodology. In this particular diary case study the achievable targets with the new methodology are more meaningful providing reliable data for further design on the site heat exchanger and on the whole process.

2. Modified Total Site targeting procedure

The Modified Stream Specific Total Site targeting procedure (Figure 1.) is formulated as follows:
Step 1: Parameter specification. Individual streams, both process and utility streams, are assigned a ΔT_{cont} ($\Delta T_{min}/2$) value based on the characteristics of the stream, e.g. the phase of the stream. Heat transfer between process streams is therefore $\Delta T_{cont,P1} + \Delta T_{cont,P2}$, which is equivalent to the traditional ΔT_{min} concept. Heat exchanger between process streams are similarly, $\Delta T_{cont,P1} + \Delta T_{cont,U1}$.
Step 2: To account for individual stream characteristics, individual ΔT_{cont} values are needed for each stream in the process-level analysis. Individual process hot and cold streams are shifted with the individual stream ΔT_{cont} to construct the GCC:

$$T^* = \begin{cases} \text{sources: } T - \Delta T_{cont,Pi} \\ \text{sinks: } T + \Delta T_{cont,Pj} \end{cases} \tag{1}$$

$\Delta T_{cont,Pi}$: Minimum allowed temperature contribution for process individual hot stream, *i*.
$\Delta T_{cont,Pj}$: Minimum allowed temperature contribution for process individual cold stream, *j*.

Step 3: Process-level Pinch Analysis. Using the ΔT_{cont} shifted temperatures heat recovery targets for each site process are obtained using Pinch Analysis. The results are the Process Heat Cascade, the Grand Composite Curve (GCC), the Pinch location and the overall minimum utility heating and minimum utility cooling demands of each process.
Step 4: Extraction of the heat source and sink segments from the GCC. So-called heat recovery pockets on the GCC are removed from analysis due to the potential for internal process heat recovery.
Step 5: Specification of the utility ΔT_{cont} for each temperature range. The specified ΔT_{cont} is dependent on the type of utility that is available.
Step 6: Shift the extracted GCC segments to the temperature scale of the utilities using the utility process ΔT contribution:

$$T^{**} = \begin{cases} \text{sources: } T^* - \Delta T_{cont,Ui} \\ \text{sinks: } T^* + \Delta T_{cont,Uj} \end{cases} \tag{2}$$

$\Delta T_{cont,Ui}$: Minimum allowed temperature contribution for specific heating utility
$\Delta T_{cont,Uj}$: Minimum allowed temperature contribution for specific cooling utility

Step 7: Total Site Profiles (TSP) composition. Combination of the extracted heat source segments from step 6 into a Heat Source Profile and of the heat sink segments into a Heat Sink Profile.
Step 8: Targeting. Identification of the utility generation and usage. This step is performed in the same way as in the traditional procedure (Dhole et al., 1993, Klemeš et al., 1997). The construction of the Utility Generation Composite Curve starts from the highest-temperature hot utility and moves toward the lowest-temperature, maximising the utility generation at each utility level. Symmetrically, the construction of the Utility Use Composite Curve starts at the coldest hot utility and proceeds to the higher temperatures maximising the utility use at each level.

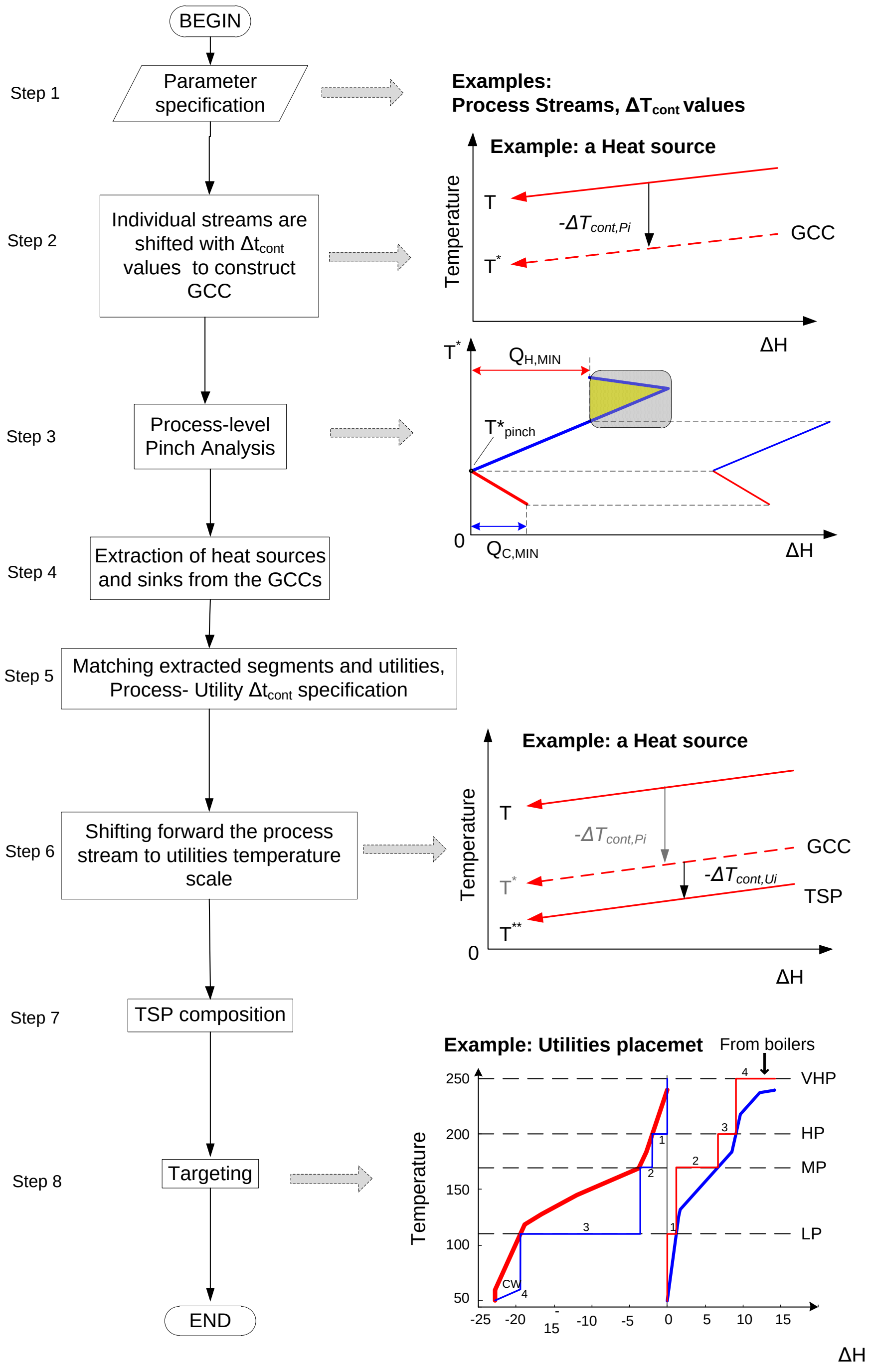

Figure 1. The Modified Stream Specific Total Site targeting procedure

3. Industrial Case Study

The diary factory has a range streams where it is known that some streams have a significantly higher or lower heat transfer coefficient. To represent streams this kind of individuality the ΔT_{cont} is used for the calculation procedure as it was introduced in the modified Total Site targeting procedure section. The case study examines three sites of the whole diary factory, namely the D4, D5 and Casein plants. For each site all the heating and cooling demands data have been extracted from the process and ΔT_{cont} is defined as shown in Table 1, 2, and 3. The ΔT_{cont} is defined empirically from the diary factory (Table 4.). Each of these sites is getting the utilities from the same utility center and all these utility streams have its own ΔT_{cont} according to the different heat transfer coefficient. Table 5 shows the contribution values between the process and utility heat transfer.

Table 1: Heating and cooling demands for D4

Stream Name	Supply Temperature °C	Target Temperature °C	ΔT_{cont} °C	Mass Flowrate °C	Specific Heat Capacity kJ/kg°C
Raw Milk Evap. Feed	10.5	80	2.5	22.3	4
Effect 1 Cow Water	81.3	20.0	2.5	4.0	4.18
Effect 3 Cow Water	68.3	20.0	2.5	2.8	4.18
Effect 4 Cow Water	64.8	20.0	2.5	2.4	4.18
Effect 5 Cow Water	57.5	20.0	2.5	2.0	4.18
Effect 6 Cow Water	58.8	20.0	2.5	1.6	4.18
Effect 7 Cow Vapour	55.8	54.8	1	1.3	2368.05
Effect 7 Cow Water	55.8	20.0	2.5	1.3	4.18
Concentrate Heater	48.8	83.5	2.5	4.6	3.10
Main Air Heater Inlet	40.0	209.5	12.5	39.6	1.02
SFB Air Heater Inlet	40.0	98.5	12.5	16.3	1.02
VF1 Air Inlet	40.0	59.3	12.5	3.1	1.02
VF2 Air Inlet	40.0	67.0	12.5	3.8	1.02
VF3 Air Inlet (Dehmid)	40.0	20.3	12.5	3.0	1.02
VF3 Air Inlet	20.3	46.0	12.5	3.0	1.02
Cyclone Recovery Air Inlet	60.0	90.0	12.5	6.0	1.11
Main Air Exhaust	68.0	25.0	12.5	58.5	1.11
VF Air Exhaust	68.0	25.0	12.5	9.9	1.06

After making the calculation following the stream specific calculation procedure, the case study was also calculated according to the traditional and process specific methodologies. For the traditional case a global ΔT_{min} and for the extended calculation a process specific ΔT_{min} was chosen. Table 6 shows the results of the total site hot and cold utility requirements using the different method. In all cases the more hot and cold utility is needed for the traditional case and the less for the stream specific one.

Table 2. Heating and cooling demands for D5

Stream Name	Supply Temperature °C	Target Temperature °C	ΔT_{cont} °C	Mass Flowrate °C	Specific Heat Capacity kJ/kg°C
Raw Milk Evap Feed	10.0	75.0	2.5	70.0	4.00
Cow Water	64.0	20.0	2.5	58.8	4.18
TVR Condenser	54.0	53.0	1	1.0	2388.20
Concentrate Heater	54.0	65.0	2.5	12.1	3.10
Main Air Heater Inlet	25.0	200.0	12.5	117.0	1.02
Well Mixed Air Inlet	25.0	50.0	12.5	10.0	1.02
VF1 Air Inlet	25.0	45.0	12.5	14.6	1.02
VF2 Air Inlet	25.0	32.0	12.5	11.0	1.02
Main Air Exhaust	75.0	20.0	12.5	159.0	1.10
Site Hot Water	15.0	55.0	2.5	30.0	4.18

Table 3. Heating and cooling demands for Casein

Stream Name	Supply Temperature °C	Target Temperature °C	ΔT_{cont} °C	Mass Flowrate °C	Specific Heat Capacity kJ/kg°C
Whey	80.0	9.0	1.5	25.7	4.08
Cow Wash	83.0	45.0	2.5	11.1	4.18
Cow Water	35.0	30.0	2.5	11.1	4.18
Skim Milk	53.0	34.0	2.5	3.0	3.94
Wash Water	45.0	40.0	2.5	12.8	4.18
Whey	40.0	80.0	1.5	25.7	4.08
Cow Water	35.0	30.0	2.5	11.1	4.18

Table 4. ΔT_{cont} specification according to different heat exchangers inside the process

	Gas ΔT_{cont} (12.5)	Liquid ΔT_{cont} (2.5)	Vapour ΔT_{cont} (1.0)
Gas ΔT_{cont} (12.5)	25	15	13.5
Liquid ΔT_{cont} (2.5)	15	5	3.5
Vapour ΔT_{cont} (1.0)	13.5	3.5	2

Table 5. ΔT_{cont} matrix for the case study, all values in °C

Utility	Type	Temperature range[°C]	Process to Utility - ΔT_{cont}
HP Steam	Hot	250-160	1
LP Steam	Hot	160-100	1
HW	Hot	<100	2.5
Cooling Towel Water	Cold	>25	2.5
Chilled Water	Cold	25-3	1.5

Table 6. Processes utility requirements - comparison

Process	$\Delta T_{min,PP}$, °C			Minimum Hot Utility, MW			Minimum Cold Utility, MW		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
D4	20	15	Table 1	10.9	10.2	10.1	5.9	5.8	5.2
D5	20	15	Table 2	33.8	31.6	23.3	11.3	9.2	0.9
Casein	20	10	Table 3	3.3	2.8	0.5	6.8	6.1	3.8
Total				**48.0**	**44.6**	**33.9**	**24.0**	**21.1**	**9.9**

Legend: (a) Traditional procedure; (b) Process specific procedure; (c) Stream specific procedure

4. Conclusion

The paper demonstrates using an industrial case study the implementation of a total site methodology using a stream specific ΔT_{cont} approach. The procedure allows making differences between heat transfer in the process streams inside the process and between process to utility and vise versa. The study also makes comparison with the traditional targeting and with the recently developed extended methodology. The aim of the calculation was to show the different calculation procedure gives different utility requirements with it over or under estimated size for the heat exchanger area in the process design. Following the stream specific calculation steps the target will be more meaningful and closer to a practical network.

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