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Process Modification for Capital Cost Reduction in Total Site Heat Integration

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The TSHI (Total Site Heat Integration) methodology is extended in this paper to manipulate the Total Site Profiles (TSP) towards further decreasing the heat transfer area (HTA), and consequently the capital cost, of heat transfer units. In the first case study, the application of Keep Hot Stream Hot (KHSH) and Keep Cold Stream Cold (KCSC) on TSP reduces the heating and cooling duties resulting in a reduction of 8 % in heat transfer area (HTA) and a saving of 8 % in heat exchangers cost. In the second case study, when KHSH/KCSC principles is applied on the selected segment of the TSP while maintaining the enthalpy constant, the TSP shape is changed to provide a larger temperature driving force, this together with the reduced heating and cooling loads, reduce the HTA by 11 % and the heat exchangers cost by 12%. Process modifications to achieve the desired shape of TSP may be limited by technical feasibilities or economic reasons. However, the potential for the feasible/profitable modifications of the TSP shapes is worth to be analysed and studied as they can be enhanced by exploring the potentials to integrate neighbouring units such as services, businesses residential and even agricultural units, i.e. the locally integrated energy sector (LIES), a concept introduced by Perry et al (2008).

1. Introduction

Process modification strategies to improve Heat Integration based on the shapes of Composite Curves (CC) have been introduced in the 1980's by Linnhoff and Vredeveld (1984). These are such as the Plus-Minus principles, Keep Hot Stream Hot (KHSH) and Keep Cold Stream Cold (KCSC), appropriate placement of utilities, etc. The Plus-Minus Principles for process modifications to increase the heat recovery and the energy targets of individual processes have been already implemented (Klemeš et al, 2010). Nemet et al. (2012a) used the Plus-Minus principles for Total Site (TS) developing the strategies for the extension planning for an existing site. Process modification approach had been recently revisited and applied to TS to target the TS processes modifications to further improve TSHI (Chew et al, 2013).
Heat transfer area targeting for Heat Exchanger Network (HEN) for single process has first been introduced in the 1980's by Townsend and Linnhoff (1984). Since then many researchers have worked on optimisation of heat transfer area and energy targets for single process mainly employing mathematical programming techniques. Nemet et al. (2012b) introduced the procedure to determine the heat transfer area for TS with single intermediate utility. Boldyryev et al. (2014) extended the methodology to include the use of more than one intermediate utilities.
Similar to the use of Composite Curve (CC) for single process, the Total Site Profiles (TSP) can be used to improve HI on a TS. In the presented work, an approach to identify the targeted change in TSP shapes that can reduce the heat transfer area and consequently the cost of heat exchangers at TSHI by the use of KHSH and KCSC Principles is proposed.

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2. Application of KHSH and KCSC Principles on TSHI

The Pinch based TS analysis uses the selected streams' data to produce the Grand Composite Curve (GCC) for each process. The process GCC shows the heat deficit and surplus above and below the Pinch respectively. The heat surplus from each process are combined to produce the Site Source Profile (SS_oP) and the heat deficits combined to generate the Site Sink Profile (SS_iP) in the TSP plot (Klemeš et al. 1997). From the TSP, potential section/s on SS_oP and SS_iP for application of KHSH and KCSC principles can be identified.

The principles of KHSH and KCSC are as simple as the acronyms, i.e. maximise the hot stream supply and/or target temperatures and minimise the cold stream supply and/or cold supply and target temperatures. The application KHSH and KCSC principles on single process to reduce energy targets and/or capital cost saving by increasing the temperature driving forces is well explained e.g. in Kemp (2007) and illustrated (Klemeš et al. 2010). The KHSH and KCSC principles can also be extended to TSP as illustrated in Figure 1 and summarised in Table 1 below, to reduce the heat transfer area (HTA) required by either reducing the heating/cooling loads or increasing the temperature driving force.

The scope of feasible process modifications are assessed using the Pinch techniques for single process, for e.g. by exploiting and optimising process soft data.

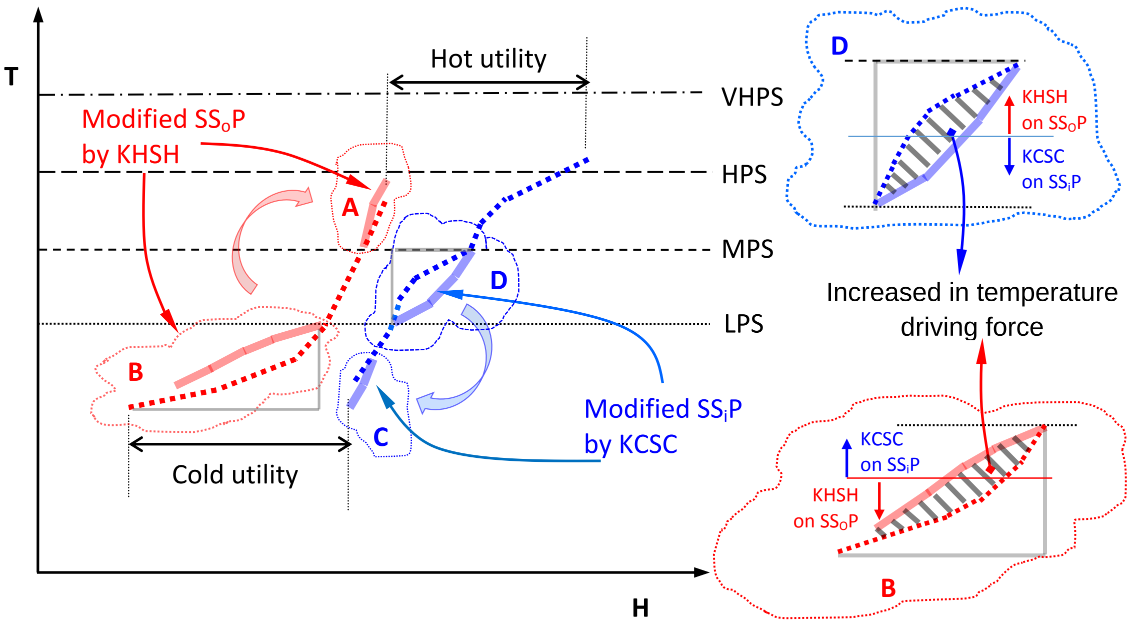

Figure 1: Analogy of the KHSH and KCSC principles to change the shape of the SS_iP and SS_oP of TSP

Table 1: Application of KHSH and KCSC on TS

	Section (Figure 1)	Application of KHSH & KCSC	Contribution to Reduction in HTA: Due to ↓ ΔH	Contribution to Reduction in HTA: Due to ↓ LMTD
KHSH on SS_oP	A	Raise the maximum SS_oP temperature (i.e. the highest process Pinch on site).	Yes	Insignificant
	B	Maximise the temperatures of streams contributing towards the SS_oP	Yes	Yes (1)
KCSC on SS_iP	C	Lower the minimum SS_iP temperature (i.e. the lowest process Pinch on site)	Yes	Insignificant
	D	Minimise the temperatures of the streams contributing towards the SS_iP	Yes	Yes (2)

Note:
1. Apply KCSC on the lower temperature intervals to reduce the slope of the SS_iP and apply KHSH on the higher temperature intervals to increase the slope of the SS_oP.
2. Apply KHSH on the lower temperature intervals to increase the slope of the SS_oP and apply KCSC on the higher temperature intervals to reduce the slope of the SS_iP.

The heat transfer area (HTA) required for heat recovery between the site Source and Sink using intermediate utilities is estimated using the well-known equation:

$$A = \Delta H / (U \times LMTD) \qquad (1)$$

Where, ΔH is the enthalpy, U, the overall heat transfer coefficient and LMTD the log mean temperature difference.

The heat exchanger area required can be reduced by either increasing LMTD or reducing ΔH. LMTD is a function of the streams' temperature which ΔH depends both streams' temperature and heat capacity. The values of U depend on several factors such as type of heat exchanger, fluid type and characteristics, fouling factors, etc.
The capital cost evaluation is based on the heat exchanger purchased cost which is a direct function of A. The cost is estimated using cost correlations for shell and tube heat exchangers which also consider material type and operating pressure (Seider et al, 2010).

3. Case Studies

In this illustration, the TS has three processes: A, B and C. Figure 2, an expanded version of TS-PTA for the site Sink and Source provided a summary of the input data and TS analysis. The utilities on site are the very high pressure steam (VHPS), high pressure steam (HPS), medium pressure steam (MPS), low pressure steam (LPS) and cooling water (CW). The ΔT_{min} between process and process is 20 ºC and the ΔT_{min} between process and utilities is 15 ºC. Typical U values of 100 W/m^{2}ºC and 300 W/m^{2}ºC are used for the process/steam and process/cooling water heat exchangers.

SINK

			PROCESS A				PROCESS B				PROCESS C				Sum of Process		Culmulative	
Stream CP MW/°C				0.227	0.08	0.225		0.1	0.133	0.086		0.05	0.04	0.074				
Stream				C1	C2	C3		C1	C2	C3		C1	C2	C3	CP	DH	DH	Pinch
T** °C	T* °C	DT °C	CP MW/°C				CP MW/°C				CP MW/°C				MW/°C	MW	MW	
95	90														0	0	0	A at 235°C
135	130	40									0.04				0.04	1.60	1.60	
160	155	25									0.016				0.02	0.40	2.00	B at 155°C
180	175	20					0.01				0.09				0.10	2.00	4.00	
200	195	20					0.2				0.05				0.25	5.00	9.00	
230	225	30					0.067								0.07	2.01	11.01	C at 90°C
240	235	10					0.1								0.10	1.00	12.01	
262	257	22	0.227												0.23	4.99	17.00	

SOURCE

			PROCESS A				PROCESS B				PROCESS C				Sum of Process		Culmulative	
Stream CP MW/°C				0.264	0.072			0.033	0.19	0.046		0.074	0.574					
Stream				H1	H2			H1	H2	H3		H1	H2		CP	DH	DH	Pinch
T** °C	T* °C	DT °C	CP MW/°C								CP MW/°C				MW/°C	MW	MW	
230	235														0	0	0	A at 235°C
175	180	55	0.037												0.04	2.04	2.04	
150	155	25	0.029												0.03	0.73	2.76	B at 155°C
120	125	30	0.031				0.017								0.05	1.44	4.20	
100	105	20					0.15								0.15	3.00	7.20	C at 90°C
85	90	15					0.236								0.24	3.54	10.74	
75	80	10									0.5				0.50	5.00	15.74	

Temp. range of interest for Case 2

Case 1 ↑ H1 supply temp.

Figure 2: Expanded TS-PTA

In the first case study, Case 1, the KHSH principle is applied on stream H1 of Process A which has the highest Pinch location (refer Section A of Figure 1 and Table 1). Suppose process modification is possible to enable the supply and target temperatures of stream H1 to be raised by 5 ºC from 135-245 ºC to 140-250 ºC. The resulted changes on TSP are shown in Figure 3. The maximum SS_oP temperature increases by 5 ºC as expected but the slope of SS_oP above 200 ºC remains the same. Below 150 ºC, the SS_oP is displaced as a hotter H1 reduces both the heating and cooling loads in the similar way as expected with the application of Plus-Minus Principles.

The heating and cooling loads reduced by 0.93 MW each. As a result. the HTA reduced by 526 m^2, or 8 % of Base Case HTA. The KHSH principle on SS_oP does not increase the temperature driving force, evident from the minimal change in the slopes of both SS_oP and SS_iP. The overall saving in HTA purchased cost is about 138,000 USD or 8 % of the Base Case.

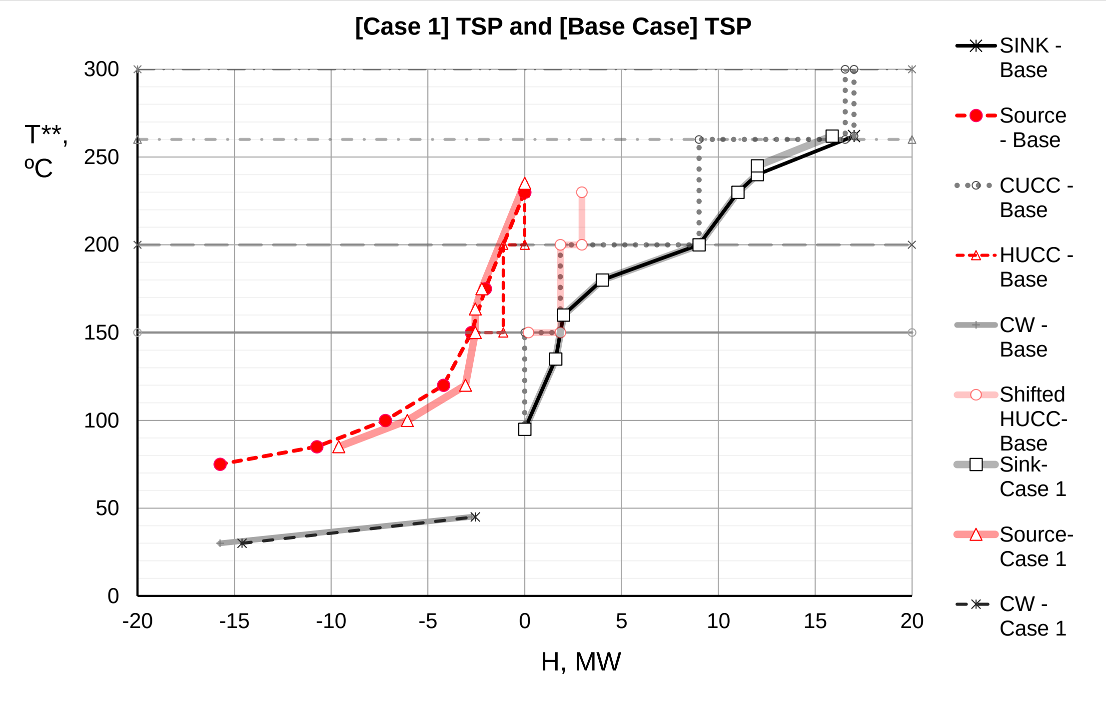

Figure 3: Changed TSP with application of KHSH as in Case 1

Table 3: Summary of results

Case		Base	1	[Base] – [1]	2	[Base] – [2]
Utilities						
Heating	MW	14.24	13.31	0.93	13.03	1.21
Cooling	MW	12.98	12.05	0.93	11.08	1.90
HTA						
Sink	m^2	5,648	5,298	350	4917	731
Source	m^2	1,566	1,390	176	1480	86
Sink & Source	m^2	7,214	6,688	526	6379	817
Purchased cost of HTA						
Sink	10^3 USD	1,427	1,322	105	1,227	200
Source	10^3 USD	355	322	33	339	17
Sink & Source	10^3 USD	1,782	1,644	138	1,566	216

In the second case study, Case 2, both the KHSH and KCSC principles are applied as shown in Section D of Figure 1. The region of interest lies between T** equals to 150 ºC and 200 ºC. The desired change in TSP shape can be achieved by increasing the slope of SSiP between say 150-175 ºC using the KCSC principle and then reduce the slope of SSiP between 175-200 ºC by using the KHSH principle.

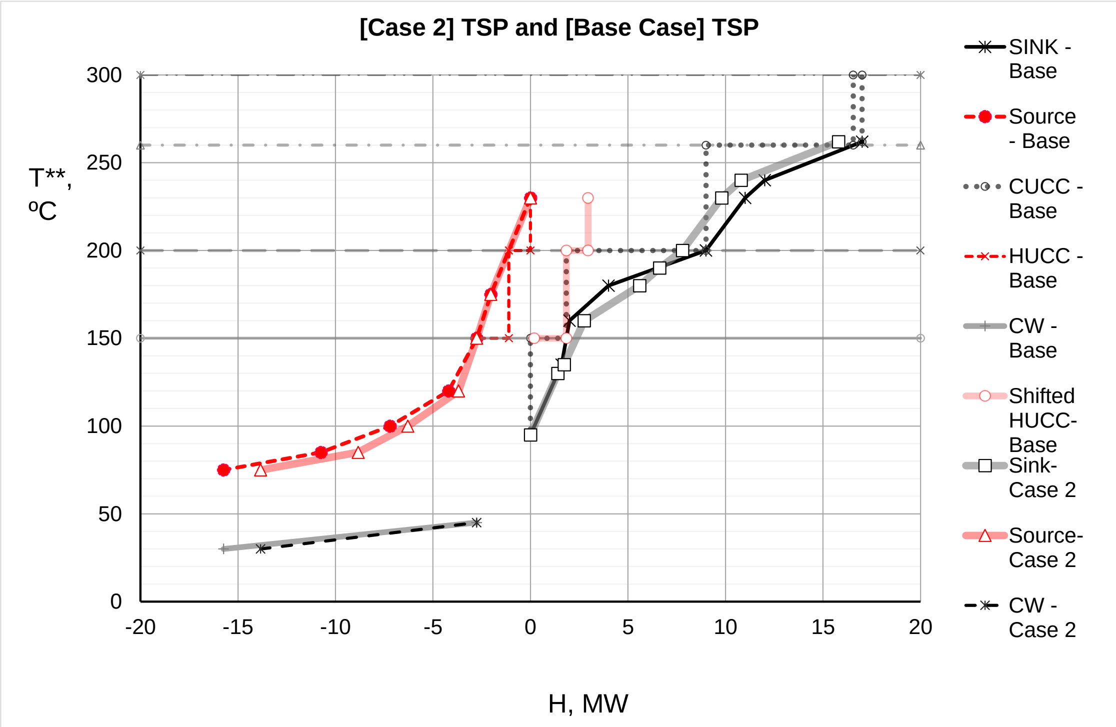

Figure 5: Changed TSP with application of KHSH/KCSC as in Case 2

Process B is selected for further evaluation because compared with A, B's streams lie more in the temperature range of interest. Compared with C, B streams have higher heat capacity (CP) values. Within Process B, stream C2 is selected for application KCSC as it has large CP and its target temperature is within the temperature range of interest. Similarly Stream H2 is selected for application of KHSH. Suppose process modification is possible to reduce the target temperature of C2 by 15 ºC (KCSC), and the CP increased by 16.7 % (for e.g. by increasing the mass flow of H1) in order to keep the enthalpy constant. In the same way, the supply temperature of H2 is raised by 10 ºC (KHSH) and the CP reduced by 10.5 % to keep the enthalpy constant. The resulted change in TSP is as shown in Figure 4. A detailed comparison of the HTA for the various utilities between Case 2 and Base Case is given in Table 4.

Table 4: Comparison of Base Case and Case 2 HTA required at various utilities

	Heating/cooling duties (MW)		**HTA** (m^2)		**HTA purchase costs** ('000 USD)	
Utilities	**Sink** (usage)	**Source** (Generation)	**Sink**	**Source**	**Sink**	**Source**
BASE CASE						
- VHPS	0.45	-	84	-	51	-
- HPS	7.55	-	2,517	-	667	-
- MPS	7.16	1.11	2,597	406	605	98
- LPS	1.84	1.65	450	464	104	106
Total Heating	12.98	-	-	-	-	-
Cooling duty/CW	-	12.98	-	696	-	151
Sink & Source	-	-	7,214		1,782	
CASE 2						
- VHPS	0.45	0	84	-	51	-
- HPS	7.55	0	2,517	-	667	-
- MPS	5.45	1.11	1,653	406	364	98
- LPS	2.34	1.65	663	464	144	106
Total Heating	13.03	-	-	-	-	-
Cooling duty/CW	-	11.08	-	610	-	134
Sink & Source	-	-	6,397		1,561	

Above 200 ºC, the slope of the SS_iP remains essentially the same, displaced by the reduction in heating duty. Between 150 ºC and 200 ºC, the slope of SS_iP reduces, providing a larger temperature driving force for the HPS to process heaters. Below 150 ºC, the slope of SSiP increases slightly. Even though the enthalpies of C2 and H2 are kept constant, a higher H2 supply temperature and lower C2 target temperature result in a reduction in heating and cooling duties of 1.21 MW and 1.90 MW (refer to Table 3).
From Table 4, the reduction in HTA, of 2,597-1,653=944 m^2 is from the MPS/process heat exchangers at the site Sink. Both the reduction in MPS consumption and increased temperature driving force contributed toward the HTA reduction. The HTA reduction is partly offset by the increase in LPS consumption. The overall reduction in HTA is at 817 m^2 (i.e. 8 % of base case HTA) and saving in purchased cost of HTA is about 12 %.

4. Conclusions

The presented work extends the TSHI methodology including the use of Keep Hot Stream Hot (KHSH) and Keep Cold Stream Cold (KCSC) principles to target decreasing the capital cost of heat transfer units at the TSHI. Application of KHSH/KCSC principles on TSP reduces the heating and cooling duties and resulted in a saving in the capital cost of heat exchangers required for the heat recovery between the site Sink and Source and the utilities. When KHSH/KCSC principles can be applied while maintaining the ΔH constant, the TSP shape can be changed to provide a larger temperature driving force to further reduce the HTA and capital cost. Process modifications to achieve the desired shape of TSP may be limited by technical feasibilities or economic reasons. However, the potential for the feasible/profitable modifications of the TSP shapes is worth to be analysed and studied as they can be enhanced by exploring the potentials to integrate neighbouring units such as services, businesses residential and even agricultural units, i.e. the locally integrated energy sector (LIES), a concept introduced by Perry et al (2008).

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