CHEMICAL ENGINEERING TRANSACTIONS
VOL. 35, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet
Guest Editors: Petar Varbanov, Jiří Klemeš, Panos Seferlis, Athanasios I. Papadopoulos, Spyros Voutetakis

ISBN 978-88-95608-26-6; **ISSN** 1974-9791
DOI: 10.3303/CET1335029

Process Modification Potentials for Total Site Heat Integration

Kew Hong Chew[a], Sharifah Rafidah Wan Alwi[a,*], Jiří Jaromír Klemeš[b], Zainuddin Abdul Manan[a]

[a]Process Systems Engineering Centre (PROSPECT), Faculty of Chemical Engineering, Univerisiti Teknologi Malaysia, 81310 UTM Johor Baru, Johor, Malaysia
[b]Centre for Process Integration and Intensification – CPI[2], Research Institute of Chemical and Process Engineering - MŰKKI, Faculty of Information Technology, University of Pannonia, Egyetem u. 10, H-8200 Veszprém, Hungary
shasha@cheme.utm.my

The technique to identify the scope for process modifications to improve energy efficiency of individual processes using the Composite Curves was developed many years ago. The potential of improving Total Site Heat Integration (TSHI) via process modification based on the Plus-Minus Principles of Pinch Analysis has been analysed in this work. An approach to target process modifications to maximise energy saving via TSHI has been proposed. The approach consists of two steps: in the first step, the options for reducing utility targets are identified by the use of Total Site Profiles (TSP) and Site Composite Curves (SCC); the second step is to link the identified changes on the TSP/SCC to the specific changes required at the individual processes. The study has shown that the Plus-Minus Principles can be applied on a TS context. By targeting the process modifications at the selected process sections, an improvement in heat recovery can be achieved.

1. Introduction

Process modification strategies to improve the Heat Integration (HI) of single processes based on the shape of Composite Curves (CC) and the Grand Composite Curve (GCC) were developed by Linnhoff and Vredeveld (1984). Some established rules for process modifications using the CC and GCC include the Plus-Minus Principles, Keep Hot Streams Hot and (KHSH) Keep Cold Streams Cold (KCSC) as well as the appropriate placement of utilities. Exploiting and optimising the process soft data, use of the appropriate minimum approach temperature (ΔT_{min}) and suitable application of insulations above and below the pinch can be effective in improving heat recovery.

The concept of Total Site (TS) was introduced by Dhole and Linnhoff (1993). Klemeš et al. (1997) established the Total Site Profiles (TSP) to represent the thermal profile of TS and the Site Composite Curves (SCC) to represent the site utility systems for utility targeting. The SCC comprises of Hot and Cold Utility Composite Curves. The Site Pinch (SP) is where the two utility CC overlaps. The Utility Grand Composite Curve (UGCC) provides a visual summary of the external utility requirement. For retrofit cases, the TSP can be constructed from the heating and cooling requirements of each process.

The Plus-Minus Principles has not been used together with the TSP to identify the scope for process modifications to improve TSHI. Hackl et al. (2011) showed that TSP and SCC can be used to identify potential changes to the utility systems to reduce the overall site heating and cooling requirements. Replacing the low pressure steam (LPS) heating with hot water (generated from Site Source) changed the shape of the SCC (the Cold Utility CC in this case) and resulted in the shifting of the SP. This increases the overlap of the Site Source and Sink Profiles and increases the heat recovery. Nemet et al. (2012) demonstrated the use of Plus-Minus principle on TS to develop the strategies to plan the extension of an existing site. The Plus-Minus principle, together with the Process Utility Matrix, is used to evaluate the benefit of integrating a new process to existing TS. In this study, the Plus-Minus principle of process modifications is used to further improve HI, and hence the utility targets of a TS.

Please cite this article as: Chew K.H., Wan Alwi S.R., Klemes J.J., Manan Z.A., 2013, Process modification potentials for total site heat integration, Chemical Engineering Transactions, 35, 175-180 DOI:10.3303/CET1335029

2. Application of the Plus-Minus Principles to Total Site

For TS that uses steam as the heating utility, and assuming that the steam levels have been optimised, further reductions of the utility targets can be made by exploring the potential for process modifications in the TS context.

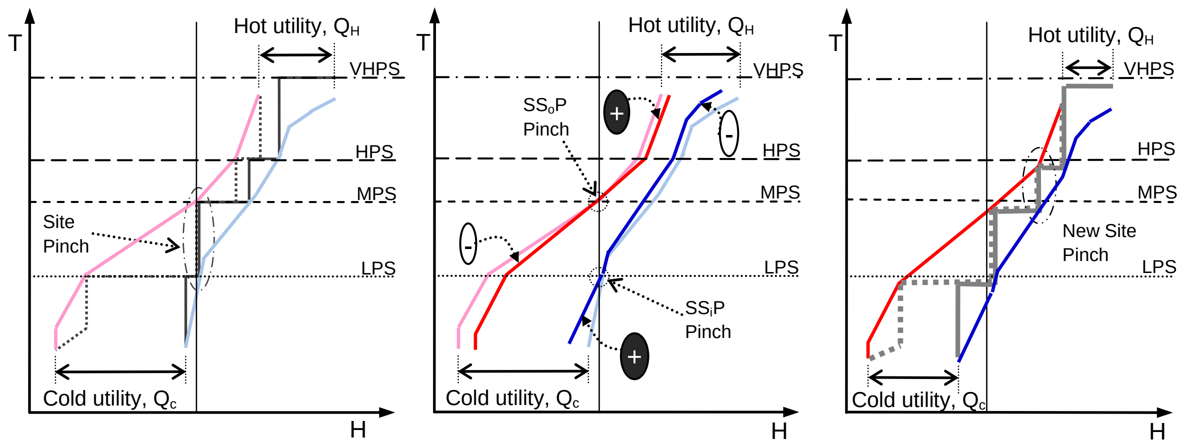
Knowledge of the Pinch location is vital during process modifications of single processes. The Site Pinch (SP) is where the Cold Utility CC first intersects the Site Sink Profile (SS_iP) or when the Hot Utility CC first intersects the Site Source Profile (SS_oP). SP is where the overlap between the Utility Composite Curves are maximised. SP limits the amount of heat that can be recovered from the utility system. By inference, the SP always spans between the temperatures of two successive utility levels.

For the SS_oP, the SP can also be taken as the temperature equal to the higher steam level of the SP. Above this temperature, increasing the duty of the SS_oP (+) reduces the hot utility, below this temperature, decreasing the duty of SS_oP (-) reduces the cold utility. For the SS_iP, the SP can be taken at the temperature equal to the lower steam level of the SP. Above this temperature, decreasing the SS_iP (-) reduces the hot utility, below this temperature, increasing the duty of SS_iP reduces the cold utility.

Below the lowest steam level, the Plus-Minus principle also applies. The increase in the duty of the Site Sink would be limited by the LP steam generation from the Site Source unless another working fluid e.g. hot water is introduced to recover the lower temperature heat.

The UGCC provides a visual impression of the external utility requirements, and can be used to prioritise the changes on the TSP segments in order to reduce utilities.

The application of the Plus-Minus Principles to a TS which uses four utility levels, that include very high pressure steam (VHPS), high pressure steam (HPS), medium pressure steam (MPS) and low pressure steam (LPS) is illustrated in Figure 1 and summarised in Table 1.



(a) Initial TSP and SCC *(b) Plus-Minus Principles* *(c) New TSP and SCC*

Figure 1: Analogy of the Plus-Minus principles to a Total Site

Table 1: Application of the Plus-Minus Principles to a Total Site (using steam as the working fluid)

Utility level	At the SS_oP		At the SS_iP	
VHPS, HPS, MPS, LPS	Above SS_oP Pinch, ↑ duty (+)	Q_H ↓, limited by Site Pinch	Above SS_iP Pinch, ↓ duty (-)	Q_H ↓, limited by Site Pinch
	Below SS_oP Pinch, ↓ duty (-)	Q_C ↓, limited by Site Pinch	Below SS_iP Pinch, ↑ duty (+)	Q_C ↓, limited by Site Pinch
Below LPS	↓ duty (-)	Q_C ↓	↑ duty (+)	Q_C ↓, limited by the LPS generation of SS_oP

3. Methodology

The two-step algorithm to target process modifications for TSHI is shown in Figure 2.

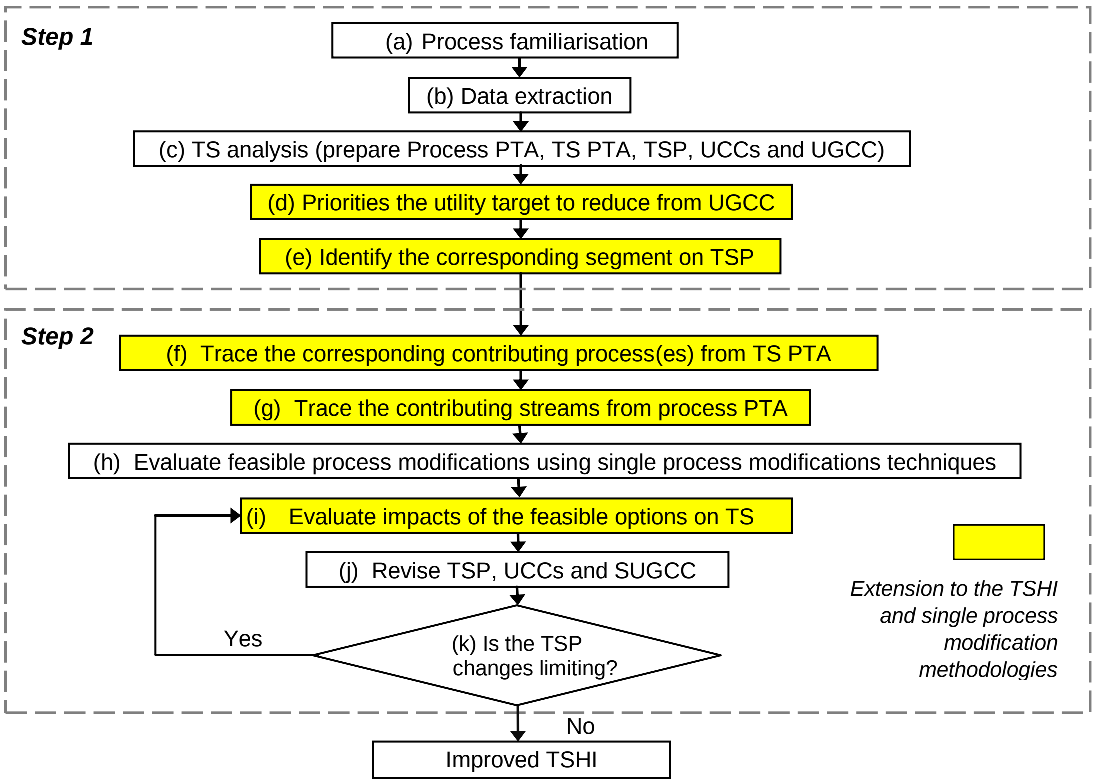


Figure 2: Algorithm to target process modifications for TSHI

In Step 1,
(a) A good understanding of the process is the prerequisite for analysis.
(b) Data extraction - select stream and obtain process data for analysis.
(c) TS analysis – prepare (i) individual process Problem Table Algorithm (PTA) – an expanded version of PTA (Cerdá et al. 1990) listing the heat capacity (CP) contribution of individual streams; (ii) TS PTA - an expanded version of TS PTA (Liew et al.. 2012) listing the heat capacity contribution of individual processes; (iii) TSP, SCC and UGCC.
(d) From the UGCC, set the priority for the utilities to be targeted.
(e) Starting with the first utility, identify the corresponding segment on the TSP using the Plus-Minus principle.

In Step 2,
(f) From the TSP segment identified, trace back the contributing process or processes from the TS PTA. This can be done easily as the TS PTA lists the contribution from each process by the temperature intervals of TSP. If more than one process is involved, there is a choice of whether to eliminate some or to include all for further evaluation. Priority of processes to target can be set by examining the process heat capacity on the TS PTA.
(g) Similarly, the contributing streams corresponding to the TSP segment and the specific process can be traced back from the process PTA. Priority of stream can be set based on the stream CP, larger CP first.
(h) Assess the scope of feasible process modifications, using the Pinch techniques for single process. Repeat steps (e) to (h) for other utilities.
(i) Select only the process modification options that would favourably change the TSP.
(j) Reconstruct TSP, SCC and UGCC using the new stream data.
(k) Check if the TSP changes is limiting as per Table 1? If yes, go back to step (h). If no, the option is acceptable.

4. Example

The TS consists of three processes A, B and C. The TS analysis is carried out by using Excel spreadsheet. The process PTA (process B), TS PTA (for Sink), TSP & SCC and UGCC are given in

Figures 3 to 6. From UGCC, Figure 3, only external VHPS and MPS are required as the HPS and LPS generation from Site Source is sufficient for the Site Sink requirement. The more expensive and the larger-enthalpy utility should be set as the priority to be reduced. For this example, the priority is (1) VHPS, (2) MPS and (3) CW.

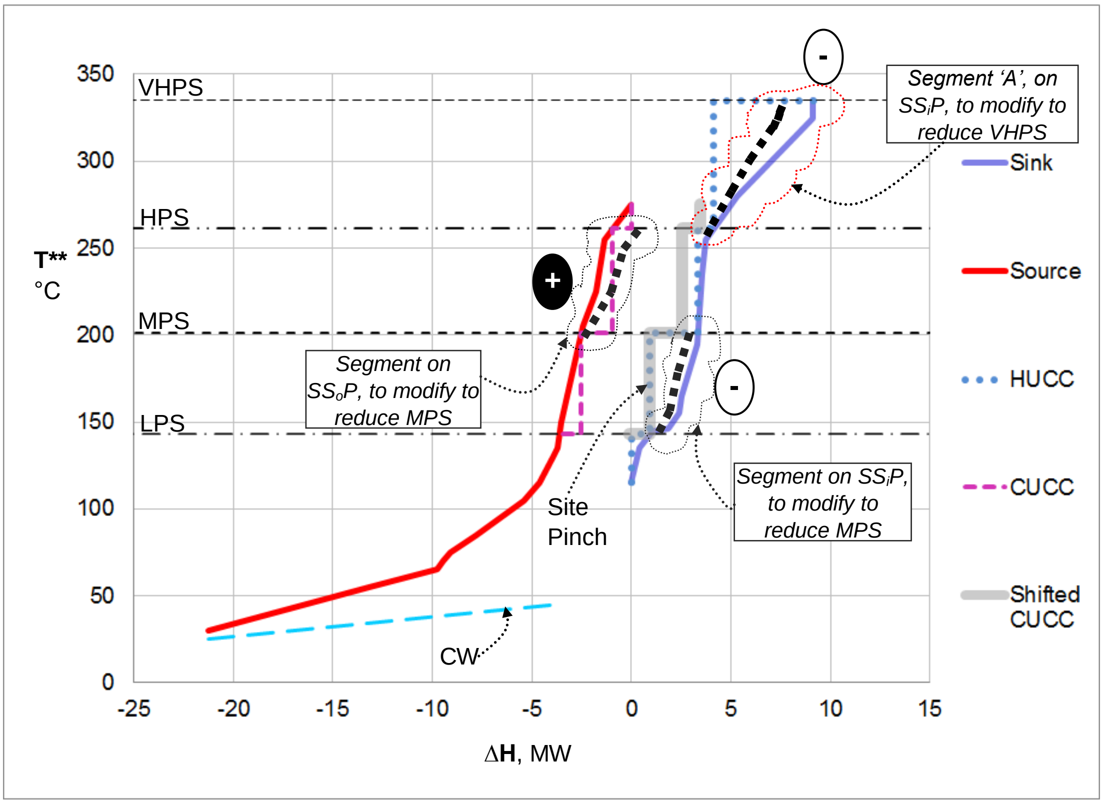
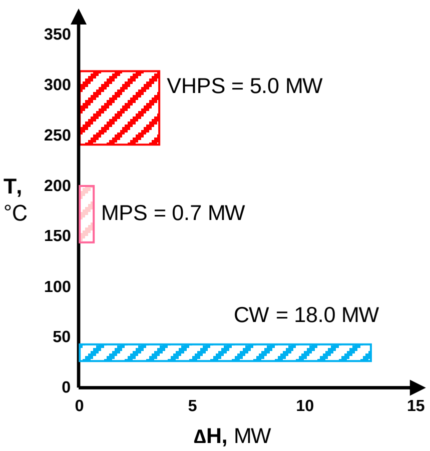


Figure 4: TSP and SCC

From the TSP, Figure 4, applying the Plus-Minus principle, VHPS may be reduced by reducing the heat duty of SS_iP as shown by Segment 'A'.
The processes corresponding to Segment 'A' is identified by the use of TS PTA for the Site Sink, Figure 5. Process 'B' is the main player as it has the largest contribution of CP, Process C has significantly lower CP and can be left out of consideration. Process A has no contribution towards Site Sink.



For Segment 'A', on SSiP, Process 'B' is the major player

T**, C	ΔT, C	Process CP A	B	C	MW/C Σ_CP	MW ΔH	MW Cul_ΔH
115							0
135	20		21		21	0.42	0.4
145	10		62		62	0.62	1.0
146	1		812		812	0.81	1.8
155	9		62		62	0.56	2.4
165	10		8		8	0.08	2.5
195	30		27		27	0.81	3.3
235	40		6		6	0.25	3.6
255	20		6	3	9	0.19	3.7
265	10		60	3	63	0.63	4.4
280	15		60	3	63	0.95	5.3
325	45		81	3	84	3.78	9.1
335	10			3	3	0.03	9.1

Figure 3: UGCC *Figure 5: TS PTA for Site Sink*

To identify the contributing streams within Process B, the PTA of Process B is used as shown in Figure 6.

T*, C	ΔT, C	Streams CP, MW/C										Σ_CP	ΔH, MW	cul_ΔH, MW	ΔH, MW Cascade
		H1	H2	H3	H4	H5	H6	H7	C1	C2	C3				
320														0	8.8
275	45								81			-81	-3.64	-3.6	5.2
250	25	21							81			-60	-1.51	-5.2	3.7
190	60	21	54						81			-6	-0.38	-5.5	3.3
160	30		54						81			-27	-0.81	-6.3	2.5
150	10		54	19					81			-8	-0.08	-6.4	
141	9			19					81			-62	-0.56	-7.0	
140	1			19					81	750		-812	-0.81	-7.8	
130	10			19					81			-62	-0.62	-8.4	
110	20			19		41			81			-21	-0.42	-8.8	0.0
90	20			19		41					22	38	0.76	-8.1	0.8
80	10			19		41		9			22	47	0.47	-7.6	1.2
70	10					41		9			22	29	0.29	-7.3	1.5
60	10				90	41	189	9			22	307	3.07	-4.2	4.6
35	25				90		189	9				288	7.19	3.0	11.8

Section of PTA corresponding to segment 'A', on SSiP,

Figure 6: The PTA of Process B

For Process B, the Sink duty is given by Eq.(1):

$$\Delta H_{Sink} = \sum CP_{hot\text{-}stream} \times \Delta T - \sum CP_{cold\text{-}stream} \times \Delta T \quad (1)$$

As the aim is to reduce the duty of SS_iP, ΔH_{sink} needs to be reduced. The ΔH_{sink} can be reduced either by increasing the hot stream duty or decreasing the cold stream duty based on Equation (1). From Figure 6, the CP of cold stream C1 is about four times that of CP of hot stream H1. Stream C1 is the obviously a priority to change in order to reduce the Sink duty. The heat duty can be changed by changing the stream heat capacity and/or temperatures. Change of heat capacity is difficult for stream C1 as well as H1 as the mass flows are dictated by the production rate while the specific heat capacity is the physical attribute of a stream. The stream temperature can be changed by exploiting the flexibility that exists in the operating conditions of the process. For demonstration purposes, suppose process modifications are feasible and resulted in a reduction of 10 °C in C1 and an increase of 5 °C in H1 outlet temperatures (assuming that the impact of lower C1 temperature and higher H1 temperature can be accommodated by the existing process). This corresponds to a reduction of 0.9 MW in Sink duty.

The same procedure is carried out to reduce the MPS duty. Note that, for the MPS, changes can be made on SS_iP or SS_oP or both as shown in Figure 4. Suppose no process modification is feasible for SS_oP, while for the SS_iP, it is feasible to increase stream H2 temperature by 3 °C at Process B and this result in a duty reduction of 0.2 MW. For the cooling water, from the SS_iP profile, there is little need for low grade heat (about 120 °C and below) by processes on site. The cold utility can be reduced either by modifying the existing processes to exploit this low grade heat, or by supplying it to other users from the neighbouring sites.

The TSP and SCC of the improved TS are given in Figure 7 and the results is summarised in Table 2

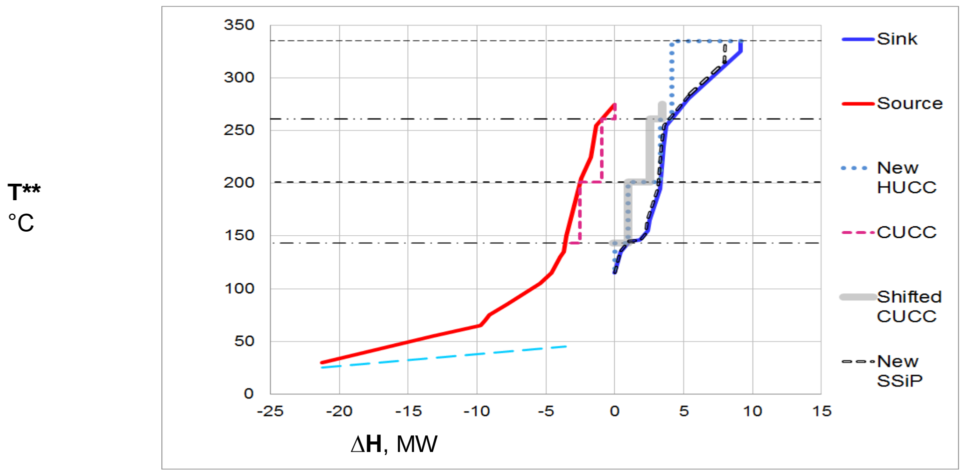


Figure 7: TSP and SCC of the improved TS

The shape of the SS_iP segments targeted has not changed much because the process modifications only involved a small change in streams' temperature. A change in the shape of TSP may affect the optimum steam temperatures thus it would be prudent to re-evaluate the optimum steam temperatures if there is a significant change in the shape of TSP. Note that the steam levels may be dictated by other requirements on site such as steam for reactor, motive steam for ejectors or pumps, etc. Also for an existing plant, the steam levels are limited by the mechanical and velocity limits of the steam network.

Table 2: Summary of the Results

Utility level	Process Modifications	Utility before improvement	Utility after improvement	Saving
VHPS	Changing streams H1 inlet and C1 outlet temperatures at Process B	5.0 MW	4.1 MW	0.9 MW (18 %)
MPS	Changing stream H2 outlet temperature at Process B	0.7 MW	0.5 MW	0.2 MW (19 %)

5. Conclusion

In a TS comprising of several processes with numerous streams, the proposed method provides a systematic and directed approach to identify the potential process modifications that are beneficial to the overall site HI. The study has shown that the Plus-Minus Principles developed for a single process can be applied to a TS with some minor adaptations. The TSP, SCC and UGCC can provide useful insights to identify strategic process modification options to improve the site HI. The process modification options identified can be conveniently merged with a retrofit project (e.g. to increase plant capacity) on the same site. Research is in progress to assess the implementation of these options from the industrial perspective that considers the aspects of design, operations, and economics (Chew et al. 2013).

Acknowledgement

The authors would like to thank the Universiti Teknologi Malaysia (UTM) for providing the financial support for this project under Vote No. Q.J130000.7125.01H95, and the Hungarian State and the European Union under the TAMOP-4.2.2.A-11/1/KONV-2012-0072 Design and optimisation of modernisation and efficient operation of energy supply and utilisation systems using renewable energy sources and ICTs.

References

Chew K.H., Klemeš J.J., Wan Alwi S.R., Manan Z.A., 2013, Industrial Implementation Issues of Total Site Heat Integration, Appl. Therm. Eng., DOI: 10.1016/j.applthermaleng.2013.03.014

Cerdá J., Galli M.R., Camussi N., Isla M.A., 1990, Synthesis of flexible heat exchanger networks—I. Convex networks. Comput. Chem. Eng., 14(2), 197-211.

Dhole V.R., Linnhoff B., 1993, Total site targets for fuel, co-generation, emissions, and cooling, Comput. Chem. Eng., 17, Supplement 1(0), S101-S109.

Hackl R., Andersson E., Harvey S., 2011, Targeting for energy efficiency and improved energy collaboration between different companies using total site analysis (TSA), Energy, 36(8), 4609-4615.

Klemeš J., Dhole V. R., Raissi K., Perry S. J., Puigjaner L., 1997, Targeting and design methodology for reduction of fuel, power and CO2 on total sites, Appl. Therm. Eng., 17(8–10), 993-1003.

Klemeš J., Friedler F., Bulatov I., Varbanov P., 2010, Sustainability in the Process industry – Integration and Optimization. McGraw-Hill, New York, USA.

Liew P.Y., Wan Alwi, S.R., Varbanov P.S., Manan Z.A., Klemeš J.J., 2012, A numerical technique for Total Site sensitivity analysis, Appl. Therm. Eng., 40(0), 397-408.

Linnhoff B., Vredeveld D.R., 1984, Pinch technology has come of age, Chem. Eng. Prog., 80(7), 33-40.

Nemet A., Klemeš J., Varbanov P.S, Atkins M., Walmsley M, 2012, Total Site Methodology as a Tool for Planning and Strategic Decisions, Chemical Engineering Transactions, 29, 115 - 120.

Smith R., Linnhoff B., 1988, The design of separators in the context of overall processes, Chem. Eng. Res. Des., 66, 195–229.