CHEMICAL ENGINEERING TRANSACTIONS

VOL. 29, 2012

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Hon Loong Lam, Jiří Jaromír Klemeš

ISBN 978-88-95608-20-4; **ISSN** 1974-9791

DOI: 10.3303/CET1229020

Total Site Methodology as a Tool for Planning and Strategic Decisions

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A Total Site (TS) is defined as a set of processes (industrial plants, residential, business and agriculture units) linked through the central utility system. The utility system incorporates a number of operating units such as boilers, steam turbines, gas turbines and letdown stations. Many sites are using the TS system representation. Heat Integration at TS level has been well developed and successfully implemented.
However, sites typically develop with time and even minor changes/extensions can affect TS heat recovery significantly. It is beneficial to plan their strategic development in advance, to increase or at least not to decrease the rate of heat recovery when integration of additional processes takes place. Even when this has not been done at the initial stage, the TS methodology can still be used as a tool for the strategic planning decision making. This work illustrates how the TS methodology can contribute to the strategic development and the extension planning of already existing TS. The aim is to reveal the potentials for Heat Integration, when new units or processes are considered for the inclusion in the TS. Moreover, some operating parameters (e.g. temperature or capacity) of the unit can be proposed to achieve the best possible heat recovery. The degrees of freedom for TS changes can be on two levels: (i) only adding an operating unit to the current utility system (the Total Site Profiles remain the same) or (ii) changing of the TS by including more processes (the Total Site Profiles are changed). The first group of changes includes the integration of heat engines to produce electricity utilising heat at higher temperature and returning it to the system at lower temperature, which is still acceptable for the heat recovery and simultaneously for the electricity production. The second group of changes is more complex. For evaluating these changes a plus/ minus principle is developed allowing the most beneficial integration of new units to the TS. Combinations of both types of changes are also considered.

1. Introduction

Achieving energy savings has become a significant issue of growing importance, because of the energy price increases and emissions consideration. Heat integration has been proven as an efficient tool for increasing the energy efficiency of the processes (Friedler, 2010). It can be performed at different levels: (i) process level and/or (ii) Total Site level (Klemeš et al., 2010).
At process level the most applied tool is Pinch Analysis. It includes construction of Composite Curves (Linnhoff et al., 1982, 1994), by which the hot and cold heat demands of all the processes are

Please cite this article as: Nemet A., Klemeš J. J., Varbanov P. S., Walmsley M. R. W. and Atkins M. J., (2012), Total site methodology as a tool for planning and strategic decisions, Chemical Engineering Transactions, 29, 115-120

presented. Using the Problem Table Algorithm the targets for hot and cold utilities are determined. When considering multiple utilities, the Grand Composite Curve (Townsend and Linnhoff, 1983) is used. It presents the net process energy demands in terms of both enthalpy and temperature. By applying Pinch Analysis, the thermodynamically optimal solution is obtained, which can be used as a target by companies. Companies, however, do not always achieve this target as there is an economic trade-off between operational and investment costs. There are Mathematical Programming models, incorporating this trade-off into a HEN synthesis superstructure. A prominent example is the model by Yee and Grossmann (1990), which considers that each hot stream can be potentially matched with each cold stream.
Heat integration can also be performed at Total Site level (Dhole and Linnhoff, 1993). It is a concept, where a number of processes present on a site are linked through the central utility system. This provides an opportunity for a further heat recovery. The excess of heat from one process can be recovered in some other process by employing intermediate-level utilities as energy exchange media.
Analysing the heat recovery potential, however, itself does not reveal all the aspects, which should be analysed, when planning for a Total Site. The companies, agricultural and residential sectors etc. are not static units, with a fixed heat demand, but they are changing rather quickly. In order to control those changes to increase or at least not to decrease the heat recovery, decisions concerning which units should be included/excluded in the Total Site, should be taken. To be able to evaluate the effects of the Total Site changes a methodology developed by Vaideeswaran (2001) has been extended for the application for the Total Site changes, which accounts for including/ excluding of different processes. The method is illustrated on a case study.

2. Methodology

The targeting in a Total Site is performed by constructing Total Site Profiles (Klemeš et al., 1997), where the Source Profile presents the excess of heat and the Sink Profile the heat demands of the processes. The heat recovery is performed through the intermediate utilities, which can be at different temperature levels e.g. high pressure steam, medium pressure steam and low pressure steam. The selected temperature of the intermediate utility can significantly affect the rate of heat recovery. However, physical restriction should be considered as well. When evaluating the heat recovery the Utility Composite Curves and also the Utility Grand Composite Curve (UGCC) are very applicable tools (Klemeš et al., 1997). The UGCC is constructed on the lines of the utility temperature. It is constructed under consideration that a hot utility should be utilised at as low temperature as possible and the cold utility at as high temperature as possible. Generally, it is the best practice since the utility prices at the extreme temperature are higher than the medium one (Figure 1a).

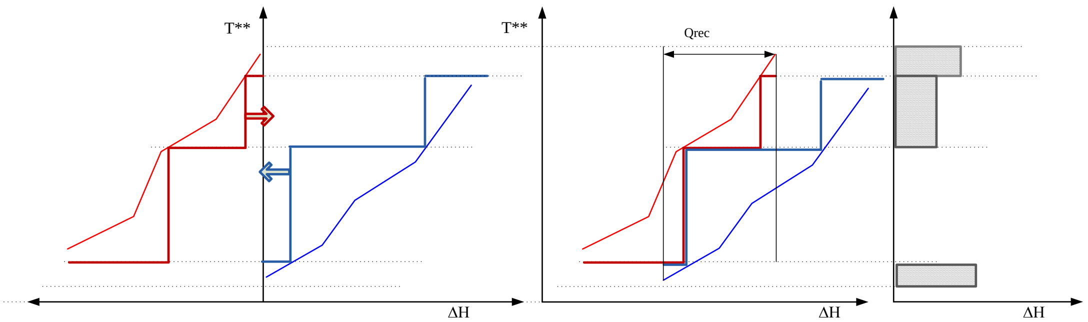


Figure 1. (a) Total Site Profiles with Utility Composite Curves (b) overlapping of the Utility Composite Curves (c) Utility Grand Composite Curve (after Klemeš et al., 1997)

The maximum heat recovery rate can be determined by overlapping the Hot Utility Composite Curve with Cold Utility Composite Curve (Figure 1b). The net utility requirement after the heat recovery is presented in the GCC.

The plus/ minus principle (Figure 2a) highlights where, in terms of TS temperature and load, it may be beneficial to increase the hot or cold utility demand in order to achieve at least partial heat recovery. Assume a single intermediate utility. Figure 2b illustrates the unfavourable scenarios. Below the current intermediate utility temperature it is not desirable to integrate processes with cooling requirement (heat supply), as this would increase the external utility consumption. Integrating a heat demand above the intermediate utility temperature similarly increases the external hot utility load. However, the integration of an additional process with heat demand below the intermediate utility is potentially beneficial, as its heat demand can be at least partially covered by heat recovery (Figure 2c). Integration of processes with cooling requirement is appropriate above the intermediate utility temperature, since the heat excess of these processes can be recovered at least partially (Figure 2d). It should be noted that the addition of processes with their heating and cooling demands in both cases (Figure 2c, d) is accompanied with appropriate shifts in the intermediate utility temperature level to accommodate the relevant additional duties available.

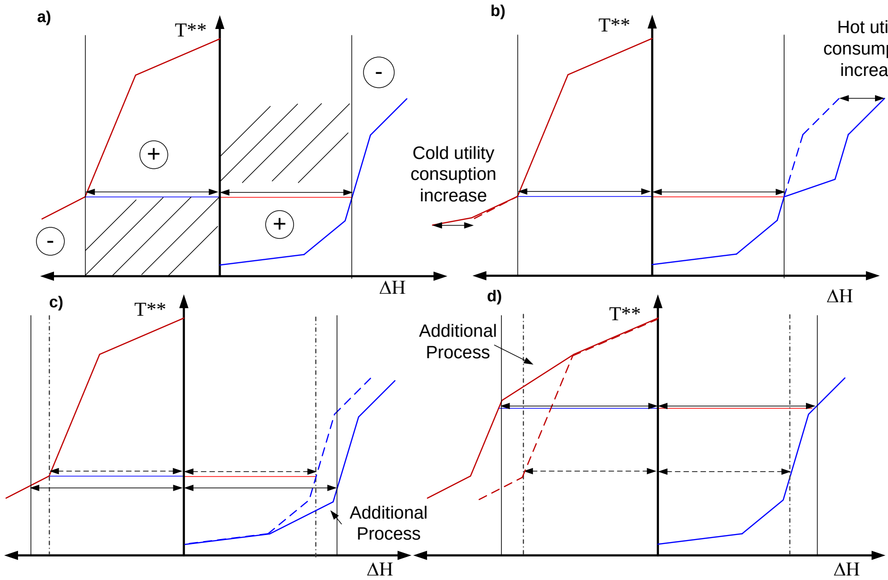
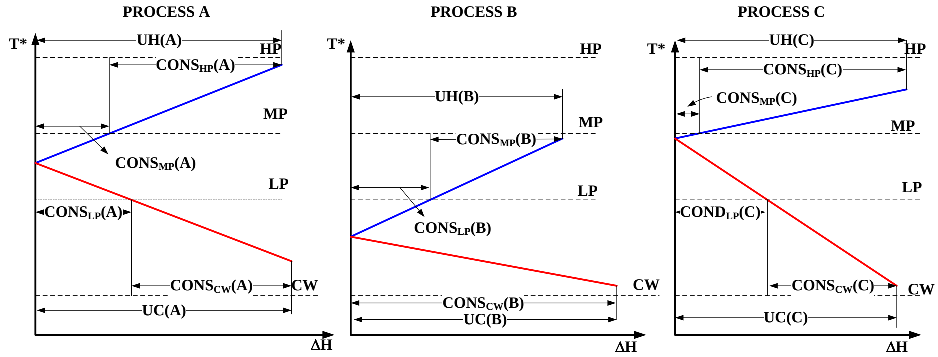


Figure 2. (a) Plus/ minus principle; (b) changes in minus zone, integration of processes; (c) with heat demand below temperature of the heat recovery; (d) with excess of heat above the temperature of the heat recovery

The heat recovery on a Total Site is achieved by using intermediate-level utilities. The presented plus/minus principle can be applied easily when only one intermediate utility is available. However in order to evaluate multiple intermediate utility the Process Utility Matrix (PUM) can be applied (Vaideeswaran, 2001). First the utility requirement at each utility level is determined in each process forming the Total Site. The results are presented in the PUM (Figure 3). The overall heat demand is determined from the summation of the minimum hot utility requirement of each process (Figure 3, ΣUH). The positive hot utility amount at a certain utility level indicates a utility demand; the negative amount presents a heat surplus (Figure 3). The maximum heat recovery target can be calculated as the difference between the overall hot utility requirement (ΣUH) and minimum hot utility requirement. The minimum hot utility requirement is the summation of the individual hot utility requirement (Figure 3, ΣHP, ΣMP, ΣLP) and is only included if the value is positive. For example if ∑LP is negative it would not be included in the minimum hot utility summation as a negative value indicates a surplus (i.e. a cooling load). After determining the recovery rate at each utility level, a suggestion of required process or evaluation of the effect of the integration of potential process can be performed. When considering new process integration to the existing TS an additional row with the utility requirement of the new process can be introduced and the net utility requirement and heat recovery at each utility level can be evaluated very quickly. Moreover, when integrating TS even the utility profile of the process, by which the heat recovery would be maximised can be proposed. This could help when selecting, which process should be included/ excluded from all the possible processes available. After all processes possible are integrated to the Total Site the options of cogenerations should be also considered.



PROCESS UTILITY MATRIX

PROCESS	UH	UC	$CONS_{HP}$	$CONS_{MP}$	$CONS_{LP}$	$CONS_{CW}$
Process A	UH(A)	UC(A)	$CONS_{HP}$(A)	$CONS_{MP}$(A)	– $CONS_{LP}$(A)	$CONS_{CW}$(A)
Process B	UH(B)	UC(B)	$CONS_{HP}$(B)	$CONS_{MP}$(B)	$CONS_{LP}$(B)	$CONS_{CW}$(B)
Process C	UH(C)	UC(C)	$CONS_{HP}$(C)	$CONS_{MP}$(C)	– $CONS_{LP}$(C)	$CONS_{CW}$(C)
TOTAL	ΣUH	ΣUC	ΣHP	ΣMP	ΣLP	ΣCW

Figure 3. Process Utility Matrix (after Vaideeswaran, 2001)

3. Example

A simple example will be used to demonstrate the method for determining the value of integrating an additional process to the TS using the PUM. Consider three existing processes (A-C) already integrated on TS with GCC for each process based on the GCCs illustrated in Figure 3. The PUM for these processes is illustrated in Table 1. There is a total of 3 MW of heat recovery, which is calculated by subtracting the minimum hot utility requirement (17 MW + 10 MW) from the overall hot utility target (30 MW). In this case the LP steam is not included in the minimum hot utility requirement because ∑LP is a negative value, indicating an excess of LP steam on site. This excess LP steam could be substituted for cooling water although it would be more beneficial to attempt to utilise it elsewhere.

Table 1: Problem Utility Matrix for base case. All units are MW. Heat recovery = 3 MW

Process	UH	UC	$CONS_{HP}$	$CONS_{MP}$	$CONS_{LP}$	$CONS_{CW}$
A	10	12	7	3	-3.5	8.5
B	8	14	0	5	3	14
C	12	10	10	2	-5	5
Total	30	36	17	10	-5.5	27.5

Now consider an additional process (D) that could be integrated into the TS and the effect on overall heat recovery is to be quickly assessed. From the GCC of process D (not shown) it can be quickly determined the amount of individual utility required/generated. These values can then be simply included in the PUM and the amount of heat recovery calculated. The PUM for the TS including process D is given in Table 2. Although the required utility has increased the amount of heat recovery has also increased from 3 MW to 8.5 MW, which is due to the ability of process D to utilise the excess LP steam. This indicates that the pinch temperature for process D is below the LP steam temperature.

This is a case where an additional amount of HP and MP steam usage at the total site level results in an additional 5.5 MW of heat recovery. It should also be noted that if process D was operating independently of the TS all of the utility requirements would still need to be met.

Table 2: Problem Utility Matrix with Process D integrated. Heat recovery = 8.5 MW

Process	UH	UC	$CONS_{HP}$	$CONS_{MP}$	$CONS_{LP}$	$CONS_{CW}$
A	10	12	7	3	-3.5	8.5
B	8	14	0	5	3	14
C	12	10	10	2	-5	5
D	11	10	2	3	6	10
Total	41	46	19	13	0.5	37.5

If the Pinch temperature for process D was between the MP and LP steam temperature and LP steam is generated by process D there is no additional heat recovery over the base case. The PUM for this case is shown in Table 3 where 2 MW of LP steam is generated by process D. Therefore for this case there is clearly no net benefit from integrating process D into the TS.

Table 3: Problem Utility Matrix for with Process E integrated. Heat recovery = 3 MW

Process	UH	UC	$CONS_{HP}$	$CONS_{MP}$	$CONS_{LP}$	$CONS_{CW}$
A	10	12	7	3	-3.5	8.5
B	8	14	0	5	3	14
C	12	10	10	2	-5	5
D	5	12	2	3	-2	10
Total	37	48	19	13	-7.5	37.5

The PUM can also be used as a guide to select processes that would be beneficial to integrate into the TS. By inspection of the PUM for the base case (Table 1) it is fairly obvious that any process that could utilise the excess LP steam would increase the amount of heat recovery and the maximum heat recovery possible would be 8.5 MW (i.e. all of the excess LP steam is used). More heat could be potentially recovered if the utility temperatures where altered or an additional hot steam level was introduced. Unfortunately the PUM in its current form does not allow this to be assessed simply. When considering alters utility level from the current one the whole PUM should be recalculated.

Utility requirements for other candidates for integration with the base case TS are given in Table 4.The amount of heat recovery is also indicated if only that process is integrated with the base case TS. There is now a trade-off to consider between additional heat recovery and additional utility use. Although maximum heat recovery could be achieved with either process G or H there is a much greater overall utility use with process H than for G. Slightly less heat recovery could be achieved with process F and there is a large drop in the required hot utility when compared to process H or G. Only 1 MW of additional MP steam would be required for a 5 MW increase in heat recovery over the base case. Finally, if process E is integrated into the base case there is an additional 3 MW of heat recovery over the base case for no additional hot utility demand. If more than one process was going to be considered then the analysis could be expanded to examine the best processes to integrate.

Table 4: Processes that could be integrated with base case TS

Process	UH	UC	$CONS_{HP}$	$CONS_{MP}$	$CONS_{LP}$	$CONS_{CW}$	Heat Recovery if Integrated with TS
E	3	3	0	0	3	4	6
F	6	9	0	1	5	9	8
G	11.5	4	3	3	5.5	4	8.5
H	22	6	10	4	8	6	8.5

4. Future Work

The PUM is a relatively simple method for quick evaluation of the merits of integrating additional processes to the TS. It allows estimates of heat recovery to be determined based on fixed utility levels and inspection of the individual process GCC without having to develop a complete TS profile. The plus/ minus principle is useful for an indication from the TS profile where integrating an additional process would be beneficial. In the future a tool for fast evaluation of the utility generation at different temperature levels and optimization of the number and temperatures of the utility will be developed.

5. Conclusion

Total Sites including many different processes are not included. However, the number and utility requirement of the processes are not constant; they change often, as there is a development. Therefore the energy planning of the TS is quite substantial. For an evaluation of heat recovery through the central utility system, when considering integration of additional processes, the process utility matrix was used. By applying this approach a quick evaluation of effect on the heat recovery can be performed. As presented in the case study integrating different processes can have very different effect on the heat recovery. When there is no additional heat recovery by integrating new process it is better to exclude form the TS as this would only cause additional investment e.g. for piping, however there will be no benefit regarding heat recovery. In the best case all the utility requirement of the newly integrated process can be covered by heat recovers in a TS.

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