CHEMICAL ENGINEERING TRANSACTIONS

VOL. 29, 2012

Guest Editors: Petar Sabev Varbanov, Hon Loong Lam, Jiří Jaromír Klemeš
Copyright © 2012, AIDIC Servizi S.r.l.,
ISBN 978-88-95608-20-4; **ISSN** 1974-9791

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

DOI: 10.3303/CET1229006

Mapping of Thermal Energy Integration: Retrofit Assessment of Industrial Plants

Luciana Savulescu*, Zoé Périn-Levasseur and Marzouk Benali

Natural Resources Canada, CanmetENERGY, Industrial Systems Optimization, 1615 Lionel-Boulet Blvd., P.O. Box 4800, Varennes, J3X 1S6, Quebec, Canada
Luciana.Savulescu@nrcan-rncan.gc.ca

Improving the performance of existing industrial plants through new technologies and innovative eco-energy solutions is raising a lot of challenges for researchers and practitioners. In the search for new sustainable designs, understanding the current energy distribution within a plant in regards to its energy requirements is essential for the decision-making process. The technique of Composite Curves is commonly employed to evaluate the scope for energy savings. However, such graphical representation is seldom self-explanatory. In the present work, an alternative to the energy Composite Curves representation is proposed to complement the visualization of energy integration opportunities. A novel energy management assessment based on mapping of the overall process energy is introduced as a simpler, yet practical and resourceful illustration to support the initiation and application of thermal energy integration.

1. Introduction

Today, industrial sites in general and pulp and paper industry in particular are continuously seeking and exploring new and innovative ways to improve their efficiency towards higher profitability in the current competitive market context. This challenging step requires a systematic strategy to account for the complex interactions between all sub-systems. More specifically, the optimal use of energy and water resources by revamping their overall integrated network distribution requires a global approach. This should include the identification and evaluation of all direct and indirect links between the process and utility through a site-wide system management.

2. Energy system retrofit

Researchers and engineers have been addressing the energy system design and management issues from different viewpoints and have developed a number of suitable methodologies (Linnhoff et al., 1994; Bengtsson et al., 2002, Smith, 2005; El-Halwagi, 2006; Kemp, 2007; Klemeš et al., 2011). There is, however, a gap between these concepts and their practical application. Although the process integration (graphical and mathematical model-based) tools estimate energy targets and provide design guidelines, the data selection, representation and interpretation of local inefficiencies, opportunities are still challenging issues in the application of these methodologies. Specialized expertise is therefore required to screen and select the relevant data to be used in the retrofit analysis. The balance between simplified assumptions and practical elements has also to be captured to address the complexity of the process.

Please cite this article as: Savulescu L., Périn-Levasseur Z. and Benali M., (2012), Mapping of thermal energy integration: retrofit assessment of industrial plants, Chemical Engineering Transactions, 29, 31-36

Energy-efficient design and operation improvements are often achieved through the application of techniques such as energy audits, simulation-based analysis, process control, monitoring and targeting, and process integration. There is a wide range of issues covered by these methods that however, are specific in their nature. The audits are focused in equipment-based analysis, checking mostly the local performance while minimum considerations are given to the interactions within the energy system. On the other hand, an overall plant simulation accounts for all the links between the process and resources supporting systems as it incorporates a large amount of information albeit is limited in pointing out the thermodynamic inefficiencies. Evaluating savings prior to design is a key feature that process integration is providing being a global system approach. Also, this approach allows to identify energy bottlenecks such as steam usage for warm water production and waste heat losses. A combined approach based on these techniques is often considered.

From the perspective of energy sustainability, graphical methods capturing key energy system insights are proven to be essential. They deliver to engineers a global vision assisting them in prioritizing specific issues such as resources management. However, from the standpoint of industry operating with multidisciplinary teams, the application, interpretation and benefits of Composite Curves might be diminished due to its abstract character. Therefore, in this paper a novel visualisation technique will be introduced to facilitate and increase the receptivity of the industrial engineers towards the need and benefits of a detailed process integration study. This technique aims at illustrating the current energy distribution of a targeted plant in a concrete and easy manner that reveals the allocation of energy sources and sinks within the whole process. It also highlights possible bottlenecks based on the specific repartition of energy as quality (temperature levels) and quantity (energy load) making it advantageous for quick and practical preliminary assessments by industrial engineers. Furthermore, the objective of such technique is to capture process know-how and to ensure that appropriate operating details are included in user-friendly tools.

3. Thermal mapping

Several diagrams have been developed to visualize a plant energy distribution and to characterise its steam use, waste heat sources, and non-isothermal stream mixing. The steam mapping diagram embeds the information on steam use from the process perspective. This plant-wide representation considers all the steam consumption points in relation with its corresponding process energy demands to reveal opportunities for reduction of steam demand. The diagram includes the details on the steam pressure levels, temperature levels and energy loads. Waste heat sources are tracked and ranked through their energy load, and temperature level.

Table 1: Heat exchanger network data – Example

		Hot side			Cold side		
Name	Load (kW)	Name Hot Stream	Tin (°C)	Tout (°C)	Name Cold Stream	Tin (°C)	Tout (°C)
Heater 1	1000	Steam	-	-	CSH1	10	30
Heater 2	2500	Steam	-	-	CSH2	35	80
Heater 3	1500	Steam	-	-	CSH3	100	120
HEX1	2000	HS1	97	50	CS1	30	65
HEX2	5000	HS2	55	30	CS2	5	35
Effluent	3000	Effluent	45	30	Environment	-	-

A simple heat exchanger network example including two heat exchangers (HEX1, HEX2), three steam heaters (Heater 1 to 3) and one waste effluent stream (Effluent) discharged to sewer is considered below to illustrate the thermal mapping concepts. The numerical data are given in Table 1 whereas the Composite Curves associated to this example are presented in Figure 1.

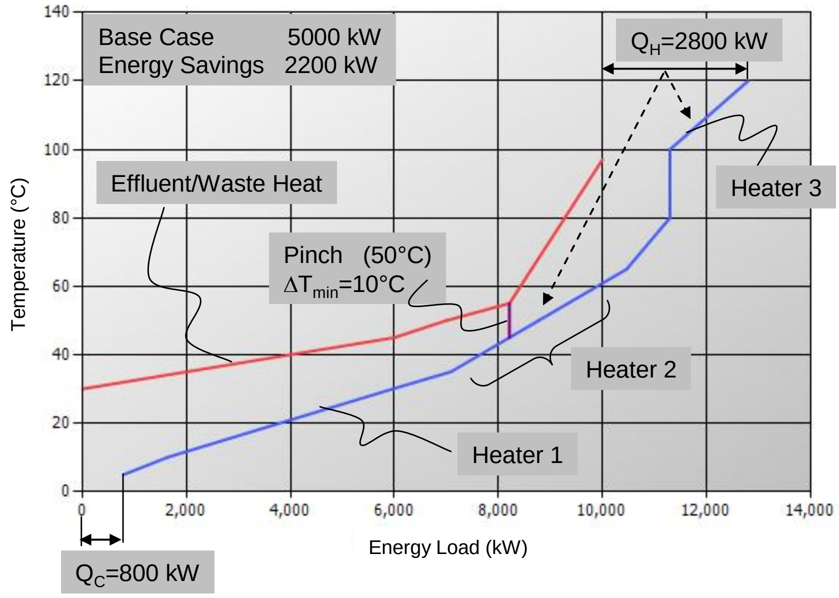


Figure 1: Energy Composite Curves - Example

The Composite Curves provide the energy targeting for the minimum hot utility (Q_H) to be 2800 kW while the cooling represents (Q_C) 800 kW. Also, the critical temperature level of Pinch is found to be 50 °C. The sources and sinks of energy as hot and cold streams are combined and globally illustrated as hot and cold Composite Curves. Although this is an overall illustration of the problem, the identity of the streams as point of use, repartition across temperature intervals, and heat exchanger network matching are unfortunately lost in the representation. Therefore, a steam mapping has been considered to obtain a global profile of all steam users from the perspective of the cold streams as this will give indications on the inefficient use of steam. Using this mapping, the energy/steam saving task will profit from this complementary representation for the visualisation and analysis of the plant wide energy profile.

The steam mapping represents the process information as it indicates what are the streams receiving this heat and what is the temperature lift for each one, as well as the utility data (e.g., medium/low pressure level (MP/LP) and the amount of steam consumed with its corresponding process energy load of individual users) – *Figure 2*.

The temperature range is divided by two temperature plateaus at 50°C and at 100 °C into three zones: **zone 1 –** below 50 °C; **zone 2 –** between 50 °C and 100 °C; **zone 3 –** above 100 °C. The temperature level of 50 °C corresponds in this case with the pinch temperature and also can be considered as a low energy temperature level. Therefore, in zone 1, steam use should be minimized and waste heat use should be maximized. At the other end, the high temperature zone is bordered by the 100 °C temperature level as above this value steam is one of the common energy sources. This diagram provides the steam allocation for each zone and detailed information on the preliminary energy scope including its heat load and specific location. By analogy to the heat exchanger cross-pinch table, the steam mapping diagram visualizes the inefficiencies at the level of steam usage and can support the reallocation of energy within the network to reduce the overall steam consumption when coupled with the waste energy. This will provide a preliminary diagnostic for quick wins opportunities and minimum changes to the existing process-process heat exchangers.

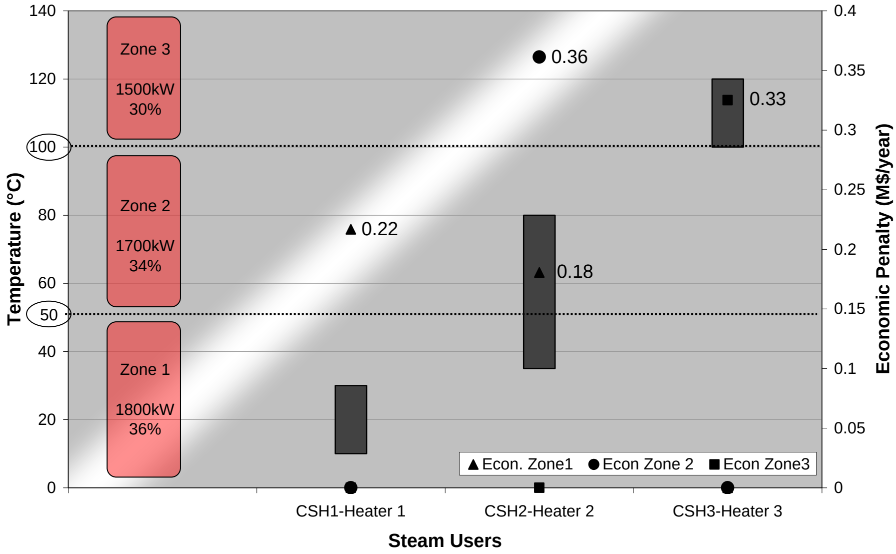
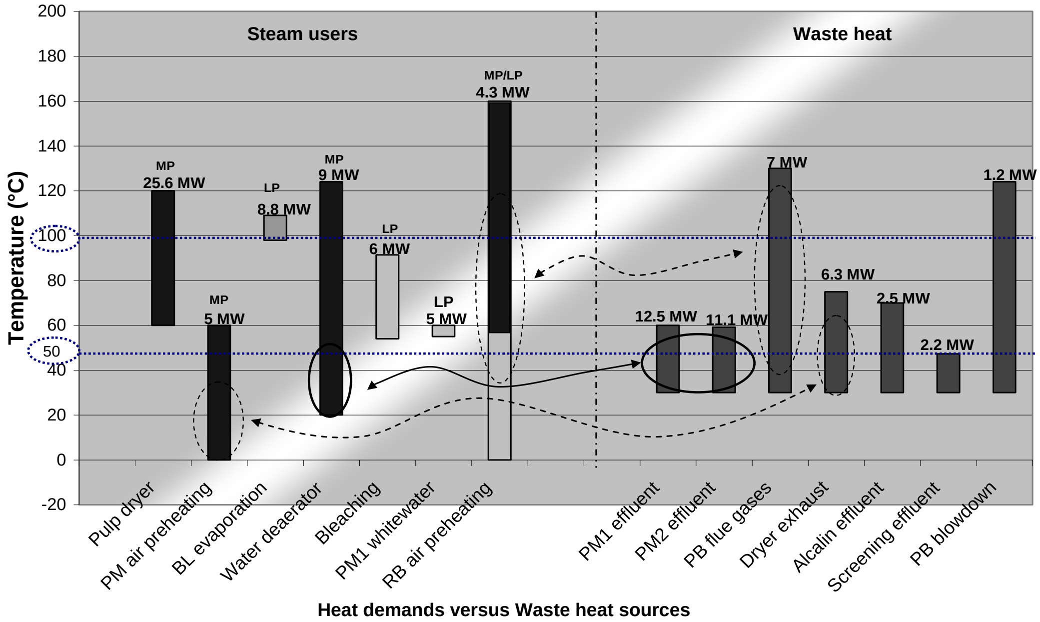


Figure 2: Steam mapping – Example

The repartition of the steam use for this example (*Figure 2*) has been mapped and a rapid preliminary target has been estimated at 36 % steam savings (1800 kW), corresponding to 82 % of the theoretical energy target (2200 kW) defined by the Composite Curves. Assuming a 7 $/GJ steam cost, the economic projection of the steam usage has also been calculated and included in the diagram as an economic penalty (M$/y) from the perspective of lost opportunity for heat recovery. The economic values have been evaluated for each zone and then displayed for every steam users. These values are illustrated by ▲/triangle for zone 1, ●/circle for zone 2 and ■/square f and its equivalent steam cost reduction of 0.4 M$/y. This economic information might be accounted as an opportunity cost.

4. Case study

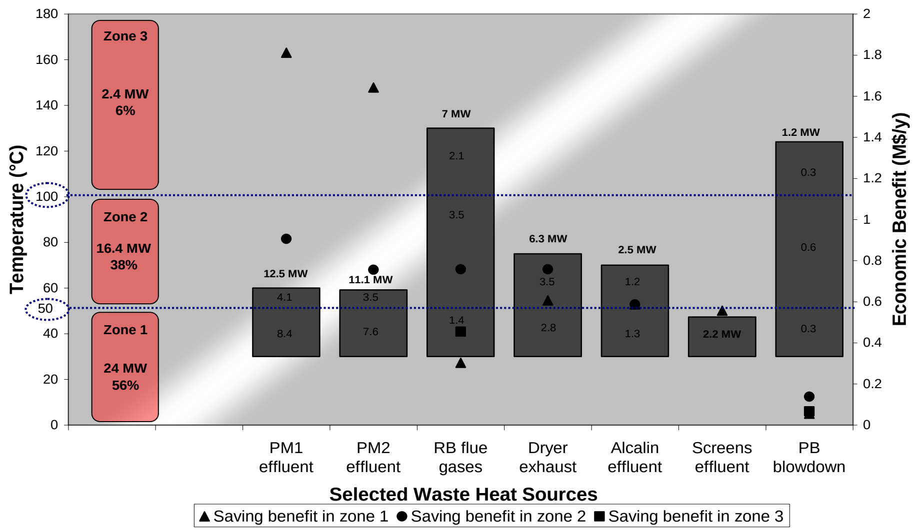
A Canadian Kraft pulp and paper mill is used as a case study to validate the effectiveness of this graphical technique as compared to the conventional representation of Composite Curves. As a part of energy-based plant retrofit strategies the thermal energy mapping diagrams were developed to complement the classical analysis and to facilitate the exchange with the industrial practitioners via a novel data/results visualisation approach.
The rules to evaluate the steam mapping diagram are very much based on the pinch analysis principles according to which steam should not be used below pinch to ensure minimum consumption in the mill. All the steam consumption points have been collected and plotted together. Throughout the mapping assessment, seven key steam users have been selected and plotted together with seven relevant waste energy streams, bringing them together such as in a heat exchanger network diagram for potential matching opportunities. The potential for heat recovery can be straightforwardly observed in the case of the waste energy recovery from the paper machine effluents (PM1/PM2 effluent) to preheat make-up water supplying the deaerator (Zone 1 in Figure 3). For this opportunity, the detailed steam mapping diagram indicates that 3.5 MW of steam energy can be substituted by waste heat, giving an opportunity for economic benefit of 0.76 M $/y based on the operating cost estimates. Other waste heat recovery opportunities could be rapidly screened as load and economic benefit for each zone.



PM: paper machine, Bl: black liquor, RB: recovery boiler, PB: power boiler

Figure 3: Steam and waste heat mapping assembly – Case study

The waste heat mapping provides information that can support the user in the decision making process for screening and selection of the most appropriate waste heat recovery opportunities and energy savings options (*Figure 4*).



PM: paper machine, PB: power boiler

Figure 4: Waste mapping – Case study

These diagrams can be used as a short-cut analysis to rapidly identify opportunities to save steam through waste heat recovery. The detailed process integration study should be applied for evaluation of all the opportunities, accounting for all the energy saving paths across the existing heat exchanger network for an improved retrofit solution. The mapping and Composite Curves diagrams of this case study have lead to practical heat recovery opportunities in the same order of energy savings. Accounting for the process and operating constraints, the plant has selected projects leading to 16 MW steam savings, thus corresponding to 15 % of energy savings and approximately 3.5 M$/y operating cost reduction.

5. Conclusions

The presented diagrams provide new insightful visualisation, and a systematic way of investigating the energy system of a process at the local level as well as the global level. It provides the global view without losing the specifics through merging as it is in the case of the Composite Curves. The representation should incorporate constraints on steam usage and temperature level for waste energy to allow practical evaluation of the energy scope. Moreover, the assembly of steam and waste mapping could provide preliminary design changes when placed at a minimum temperature difference relation. In the context of already highly integrated energy network, it is recommended to use the novel diagram also to represent the existing process-process heat exchangers together with the heaters, coolers and waste energy streams as a visualisation tool for the data/results of the detailed process integration.
Mapping of steam and waste heat profiles through the thermal energy integration embeds information and process constraints to facilitate a quick screening of opportunities for impending energy recovery and upgrading. Thus, these graphs provide a different site-wide energy view for industry yet following the principles of process integration. Economic insights have been added to the profile to give the user with additional information for the ranking and selection towards energy efficient decision.

Acknowledgments

The authors acknowledge the financial support provided by the Program on Energy Research and Development of Natural Resources Canada.

References

Linnhoff B., Townsend D. W., Boland D., Hewitt G. F., Thomas B. E. A., 1994, A user guide on process integration for the efficient use of energy. Rugby, UK (Revised edition).

Bengtsson C., Nordman R., Berntsson T., 2002, Utilization of excess heat in the pulp and paper industry – A case study of technical and economic opportunities, Applied Thermal Engineering. 22(9), 1069–1081.

Smith R., 2005, Chemical Process Design and Integration, John Wiley, Chichester, UK.

El-Halwagi M. M., 2006, Process Integration. Amsterdam: Academic Press, the Netherlands.

Kemp I. C., 2007, Pinch analysis and process integration. A user guide on process integration for efficient use of energy. Amsterdam: Elsevier, the Netherlands.

Klemeš J., Friedler F., Bulatov I., Varbanov P., 2011, Sustainability in the process industries. Integration and optimisation, New York: McGraw-Hill, USA.