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/CET1229050

Ensuring Cost-effective Heat Exchanger Network Design for Non-Continuous Processes

Andrew S. Morrison, Martin J. Atkins, Michael R. W. Walmsley

University of Waikato, Hamilton, New Zealand
asm10@waikato.ac.nz

The variation in stream conditions over time inevitably adds significant complexity to the task of integrating non-continuous processes. The Time Averaging Method (TAM), where stream conditions are simply averaged across the entire time cycle, leads to unrealistic energy targets for direct heat recovery and consequently to Heat Exchanger Network (HEN) designs that are in fact suboptimal. This realisation led to the development of the Time Slice Method (TSM) that instead considers each time interval separately, and can be used to reach accurate targets and to design the appropriate HEN to maximise heat recovery. However, in practise the HENs often require excessive exchanger surface area, which renders them unfeasible when capital costs are taken in to account.
An extension of the TSM that reduces the required overall exchanger surface area and systematically distributes it across the stream matches is proposed. The methodology is summarised with the help of a simple case study and further improvement opportunities are discussed.

1. Introduction

Energy prices continue to trend higher. In many industrial plants energy now qualifies as the second highest operating cost after primary feedstock costs. Figure 1 displays the relationship that has developed between fuel costs and equipment costs in recent times.

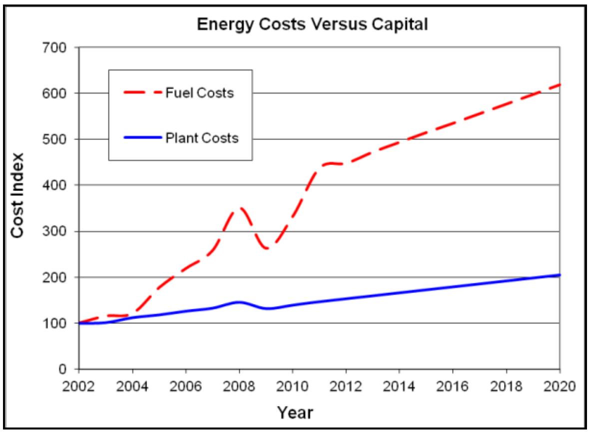

Figure 1: Energy costs have increased at a greater rate than capital costs in recent years

Please cite this article as: Morrison A. S., Atkins M. J. and Walmsley M. R. W., (2012), Ensuring cost-effective heat exchanger network design for non-continuous processes, Chemical Engineering Transactions, 29, 295-300

The increase in the cost of energy has been at a far greater rate than the increase in equipment costs (Cru Group 2012). A project that had a five year payback in 2002 will now have a payback of less than two and a half years. This change provides a greater incentive for companies to implement energy saving projects; however they are still often found to be uneconomic for non-continuous processes. This is because the time dependent nature of the process streams results in a reduced economic benefit for the same capital expenditure. Non-continuous processes include not only batch processes, but any process where stream conditions alter over time. These variations can be due to seasonal changes, required production specifications, or operational procedures.

As the relationship between energy and capital costs changes, industry has been driven to place more of a focus on energy reduction of non-continuous processes. Online optimisation tools that take real-time operating data and adjust process variables accordingly are becoming more popular. Often these systems are combined with R-curve analysis that allows the site target cycle efficiency to be updated based on the steam to power ratio. This information can then be used in tandem with software, such as KBC's ProSteam™ as shown in Figure 2, to model the site steam and power system and to ensure that the online modifications always consider the real cost of utilities as well as any equipment or system constraints. The model outputs can also be in the form of mode-dependent metrics to guide operators as they adjust the process to maximise energy savings during non-continuous operation.

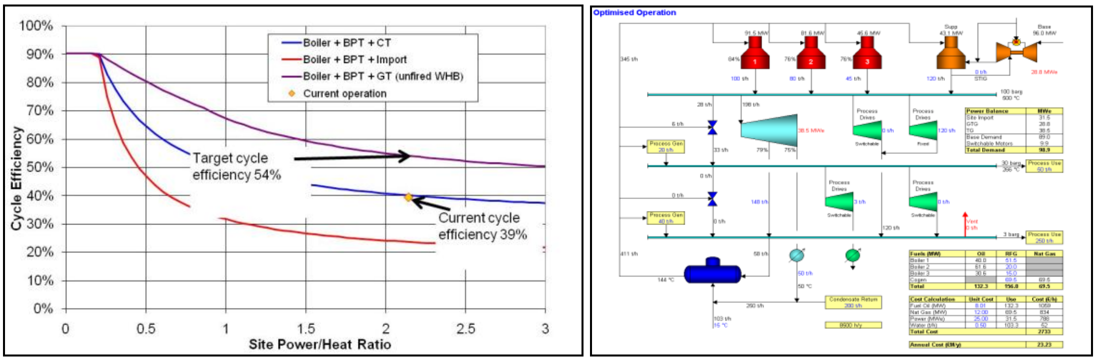

Figure 2: R-curve analysis and Prosteam™ software are used to optimise site utility systems

While operational systems can better deal with non-continuous processes, the design methods for heat integration have not evolved to the same degree. Pinch analysis is a tool most well known for designing heat exchanger networks (HEN), and over the last 30 years it has been successfully applied to an array of industrial applications. The recent escalation in energy costs, coupled with concerns about future supplies of non-renewable energy sources, has led to developments in the pinch analysis field. These developments have focused on the integration of non-continuous energy supply (Atkins 2010), in particular from renewable sources. However, the fundamental methods for carrying out pinch analysis of non-continuous process have not been progressed.

There are two established methods for pinch analysis of non-continuous processes. The Time Averaging Method simplifies the problem by averaging the stream duties across the entire operating cycle. This approach results in unrealistic targets for direct heat exchange (DHE), and consequently to poorly designed HENs. Alternatively, the Time Slice Method considers each time interval separately and reaches feasible targets for DHE. However, in reality the total exchanger surface area (TESA) required to recover the target energy is excessively high when using the TSM.

The following sections will investigating the target required TESA, as well as the target energy consumption for both the TAM and TSM. The results show that neither method is likely to produce the most cost-effective HEN when both capital costs and energy costs are considered. Instead, an extension to the TSM that can provide improved configurations will be briefly summarised. A full and detailed explanation of the methodology is outside the scope and size of this paper, and has not been attempted. The results have been discussed and further extensions that provide additional benefits have been identified.

2. Comparison of Established Methods

The TAM is a very simplistic method of dealing with non-continuous processes, and for this reason it is still commonly utilised. For processes where the time dependent nature is not significant it can be an acceptable approach. As a precaution, the surface area of each exchanger is often increased above the design targets to supposedly account for the time periods where area requirement is highest. However, for batch processes or other processes where conditions fluctuate widely the TAM is not preferable. Typically the TAM HEN will fail to meet heat recovery targets and will also unnecessarily oversize some of the exchangers.

The TSM uses a very different approach. The process is separated in to individual time intervals, and an optimal HEN is designed for each time interval. These HENs are then combined, and the overall HEN is created by analysing each combination of matching hot and cold streams in turn. To obtain the target DHE it is necessary to select for each match the largest exchanger area that is found across the time intervals. For example, if Hot Stream 1 and Cold Stream 1 require an exchanger area of 100 m^2 in the first time interval, and 200 m^2 in the second time interval, then the overall HEN must utilise an exchanger of 200 m^2. This ensures that the target DHE can be achieved in both time intervals, but also results in excess area in the first time interval.

While the TSM requires significantly more calculations than the TAM, the use of software packages for carrying out pinch analysis has downgraded the importance of calculation time. However, pinch analysis software for completing the TSM is not currently commercially available (Morrison 2007).

A three-part paper by Kemp and Deakin (1989a,1989b,1989c) provides a full explanation of the TSM, and compares the TSM DHE targets to those obtained using the TAM. However, the paper does not calculate the actual DHE that would be achieved by the TAM HEN, or the TESA requirements for either method. The HENs have been simulated for the same example problem used by Kemp and Deakin, and these additional results have been calculated for both methods as shown in Table 1 and Figure 3.

Table 1: Heat exchange and surface area requirements for the TAM and TSM HENs

	Direct Heat Exchange (kWh)	Total Exchanger Surface Area (m^2)
TAM	207.8	99.0
TSM	272.2	218.1

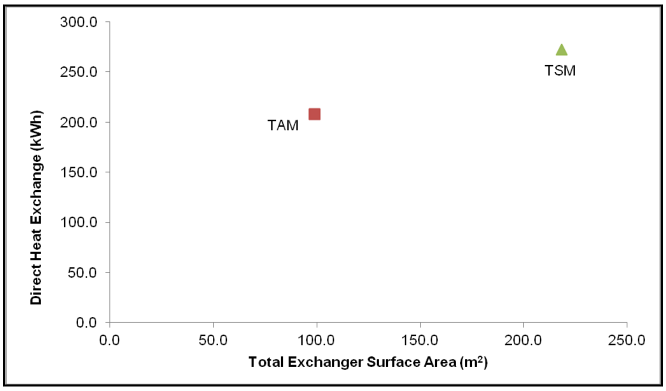

Figure 3: Heat exchange and surface area requirements for the TAM and TSM HENs

It is very unlikely that either the TAM or the TSM will combine the most effective combination of energy costs and capital costs so as to minimise the total annualised cost (TAC) of the HEN. The TSM method will only produce the optimum HEN if energy costs far exceed capital costs to the stage where capital cost contributions are insignificant when calculating the TAC. A comparison of the results shows that the TSM uses over 200 % more TESA, but only increases DHE by approximately 30 %.

3. Methodology Extensions

This section provides an overview of four possible scaling extensions to the TSM for generating an overall HEN for a non-continuous process. The extensions begin with the TSM HEN, but then systematically reduce the TESA requirement. Each extension distributes the TESA across the individual exchangers using a different approach and results in a different HEN. The example problem from Kemp and Deakin (1989a) has again been used to allow direct comparisons. In each extension the HEN TESA has been scaled to match the TESA used in the TAM HEN, and the amount of DHE achieved by the extension has also been compared to the TAM results.

Each of the following tables contains an overview of the scaling method that was used for that particular extension. The result, any noticeable problems with the result, and a conclusion are also summarised.

3.1 “Area Scaling” Extension

Table 2: Area Scaling extension summary

Method	TSM exchanger areas are scaled (by the same %) to match the total TAM area
Result	Improvement in DHE compared to the TAM HEN
Problem	Some low-use exchangers are oversized, while high-use exchangers are undersized
Conclusion	“Time” must be factored in to the scaling method, cannot use the same percentage

3.2 “Time Scaling” Extension

Table 3: Time Scaling extension summary

Method	TSM exchanger areas are scaled based on the % of time they are in operation
Result	Only a small improvement over the Area Scaling extension
Problem	Method only considers time in use, but not the amount of heat being recovered
Conclusion	Need to consider “Utilisation”, not just “Time”

3.3 “Utilisation Scaling” Extension

Table 4: Utilisation Scaling extension summary

Method	TSM exchanger areas are scaled by utilisation
Result	Large improvement in DHE when compared to the previous methods
Problem	Nothing significant
Conclusion	Attempt another scaling method that is similar to utilisation

3.4 “Heat Recovery Scaling” Extension

Table 5: Heat Recovery Scaling extension summary

Method	TSM HX areas are scaled by “Heat Recovery” to match the total TAM area
Result	Slight improvement over the “Utilisation” method provides the best results overall
Problem	None, analysis suggests the distribution of area is near optimal
Conclusion	The TESA should be distributed between exchangers based on “Heat Recovery”

4. Discussion of Results

The DHE and TESA results from the four scaling extensions are displayed in Table 6, and have also been plotted alongside the TAM and TSM results in Figure 4.

Table 6: Heat exchanged and surface area requirements for the four scaling extensions

	Direct Heat Exchange (kWh)	Total Exchanger Surface Area (m^2)
TAM	207.8	99.0
TSM	272.2	218.1
Area Scaling	211.4	99.0
Time Scaling	211.6	99.0
Utilisation Scaling	224.0	99.0
Heat Recovery Scaling	229.7	99.0

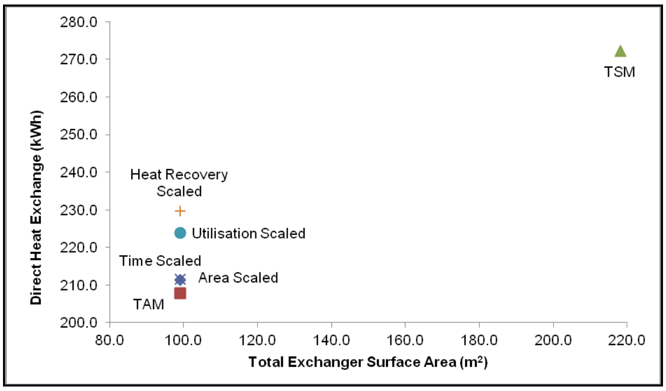

Figure 4: Heat exchanged and surface area requirements for the four scaling extensions

As mentioned earlier, in all scaling extensions the TESA has been arbitrarily set to match the TAM HEN. By using the same TESA it is possible to directly compare how the various extensions are able to utilise the area distribution to exchange heat. It is also possible to use a TESA that does match the TAM HEN, and there are established pinch analysis methods for area targeting that will recommend a TESA based on the ratio of energy and area costs. Area targeting has not been performed in this case study; however Figure 5 provides an indication of the results when the scaling extension is carried out for multiple TESA values.

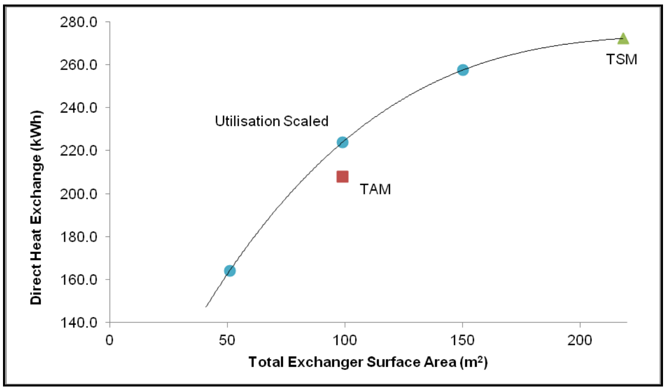

Figure 5: Trend-line of "Utilisation" scaling extension results for various TESAs

The "Utilisation" scaling extension has been repeated using a TESA of 150 m^2, as well as a TESA of a 50 m^2. As the TSM results coincide with the maximum DHE target, the results for each extension can be approximated as a trend-line on the diagram.

The results can also be displayed on a diagram that shows the relationship between TAC and TESA. Price factors for both exchanger surface area and utilities are required. For this example, the annual energy cost was set at 44.4% of the TAC, while the annualised exchanger capital cost accounted for the remaining 56.6% of the TAC.
Figure 6 displays the TAC results for each HEN that has been considered in this case study.

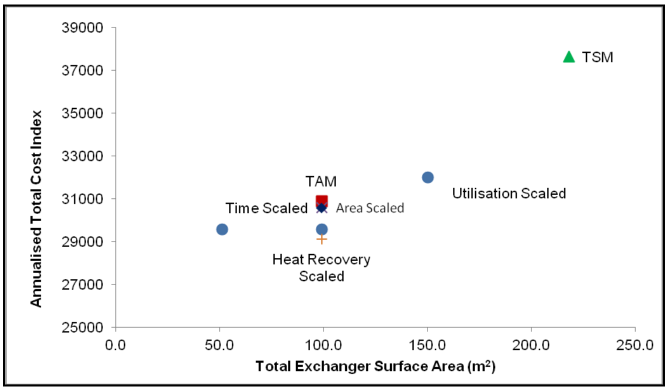

Figure 6: Total annualised costs for each HEN

5. Conclusions

When designing a HEN for an industrial application the typical aim is not to maximise DHE, but instead to minimise the TAC. Therefore, the HEN must correctly balance the annualised capital costs and the annual energy costs. This paper has investigated the two established methods used when generating an overall HEN for a non-continuous process. The results have shown that both the TAM and TSM are likely to produce suboptimal configurations that do not minimise the TAC. It has been demonstrated that improvements in the TAC can be obtained by implementing a scaling extension to the TSM that reduces the amount of TESA and systematically distributes the area across the necessary stream matches.
Further improvements can be obtained by applying improvised pinch analysis area targeting techniques. Likewise, additional improvements can be obtained by increasing the complexity of the TSM to examine time intervals with non-global minimum approach temperatures. Neither of these opportunities are covered in this case study due to space limitations.

6. References

Atkins M.J., Walmsley M.R.W., Morrison A.S. 2010, Integration of solar thermal for improved energy efficiency in low-temperature-pinch industrial processes, Energy, 35, 1867-1873.

Kemp I.C., Deakin A.W., 1989a, The cascade analysis for energy and process integration of batch processes. Part 1. Calculation of energy targets, Chemical Engineering Research & Design, 67, 495-509.

Kemp I.C., Deakin A.W., 1989b, The cascade analysis for energy and process integration of batch processes. Part 2. Network design and process scheduling, Chemical Engineering Research & Design, 67, 510-516.

Kemp I.C., Deakin A.W., 1989c, The cascade analysis for energy and process integration of batch processes. Part 3. A case study, Chemical Engineering Research & Design, 67, 517-525.

Morrison A.S., Walmsley M.R.W., Neale J.R., Burrell C.P., Kamp P.J.J., 2007, Non-continuous and variable rate processes: optimisation for energy use, Asia-Pacific Journal of Chemical Engineering, 2, 380-387.

Cru Group, 2012, Market analysis – cost curves<www.crugroup.com>, Accessed 08.03.2012