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A Comparison of Utility Heat Exchanger Network Synthesis for Total Site Heat Integration Methods

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This paper compares Utility Heat Exchanger Network (UEN) design between two Total Site Heat Integration (TSHI) methods, the Conventional Total Site Targeting method (CTST) and the recently developed Unified Total Site Targeting (UTST) method. A large Kraft Pulp Mill plant has been chosen as a case study. Total Site targets have been calculated using a Excel™ targeting spreadsheet and networks have been designed with the help of Supertaget™ for both the CTST and UTST methods. To achieve heat recovery and utility targets, both series and parallel utility heat exchanger matches for non-isothermal utilities are allowed in the CTST method, while series matches are allowed in the UTST method if the heat exchangers in series are from the same process. Series matches based on CTST method may create a dependency on two or more separate processes, which operational and control issues may occur, higher piping costs may be imposed, and utility target temperatures may not be achieved in the consecutive processes if one or more processes were to be out of service. Relaxation of the network can resolve these issues for the CTST method; however, if the relaxation occurs on the side of the utility loop that constrains heat recovery, the net heat recovery targets may not be achieved within the Total Site. The UTST method with its modified targeting procedure may offer slightly lower heat recovery targets but with simpler UEN design compared to CTST method are more realistic and achievable. Finally, after UEN design, non-isothermal utility loops need to be balanced in terms of mass and energy for both methods.

1. Introduction

A Heat Exchanger Network (HEN) for an industrial process may be considered to contain a Heat Recovery Network (HRN) and a Utility Exchanger Network (UEN). HRN refers to intra-plant heat integration (HI), which may be targeted, together with utility use, using Process Integration (PI) techniques, such as Pinch Analysis. PI is well developed in literature and includes methods to perform HEN synthesis based on heuristics, mathematical programming, and genetic algorithms (Klemeš and Kravanja, 2013).

The early efforts of inter-plant HI, commonly referred to as Total Site Heat Integration (TSHI), focused on setting heat recovery and utility targets (Klemeš, 2013). Central utility systems are employed to provide required heat and power for processes within a site while also being used to recover heat. In the first instance, TSHI focused on high temperature processes (Pinch Temperature, >120 °C) where steam (an isothermal utility) was used to indirectly recovery and supply heat. For low temperature processes (Pinch Temperature, <120 °C), Heat Recovery Loops (HRL), which use non-isothermal fluids such as water for heat transfer medium, act as a dedicated Heat Recovery system that may be enhanced by the integration of renewable energy (Walmsley et al., 2015) and heat transfer enhancement (Tarighaleslami et al., 2016a). Improving from these previous studies, Tarighaleslami et al. (2017) recently introduced a new Unified TSHI targeting method (UTST). This method aims to set more realistic and achievable targets for heat recovery and utility use. It may be applied to sites with low and/or high temperature processes, where isothermal and/or non-isothermal utility is needed.

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After targets are set, the challenge is then to design a HEN that meets (or nearly meets) the target. In the presentation of conventional TSHI (Klemeš et al., 1997), no details on the synthesis of a UEN are presented. This was likely due to the simplicity of the problem for a steam utility system where all utility exchangers may be in a parallel arrangement. A graphical method was proposed by Wang et al. (2014) to determine energy target of inter-plant heat integration with three different indirect connection patterns (parallel, split, and series) considering Site Pinch region. They showed that the parallel pattern connection will always recover more heat, but require more complex networks and higher investment costs. When the heat quality requirements of two heat sinks are similar, the split connection pattern achieves a better energy-capital trade-off. Series connection pattern is more attractive when the heat quality requirement of two heat sinks are very different as it offers shorter pipeline requirement.

Song et al. (2016a) presented a new strategy to select streams for inter-plant heat recovery to achieve maximum possible heat recovery via indirect HI. Using this technique, the existing HEN remains unchanged but the number of the participated streams may be reduced. The technique has only been applied to a two plant problem. They extended their work introducing Interplant Shifted Composite Curves (ISCC) to select participant plants and hot/cold streams for inter-plant HI among three plants, which will be able to reduce the number of participant streams before integration, while keeping energy targets unchanged (Song, et al., 2016b). Tarighaleslami et al. (2016b) introduced a procedure to optimise utility temperature selection, heat recovery, and shaft work production based on the Unified TSHI method. Zhang et al. (2016) presented a MINLP model for simultaneous HEN design for HI using hot direct discharges/feeds between process plants. However, there is still a gap in literature to present UEN synthesis based on TSHI techniques for utility systems that use non-isothermal utilities, such as water.

The aim of this paper is to compare UENs that achieve the TSHI heat recovery and utility targets of the conventional method and the new unified method. To achieve the aim, UEN synthesis methods are defined for the conventional and Unified TSHI methods such that their targets may be achieved through the design. SuperTarget™ by KBC Advanced Technologies (KBC, 2016) has been used to design the networks. An Excel™ spreadsheet has been developed to calculate targets based on both conventional and unified TSHI methods. The results are based on the analysis of a Kraft Pulp Mill case study.

2. Method

This paper applied two methods to perform both HRN and UEN synthesis, with emphasis on the UEN. The network design in each method are as follows:

2.1 Utility Exchanger Network design based on the Conventional TSHI targeting (CTST) procedure

To design UEN based on CTST method the following steps should be applied.

1) Target process heat recovery and utility use;
2) Design HRN and identify/extract stream segments that need utility for each process;
3) Target TSHI using the composite of process stream segments that require utility; and,
4) Design the arrangement of the UEN based on the process stream segments available.

2.2 Utility Exchanger Network design based on the Unified TSHI targeting procedure

To design UEN based on UTST method, as the utilities are targeted in process level (Tarighaleslami et al., 2017) based on methods constraint TS network design is easier. Therefore, the following steps should be applied.

1) Target process heat recovery and utility use;
2) Simultaneously design the HRN and UEN for each process assuming a utility may be constrained to be supplied from and returned to the utility system at specified temperatures; and,
3) Calculate the quantum of TS heat recovery that is achievable based on the balance of sources and sinks for each utility.

Following each of these methods, the automated network design function in SuperTarget™ is applied to generate the HRN and UEN based on the two procedures.

3. Industrial case study description

A large Kraft Pulp Mill plant has been chosen as the case study. This site has a high potential to generate combined heat and power as well as to use the hot water utility system to recover heat. The stream data for this case study, including minimum approach temperatures, have been taken from Bood and Nilsson (2013). The cluster has 10 different processes with a total of 64 streams.

Table 1 presents the utility levels that are used in the plant. Very High Pressure Steam (VHPS) enters the turbine to generate power and supply heat at the various levels. Other than VHPS, utility temperatures have been optimised by minimising a total cost target using a modified method from Tarighaleslami et al. (2016b).

Table 1: Optimal required utilities for Kraft Pulp Mill plant.

Utility Name	Utility Type	T_s (°C)	T_t (°C)	P (bar g)
Very High Pressure Steam (VHPS)	Hot	450.0		90
High Pressure Steam (HPS)	Hot	198.4		15
Low Pressure Steam (LPS)	Hot	158.9		9
High Temperature Hot Water (HTHW)	Hot	93.0	77.3	
Low Temperature Hot Water (LTHW)	Cold	57.0	25.0	
Cooling Water (CW)	Cold	25.0		

4. Utility heat exchanger network synthesis

UEN has been strictly designed based on the CTST and UTST methods. CTST methods inherently allow a utility's target temperature to be met using heat exchanger matches in series and/or in a parallel configuration or even by only a single heat exchanger from any process. On the other hand, new UTST method allows heat exchangers to be in both parallel and series configuration to achieve the utility target temperature, if and only if the heat exchangers in series are from the same process (Tarighaleslami et al., 2017). To demonstrate the merits of new Unified TSHI method and its target, non-isothermal utility networks for a Kraft Pulp Mill (i.e. HTWH and LTHW) are targeted, and HENs designed and analysed.

4.1 High Temperature Hot Water network design

Figure 1 shows a comparison of UEN designs based on CTST method versus UTST method for HTHW utility in the Kraft Pulp Mill plant. There are three matches in series in the CTST design (Figure 1a). These matches require (before network relaxation) the HTHW utility to be supplied to the Causticizing process, then piped to Miscellaneous 4, and then finally to the Digestion process. The UTST design avoids such matches (Figure 1b).

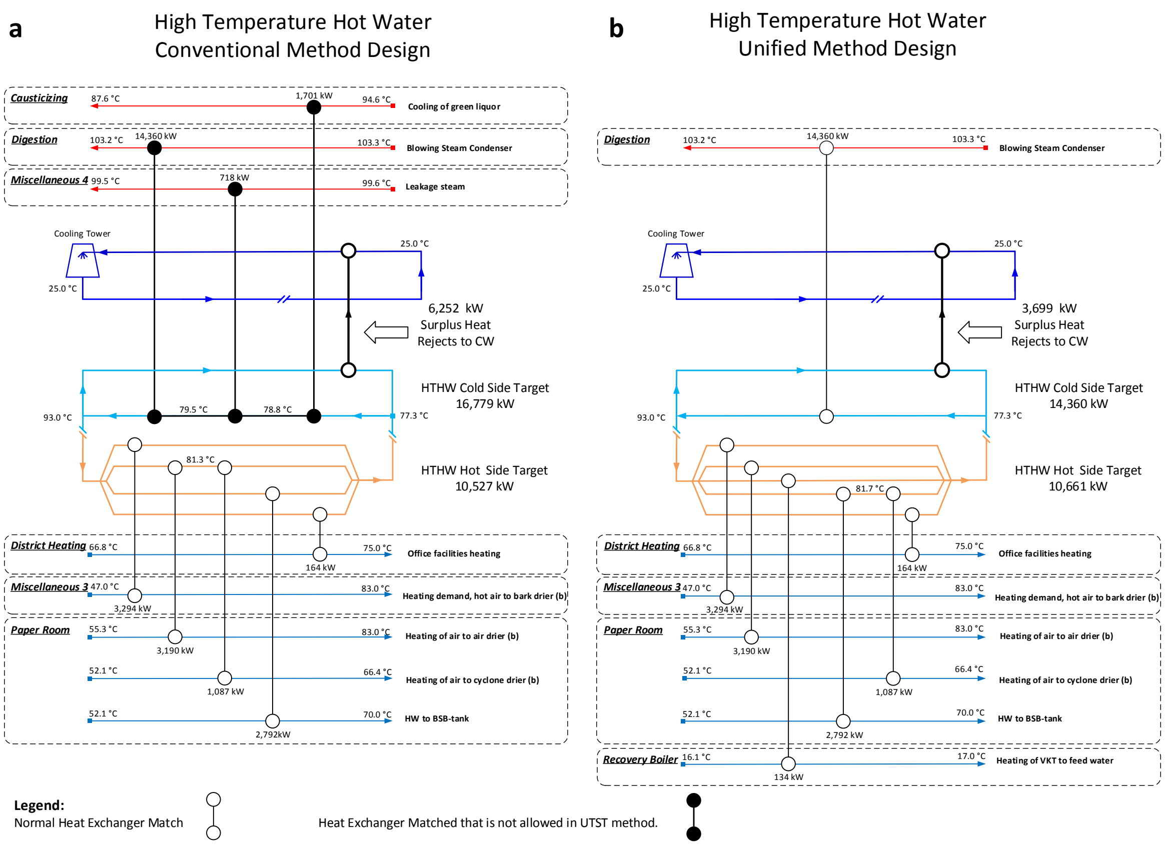

Figure 1: High Temperature Hot Water Loop design a) Conventional method; b) Unified method.

4.2 Low Temperature Hot Water network design

Figure 2 shows a comparison of UEN designs based on CTST method versus UTST method for LTHW utility of the mill. As shown in *Figure 2*a, all matches on the cold side of the loop are in a series arrangement. This means LTHW utility is supplied to the Wash process, then passed to the Digestion process, and so on through each of the series matches. Two branches on the hot side of the loop also contain series matches between different processes. Like the HTHW designs, the UTST design avoids such an arrangement (Figure 1b).

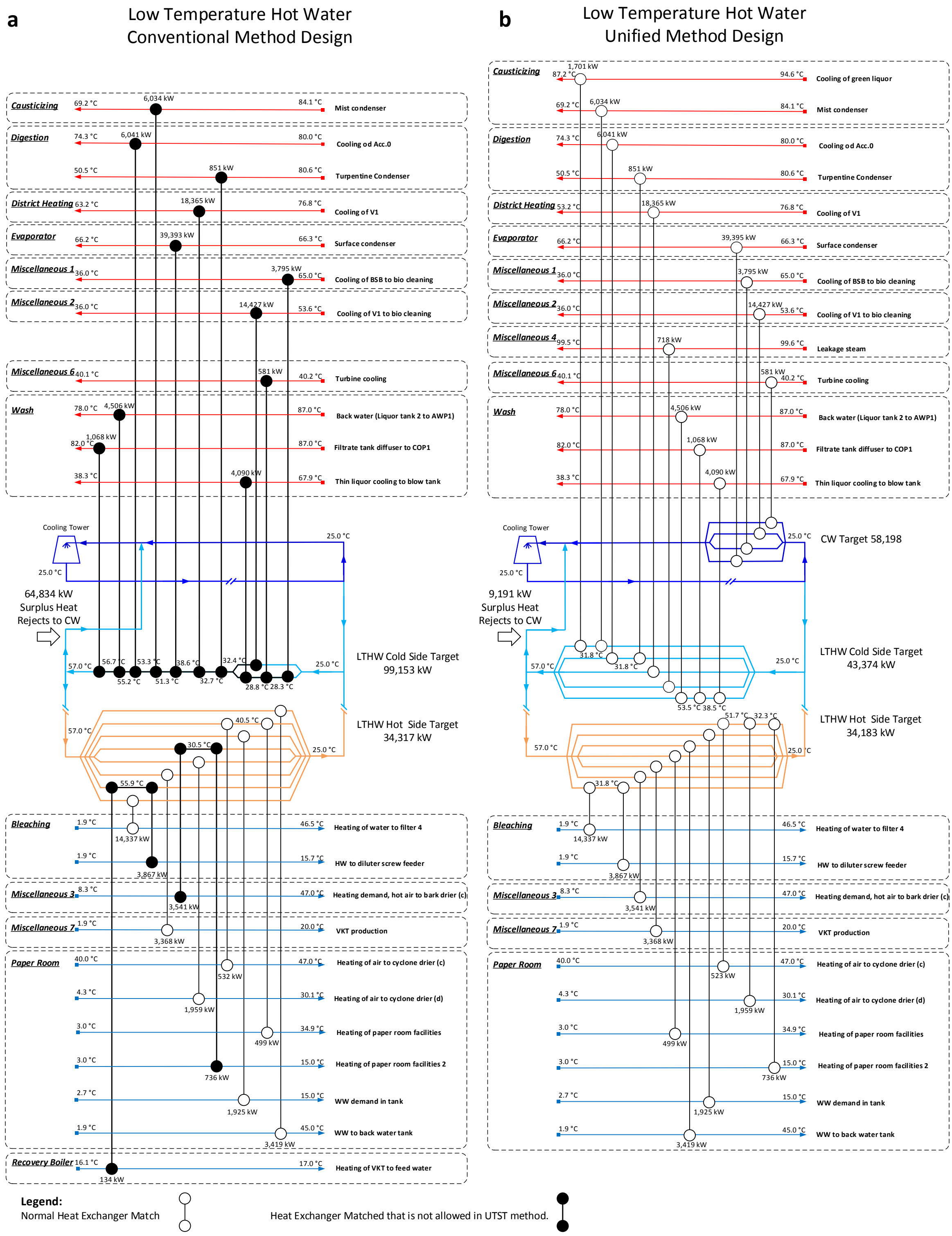

Figure 2: Low Temperature Hot Water Loop design a) Conventional method; b) Unified method.

5. Results and Discussion

The difference between UEN designs may be considered in three aspects: (1) Structural differences in design, (2) Energy and mass balance of utility loop, and (3) Heat recovery targets.

5.1 Impact of TSHI method on utility exchanger network design

Different TSHI methods may generate different UEN designs because of the differences in the targeting method and any inherent constraints.

As it can be seen in Figures 1a and 2a, the hot side of HTHW loop and both cold and hot sides of LTHW loop, series matches are required to achieve the conventional TS target. For instance, to achieve the target of hot water generation for the LTHW loop, 11 heat exchangers receiving heat from 8 different processes and zones. To implement such as solution, which is required to achieve the conventional TS heat recovery and utility targets, would be problematic. The pipework required for such a series of matches would be extremely expensive. If one of the processes were to be out of service, it would affect the utility supply temperature to the subsequent process, which may cause operational and/or control issues. It also means the specified target temperature of the utility may not be achieved, potentially propagating process control issues to the hot side of the LTHW system. For this case study, the UEN for the LTHW may be relaxed with no decrease in heat recovery because the sources for the LTHW greatly exceed the sinks. In other cases, such relaxation may not be possible, effectively decreasing the usefulness of the TS target with respect to non-isothermal utility loops.

The unified TS method forbids series matches of utility between different processes (Figures 1b and 2b). This is inherent in the way the TS target is formulated. As a result, the unified method does not use similar series utility matches between processes. Some process-utility matches are therefore different. For example, “Heating of VKT to feed water” stream is on LTHW for the conventional TS method design and on the HTHW for the unified TS method.

5.2 Heat and mass balancing of non-isothermal utility loops

Since the case study is a Kraft Pulp Mill plant, the process inherently generates large quantities of low grade heat. As a result, the LTHW and HTHW loops have excess heat, i.e. the source duty is much greater than sink duty. In a final design of UEN, each utility must be balanced in terms of mass and energy for both cold and hot sides. Surplus heat must be rejected to a cooling system, e.g. air-cooled heat rejection, to maintain a successful operation. The surplus heat may also be considered as a heat source for other uses within another local system such as district heating stream or to the other plants in the cluster. In other cases, a utility loop may have a deficit of heat, which must be provided from higher temperature utilities, e.g. LP steam, or directly from the furnace. As it can be seen in Figure 1a, the HTHW loop receives 16.8 MW from process sources on its cold side; however, it only transfers 10.5 MW from the hot side to process sinks. The 6.3 MW surplus heat must be rejected from the utility, e.g. the CW in cooling tower cycle. Similarly, in LTHW loop, the cold side receives 99.1 MW from the process sources and supplies 34.3 MW to process sinks in the UEN design based on the conventional method, *Figure 2*a. The difference, 64.8 MW, must be rejected to the cooling system or to another process. A similar balancing must occur for the UTST method (Figures 1b and 2b).

A network relaxation approach may be applied to reduce the imbalance between sources and sink connected to a non-isothermal utility. Relaxation may help reduce and eliminate series matches in CTST. In this case, excluded streams may provide surplus heat directly to the cooling system. Another option to transfer heat from the utility loop itself to the cooling system. This heat may be transferred indirectly using a heat exchanger (Figure 1) or by directly mixing fluids if the two systems use the same fluid, i.e. water.

5.3 Heat recovery targets in each design

After the full HRN and UEN networks are designed, it may not achieve the targets set for the CTST method. Targets assume the HRN is designed such that stream segments that require utility exactly match GCC segments.

Table 2: Comparison of utility targets before/after UEN design based on Conventional and Unified methods.

Targeting Method	Q_{Hot} (MW)	Q_{Cold} (MW)	Heat Supplier Utility HPS (MW)	Heat Supplier Utility LPS (MW)	Heat Supplier Utility HTHW (MW)	Heat Supplier Utility LTHW (MW)	Heat Receiver Utility HTHW (MW)	Heat Receiver Utility LTHW (MW)	Heat Receiver Utility CW (MW)
Unified TSHI Targets	213.0	115.9	27.7	140.4	10.7	34.2	14.3	43.4	58.2
Unified TSHI Targets after Network Design	213.0	115.9	27.7	140.4	10.7	34.2	14.3	43.4	58.2
Conventional TSHI Targets	213.0	115.9	27.7	140.4	10.6	34.3	17.4	98.5	0
Conventional TSHI Targets after Network Design	213.0	115.9	28.3	139.9	10.5	34.3	16.8	99.1	0

GCC is an extreme condition in the network design. Any time there is a temperature difference between utility profiles and process profiles; there is a flexibility that the site does not have to operate at exact minimum approach temperature and exact targets won't necessarily be achieved that match the GCC. The final split between utilities is affected by the design of the HRN because it determines the actual stream segments left over for use at the Total Site level and, therefore, how much utility is consumed. The UTST method does not face the same problem because both the HRN and UEN are designed at the process level. If process level targets are achieved, TS targets must also be achieved. Table 2 presents a comparison between total cold utility and total hot utility targets as well as heat receive and supply targets for each utility loop before and after network design based on both conventional and unified TS methods.

6. Conclusions

This paper compared Utility Heat Exchanger Networks (UEN) that were strictly designed to achieve the targets for two Total Site Heat Integration methods. UEN designs show that in many instances it is impractical to achieve Conventional Total Site (CTST) heat recovery (HR) and utility targets for low temperature processes that require non-isothermal utilities. This impracticality arises from the need, at times, for several process sources or sinks to be matched in a series arrangement to achieve the Total Site target. Relaxation of the network can help solve this problem with the conventional method but if the network relaxation occurs on the side of the utility loop that constrains HR, there will be an increase in the site's net utility consumption. The recently developed Unified Total Site method uses a modified targeting procedure. HR targets tend to be lower but more realistic to achieve, which was demonstrated by the simpler UEN design compared to the design based on the CTST method.

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