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Targeting the maximum heat recovery for systems with heat losses and heat gains

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ABSTRACT

Process Integration using the Pinch Analysis technique has been widely used as a tool for the optimal design of heat exchanger networks (HENs). The Composite Curves and the Stream Temperature versus Enthalpy Plot (STEP) are among the graphical tools used to target the maximum heat recovery for a HEN. However, these tools assume that heat losses and heat gains are negligible. This work presents an approach that considers heat losses and heat gains during the establishment of the minimum utility targets. The STEP method, which is plotted based on the individual, as opposed to the composite streams, has been extended to consider the effect of heat losses and heat gains during stream matching. Several rules to guide the proper location of pipe insulation, and the appropriate procedure for stream shifting have been introduced in order to minimise the heat losses and maximise the heat gains. Application of the method on two case studies shows that considering heat losses and heat gains yield more realistic utility targets and help reduce both the insulation capital cost and utility cost of a HEN.

1. Introduction

Pinch Analysis (PA) was introduced by Linnhoff and Flower in 1978 [1]. The Composite Curves (CCs) [2], which are a plot of hot and cold streams composites on a ‘Temperature versus Enthalpy’ diagram is one of the most established tools of PA. The CCs allow the minimum energy targets of a plant heat exchanger network (HEN) to be determined. Pinch Analysis has been well utilised in sectors such as the petrochemical [3], chemical [4] and food [5] industries. Apart from the CCs, other utility targeting methods include Problem Table Algorithm (PTA) [1], Simple Problem Table Algorithm (SPTA) [6], Geometry-based Approach [7], Enthalpy Flow rate and Temperature technique [8], Modified Problem Table Algorithm (MPTA) [9], Universal Targeting Algorithm (UTA) [10], Grid Diagram Table (GD) [11], Stream Temperature versus Enthalpy Plot (STEP) [12], Rigorous Multiple Utility Targeting (RMUT) [13], Segregated Problem Table Algorithm (SePTA) [14] and Floating Pinch Method [15]. The Conventional PA has also been improvised via the introduction of virtual heat exchangers that convert components, i.e. reactors into equivalent heaters or coolers while the stream compositions remain unchanged [16] and to include chemical reactions [17]. All these targeting methods, however, assume negligible heat losses and heat gains both during stream heat exchange and during transfer of streams between process units and heat exchangers. Consideration of heat losses and heat gains can actually reduce the minimum heating and cooling requirements of a HEN as well as reduce the pipe insulation cost.

Kemp [18] considers heat losses or heat gains under the category of process modifications. Heat losses or heat gains can be optimised by following the Plus-Minus Principle (PMP) introduced by Linnhoff and Vredeveld [19], which states:

(a) To reduce the hot utility requirement ($Q_{H,min}$), increase the total hot stream heat load above the Pinch or decrease the total cold stream heat load above the Pinch.
(b) To reduce the cold utility requirement ($Q_{C,min}$), decrease the total hot stream load below the Pinch or increase the total cold stream heat load below the Pinch.

Although these are well-known rules, they have not been used and combined with the PA targeting method due to the difficulties of analysing heat losses from the composite streams. Extension of the STEP technique [12] that involves individual stream matching during the simultaneous Maximum Heat Recovery (MHR) targeting and design allows heat losses and heat gains to be easily

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Nomenclature

T	stream temperature (°C)
$T_{s,l/g}$	supply stream temperature going into heat exchanger (after heat loss/gain) (°C)
T_s	stream supply temperature (°C)
$T_{t,l/g}$	stream target temperature coming out from heat exchanger (before heat loss/gain) (°C)
T_t	stream target temperature (°C)
T_a	ambient temperature (°C)
F	Mass flow rate (kg/s)
C	heat capacity flow rate (W/°C)
C_p	specific heat capacity (kJ/kg °C)
h_i	convective coefficient on the inside of the pipe wall (W/m^2 °C)
h_o	convective coefficient on the outside of the pipe wall (W/m^2 °C)
A_o	area of heat transfer outer pipe (m)
r_i	inner radius of the pipe (m)
r_o	outer radius of the pipe (m)
L	length of pipe (m)
$Q_{H,min}$	hot utility requirement (kW)
$Q_{C,min}$	cold utility requirement (kW)

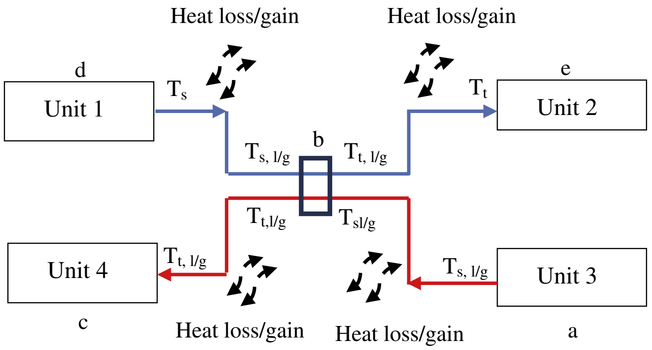

Fig. 1. Illustration of heat gains and losses for process streams.

incorporated into the targeting stage. This enables a designer to assess the effects of heat losses and heat gains on minimum utility targets as well as the extent of insulation needed, or to be avoided.

This paper introduces a set of heuristics to design an optimal MHR network that considers heat losses and heat gains of streams between process units (but not losses from units such as heat exchangers). The heuristics are incorporated in the extended STEP method to create an improved targeting technique that will ultimately reduce pipe insulation costs and increase utility savings (thereby reducing utility costs).

2. Heuristics for optimisation of heat losses and heat gains

Heat losses occur if the temperature of a stream (T) is higher than the ambient temperature (T_a) and heat gains occur if T is lower than T_a. In most processes the temperatures of the streams will be above T_a, and they will therefore be subject to heat losses, whereas in cryogenic and refrigeration systems, the temperatures of the streams will generally be lower than T_a and they will experience heat gains. Heat will be lost/gained from/by the entire stream; i.e. starting from its origin until it reaches its destination. Hence, heat losses/gains will affect the effective stream supply temperature ($T_{s,l/g}$). Heat losses/gains occur between process units and heat exchangers, and also between heat exchangers. Hence, this will affect the effective stream target temperature that must be set at the heat exchanger exit ($T_{t,l/g}$) so that the target temperature (T_t) for the next process unit can be achieved. Fig. 1 shows impact of heat losses on both hot streams and cold streams. Note that whenever heat exchange takes place, both the hot and the cold stream involved will have to move from their source to their destination via the heat exchanger. At this early design stage it cannot be assumed a priori where the heat exchangers will be located relative to the process units.

Fig. 2 shows the effect of heat losses or heat gains on hot and cold streams. The lines are extracted from the Temperature versus Enthalpy diagram. Fig. 2a shows that a hot stream with a T_s of 130 °C and a T_t of 100 °C. Let's assume a heat loss situation. With reference to Fig. 1, as the hot stream is routed from Process Unit 3 at location 'a' to a heat exchanger at location 'b', the stream supply temperature will drop (e.g. to 125 °C). This new, and lower supply temperature is labelled as $T_{s,l/g}$. As the hot stream exits the heat exchanger and moves to Process Unit 4 at location 'c', the stream will undergo a further temperature drop. However, since we would like to maintain the T_t at 100 °C, a higher heat exchanger exit temperature needs to be set ($T_{t,l/g} = 105$ °C) to take into account the temperature drop when the stream arrives at location 'c'. Let us now consider the cold stream. The cold stream moves from Process Unit 1 at location 'd' to the heat exchanger at location 'b', and stream moving from Process Unit 1 to Process Unit 2 has a T_s of 50 °C and a T_t of 80 °C then to the Process Unit 2 at location 'e'. Assuming that the piping distance is shorter between locations 'd', 'b' and 'e', the heat loss will be less, e.g. 2 °C temperature drop for $T_{s,\ l/g}$ and $T_{t,\ l/g}$ to 48 °C and 82 °C (see Fig. 2d). Note that the extent of the temperature change is a function of how long the pipe is carrying the stream between the process units. Fig. 2c and b shows the possible temperature effects due to heat gain.

Such considerations lead to the following heuristics to optimise heat losses and heat gains in a HEN:

Above the Pinch:

(i) If $T > T_a$ (heat loss), the stream needs to be insulated.
(ii) If $T < T_a$ (heat gain), the stream does not need to be insulated. This will result in reduction of $Q_{H,min}$.

Below the Pinch:

(i) If $T > T_a$ (heat loss), the stream does not need to be insulated. This will result in reduction of $Q_{C,min}$.
(ii) If $T < T_a$ (heat gain), the stream needs to be insulated.

For a stream that leaves a heat exchanger at the Pinch point, whether it is above or below the Pinch:

In order to maintain the Pinch point, all streams exiting heat exchangers at the Pinch need to be insulated.

3. The extended STEP method considering heat losses and heat gains

The Streams Temperature vs Enthalpy Plot (STEP) and Heat Allocation and Targeting (HEAT) Diagram introduced by Wan Alwi