CHEMICAL ENGINEERING TRANSACTIONS Volume 25, 2011
Editors Jiří Jaromír Klemeš, Petar Sabev Varbanov, Hon Loong Lam
Copyright © 2011, AIDIC Servizi S.r.l., ISBN 978-88-95608-16-7 ISSN 1974-9791
DOI: 10.3303/CET1125031

Application of Heat Recovery Loops for Improved Process Integration between Individual Plants at a Large Dairy Factory

Martin J. Atkins*, Michael R.W. Walmsley, James R. Neale

Univ. of Waikato, Energy Research Centre, School of Engineering,
Private Bag 3105, Hamilton, New Zealand
matkins@waikato.ac.nz

Indirect heat transfer between individual plants at a large industrial site, such as at a large dairy factory, can be accomplished using a Heat Recovery Loop (HRL) operating at relatively low temperatures (20 – 50°C). Direct heat transfer between plants is problematic because of the production schedule and frequent process start-up and shutdown that occur due to the need for regular cleaning. The dynamic operation of an industrial HRL at a large dairy factory is presented and briefly discussed. A HRL based on a set of stream data is used to examine the affect of heat storage capacity and HRL temperature on the amount of heat recovery. Storage volume can significantly improve the amount of heat recovery. The interface level in the storage tank is also modelled for different volumes and the resulting system is very dynamic and therefore good control needs to be incorporated into the HRL.

1. Introduction

Total site analysis is often used to integrated entire processing sites or groups of sites (Dhole and Linnhoff, 1993; Klemeš et al., 1997) and the method has recently been extended to consider individual processes with different minimum approach temperatures (ΔT_{min}) (Fodor et al., 2010). However for processing sites and individual plants with low pinch temperatures (<≈100°C), indirect heat transfer and integration via the steam or utility system is not feasible or economic. Improving the integration of large industrial sites with many individual plants operating and low pinch temperatures is a challenging undertaking, especially when those plants operate in a non- and semi-continuous manner. At large dairy factories with a mixture of processes on site the opportunity often exists to indirectly transfer heat between processes using a liquid heat recovery loop (HRL) operating at moderate temperatures (Atkins et al., 2009; 2010). Thermal storage is often incorporated in order to maximise heat recovery and is in many cases a single stratified tank (Walmsley et al., 2009; 2010).

The dynamic operation and variability of a HRL at a typical dairy factory with multiple plants on site will be examined in this paper. The issue of the dynamic operation and control of the HRL and the inherent need to balance the total heating and cooling loads will be discussed. Furthermore the effect of the capacity of the thermal storage system on the operation of the HRL and the amount of total heat recovery is also examined.

Please cite this article as: Atkins M., Walmsley M. and Neale J., 2011, Application of heat recovery loops for improved process integration between individual plants at a large dairy factory, Chemical Engineering Transactions, 25, 183-188
DOI: 10.3303/CET1125031

2. Heat Recovery Loop

A schematic of the HRL concept using a stratified tank is shown on the left in Figure 1. Source and sink streams are likely to be located within different parts of the plant as a source and sink stream within the same process suggests the opportunity for direct heat transfer and integration. Individual processes at large dairy factories often include a mixture of different processes such as milk powder production, Anhydrous Milk Fat (AMF), butter, cheese, whey, lactose, and cream products. These plants operate in a non-continuous manner due to the need for regular cleaning of the process equipment.

A characteristic temperature profile along the height of a stratified tank is shown in Figure 1. Thermocline growth and movement accelerates the loss of stratification and therefore decreases the effective capacity of the tank (Walmsley et al., 2009; 2010). The operability of the HRL can be severely affected by poor thermocline management.

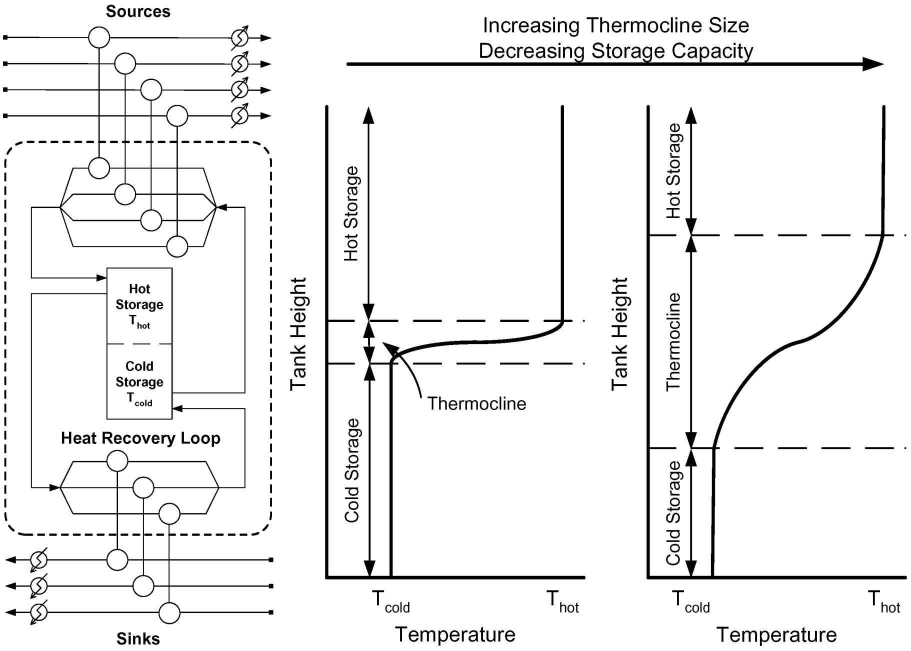

Figure 1: schematic of heat recovery loop (left) and characteristic temperature profile along stratified tank height, degrading as thermocline height increases (right).

2.1 Industrial Heat Recovery Loop - Example

The data presented in Figure 2 is operational data for an installed HRL with a 500 m^3 stratified tank over a seven day period close to peak milk production. The total heat transferred from the HRL to the sources and sinks is shown in Figure 2 (top) with the duty of the sources shown as a negative value to separate the data. The stratified tank stores hot water at 40°C and cold water at 20°C and excess hot or cold water is produced when there is an imbalance between the total duty of the heat sources and sinks as shown in Figure 2 (middle). The position of the thermocline or interface between the hot and cold regions can move up and down significantly within the tank in response to changes in the heating and cooling loads as shown in Figure 2 (bottom). When the load imbalance is large the rate of change in thermocline height is fast and therefore the stratification degrades more quickly. The hot and cold temperatures (T_{hot} and T_{cold}) are also shown in the figure.

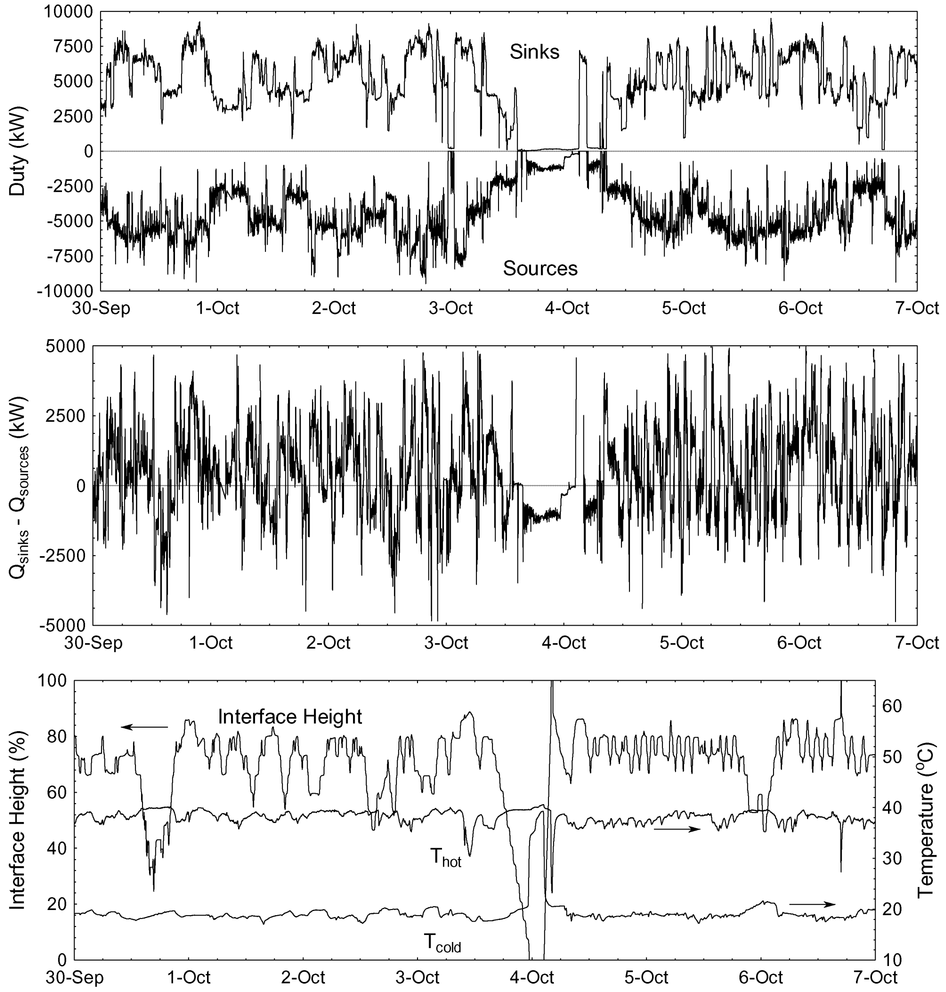

Figure 2: operational data for an industrial HRL with source/sink duties (top), duty imbalance (middle), and tank temperatures and interface height (bottom).

3. Heat Recovery Loop - Case Study

A large dairy plant with multiple processes will be considered in this paper and a more detailed description of this plant has been presented elsewhere along with the methodology regarding targeting and loop temperature selection (Atkins et al., 2009, 2010). The stream data for potential candidates is presented in Table 1 with the supply and target temperatures (T_s and T_t respectively) and the average heat flow rate (mc_p)

shown. Depending on the supply temperature and the hot temperature of the loop (T_{hot}) not all streams will be able to be on the HRL. To balance the loop when insufficient storage is available, each stream is designated to be either dropped off the HRL or to have load trimmed. There is a priority to the order that streams are trimmed or taken off the HRL which needs to be optimised to avoid control issues.

Table 1: Stream data of potential HRL streams.

Stream	Plant	Stream Type	T_s (°C)	T_t (°C)	Average mc_p (kW/°C)
Cow Water A	Dryer A	Hot/Source	52	10	19.2
Cow Water B	Dryer B	Hot/Source	50	10	96.0
Cow Water C	Dryer C	Hot/Source	55	10	223.8
AMF	AMF	Hot/Source	60	12	18.6
Site Hot Water	Site	Cold/Sink	10	65	156.8
Product Heating	Cream	Cold/Sink	10	50	27.2
CIP Water	Milk Treatment	Cold/Sink	10	60	20.9

4. Source/Sink Variability

Each of the streams shown in Table 1 has a certain amount of variability in flow rate due to process fluctuations and non-continuous operation of the plants due to regular cleaning and the like. For example, a single source and sink stream is shown in Figure 3 to illustrate the variability in heat flow rate over a period of several hours.

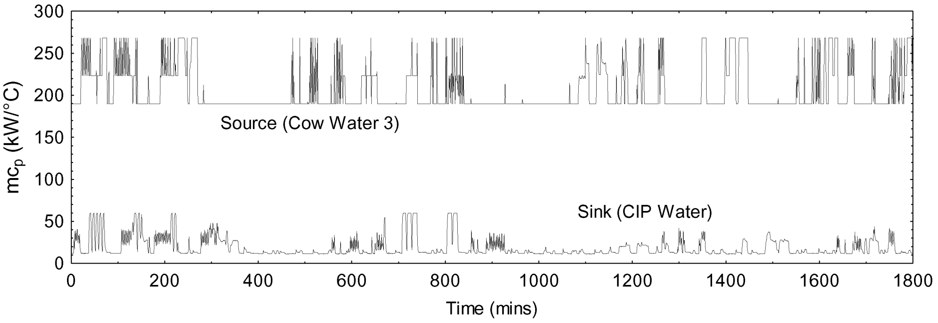

Figure 3: variability in heat flow rate (mc_p) for a source and sink stream considered for inclusion on a HRL.

A simulation tool for a HRL was developed to determine the affect of important design variables, such as T_{hot}, T_{cold}, tank volume, and control strategies, on the amount of heat recovery. Historical data for each stream was used to assess the affect of variability on tank performance and model hot and cold storage levels. A ΔT_{min} of 5°C and T_{cold} of 20°C was used. The growth of the thermocline region is not modelled in the simulation due to the complexity of the problem. Computational Fluid Dynamics has been successfully used to model this for industrial stratified tanks including the effect of the movement of the thermocline (Walmsley et al., 2010).

5. Stratified Tank Volume

The volume of the storage tank is an important design decision that has an important affect on the economics of the project. An oversized stratified tank is a misapplication of capital while an undersized tank will result in less total heat recovery and an increase in total energy use. If there is no storage then the heating and cooling loads on the HRL will be controlled so that they always balance. A small buffer tank would be needed to allow for the dynamics of the system but this would not be considered as storage. The affect of storage on the amount of heat recovery is shown in Figure 4 (left) for three different hot temperatures. As the storage volume is increased the average HRL duty increases quickly before reaching a maximum.

The normalised load imbalance for the three T_{hot} at a tank volume of 100 m^3 is shown in Figure 4 (right). The normalised load imbalance is calculated using Equation 1, where Q_{sink} and Q_{source} is the instantaneous load imbalance between the heat and cooling side of the loop, and $Q_{average}$ is the average duty of the loop. When this value is equal to zero then both sides of the loop are balanced and no storage is being used. This occurs when the tank is full of either cold or hot water. If the volume of the tank is sized too large (e.g. T_{hot}=45 and 47°C) then there is a tendency for the tank to fill with hot water because in this case there are excess heat sources, resulting in a tank that is used only a small portion of the time.

The interface level of a 50 and 100 m^3 tank for T_{hot}=50°C is shown in Figure 5. The interface can move quickly due to large load imbalances, which would result in an accelerated loss of tank stratification due to thermocline growth. The rate of interface movement is much greater for the smaller tank illustrating the importance of tank size not only on the amount of heat recovery but also on the operability of the HRL.

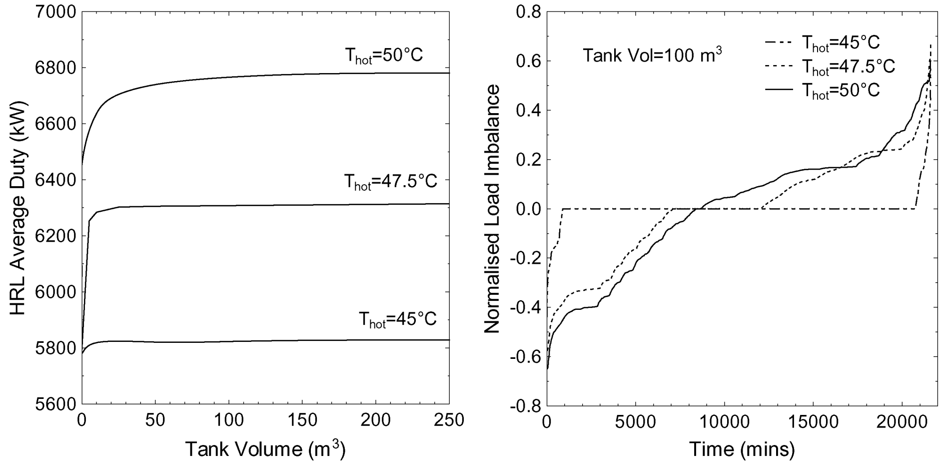

Figure 4: average HRL duty for different storage volumes (left) and a sorted normalised load imbalance between the heating and cooling sides of the HRL for three T_{hot} (right).

$$\text{Normalised Load Imbalance} = \frac{Q_{sink} - Q_{sources}}{Q_{average}} \qquad (1)$$

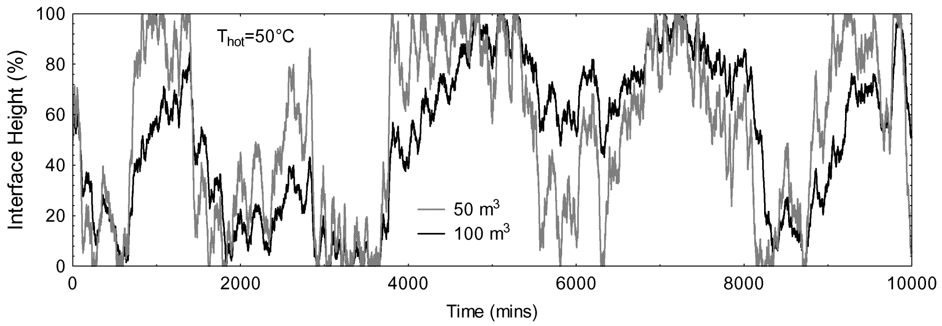

Figure 5: tank interface height for a 50 and 100 m^3 stratified tank.

6. Conclusions

Heat recovery loops can be used to indirectly integrate large industrial sites, which have low pinch temperatures, such as dairy factories,. The variability of the source and sink streams needs to be accounted for when optimising the hot and cold loop temperatures and stratified tank volume. The effect of storage volume on the amount of heat recovery is highly dependent on the hot temperature of the loop and reaches a maximum after which extra storage yields no further benefit. The resulting system is very dynamic and therefore good control needs to be incorporated to minimize thermocline growth in the tank and maximize heat recovery.

References

Atkins, M.J., Walmsley, M.R.W. and Neale, J., 2009, The challenge of integrating non-continuous processes – milk powder plant case study, Chemical Engineering Transactions, 18, 445-450.

Atkins, M.J., Walmsley, M.R.W. and Neale, J., 2010, The challenge of integrating non-continuous processes – milk powder plant case study, Journal of Cleaner Production, 18(9), 927-934.

Dhole, V.R. and Linnhoff, B., 1993, Total site targets for fuel, co-generation, emissions, and cooling, Computers and Chemical Engineering, 17, S101-S109.

Fodor, Z., Varbanov, P.S. and Klemeš, J.J., 2010, Total site targeting accounting for individual process heat transfer characteristics, Chemical Engineering Transactions, 21, 49-54.

Klemeš, J.J., Dhole, V.R., Raissi, K., Perry, S. and Puigjaner, L., 1997, Targeting and design methodology for reduction of fuel, power and CO2 on total sites, Applied Thermal Engineering, 17(8-10), 993-1003.

Walmsley, M.R.W., Atkins, M.J. and Riley, J., 2009, Thermocline management of stratified tanks for heat storage, Chemical Engineering Transactions, 18, 231-236.

Walmsley, M.R.W., Atkins, M.J., Linder, J. and Neale, J., 2010, Thermocline movement dynamics and thermocline growth in stratified tanks for heat storage, Chemical Engineering Transactions, 21, 991-996.