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Process Integration Study for the Use of Industrial Low Grade Heat

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Improving energy efficiency for the process industry has received great attentions due to strong competitiveness in the market and societal demand for sustainable industrial manufacturing. Significant development has been made to develop design methods for achieving efficient use of fuel and raw materials in the generation and utilization of heat and power. Considerable low grade heat in process industries are often wasted without being recovered. This is mainly because the techno-economic impact gained from the heat recovery of low grade heat is much less than that from high grade heat. Therefore, it is necessary to evaluate and screen possible design options for the utilization of low grade heat and provide strategies for implementing energy-efficient process design in industrial practice. Two design aspects will be covered in this paper in the context of integrated design for the recovery of low grade heat in the industrial site. One is to study technologies using low grade heat, for example, heat pump and ORC (Organic Rankine Cycle), which allows identifying the most appropriate way for using waste heat. Site analysis technique has been applied to collectively review the current heat recovery of the industrial plant, to identify how much low grade heat is wasted and to estimate the potential for the further recovery of low grade heat. Modeling and simulation of heat-upgrading and heat-utilizing processes has been made and their characteristics have been considered during the analysis. The other is to integrate the waste heat from the industrial site with local energy systems, in which discontinuous characteristics of energy recovery and heat storage is systematically considered. Energy usage for the local energy systems has been modeled with multi-period representation, which was systematically integrated with the profile of low grade heat provided from the industrial plant. Case studies will be presented to demonstrate how the process integration design method can be applied.

1. Introduction

The efficient use of energy has been a key issue in the process industries, and significant effort has been made to improve energy efficiency of unit operations as well as maximise energy recovery in the plant. Design methodologies based on Process Integration concept have been widely applied in industrial practices, in order to investigate how much energy can be saved, and how cost-effectively energy is produced and utilized. Various profiles have been used to characterize the usage of energy in the process, including energy composite curves, grand composite curves, site steam profiles, site profiles, etc, with which it can be attempted to reduce cost for generating energy in a holistic manner – Smith (2005) emphasising the overall chemical process design; Kemp (2007) updating the classical user guide on PI, Klemes et al. (2010) presenting the overall family of PI approaches. Optimization methods are widely used in these days, due to its effectiveness in dealing with complex design interactions and performing rigorous economic trade-offs. Optimal configuration of energy systems is

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typically identified by representing a synthesis problem with a superstructure and solving it with deterministic or stochastic solvers, for example, heat exchanger networks (Smith et al., 2010), site utility steam networks (Varbanovet al., 2005), power systems (Zheng and Kim, 2011).
Focus on the development of design methodology and its application into process industries has been on the generation and utilization of high grade heat, rather than that of low grade heat. Because of social demand for reducing carbon emissions, industrial practitioners are now looking at new initiatives to which little attentions had been paid in past. One of measures in terms of improving heat recovery for industrial plants is to exploit industrial low grade heat. The recovery of low grade heat, typically below 180 ^{o}C, is often regarded as non-promising, due to relatively low economic benefits, compared to that of high grade heat. The current study aims to investigate options available for the recovery of waste heat within and beyond industrial sites and to maximise the effectiveness of low grade heat recovery with the aid of process integration method.
Various studies have been reported in the area of low grade heat recovery. One of recent work is carried out by Kapil et al. (2010, 2012) who presented how much energy cost can be saved by utilizing low grade heat in the site with heat pump, organic Rankine cycle, absorption refrigeration, and boiler feed water preheating. Although Kapil et al. (2012) recognize the benefit of low grade heat recovery, process modelling of heat-utilizing options and its simulation was relatively simple, and only impacts on energy cost were considered. The first part of this work is, therefore, to investigate various design options to increase the efficiency of technology employed for low grade heat and to understand economic trade-off existed in the introduction of low grade heat technologies into the existing plant.
Another aspect highlighted in this study is to transfer waste heat in the industrial site to the local energy systems, in which discontinuous nature of energy demand in the local energy infrastructure is systematically incorporated in the targeting for energy minimization, with the simultaneous consideration of heat storage.

2. Design of heat recovery systems using industrial low grade heat

2.1 Heat pump using low grade heat

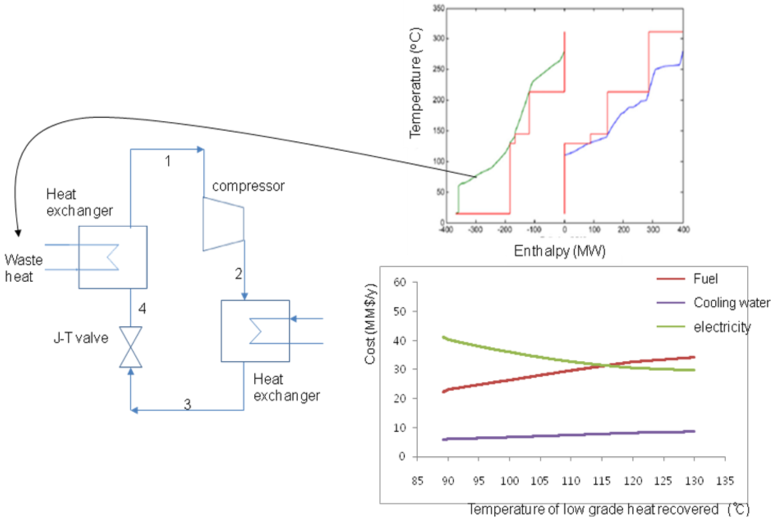

Figure 1: Heat pump using low grade heat

One of options for utilizing low grade heat in process industries is to upgrade the quality of heat with the aid of heat pump as shown in Figure 1. If the heat pump is not used, the low grade heat is to be discharged to cooling water for the modest temperature or to be used for generating low pressure steam or giving heat to process cold streams if the temperature is high enough to do. When the temperature of waste heat recovered in the heat pump is high, the fuel required for low pressure steam generation as well as cold utility (i.e. cooling water) to be used in the utility systems are increased, but electricity required for compressor is reduced. This trade-off is performed and its results are illustrated in Figure 1. Heat pump is simulated with a commercial simulator and the profile of low grade heat is taken from Kapil et al. (2012). Another design issue to be considered is to investigate how much the amount of low grade heat is utilized in the heat pump, because it is typical that industrial low grade heat is not available at the constant temperature, but at the wide range of temperature.

2.2 ORC using low grade heat

Another application for the utilization of industrial low grade heat is ORC (organic Rankine cycle), which is shown in Figure 2. The choice of organic fluid in the cycle is one of design variables, while energy efficiency can be compromised for generating more electricity from the cycle. Figure 2 shows trade-off between energy efficiency and electricity generated, which is obtained by plotting the profile of maximum efficiency points of the cycle for the given electricity generated, when n-pentane is used in the cycle.

In order to fully accommodate characteristics of waste heat and to improve energy efficiency of the cycle, various configurations can be considered, and determination of its optimal configuration is another important decision variable for the ORC. Figure 3 illustrates how the basic configuration of heat pump shown in Figure 2 is evolved to become a more complex cycle which have two levels of heat recovery, leading to better energy efficiency at the expense of design complexities.

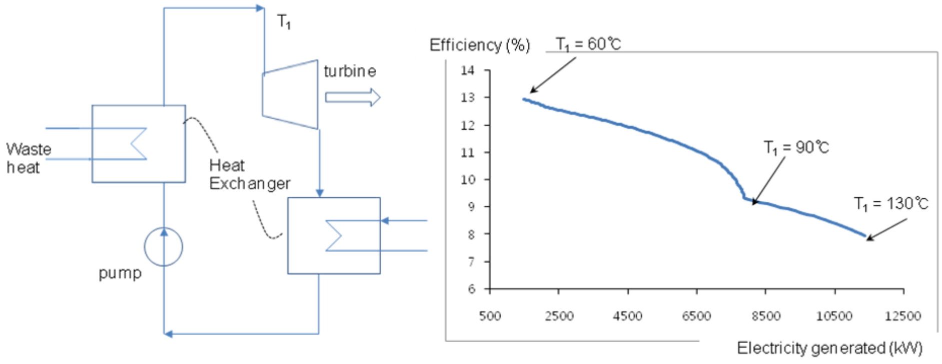

Figure 2: ORC using low grade heat (I)

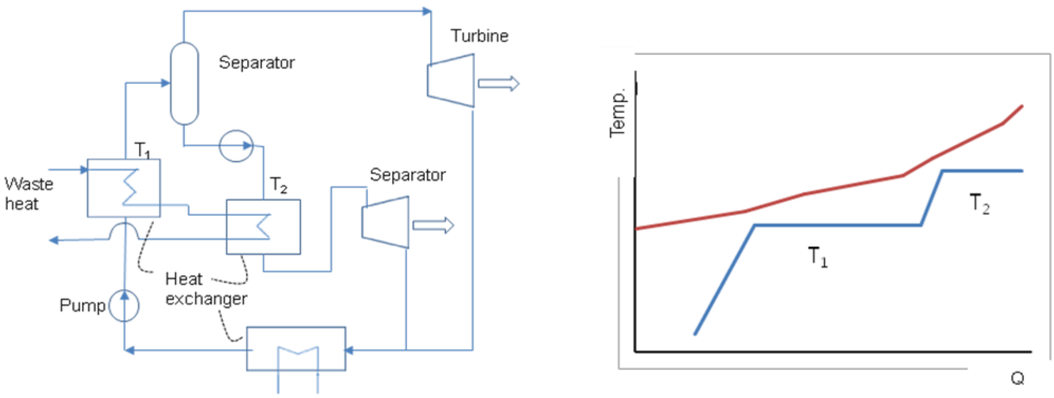

Figure 3: ORC using low grade heat (II)

3. Targeting and design of local energy systems

The supply of energy to or the removal of energy from local energy systems (e.g. hospitals, building, etc) is time-dependent and different quantity and quality of energy to be supplied to the systems is needed. Heat recovery should be maximised for the particular time interval, for example, through heat exchange between hot streams and cold streams, and any surplus energy at the particular time interval should be transferred to the next available time interval for further heat recovery through heat storage facility. The targeting for determining average capacity for a steam generator can be made by arranging heat recovery between time intervals, which is depicted in Figure 4.

First, energy flow in the local energy systems are characterized in multi-period format, in which hot and cold streams for each time interval is assumed to be operated continuously and energy demand required for each time interval is minimized, using energy composite curves (Figure 5). Heat storage can be used for transferring surplus heat to the time interval requiring external heat source, and the amount of heat available to be transferred or to be recovered, can be calculated with the aid of grand composite curve. Heat exchanged within the local energy systems can improve the effectiveness of energy usage, which can minimize unnecessary capacity of an energy-generating unit, and identify the optimal capacity. Energy can be supplied within the local energy systems, but can be also supplied from external sources. Industrial waste heat can be used for this purpose, and the amount of waste heat available from the industrial site and its temperature can be obtained from grand composite curves for processes or total site profiles for the site, as shown in Figure 6.

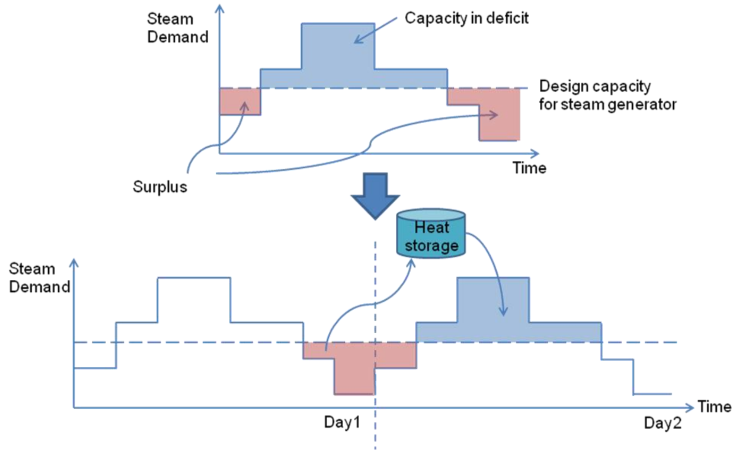

Figure 4: Targeting of design capacity for a steam generator in local energy systems

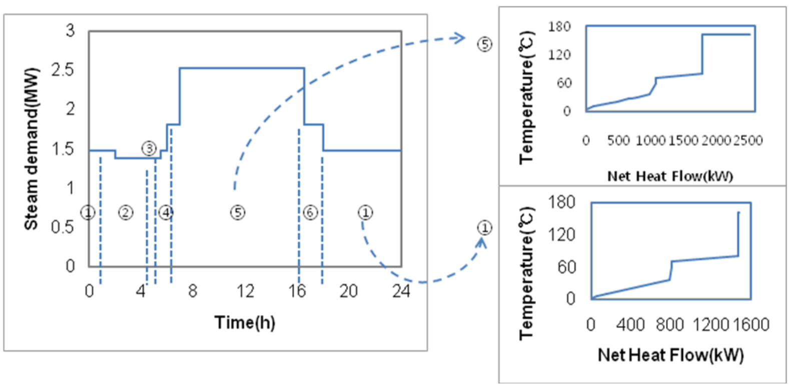

Figure 5: Multi-period heat recovery for local energy systems

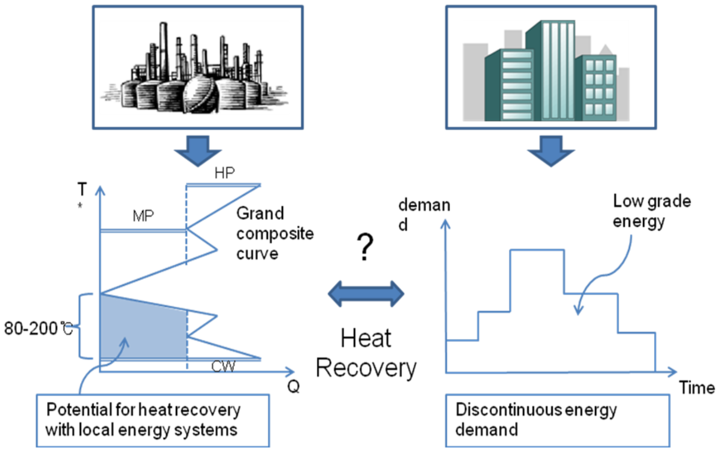

Figure 6: Heat recovery between industrial sites and local energy systems

Table 1: Stream data for a case study (Kemp, 2007)

Stream	Times of operation	Hot streams (Temperature / Heat load)	Cold streams (Temperature / Heat load)
1	24 h	20-15 °C / 43 kW	5-37 °C / 780 kW
2	19:00-07:00		2-37 °C / 681 kW
3	24 h	20-15 °C / 27 kW	71-80 °C / 709 kW
4	19:00-07:00		71-80 °C / 665 kW
5	24 h		5-60 °C / 244 kW
6	19:00-07:00		5-60 °C / 48.5 kW
7	24 h		162 °C / 13 kW
8	05:30-02:00		5-30 °C / 101 kW
9	07:00-16:30	37-30 °C / 67 kW	20-162°C / 797 kW

Table 2: Results of a case study

Cases	Energy source: Steam generator	Energy source: Industrial waste heat	Heat loss considered?	Capacity for steam generator	Heat flow required from the industrial site (avg.)	Electricity to be imported (avg.)
Case A	Yes	No	No	1.92 MW	-	-
Case B	Yes	No	Yes	2.07 MW	-	-
Case C	No	Yes*	Yes	-	1.65 MW	0.303 MW
Case D	No	Yes**	Yes	-	1.86 MW	0.144 MW

* Waste heat is available at 150 °C
** 2.5 MW of waste heat is available from 60 to 180 °C

This concept has been applied to energy systems of a local hospital (Table 1), of which stream data was taken from Kemp (2007). Four cases have been considered and results from targeting are given in Table 2. Cases A and B have a steam generator (e.g. boiler) on the hospital site for supplying steam required in various places, while Cases C and D utilize external industrial waste heat for fulfilling energy demand of the hospital. When heat loss is considered for heat exchanged through the heat storage, it is assumed that 10 % of heat available is lost per hour. 10 °C of minimum approach temperature is used throughout the case study. Average heat flow required from the industrial site for Case D is bigger than Case C, because industrial low grade heat available for the Case C is 150 °C, and, therefore, steam demand in the hospital is not fully satisfied from the waste heat.

4. Conclusions

Industrial low grade heat can be useful by either upgrading through ORC and heat pumping, or integrating it with local energy systems. Care should be taken for the implementation of low grade heat utilization, because there exist complex design interactions and economic trade-offs associated with integrated design.

Acknowledgement

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References

Kapil A., Bulatov I., Kim J., Smith R., 2010, Exploitation of Low Grade Heat in Site Utility Systems. Chemical Engineering Transactions, 21, 367-372.

Kapil A., Bulatov I., Smith R., Kim J., 2011, Integration of Low Grade Heat with District Heating, Chemical Engineering Transactions, 25, 123-128.

Kapil A., Bulatov I., Smith R., Kim J., 2012, Site-wide Low-Grade Recovery with a New Cogeneration Targeting Method, Chemical Engineering Journal, 90, 677-689.

Kemp I.C., 2007, Pinch Analysis and Process Integration: A user Guide on Process Integration of the Efficient Use of Energy, 2nd edition, Elsevier, Oxford, United Kingdom.

Klemeš J., Friedler F., Bulatov I., Varbanov P., 2010. Sustainability in the Process Industry: Integration and Optimization, McGraw Hill Companies Inc, USA, ISBN 978-0-07-160554-0, 362 ps.

Smith R, 2005, Chemical Process Design and Integration, Wiley, Chichester, United Kingdom.

Smith R., Jobson M., Chen L., 2010, Recent development in the retrofit of heat exchanger networks, Applied Thermal Engineering, 30, 2281-2289.

Zheng X., Kim J., 2011, Optimization of Power-Intensive Energy Systems with Carbon Capture, Ind. Eng. Chem. Res., 50, 11201-11225.

Varbanov P.S., Perry S., Klemes J., Smith R., 2005 Synthesis of industrial utility systems: cost-effective de-carbonization, Applied Thermal Engineering, 25, 985-1001.