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Incorporating District Cooling System in Total Site Heat Integration

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Total Site Heat Integration (TSHI) is an extension of Pinch Analysis for energy recovery between processes via centralised utility system. Locally Integrated Energy Sector (LIES) is introduced to integrate renewable energy sources and urban energy consumptions with industrial process. This concept has been extended to utilise the industrial low grade heat for district heating system. However, the concept has not been considered for district or centralised space cooling system which are more demanded in tropical countries. In tropical countries like ASEAN, residential and service buildings consumed 59% of the total energy consumption. For Malaysia, the energy consumption for buildings sector is projected to increase by 3.1% per year between 2011 and 2035. The main contributor for this high energy consumption is the cooling system requirement, which includes air conditioners and refrigerators. Industrial low-grade heat can be utilised for operating an absorption refrigerator to generate cooling. This can reduce the energy consumptions for industrial processes, as well as space cooling proposes. This paper introduces a new methodology which incorporates absorption chillers in TSHI to reduce the site cooling requirements. The methodology is illustrated by a literature case study.

1. Introduction

Energy-efficiency is one of the key strategies to reduce operating cost and enhance profit margin in industry. Heat Pinch Analysis for a single process has been widely implemented in chemical processing industry since its induction in the 1970s (Linnhoff and Vredeveld, 1984). Inter-process Heat Integration has been implemented to maximise energy recovery between processes via utility system (Dhole and Linnhoff, 1993). This site-wide heat integration concept is also known as Total Site Heat Integration (TSHI) (Raissi, 1994) and waste Heat Integration between process (Kralj et al., 2002).
The combined heat and power, or the co-generation system has been widely utilised to recover high temperature waste heat. However, there is always some waste heat available with low energy content. Industrial low-grade waste heat utilisation has recently been studied to maximise the thermal energy recovery between processes (Kapil et al., 2011). Perry et al. (2008) introduced Locally Integrated Energy System (LIES) concept for integrating district heating system and renewable energy system with industrial processes. Liew et al. (2013) proposed the heat requirement targeting methodology for TSHI considering the seasonal energy variation due to the integration of renewable energy and batch processes. Heat pumping is another option for utilising the industrial waste heat (Bagajewicz and Barbaro, 2003), which is being actively discussed for recovering low temperature excess heat to satisfy heat deficit at high temperature. Tri-generation system with simultaneous heating and cooling cycles is integrated in TSHI using R-curve concept by Ghaebi et al. (2012).
Space cooling system is essential for tropical countries and during summer in four-season countries. For tropical regions like the ASEAN countries for example, service and residential buildings consumed 59 % of

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the total energy consumption (IEA, 2013). In fact, the energy consumption in service and residential buildings is mainly used for operating air conditioning system. As a result, it would be beneficial if the industrial low-grade heat could be used for operating space cooling proposes.
Absorption chiller applies the thermodynamic closed-loop system, which is able to utilise waste heat for providing cooling energy or refrigeration. This system has lower efficiency compared to vapour compression cycles. Absorption chiller has an advantage for utilising low temperature waste heat (< 100 °C) to deliver cooling or chilling medium (Somers et al., 2011). So far, a number of research has been done on waste heat-driven absorption chiller.
This work introduces the use of absorption chillers in TSHI for the utilisation of low-grade heat. The absorption chillers are expected to power a centralised chilled water network or district space cooling system. The schematic diagram of this system is shown in Figure 1. A simple methodology is introduced to incorporate adsorption chillers in TSHI energy targeting methodology.

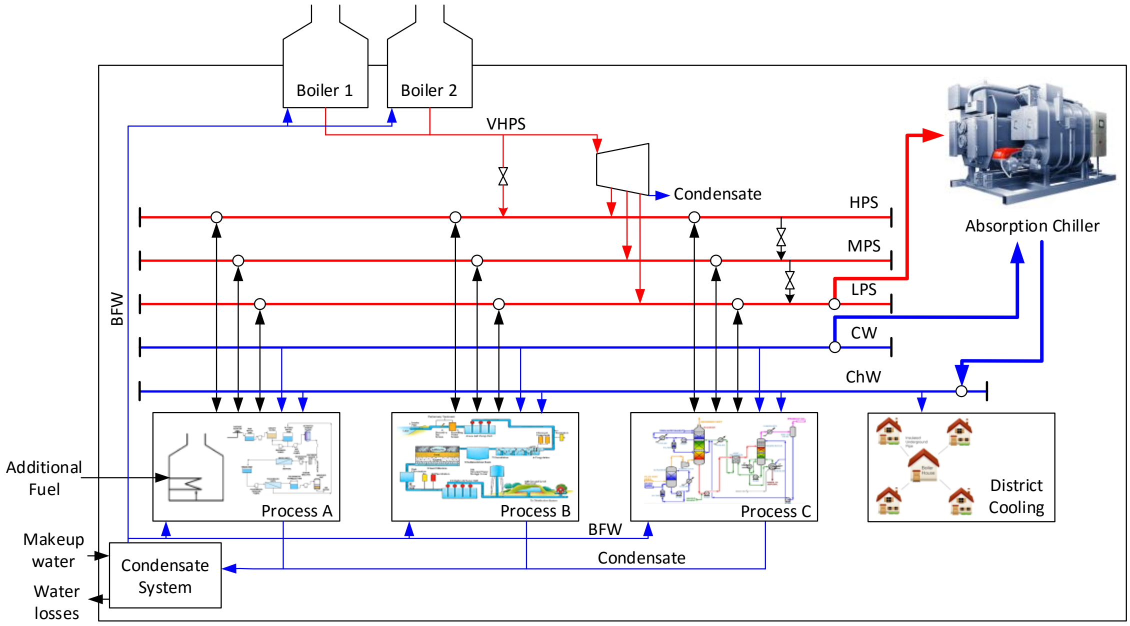

Figure 1: A Total Site with an integrated centralised cooling system

2. Absorption Chillers

International Institute of Refrigeration (IIR) estimated that the refrigeration and chilling demands consumed about 15% of the total electricity generated in the world (Hong et al., 2010). Vapour compression has been the most popular system in the current refrigeration technology market due to its high delivery efficiency. However, this type of system uses non-natural working fluid such as chlorofluorocarbon (CFC), which are identified as the cause of environmental issues. Vapour compression cycle consumed huge amount of electricity, which promotes the waste heat utilisation to drive refrigeration or chilling process.
In order to solve these problems, absorption chiller technology was introduced for generating chilled water by removing heat from chilled water return and transferring the heat to vaporisation refrigerant (Jaruwongwittaya and Chen, 2010). Absorption chiller has four major equipment, which are generator, condenser, evaporator and absorber. Heat is required to be supplied to the generator for heating sorbent solution, which is used for boiling off refrigerant vapour. Low grade heat could be supplied to operate absorption chillers, which can be harvested from renewables or process waste heat. Single-effect system has coefficient of performance (COP_{AC}) around 0.70 to 0.76 (Somers et al., 2011).
Double-effect absorption system has high efficiency as compared to the single-effect system. This type of absorption chilling cycle is designed for higher temperature heat sources, which allows the system to produce lower temperature refrigerant as compared to the single-effect system. The COP_{AC} of this type of system typically falls between 1.0 and 1.3 (Jaruwongwittaya and Chen, 2010). There are two generators and two condensers with different temperature ranges in this system, which requires higher-temperature heat source and generates lower temperature chilled water for a chilling system.

Low coefficient of performance of absorption chillers become the main concern in technology selection during process design. This system is still attractive for industry with huge amount of low temperature waste heat sources and large capacity chilling demands. In order to enhance the COP_{AC} and reduce the costs of the absorption chiller system, research and development works have primarily focused on finding good absorbent and refrigerant working pairs and appropriate advanced absorption refrigeration cycle.

3. Total Site Targeting

Total Site energy targeting methodology with absorption chillers is proposed in this study. The methodology considers a single scenario steady state TS system operation. Energy fluctuation with time (Liew et al., 2014) is not considered in this methodology. The methodology is summarised in Figure 2.

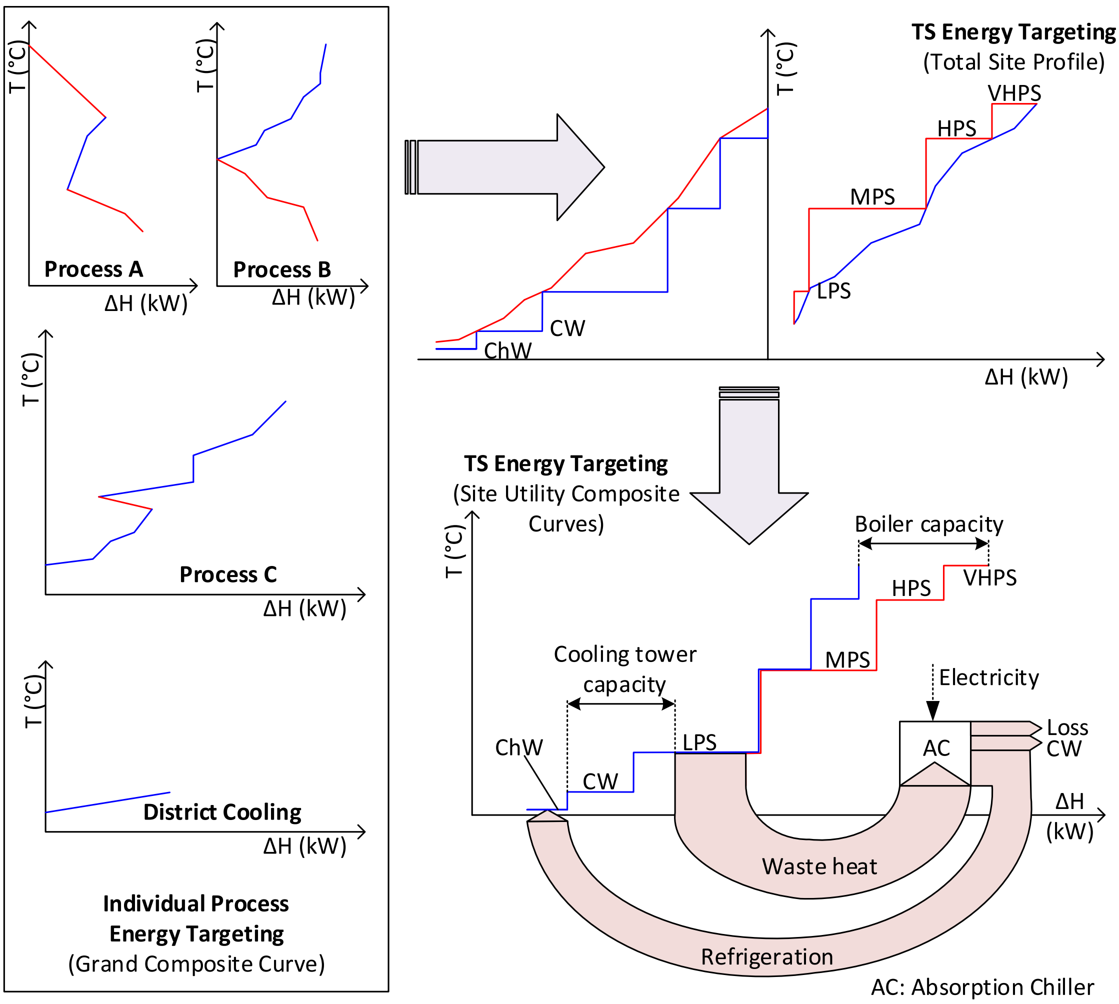

Figure 2: TS energy targeting with absorption chiller

The proposed methodology is described as follows:

(a) Extract the data for all processes in the TS system, including the energy demand for district cooling or centralised cooling system. The process stream specification required are the source and target temperature, heat capacity flowrate and heat duty;

(b) Perform energy targeting for individual process for all processes involve in the TS system by using Grand Composite Curve – GCC (Linnhoff and Vredeveld, 1984) or Multiple Utility Problem Table Algorithm - MU-PTA (Liew et al., 2012);

(c) Perform energy targeting for TS system with all the industrial processes and the district cooling or centralised cooling system by using Total Site Profile - TSP and Site Utility Composite Curve - SUCC (Klemeš et al., 1997);

(d) If LPS level is located at below TS Pinch region, the heat excess at LPS level could be used to operate waste heat-driven absorption chiller for generating chilling water (ChW). The ChW is then used for satisfying the needs of industrial processes and district cooling or centralised cooling system. The COP_{AC} needs to be considered for the targeting amount of waste heat required to be supplied to the absorption chiller. Eq (1) shows the relationship between COP_{AC}, chiller load and waste heat input. The ChW demand and waste heat excess ratio (CHR) (Eq 2) is used for accessing the implementation potential for an absorption chiller;

$$COP_{AC} = \text{Chiller Load / Heat Input} \quad (1)$$

$$CHR = \text{ChW demand / LPS excess} \quad (2)$$

i. If the CHR is larger than COP_{AC}, the LPS available in the TS system become the limiting component for the absorption chiller application. The chiller load or ChW generation from the absorption chiller should be determined by the COP_{AC} and the LPS excess in the system;
ii. If the CHR is smaller than COP_{AC}, the ChW demand of the TS system is the limiting factor for the absorption chiller application. The LPS requirement of the absorption chiller should be determined by the equipment's COP and the ChW demand in the TS system.

(e) Determine the cooling water demand of the refrigerant condenser and absorber intercooler in absorption chiller unit.

(f) Determine the new minimum external hot and cooling utility requirements to obtain the minimum boiler, cooling tower and chiller capacities considering waste heat utilisation and the ChW generation by the absorption chiller.

4. Case Study

The proposed methodology has been applied on a modified illustrative literature case study from Liew et al. (2013). There are three industrial processes in the existing TS system for this case study. The district cooling system has been added in the TS system as the fourth process. The stream data is listed in Table 1. The minimum temperature difference between the process streams and the utility ($\Delta T_{min,up}$) and the minimum temperature difference between the process streams ($\Delta T_{min,pp}$) are assumed to be 10°C and 20 °C. Four types of utilities are available in the existing industrial processes. These include the High Pressure Steam (HPS) at 270 °C, Medium Pressure Steam (MPS) at 180 °C, Low Pressure Steam (LPS) at 133 °C and cooling water (CW) at 15–20 °C. In order to serve the chilling demand of the district cooling system, Chilled Water (ChW) header at 10 °C is added to the system, in which the ChW could be supplied by the waste heat-driven absorption system (COP_{AC} = 0.723) or electricity-driven chiller system.

To solve this case study, a numerical TSHI energy targeting methodology (Liew et al., 2012) was used to analyse energy requirement of the TS system. Table 2 shows the Total Site Problem Table Algorithm (TS-PTA) for this Case Study, which shows the balanced utility requirements for the TS system. The 'Heat Requirement' column in Table 2 is referring to the net energy requirements of the TS system. These values have considered the energy recovering within the same utility level and without considering the heat recovery between utility levels in the TS system.

From these energy requirements, heat cascade methodology is used to examine the possible energy recovery between utility levels and determine which excess energy at higher temperature level could be let-down or supplied to utility level with lower temperature. The 'Final Cascade' in the TS-PTA is able to determine the ultimate external heating and cooling requirements of the TS system. The 'Final Cascade' determines the TS Pinch of the integrated system, which divides the utility profile into net heat excess and demand region. The net heat excess region is located below the TS Pinch, which requires cooling facility to release its energy. The net heat demand region is located above TS Pinch. There are some process streams required to be heated by boiler system in this temperature range.

In the last part of the table, 'Multiple Utility (MU) Cascade' is used for distributing the boiler and cooling requirement according to the demands at respective utility levels. The result of the distributed energy requirement is shown in the 'Utility Requirement' column. Alternative energy sources could be suggested for satisfying the heating or cooling requirement of the TS system. The cogeneration potential also can be read from the utility requirements determined. In this work, the 'Utility Requirement' column is essentially important for determining the amount of energy excess available to operate the absorption chilling system.

Based on 'Final Cascade' in Table 2, the boiler steam generation demand for this TS system (highest end of the cascade) is 10.65 MW, while the CW demand is 36.39 MW to satisfy the cooling requirement of heat excess at LPS and CW levels (lowest end of the cascade). More importantly, there is 5.04 MW of ChW demand in this TS system, which is supplied by an electricity-driven chiller system. In fact, a waste heat-

Table 1: Stream Table for Case Study

Stream	T_S (°C)	T_T (°C)	ΔH (kW)	mCp (kW/°C)	T_S' (°C)	T_T' (°C)
Process A						
A1 Hot	200	100	20,000	200	190	90
A2 Hot	150	60	36,000	400	140	50
A3 Cold	50	220	-25,500	150	60	230
A4 Hot	170	150	10,000	500	160	140
Process B						
B1 Hot	200	50	4,500	30	190	40
B2 Hot	200	119	18,630	230	190	109
B3 Cold	30	200	-6,800	40	40	210
B4 Cold	130	150	-3,000	150	140	160
Process C						
C1 Hot	240	100	2,100	15	230	90
C2 Cold	50	250	-4,000	20	60	260
C3 Cold	40	190	-15,000	100	50	200
C4 Cold	109	140	-1,860	60	119	150
District Cooling System						
D1 Hot	30	16	5,040	360	20	6

Table 2: Total Site Problem Table Algorithm for the Case Study

Utility	Heat Source (kW)	Heat Sink (kW)	Heat Requirement (kW)	Initial Cascade (kW)	Final Cascade (kW)	MU Cascade (kW)	Utility Requirement (kW)
				0	17,105	0	
HPS	0	10,650	-10,650				10,650
				-10,650	6,455	0	
MPS	500	6,955	-6,455				6,455
				-17,105	0	0	(TS Pinch)
LPS	15,490	9,955	5,535				-5,535
				-11,570	5,535	0	
CW	30,850	0	30,850				-30,850
				19,280	36,385	0	
ChW	5,040	0	5,040				-5,040
				24,320	41,425	0	

driven absorption chiller could be installed to utilise the excessive LPS generation potential and to satisfy the system's ChW demand. In other words, the waste heat absorption cycle option reduces the CW and ChW demands simultaneously.

The CHR for this case study is found to be 0.91 using Eq(2), which shows that the CHR is higher compared to the COP_{AC} given at 0.723. In this case, the LPS excess has limited availability for satisfying the amount of ChW demand from the centralized cooling system. All the LPS excess is assumed to be supplied to the waste heat-driven absorption chiller to generate the maximum amount of ChW. The quantity of potential ChW generation of the absorption chiller in this TS system is targeted using Eq(1), which is found to be 4.00 MW (COP_{AC} x LPS excess = 0.723 x 5.54). The remaining ChW demand of 1.04 MW is required to be satisfied by electricity-driven chillers.

The absorption chiller requires CW in the refrigerant condenser and absorber intercooler. The CW demand is essential to be included in this analysis for showing the significance of the energy demand of this system. In this case study, the heat rejected by the condenser and absorber are 4.31 MW and 5.26 MW.

The installation of waste heat-driven absorption chiller reduces the chiller system load of the TS system by 4.00 MW. The cooling tower load increased by 4.03 MW due to high CW demand of the chiller, although the absorption chiller utilised the excess LPS of the TS system. Note that the boiler generation demand is not affected by the chiller installation. The installation of absorption chiller in the integrated TS system not only reduces the electricity bill for the industrial site and the district residents.

5. CONCLUSION

This paper introduces a methodology for the integration of industrial process with the space or district cooling system or centralised chilled water network. The new integration methodology is capable of reducing the cooling tower capacity and the chiller system load simultaneously. Application of the methodology on an illustrative case study resulted in reduction of 4.00 MW of ChW demand. However, the required cooling tower capacity for the TS system increased by 4.03 MW due to the extra CW demand of the absorption chiller. The industrial site applying this integrated system could be benefitted from electricity bill reduction for the chillers. For further study, the work should be extended to include rigorous models of an absorption chiller. The capital investment involved in the absorption chiller installation should be examined, to ensure the economic benefits of this suggested integrated system.

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References

Bagajewicz M.J., Barbaro A.F., 2003, On the use of heat pumps in total site heat integration, Computers & Chemical Engineering, 27 (11), 1707-1719.

Dhole V.R., Linnhoff B., 1993, Total site targets for fuel, co-generation, emissions, and cooling, Computers & Chemical Engineering, 17 (1), S101-S109.

Ghaebi H., Karimkashi S., Saidi M.H., 2012, Integration of an absorption chiller in a total CHP site for utilizing its cooling production potential based on R-curve concept, International Journal of Refrigeration, 35 (5), 1384-1392.

Hong D., Tang L., He Y., Chen G., 2010, A novel absorption refrigeration cycle, Applied Thermal Engineering, 30 (14–15), 2045-2050.

IEA, 2013, SouthEast Asia Energy Outlook: World Energy Outlook Special Report, Paris, France, International Energy Agency (IEA).

Jaruwongwittaya T., Chen G., 2010, A review: Renewable energy with absorption chillers in Thailand, Renewable and Sustainable Energy Reviews, 14 (5), 1437-1444.

Kapil A., Bulatov I., Smith R., Kim J.K., 2011, Integration of low grade heat with district heating, Chemical Engineering Transactions, 25, 123-128.

Klemeš J., Dhole V.R., Raissi K., Perry S.J., 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.

Kralj A.K., Glavič P., Krajnc M., 2002, Waste heat integration between processes, Applied Thermal Engineering, 22 (11), 1259-1269.

Liew P.Y., Wan Alwi S.R., Klemeš J.J., Varbanov P.S., Abdul Manan Z., 2013, Total Site Heat Integration with seasonal energy availability, Chemical Engineering Transactions, 35, 19-24.

Liew P.Y., Wan Alwi S.R., Klemeš J.J., Varbanov P.S., Abdul Manan Z., 2014, Algorithmic targeting for Total Site Heat Integration with variable energy supply/demand, Applied Thermal Engineering, 70 (2), 1073-1083.

Liew P.Y., Wan Alwi S.R., Varbanov P.S., Manan Z.A., Klemeš J.J., 2012, A numerical technique for Total Site sensitivity analysis, Applied Thermal Engineering, 40, 397-408.

Liew P.Y., Wan Alwi S.R., Varbanov P.S., Manan Z.A., Klemeš J.J., 2013, Centralised utility system planning for a Total Site Heat Integration network, Computers & Chemical Engineering, 57, 104-111.

Linnhoff B., Vredeveld D.R., 1984, Pinch Technology has Come of Age, Chemical Engineering Progress, 80 (7), 33-40.

Perry S., Klemeš J., Bulatov I., 2008, Integrating waste and renewable energy to reduce the carbon footprint of locally integrated energy sectors, Energy, 33 (10), 1489-1497.

Raissi K., 1994, Total Site Integration, PhD Thesis, UMIST - University of Manchester Institute of Science and Technology, Manchester, UK.

Somers C., Mortazavi A., Hwang Y., Radermacher R., Rodgers P., Al-Hashimi S., 2011, Modeling water/lithium bromide absorption chillers in ASPEN Plus, Applied Energy, 88 (11), 4197-4205.