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Optimal match between heat source and absorption refrigeration

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ABSTRACT

In process industries, there is usually a great amount of waste heat available at different temperatures, and at the same time, there are cooling or refrigeration demands at different temperatures. In this paper, a single effect water–lithium bromide absorption refrigeration system is modeled and simulated using the process modeling software Aspen Plus. The optimal matches between heat source temperatures and refrigeration levels of the absorption refrigeration cycle are determined. The performance of the absorption refrigeration cycle is assessed in terms of two indicators: coefficient of performance (COP) and exergy efficiency. At a certain evaporator temperature of the absorption refrigeration cycle, which indicates a certain refrigeration level, the COP of the cycle rises rapidly at first and then gently with increasing heat source temperature because higher temperature generates more refrigerant vapor. The exergy efficiency of the cycle, by contrast, exhibits a maximum value because both the system performance and the system irreversibility increase with increasing heat source temperature. Ensuring a proper match between heat source and absorption refrigeration can lead to efficient use of waste heat and decrease degradation loss of waste heat.

1. Introduction

Most industrial enterprises burn fuel to supply heat, steam and power required by a multitude of processes. These processes typically discharge a great amount of waste heat at different temperatures to the environment. Obviously, considerable energy can be recovered from such waste heat sources. In China, the amount of waste heat discharged by industrial processes accounts for about 17–67% of the consumed fuel, and about 60% of which can be recovered (Lian et al., 2011). In the UK, up to 14 TWh per annum (4% of total energy use) of the process industries' energy consumption is lost as recoverable waste heat (Law et al., 2016). Recovering this type of waste heat can effectively reduce fossil fuel energy consumption, which has a significant and positive relationship with carbon dioxide emissions (Khan et al., 2016). For example, substantial recovery of 14 TWh per annum in the UK would have environmental benefits of hundreds of thousands of tonnes of carbon dioxide equivalent per year (Law et al., 2016).

A number of methods are available for waste heat recovery including direct heat transfer from source-to-sink using heat exchangers (Hammond and Norman, 2014; Law et al., 2016); upgrading waste heat to a more desirable temperature using heat pumps (Hammond and Norman, 2014; Law et al., 2016); conversion of waste heat energy to fulfill a chilling demand using absorption refrigeration (Hammond and Norman, 2014); and conversion of waste heat energy to electrical energy using (Organic) Rankine, or Kalina cycles (Hammond and Norman, 2014; Law et al., 2016; Markides, 2013). Of these options, direct heat transfer is preferred if suitable heat sinks are available (Hammond and Norman, 2014; Markides, 2013). In the absence of suitable heat sinks, when the temperature of the waste heat is in the range of 100–300 °C and the magnitude of the waste heat is less than 3 MWth, absorption refrigeration is the most effective way to recover the waste heat (Hammond and Norman, 2014).

Absorption refrigeration is a cycle that uses waste heat to provide cooling or refrigeration. It uses a refrigerant-absorbent pair as a working fluid, the most common of which are water/lithium bromide (LiBr) and ammonia/water. A basic absorption refrigeration cycle consists of a generator, a condenser, two throttle valves, a pump, an evaporator and an absorber, as shown in Fig. 1. Heat is added at the generator, separating gaseous refrigerant and liquid solution. The gaseous refrigerant is sent to the condenser, where it rejects heat and becomes saturated liquid. It is expanded through throttle valves and then evaporated in the evaporator by receiving heat from a low temperature heat source, resulting in useful cooling/refrigeration. The liquid solution from the generator is also

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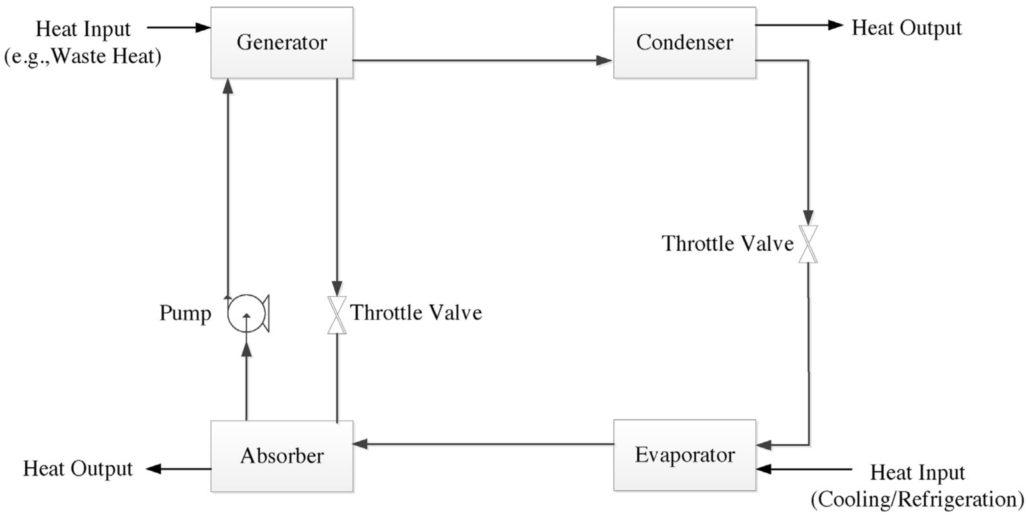

Fig. 1. Schematic diagram of a basic absorption refrigeration cycle.

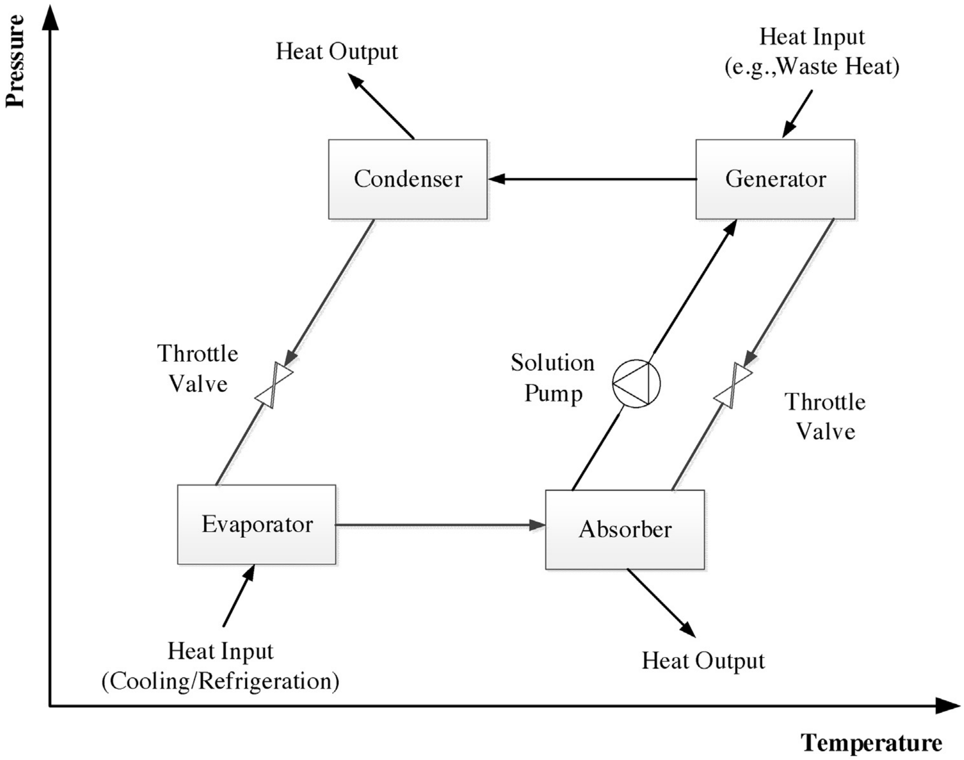

Fig. 2. Temperature-Pressure diagram of a basic absorption refrigeration cycle.

expanded through a throttle valve, and then recombines with the gaseous refrigerant from the evaporator in the absorber through a pump. The corresponding Temperature-Pressure diagram is shown in Fig. 2.

Many studies have been carried out to assess the performance of an absorption refrigeration cycle, mainly based on the coefficient of performance (COP) (Mazzei et al., 2014) or/and exergy efficiency (Gong and Boulama, 2014). Mazzei et al. (2014) established an NLP model to optimize the cycle with COP and the total heat transfer area as the objective function. In this paper, we also use the COP and exergy efficiency indicators to study the energy performance of an absorption refrigeration cycle used to recover waste heat. Karamangil et al. (2010) found that adding a solution heat exchanger to the basic cycle can increase the COP by up to about 66%. This enhancement is due to a reduction in the heat input to the generator. Anand et al. (2013) obtained results similar to those of Karamangil et al. (2010) through simulation for a range of operation temperatures and heat transfer efficiencies obtained with different working fluids. Kaynakli and Kilic (2007) studied the effect of various operation parameters on the COP indicator, and also found that adding a solution heat exchanger can increase the COP by up to about 44%. This paper will also study the basic cycle equipped with a solution heat exchanger.

Some studies investigated the effect of cycle parameters on the system performance. Karamangil et al. (2010) developed a visualized software to simulate the cycle performance and found that the operation temperatures in the generator, absorber, evaporator and condenser affect the cycle performance. COP of the cycle