International Journal of Heat and Mass Transfer 118 (2018) 193–200

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Simulation analysis of solution transportation absorption chiller with a capacity from 90 kW to 3517 kW

Koji Enoki [a], Fumi Watanabe [b], Seigo Tanaka [c], Atsushi Akisawa [b,*], Toshitaka Takei [b]

[a] Department of Mechanical Engineering and Intelligent Systems, The University of Electro-Communications, 1-5-1, Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan
[b] Department of Mechanical System Engineering, Tokyo University of Agriculture and Technology, 2-24-16, Koganei-shi, Tokyo 184-8588, Japan
[c] Former affiliation: Department of Mechanical System Engineering, Tokyo University of Agriculture and Technology, 2-24-16, Koganei-shi, Tokyo 184-8588, Japan

ARTICLE INFO

Article history:
Received 30 March 2017
Received in revised form 22 September 2017
Accepted 22 October 2017

Keywords:
Absorption chiller
Thermal energy transportation
Solution transportation
Ammonia-water
COP
Simulation

ABSTRACT

The utilization of waste heat instead of fuel combustion is effective in reducing primary energy consumption to mitigate global warming problems. As waste heat sources are not necessarily located close to areas of heat demand, one of the difficulties is that waste heat must be transferred from the heat source side to the heat demand side, which may require the transportation of heat over long distances. From this point of view, we proposed and examined a new idea of heat transportation using ammonia-water as the working fluid in the system named the Solution Transportation Absorption chiller (STA). Our previous studies of the STA were mainly based on the experimental investigation with the STA facility where the cooling power was 25 RT (90 kW). Thus, the Coefficient of Performance (COP) of STA was found to have almost the same value of 0.65 with conventional absorption chillers without depending on the transportation distances. The simulation using AspenHYSYS also examined the same experimental condition. The experimental data showed good agreement with the simulation calculation. In this study, we examined the large-scale cooling power of the STA on the simulation. The intention of this study was to analyze sensitivity with large cooling capacities, the examined cooling powers were from 90 kW (25 RT) to 3517 kW (1000 RT). All cooling power achieved around COP 0.64 including pump power consumption. In addition, we performed a dynamic simulation. The results showed that pipeline size did not affect the cooling capacities and mass flow rates. Furthermore, the stability time of the cooling capacities and mass flow rates were almost the same regardless of the pipeline size and cooling capacity. In other words, the STA may achieve the same COP despite having various complex conditions compared with the conventional absorption chiller.

1. Introduction

Utilizing waste heat instead of fuel combustion is an effective way to reduce primary energy consumption for mitigating global warming problems. As waste heat sources are not necessarily located close to areas of heat demand, one of the difficulties is that waste heat must be transferred from the heat source side to the heat demand side, which may require the transportation of heat over long distances. Conventional ways conducted in actual heating and cooling systems are to transport steam and chilled water to district for heating and cooling, respectively. Both working media need to be insulated to prevent heat loss.

Generally, the conventional absorption cycle consists of four major heat exchangers: the generator; condenser; evaporator; and absorber (represented by the symbols of G, C, E and A in Fig. 1a). Cooling is generated when ammonia evaporates in the evaporator. The refrigerant vapor is then absorbed into the weak solution at the absorber. The process produces a strong solution and absorption heat, which needs to be ventilated outside. When the strong solution is heated in the generator, the refrigerant vapor goes into the condenser where it turns into liquid by cooling. Next, the liquid refrigerant returns to the evaporator and the same process is repeated continuously. If the demand for chilled water is needed to be transported over a long distance, it is necessary to insulate the pipeline, otherwise it would surely be occurred heat loss.

As just described, the heat transportation is a traditional issue to utilize unexploited heat from industry. In order to solve this problem, for example, chemicals such as methane or methanol have been examined to transfer thermal energy over long distances [1]. Exothermic and endothermic reactions work to absorb heat

* Corresponding author.
E-mail address: akisawa@cc.tuat.ac.jp (A. Akisawa).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.091
0017-9310/

Nomenclature

A	inner diameter unit of JIS, which symbol almost accord with the inner diameter in a unit of mm
COP	coefficient of performance
COP_H	the definition of COP, Q_{EVA}/Q_{GEN}
COP_E	the definition of COP including pump power consumption, $Q_{EVA}/(Q_{GEN} + E)$
E	pump power consumption, W
e	system deviation
JIS	Japanese industrial standards
K	gain
OP	operating value
Q	thermal energy, W
RT	refrigeration ton (1 RT = 3.517 kW)

Subscripts

EVA	evaporator
GEN	generator
i	integral
p	proportional

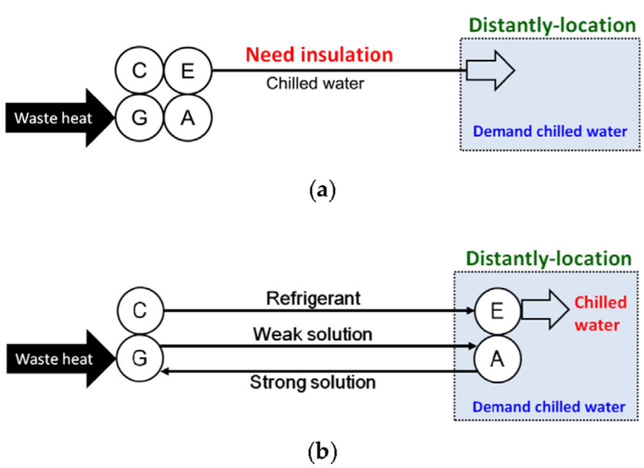

Fig. 1. Comparison between the (a) conventional absorption system and (b) the STA.

from the outside and discharge heat to the demand side, respectively. In the case of methanol, H_2 and CO decomposed from methanol at the heat source side (with a temperature of 150–200 °C) are transported to the user side, where a methanol synthesis reaction is operated to supply heat of 150 °C. The methanol then returns to the heat source side. These systems incorporate pipelines to transport the chemical components. In contrast, batch systems exist to carry phase change materials (PCM) by truck vehicles [2–4]. It is possible to transfer thermal energy at different temperature levels of 50 °C or 100 °C by selecting appropriate PCM materials, where heat from 100 °C can be converted into cooling at the heat use side. This kind of system has been operating in some places in Japan to utilize waste incineration heat [5]. Transporting chemical materials by trucks also works for heat transportation in a similar way. Ogura [6] analyzed a system with a "chemical heat pump container", which uses $CaSO_4$ and water as the working pair. A model analysis of PCM transportation to utilize industrial surplus heat for a district heating system was conducted by Chiu et al. [7] and compared the performance of various transportation modes including trucks; railways; and maritime systems.

From this point of view, one of the authors proposed and examined a new idea of heat transportation using ammonia-water as the working fluid [8]. The system is named the Solution Transportation Absorption chiller (STA). This system transfers ammonia refrigerant, together with an exchange of a strong and weak solution between them as shown in Fig. 1(b).

2. Solution transportation absorption chiller (STA)

The STA is based on an absorption heat pump mechanism working as a chiller. Conventional absorption chillers are located on the heat source side and produce chilled water, which is transported to the heat demand side through pipelines. In contrast, the proposed system divides an absorption chiller into two parts. The generator and the condenser are located on the heat source side while the evaporator and the absorber are on the heat demand side. Both systems utilize waste heat and finally satisfy cooling load at the demand side nevertheless of different system configurations. In other words, both systems achieve the same function of cooling supply, which implies that thermal energy can be transferred by transporting the solutions and the refrigerant separately. From this point of view, it can be said that thermal energy is converted and stored in the concentration difference of the working media. STA system is regarded as an application of chemical potentials to heat transportation. The thermal energy of waste heat is converted into the concentration difference among the refrigerant of almost pure ammonia; a strong solution with a higher ammonia concentration; and a weak solution with a lower ammonia concentration. As the thermal energy is then free from the temperature, it can be transported at an ambient temperature. With no requirement of insulation, the pipelines can be simplified and cost-effective. Furthermore, the pressure at the heat source side, which has a generator and condenser, is approximately 1.5 MPa, about four times higher compared with the heat demand side, so the transporting pump for the refrigerant and weak solution are not necessary. Compared to the conventional absorption chiller, these advantages of the STA might be suitable for community central heating and air-conditioning.

Our previous studies of the STA were to mainly examine the effect of transportation distance, the behaviors of the part-load cooling operation and the effect of generator temperature on the performance in steady/non-steady conditions using an experimental facility where cooling power was 90 kW (25 RT) [9–12]. Figs. 2 and 3 show the experimental facility and the schematic flow diagram of the STA. In Fig. 3, when performing experiments with the normal absorption chiller, V1, V3, and V5 were kept open and V2, V4, and V6 were kept closed. When conducting the STA experiments, the valves V1, V3, and V5 were closed, while V2, V4, were V6 kept open. The experimental results showed that the solution transportation distances did not affect the COP and its value was 0.60–0.70, almost the same as the conventional absorption chiller. Furthermore, the behavior of the part-load cooling operations in non-steady conditions (cooling power changing from 100% to 60% and from 60% to 100%) were almost the same behavior despite the solution transportation distances. We built a simulation model of the STA (25 RT) using the simulation software AspenHYSYS, where the simulation data could reproduce the characteristics of the experimental data, especially the COP, and the behavior of the facility between the experimentation and simulation showed a good match [12,13]. For example, Fig. 4 shows the comparison between the experimental result and the simulation analysis at 200 m transportation with 90 kW (25 RT).