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Static analysis of triple-effect adsorption refrigeration with compressor

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ABSTRACT

In order to improve the efficiency of the adsorption refrigeration cycle, this study proposes a triple-effect adsorption refrigeration cycle equipped with a compressor. This cycle can run in order to create a large variation in adsorbent concentration range by the compressor, even if there is little temperature variation in the desorption and adsorption processes. The objective of this study is to clarify the effect that regulating adsorption pressure using a compressor has on the adsorption refrigeration cycle, and to that end cycle efficiency was calculated using a static analysis based on a state of equilibrium. As a results from the simulation, the triple-effect cycles can operate by regulating adsorption pressure. Both COP and exergy efficiency can be improved by a factor of 1.2 if the cycled is regulated the adsorption pressure of each cycle rather than using a shared adsorption pressure. For heat sources in the temperature range of 70–100 °C, this method is superior in terms of COP and exergy efficiency. COP values of approximately 1.7–1.8 can be obtained, which is three times higher than single-effect cycles. The triple-effect cycles have one-third the SCE of single-effect cycles but about the same SCE as double-effect cycles.

1. Introduction

Factory production processes such as steam condensation and heat conversion with combustion exhaust vapors generate hot water with a temperature of around 90 °C, but much of this hot water is discarded. Since the adsorption refrigeration cycle is driven by this temperature range and can be used for air-conditioning and other cooling processes, it has the potential to use energy more efficiently. The challenge is how to increase the efficiency of current implementations of adsorption refrigerators.

To accomplish this, studies are being done on improving the coefficient of performance (COP; the ratio of energy input to energy output), and research into systems that incorporate cascading adsorption refrigeration cycles [1,2] or heat recovery functionality [3] is underway. Marlinda et al. [4] conducted a static analysis of a double-effect adsorption refrigeration cycle that utilized the heat of condensation; those results demonstrated that the double-effect cycle has a higher COP than single-effect cycles in the 100–150 °C range. In addition, Akisawa [5] performed a statistic analysis of both adsorption heat recovery and condensation heat recovery for a double-effect adsorption refrigeration cycle with a heat source of 120 °C. In that study, the cycle which recovered adsorption heat had the higher COP of 1.1. The double-effect cycle which recovers the adsorption heat uses two different adsorbents, one in the high-temperature cycle and the other in the low-temperature cycle. Using adsorbents which create large variations in the adsorption and desorption of refrigerant for each of the temperature and pressure during the adsorption and desorption processes has improved the efficiency of the cycle. Research into the triple-effect cycle has achieved a COP of 1.8 at 170 °C for absorption refrigeration cycles [6],

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Nomenclature

c	Specific heat, kJ (kg K)$^{-1}$
COP	Coefficient of performance (Dimensionless)
H	Enthalpy, kJ kg^{-1}
L	Latent heat of vaporization, kJ kg^{-1}
M	Mass of adsorbent, kg
P	Pressure, kPa
P_r	Relative pressure, (Dimensionless)
q_{st}	Adsorption heat, kJ kg^{-1}
SCE	Specific cooling energy, kJ kg^{-1}
T	Temperature, K
x	Adsorbent concentration, kg kg^{-1}
η	efficiency, (Dimensionless)
τ	Pressure ratio, (Dimensionless)

Subscribe

ads	Adsorption process/Adsorbent
all	Total
cond	Condenser
cool	Cooling
comp	Compressor
cw	Cooling water
des	Desorption process
eva	Evaporator
elec	Supplied electricity
ex	Exergy
h	High-temperature side
heat	Heating
l	Low-temperature side
m	Middle
preh	Pre-heating process
r	Refrigerant
s	Sensible

but adsorption refrigeration cycles have not been studied. The triple-effect cycle needs to select an adsorbent which allows for efficient adsorption and desorption at each of the three temperature levels. At temperatures below 100 °C, temperature variation between the adsorption and desorption processes is small and the adsorbent concentration range is too limited, meaning the cycle cannot operate. And even if the temperature of the heat source is increased to create a larger temperature difference, there are no adsorbents which can work efficiently at high temperatures. Therefore, in order to make the triple-effect adsorption cycle operate, the cycle needs to create a large range of adsorption concentration even when temperature variation is low.

Hybrid designs which include compressors within their cycles have already been demonstrated for both absorption [7] and adsorption [8] refrigerators. These cycles feed a small amount of electricity to their compressors in order to lower the desorption pressure and enable the refrigerator to be driven by a low-temperature heat source. Also, static analyses have shown that if a compressor is installed in a double-effect adsorption refrigeration cycle that recovers adsorption heat, and if the heat source is 60–80 °C, a COP of about 1.2 can be achieved by regulating the desorption pressure of the areas with large adsorbent concentration variation [9]. The range of adsorbent concentration will expand by adjusting the pressure, even if temperature variation is low during the desorption and adsorption processes.

In order to improve the efficiency of the adsorption refrigeration cycle, this study proposes a triple-effect adsorption refrigeration cycle equipped with a compressor. To make the three cycles of a triple-effect cycle work, the temperature range reduces between the adsorption and desorption processes of one of the cycles, but this decreases the adsorbent concentration range and prevents operation. If a compressor install in the triple-effect cycle to regulate the pressure, however, this cycle can run in order to create a large variation in adsorbent concentration. The objective of this study is to clarify the effect that regulating adsorption pressure using a compressor has on the adsorption refrigeration cycle, and to that end cycle efficiency was calculated using a Static analysis based on a state of equilibrium.

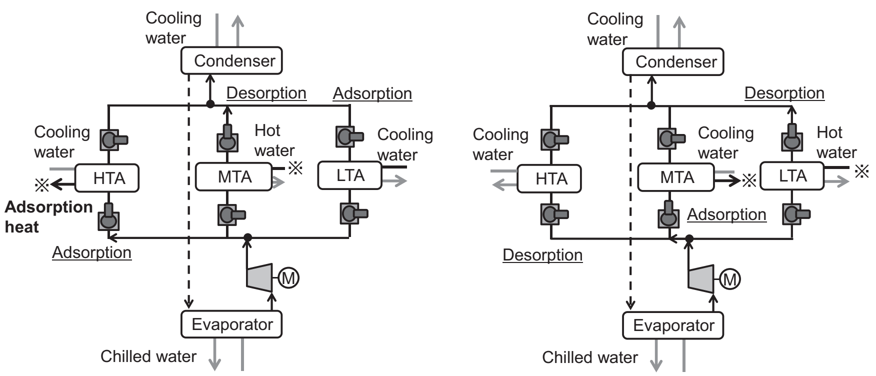

Fig. 1. Schematic diagram of triple-effect adsorption refrigeration cycle with the mechanical compressor.