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Open air–vapor compression refrigeration system for air conditioning and hot water cooled by cool water

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Abstract

This paper presents an open air–vapor compression refrigeration system for air conditioning and hot water cooled by cool water and proves its feasibility through performance simulation. Pinch technology is used in analysis of heat exchange in the surface heat exchanger, and the temperature difference at the pinch point is selected as 6 °C. Its refrigeration depends mainly on both air and vapor, more efficient than a conventional air cycle, and the use of turbo-machinery makes this possible. This system could use the cool in the cool water, which could not be used to cool air directly. Also, the heat rejected from this system could be used to heat cool water to 33–40 °C. The sensitivity analysis of COP to η_c and η_t and the simulated results T_4, T_7, T_8, q_1, q_2 and W_m of the cycle are given. The simulations show that the COP of this system depends mainly on T_7, η_c and η_t and varies with T_3 or T_{wet} and that this cycle is feasible in some regions, although the COP is sensitive to the efficiencies of the axial compressor and turbine. The optimum pressure ratio in this system could be lower, and this results in a fewer number of stages of the axial compressor. Adjusting the rotation speed of the axial compressor can easily control the pressure ratio, mass flow rate and the refrigerating capacity. The adoption of this cycle will make the air conditioned room more comfortable and reduce the initial investment cost because of the obtained very low temperature air. Humid air is a perfect working fluid for central air conditioning and no cost to the user. The system is more efficient because of using cool water to cool the air before the turbine. In addition, pinch technology is a good method to analyze the wet air heat exchange with water.

Keywords: Turbo-machinery; Air cycle; Air conditioning units; Natural working fluid; Refrigeration; Pinch technology

1. Introduction

The outdoor air temperature can reach 38–40 °C in middle China in summer, while the temperature of the water from the water supply system and underground is about 17 °C and that of the refilled underground water could be lower. These waters are too cool for people to bath directly at the hotel, and the bath water is usually heated by a boiler. If these waters were used to cool air for air conditioning directly, it is not efficient because of the small temperature difference and large amount of consumed water.

The air compression refrigeration cycle was studied long ago. Several disadvantages prevented air from being used as a working fluid in refrigeration. These included low volumetric refrigerating effect, which may result in a large compressor, and low COP due to low efficiencies of the compressor and expander. After CFC's invention in the 1930s, people paid little attention to air compression refrigeration.

Recently, as a result of the destruction of the ozonosphere by chlorofluorocarbons (CFC) and the pressure of environmental protection, research upon air refrigeration cycles has received more attention [1–3]. Optimizations of

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Nomenclature

B	wet air pressure, Pa	R	gas constant, kJ/kg K
D	humidity ratio of wet air, g/kg(d.a.)	n	exponent
H	enthalpy of wet air, kJ/kg(d.a.)		
P	pressure, Pa	*Subscripts*	
T	temperature, K or °C	air	dry air
T_{wet}	wet bulb temperature, K or °C	vapor	water vapor in moist air
W_c	ideal input work of compressor, kJ/kg(d.a.)	s	saturated
W_t	ideal output work of turbine, kJ/kg(d.a.)	last	last time
W_m	practical work consumed by system, kJ/kg(d.a.)	hot	hot stream
η_c	efficiency of compressor	cold	cold stream
η_t	efficiency of turbine	w	water
ratio	mass flow rate ratio of cooling water to dry air		

air cycles are also conducted using finite time thermodynamics (FTT) or entropy generation minimization (EGM) [4–7].

Chen et al. investigated the cooling load versus COP characteristics of a simple [8] and a regenerated [9,10] air refrigeration cycle with heat transfer loss and/or other irreversibilities. Luo et al. [11] optimized the cooling load and the COP of a simple irreversible air refrigeration cycle by searching for the optimum pressure ratio of the compressor and the optimum distribution of heat conductance of the hot and cold side heat exchangers for fixed total heat exchanger inventory.

With the development of the aeronautical industry, highly efficient axial compressors and turbines have become a reality. At present, the stagnation isentropic efficiencies of a single stage axial compressor and a turbine can reach 0.88–0.91 [12]. High speed fans have been used in ordinary air conditioning systems nowadays.

However, the water vapor in the working fluid was not considered in all the above researches [1–11] on the air compression refrigeration cycle, and the used equipments were a centrifugal compressor and a centripetal turbine, which have lower efficiencies than axial compressors and turbines. The amount of water extracted from high pressure wet air can reach 18–30 g/kg(d.a.), and the amount of latent heat discharged from the vapor condensed is about 45–75 kJ/kg(d.a.), exceeding the sensible heat from the air of 30–50 kJ/kg(d.a.).

Hou and Li presented an axial flow air–vapor compression refrigerating system for air conditioning in 1992 [13] in which wet air is the working fluid and an axial compressor and turbine were used, but these have not yet attracted people's attention so far.

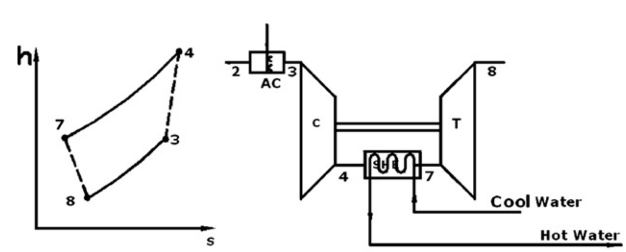
Hou and Zhang presented an axial flow air–vapor compression refrigerating system for air conditioning cooled by circulating water in Ref. [14] (2004) in which wet air is the working fluid, an axial compressor and turbine were used and the wet air is cooled by circulating water. The paper proves its feasibility through performance simulation and also indicates its advantages. These include the possibility to simplify air conditioning systems, to reduce the amount of initial investment of an air conditioning system and to make air conditioned rooms more comfortable.

The aim of this paper is to present an open system, which is an open air–vapor compression refrigeration system for air conditioning and hot water cooled by cool water and its performance from simulation. In this open air–vapor refrigeration cycle, water from the water supply system or underground is used. Thus, we could get a lower wet air temperature before the turbine. In addition, the cool water is heated for the bath.

2. System

Representation on enthalpy–entropy coordinates and a circuit diagram of an open air-compression refrigeration system for air conditioning and hot water cooled by cool water are shown in Fig. 1.

The outdoor air at 2 is drawn into the atomizing chamber, cooled to saturated air at 3 with some fine water droplets and then compressed by an axial compressor. A flow of compressed air at 4 with higher temperature, T_4, and high pressure, P_4, is obtained. Then, the compressed air at 4 is cooled to saturated air at 7 with a temperature T_7 by cool water/underground water in a surface heat exchanger after



AC	Atomizing chamber	C	Compressor
SHE	Surface Heat exchanger	T	Turbine

Fig. 1. Representation on enthalpy–entropy coordinates and circuit diagram of an open air-compression refrigeration system for air conditioning and hot water cooled by cool water.