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Performance analysis of an ejector cooling system with a conventional chilled water system

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HIGHLIGHTS

- The central chilled water system is combined with the ejector cooling system.
- The function of the cooling tower is replaced by an ejector cooling system.
- The combined system is studied by developing models of all the components.
- It is shown that the combined system has several advantages.

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ABSTRACT

The central chilled water system servicing one of the academic buildings at the KFUPM campus located in Dhahran has been modeled numerically to combine with the ejector cooling system. This ejector system cools the water which is in turn utilized to cool the refrigerant in the chiller condenser and hence, the function of the cooling tower in a conventional chilled water system is eliminated by an ejector cooling system. By replacing the cooling tower of the chilled water system with an ejector cooling system, constant water inlet temperature for the chiller condenser is assured, regardless of the ambient relative humidity and this effect is analyzed in detail. Results indicate that this combined system is quite advantageous at conditions of high ambient relative humidity when the cooling capacity of the cooling tower is greatly diminished but the performance of the ejector cooling system remains unaffected.

1. Introduction

The central air conditioning plants are divided into two main components: the chillers and the air handling units (AHU). Chillers can be either of absorption or vapor compression type. The chillers are further classified as air cooled or water cooled, based on whether air or water is used to cool the refrigerant in the condenser. In the Kingdom of Saudi Arabia, vapor compression chillers are most widely used for nearly all applications. As the name suggests the vapor compression chillers follow the refrigeration cycle to produce chilled water. This water is then pumped to the air handler. The air handler utilizes the supplied water to generate cool air and also supplies the cool air to the conditioned space via ducts. Based on the cooling load, the central air conditioning plant may consist of several chillers and air handlers.

Supplying chilled water to the AHU is perhaps one of the most important aspects of the air conditioning system. The chilled water, in turn, provides a means to transfer the heat from the conditioned spaces to the refrigeration system. All air conditioning plants at King Fahd University of Petroleum and Minerals (KFUPM) are central chilled water systems, employing constant speed primary-flow pumping scheme to deliver the chilled water to the air handler. In this scheme, a single (constant speed) pump operates continuously to maintain a constant flow rate of water throughout the entire system. Additionally, the chillers being employed are water cooled i.e. water is used to cool the refrigerant in the condenser, which is in turn cooled by the cooling tower.

An ejector refrigeration system is similar to a vapor-compression system except for the method of compressing the refrigerant. Instead of a mechanical compressor, an ejector is used to compress the refrigerant vapor from the evaporator to the condenser. As the ejector does not contain any moving parts, no external power is required for its operation and thus considerable amount of energy can be saved when compared with the conventional system. It is important to note that ejector is the most

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Nomenclature

A	area (m^2)
C_p	specific heat (kJ/kg K)
C_r	heat capacity ratio
C_s	saturation specific heat (kJ/kg K)
D	diameter (m)
f_f	friction factor for fins
f_i	friction factor for inner surface of tubes
f_{loop}	friction factor for the pipe flow loop
f_{tube}	friction factor for outer surface of tubes
g	gravitational constant (m/s^2)
G_a	mass velocity based on minimum area (kg/h m^2)
GPM	gallons per minute
ht	heat transfer coefficient (kW/m^2 K)
h	enthalpy (kJ/kg)
K	bend coefficient
k	thermal conductivity (kW/m K)
L	length (ft or m)
MW	mega watts
$\dot{m}$	mass flow rate (kg/h)
n_{column}	number of columns
n_{row}	number of rows
n_t	number of tubes
NTU	number of transfer units
P	pressure (kPa)
$\dot{Q}$	heat transfer rate (kW)
Re	Reynolds number
T	temperature (°C, K)
TR	ton of refrigeration
UA	overall heat conductance(kW/K)
V	velocity (m/s)
$\dot{W}$	rate of work done (kW)

Greek symbols

Δ	change/difference
ε	effectiveness
ε_{pipe}	average roughness of pipe
η	efficiency, surface effectiveness
ρ	density
σ	ratio of free flow area to frontal area
χ	dimensionless correction factor

Subscripts

1,2…6	ejector cooling cycle locations
a	air
ah	air handler
b	based on longitudinal spacing
chw	chilled water system
comp	compressor
cond	condenser
D	based on diameter
ejec	ejector
evap	evaporator
f	fin
fan	fan
gen	generator
i	inside
in	inlet
m	mean
max	maximum
min	minimum
o	outside
out	outlet
p	pump
ref	refrigerant
s	saturation
t	tubes
tot	total
tow	cooling tower
w	water

important component of the system, which is a pump-like device that uses the "Venturi Effect" to convert the pressure energy of a motive fluid to velocity energy, which creates a low-pressure zone. This sector draws in and entrains a suction fluid, which then recompresses the mixed fluids by converting velocity energy back into pressure energy.

In the present study, the effect of incorporating an ejector cooling system into the existing central plant, in place of the cooling tower that is required to cool the condenser water of the chilled water system, is investigated for Dhahran. In addition the use of solar energy as an auxiliary energy source for the generator of the ejector cooling system is also investigated.

2. Literature review

Most recently, Zhu and Jiang [1] performed a numerical study on a hybrid vapor compression refrigeration system with an integrated ejector cooling cycle. In this analysis, the waste heat of the condenser of the vapor compression system served as the driving source of the ejector cooling system. The addition in the cooling capacity obtained by the incorporation of the ejector cooling system was directly utilized in the vapor compression system. The effects of operating temperatures as well as different refrigerants on the COP of the system were analyzed and reported. A maximum increase in COP by 8.6% was reported when R22 was used as the refrigerant, provided that the condenser temperature was more than 100 °C. It was also found that the ejector geometries have a significant effect on the COP of the hybrid system.

Rusly et al. [2] performed a computational fluid dynamics (CFD) analysis on an ejector cooling system combined with the vapor compression system. In this combined system, the evaporator of the ejector cooling system was used as an intercooler to cool the refrigerant being used in the vapor compression system. It was argued that the CFD analysis offered more complete flow field information and the results thus obtained were more in agreement with the experimental data than the one dimensional model. The effect of ejector geometry on the performance of the system was the main focus of the study. For a range of area ratios, it was shown that the performance of the ejector system was improved with an increase in the area ratio as long as the ejector operated in the critical (double-choking) mode. Moreover, for selected refrigerants and a range of operating conditions, the location of the maximum entrainment ratio was also determined.

Vidal and Colle [3] also performed a numerical study of a combined vapor compression ejector cooling cycle. The method of combination of these two systems was the same as that of Rusly et al. [2]. Refrigerant R134a was used as the working fluid in the mechanical vapor compression system whereas R141b was chosen for the solar energy driven ejector cycle. The performance of the system was simulated for the climatic conditions of Florianópolis, Brazil, with specific values of cooling load, ejector dimensions and solar collector configuration. Variation of COP of the individual