Available online at www.sciencedirect.com

ScienceDirect

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

Development and performance of steam ejector refrigeration system operated in real application in Thailand

Natthawut Ruangtrakoon, Satha Aphornratana*

Sirindhorn International Institute of Technology, Thammasat University, P. O. Box 22, Thammasat Rangsit Post Office, Pathumthani 12121, Thailand

ARTICLE INFO

Article history:
Received 15 July 2014
Received in revised form
1 August 2014
Accepted 22 August 2014
Available online 23 September 2014

Keywords:
Steam
Ejector
Jet refrigeration
CFD
Chiller
Air-conditioning

ABSTRACT

This paper presents the design and construction of a prototype steam ejector refrigeration system which can be operated under the actual condition of Thai environment, which is rather hot and humid. The prototype refrigerator was designed to produce a cooling capacity of approximately 3 kW. Water was selected to be used as the working fluid. The steam boiler used was a vertical fire tube type and it was designed to be used with LPG compact gas burner. The condenser was cooled by water obtained from a conventional cooling tower. The prototype refrigerator was used to produce chilled water which was used to cool a small tested room. It was observed that the room temperature of 24.2 °C was obtained at the cooling load of 3000 W. The cooling water was supplied to the condenser at about 30 °C. The COP obtained was 0.45. This prototype refrigerator is proven to be practical and can be used in actual environment of Thailand.

Développement et performance d'un système de froid à éjecteur de vapeur fonctionnant dans une application réelle en Thaïlande

Mots clés : Vapeur ; Ejecteur ; Réfrigération par jet ; CFD ; Refroidisseur ; Conditionnement d'air

1. Introduction

Over the last three decades, the world has been experiencing an increase in natural disasters. The increase in world energy consumption is the origin of this problem. Air-conditioning systems are regarded as one of the major energy usages. There is one type of refrigeration system, the heat-powered refrigeration system, a refrigeration system which can be driven by thermal energy in the temperature range between 100

* *Corresponding author*. Tel.: +66 2 9869009x2203; fax: +66 2 9869009x2201.
E-mail address: satha@siit.tu.ac.th (S. Aphornratana).
http://dx.doi.org/10.1016/j.ijrefrig.2014.09.010

Nomenclature

A	Cross-section area (m^2)
AR	Ejector area ratio
COP	Coefficient of Performance
D	Diameter (cm, mm)
h	Specific enthalpy (kJ kg^{-1})
ID	Internal diameter (mm)
L	Length (mm)
M	Mach number
$\dot{m}$	Mass flow rate (kg sec^{-1}, kg min^{-1}, kg $hour^{-1}$)
OD	Outside diameter (mm)
NXP	Nozzle Exit Position (mm)
$\dot{Q}_{boiler}$	Thermal energy supplied to the boiler (kW)
$\dot{Q}_{evap}$	Cooling effect produced at the evaporator (kW)
Rm	Entrainment ratio of an ejector
Ø	Diameter (mm, inch)

Subscripts

cri	condition at critical condenser pressure
boiler	condition at boiler pressure
con	condition at condenser pressure
evap	condition at evaporator pressure
g@boiler	saturated vapour at the boiler temperature
g@evap	saturated vapour at the evaporator temperature
f@con	saturated liquid at the condenser temperature
P	primary fluid
S	secondary fluid

and 200 °C instead of using electrical energy. Ejector refrigeration cycle is the one of this type of refrigeration systems (Chunnanond and Aphornratana, 2004). Moreover, it is the refrigeration system that can use water as the working fluid (Ruangtrakoon et al., 2011). The major weak point of a steam ejector refrigeration system is its low COP compared to an absorption refrigeration system, another most widely used type of heat-power refrigeration system. The reduction of energy consumption and increase in refrigeration production by optimizing the ejector geometries or the system's operating conditions are the goals of improvement for many researchers (Yapıci et al., 2008; Meyer et al., 2009; Chen et al., 2013; Chandra and Ahmed, 2014). The development of the working fluid circulating system of the ejector refrigeration system (Srisastra and Aphornratana, 2005; Srisastra et al., 2007) is also the one option for improving the system performance.

Very few of existing literature tackles the experimental study, test or operation of an ejector refrigeration system, under an actual environment. A prototype 40 kW ejector refrigerator was designed and constructed by Eames et al. (Eames et al., 2013) for application in the industrial temperature control. The refrigerator was tested over a range of operating conditions. To reduce energy consumption of the ejector refrigeration system, some researchers attempted to apply renewable energy to drive the system. Pollerberg et al. (2009) designed, constructed and tested a solar steam ejector refrigeration system. The cooling capacity was 1 kW and parabolic type solar collectors were used. Later, the comparison of solar collector which could be used to drive the ejector cooling system for Mediterranean climate was presented by Zhang et al. (2012). They selected the suitable solar collector from three different types of evacuated tube solar collectors. Their parameters of consideration were efficiency, price and maintenance cost of those solar collectors.

However, in literature, most experimental researches were conducted in western countries where the ambient temperature is quite low or used a water chiller to produce cooling water for the condenser. Therefore, the flexibility of the condenser operating condition was possible, unlike Thailand, which is a hot and humid country, and where the cooling water supplied by a conventional cooling tower is rather high (29–32 °C). Therefore, low condenser saturation pressure is not possible. Design and construction of a steam ejector refrigerator for use in the Thai environment is a challenge. This study presents the design, construction and test results of a prototype steam ejector refrigerator when it is used as air conditioner in hot and humid environment of Thailand's summer.

The authors employed CFD technique to simulate the steam ejector used in the prototype refrigerator. The steam ejector used in the prototype refrigerator was simulated under the specified boundary conditions and operating conditions, which corresponds to the design and the weather conditions of Thailand. The simulated result can ensure that the prototype steam ejector refrigerator constructed has the possibility to be operated in the actual environment.

2. The operating conditions and design of the ejector

The prototype steam ejector refrigeration system was designed to provide a cooling capacity of approximately 3 kW with the evaporator saturation temperature of around 10 °C. This evaporator temperature can sufficiently be used to produce chilled water for an air conditioner to control the temperature of a small room in the range of 13–23 °C. The steam boiler used was designed to use LPG compact burner as the heat source. It is used to produce saturated steam at the temperatures in the range of 100–130 °C. The reason of using LPG compact burner is that it is very suitable to be used in the laboratory and the temperature of saturated steam is easy to control. Moreover, the use of LPG fuel can be better to illustrate the possibility of using a renewable energy source as the system's driving energy than that of using an electric heater. The condenser is cooled by cooling water provided from a conventional cooling tower. For Thailand's environment, the highest surrounding temperature in summer can be as high as 40 °C with relative humidity of 70% (wet bulb temperature of 34.7 °C). Therefore, the cooling water supplied is in the temperature range of 30–35 °C. The designed values of the operating conditions are shown in Table 1.

Table 1 – The operating conditions of the prototype steam ejector refrigeration system.

Boiler temperature	Evaporator temperature	Condenser pressure saturation (temperature)
110–130 °C	10 °C	73.8 mbar (40 °C)