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Thermodynamic model development, experimental validation and performance analysis of a MW CCHP system integrated with dehumidification system

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ABSTRACT

Combined cooling, heating and power (CCHP) systems, which have the advantages of energy saving and environmental protection, have attracted more and more attentions. Great deals of works have been done, but most of them are theoretical research. It is still lack of experimental research for large scale CCHP system in practical application, and an overall off-design thermodynamic model is also desired to simulate or exam the system performance. In this work, a novel CCHP system integrated with dehumidification system is proposed for further utilizing waste heat, in which an internal combustion engine (ICE) is used as prime mover, its heat of flue gas and the heat of jacket water above 81 °C are used to drive absorption chiller, and the heat of jacket water below 81 °C is used to drive absorption dehumidifier. A comprehensive off-design thermodynamic model and evaluation of the system is established. The tested results of a MW CCHP system integrated with dehumidification system are used to validate the model, and the thermodynamic performance analysis is also carried out. The thermodynamic performance comparison between the CCHP system integrated with dehumidification system and conventional CCHP system has been done. The results show that: the simulated values are basically in keeping with those experimental results; when the output power of ICE is 1200 kW, the primary energy rate of the MW CCHP system can go up to 84.0%, the primary energy saving ratio achieves 32.77%, and exergy efficiency is 42.45%; the thermodynamic performance of the proposed CCHP system is better than conventional CCHP system.

1. Introduction

With the developing of global economy, the problems of energy crisis and environment pollution become more and more concerned. As an advanced energy saving and emission reduction technology, combined cooling, heating and power (CCHP) systems have been received increasing attentions [1,2]. An extensive research works about CCHP systems have been reported, such as performance improvement through thermodynamic analysis, integrated with different prime movers and thermal activated technologies, optimization, design and operating strategies and so on [3–10].

Due to technology complexity and economic concern, although lots of significant advancement in the above mentioned topics have been made, most of those are only theoretical research. A few literature can be found on experimental research of CCHP systems. Zhi-Gao Sun et al. developed an experimental study on the performance of a small CCHP system, which used a micro gas turbine as prime mover. Primary energy rate and comparative saving of primary energy were presented to assess the performance of CCHP system [11]. Dheeraj Kishor Johar et al. had been set up an experimental platform of a 4.4 kW stationary compression ignition ICE coupling with a double pipe heat exchanger, vapor absorption refrigeration system and thermal energy storage system. Various combinations of thermal energy storage system integrated micro tri-generation were investigated, and experimental results of system performance and emission had been presented [12]. A micro-cogenerator, which was based on natural gas fueled reciprocating ICE coupling with a thermal-chemical absorption system, was built to experimentally study the on-site performance of both micro-cogeneration system and micro-trigeneration system under real operating conditions [13]. Kong et al. had built an experimental platform of micro-CCHP system, which consisted by a small-scale gas ICE and adsorption chiller. An energetic analysis of the tested results was performed [14]. Cuizhen

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Nomenclature

Abbreviation

CCHP	combined cooling, heating and power
ICE	internal combustion engine

Symbols

COP	coefficient of performance
E	exergy (kW)
EDR	exergy destruction ratio
I	exergy destruction (kW)
LHV	lower calorific value of fuel (J/m^3)
P	power (kW)
PER	primary energy rate
PESR	primary energy saving ratio
Q	heat (kW)
V	fuel volume (m^3/h)
c	specific heat capacity (kJ/kg °C)
m	mass flow (kg/s)
t	temperature (°C)
η	efficiency

Subscripts

a	absorption chiller
b	boiler
c	cooling
cw	cooling water
d	dehumidification
e	evaporator of absorption chiller
el	electricity
ex	exergy
f	fuel
fg	flue gas
g	generator of absorption chiller
grid	electrical grid
h	heat
in	inlet
icw	intermediate cooling water
jw	jacket water
loss	heat loss
out	outlet
p	pressure
Q	heat resource
n	nominal
0	ambient

Zhang et al. proposed a LiBr refrigeration-heat pump system integrated with CCHP system, which was used steam turbine as a prime mover. The heat of LiBr refrigeration cooling water could be recovered to heat-up the demineralized water of the boiler. Experimental research on the operating characteristics of system was carried out [15].

Above mentioned literature only presented experimental results of CCHP system. In order to more comprehensive investigate, some theoretical research has been done to analyze the behavior of CCHP systems, which could be validated by experimental results. Guillermo Rey et al. presented a micro-CCHP system with heat recovery based on a Honda gas engine (ICE), which incorporated a heat pump to meet the need for air conditioning. The TRNSYS software was used to simulate the performance of system, and the experimental results were obtained under various operating modes to validate the simulated results [16]. Ge et al. set up a test rig of a tri-generation system in the laboratory to study the performance and application feasibility, which included an 80 kW gas turbine, an absorption chiller, a recuperator etc. The TRNSYS software was used to establish system model, which had been validated with the test results [17]. Zheng et al. built a dynamic simulation model for the micro-cogeneration unit based on TRNSYS software, considering

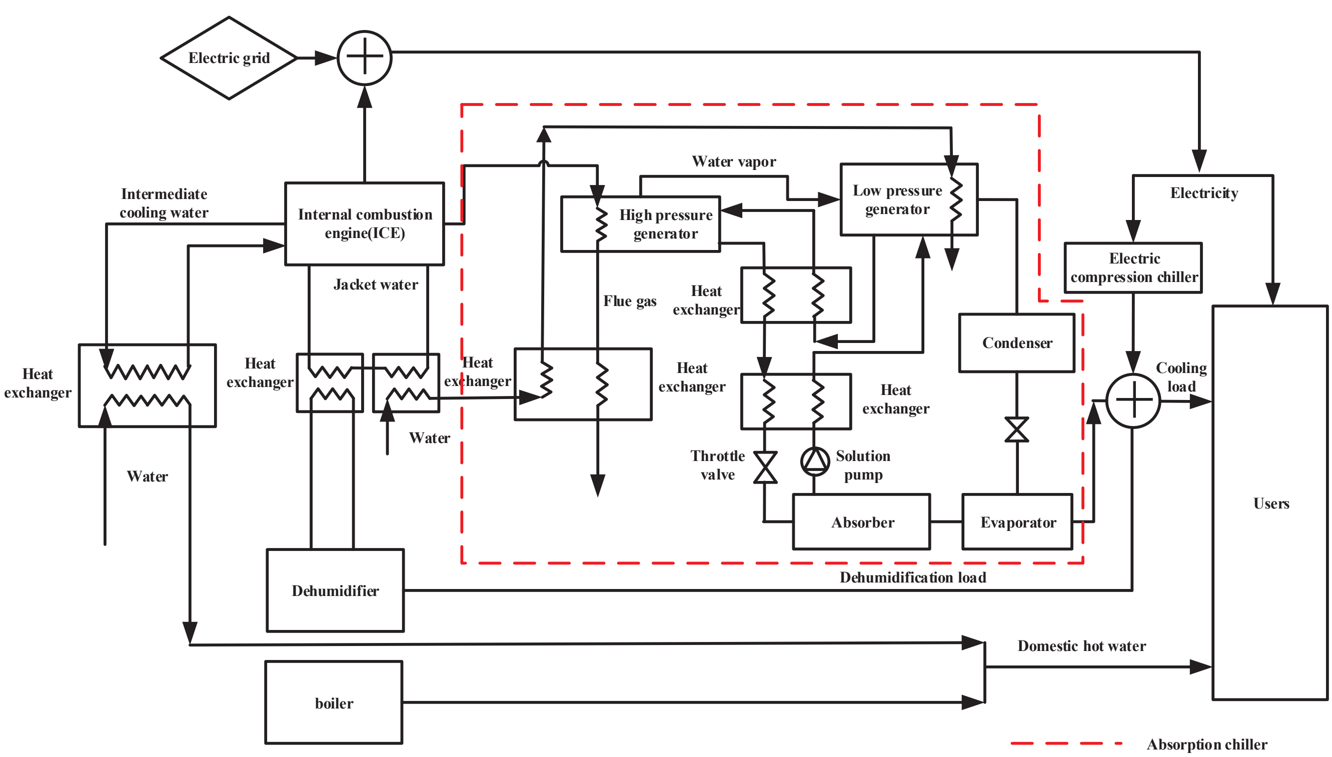

Fig. 1. The flow chart of CCHP system integrated with dehumidification system.