Applied Energy 218 (2018) 10–21

Contents lists available at ScienceDirect

Applied Energy

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

Analysis on innovative resorption cycle for power and refrigeration cogeneration

L. Jiang[a,b,*], A.P. Roskilly[b], R.Z. Wang[a], L.W. Wang[a]

[a] Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Sir Joseph Swan Centre for Energy Research, Newcastle University, Newcastle NE1 7RU, UK

HIGHLIGHTS

- A novel resorption cycle is proposed for improved performance with internal heat recovery.
- *COP* of novel resorption cogeneration cycle could achieve up to 1.31.
- The optimum total exergy efficiency is the highest among sorption cogeneration technologies.
- Novel resorption cogeneration cycle has great potentials for waste heat utilization.

ARTICLE INFO

Keywords:
Resorption
Power generation
Refrigeration
Exergy efficiency

ABSTRACT

A novel resorption cycle with internal heat recovery process is proposed, which is expected to further explore potentials of power and refrigeration cogeneration. Two sets of basic resorption refrigeration cycles are adopted, which are integrated with turbine/expander to realize quasi-continuous output in both half cycles. An improved cogeneration efficiency could be obtained with safety feature. Different ammonia composite sorbents with better heat and mass transfer performance are selected to investigate the overall performance when heat source temperature is in the range from 200 °C to 360 °C. It is indicated that energy efficiency for power generation is able to reach up to 0.263 at 360 °C heat source temperature while refrigeration coefficient of performance could achieve up to 1.31 at 200 °C heat source temperature. The optimal total exergy efficiency of novel resorption cogeneration cycle is as high as 0.74 by using working pair of $FeCl_2$-$CaCl_2$-$BaCl_2$ at 240 °C heat source temperature. Compared with other sorption cycles for power and refrigeration cogeneration at similar heat source temperatures, the proposed resorption cycle exhibits the highest exergy efficiency, which is about 30% higher than that of water-ammonia sorption cogeneration cycle, and twice higher than that of basic resorption cogeneration cycle.

1. Introduction

Low grade heat e.g. solar energy, industrial waste heat, and geothermal energy is ubiquitous, which has attracted burgeoning attentions due to depletion of fossil fuels [1]. Sorption technology has revealed great potentials in harnessing low grade heat by using environmental benign refrigerant, which results in an improved efficiency of energy utilization and CO_2 emission reduction [2]. It is widely acknowledged that sorption cycle could be developed for various functions of air conditioning and freezing [3,4], heat pump and energy storage [5,6], desiccant and desalination [7], CO_2 capture and storage [8]. These applications are mainly related with heat and cold loads whereas electricity demand is completely a different scenario. Integration of thermal dynamical cycle with turbine/expander provides enormous opportunities of power generation for low grade heat recovery.

The first attempt of absorption power generation cycle was in the 1950s, which was based on water-ammonia working pairs [9]. About 30 years later, Kalina cycle was proposed for an improved efficiency of power generation [10], and a variety of Kalina cycle systems (KCS) were investigated successively for further exploration, which implied a promising future of this technology [11]. Also worth noting that a serious of demonstration projects around world have been established based on Kalina cycles, which are driven by geothermal energy, solar thermal energy or industrial waste heat. With some modifications of ammonia-absorption cycle, Goswami cycle was proposed in 1998 for

---

[*] Corresponding author at: Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China.
E-mail address: maomaojianglong@sjtu.edu.cn (L. Jiang).

https://doi.org/10.1016/j.apenergy.2018.02.174
Received 30 September 2017; Received in revised form 18 February 2018; Accepted 28 February 2018
0306-2619/ © 2018 Elsevier Ltd. All rights reserved.

Nomenclature

COP	coefficient of performance
c_p	specific heat capacity ($J \cdot g^{-1} \cdot K^{-1}$)
E	exergy (kJ)
ENG	expanded natural graphite
HTS	high temperature sorbent
KCS	Kalina cycle systems
MOF	metal organic framework
MTS	middle temperature sorbent
m	mass (kg)
LTS	low temperature sorbent
ORC	Organic Rankine Cycle
P	pressure (Pa)
Q	heat (kJ)
R	gas constant ($J \cdot mol^{-1} \cdot K^{-1}$)
T	temperature (°C)
W	power generation (kJ)

Greek letters

ΔH	reaction enthalpy of sorbent ($J \cdot mol^{-1}$)
ΔS	reaction entropy of sorbent ($J \cdot mol^{-1} \cdot K^{-1}$)
η	efficiency

Subscripts

a	ambient
con	condensation
d	desorption
ENG	expanded natural graphite
en	energy
eq	equilibrium
ex	exergy
HTS	high temperature sorbent
i	theoretical
h	heat
in	inlet
MTS	middle temperature sorbent
LTS	low temperature sorbent
out	outlet
R	reaction
r	reactor
rec	recovery
ref	refrigeration
s	sorption
sen	sensible
salt	sorbent
tot	total
w	power generation

cold and power cogeneration, which was a combination of an ammonia-water absorption cycle and an ammonia-based Rankine cycle [12]. Through accumulative improvement of thermal cycles, higher performance could be gradually realized in terms of efficiency and output.

It is generally admitted that sorption is mainly composed of liquid-gas absorption and solid-gas sorption technology. Similar with ammonia-absorption cycle, ammonia-based chemisorption cycle is also attempted to investigate the extra power generation by combining with an expander, which further extends the spectrum of energy conversion technologies. Innovation of sorption cycle always comes along challenges and opportunities, which trudges through fierce comparison and competition. A typical chemisorption cycle consists of a sorption reactor and a condenser/evaporator. Liquid ammonia inside sorption system will cause safety problems, and system performance is also greatly influenced by condensation temperature [13]. Comparably, another type of chemisorption cycle termed as resorption cycle brings about more advantages. Condenser/evaporator is replaced with a secondary sorption reactor by using another sorbent, which results in an improved refrigeration performance due to the fact that desorption heat is usually higher than evaporation latent heat of ammonia [14]. Resorption cycle often operates at a relatively lower working pressure when compared with typical sorption cycle [15]. This unique characteristic plays a promoting role in integrated system for power generation since pressure difference between inlet and outlet of the expander will be further amplified. Therefore, integrated resorption system for power and refrigeration cogeneration is worth exploring. Similar to absorption cogeneration cycle for power and refrigeration, continuous efforts are made for various sorption chemical and physical cycles in the progress of improving thermal efficiency.

Wang et al. first established a resorption cycle for power and refrigeration cogeneration. It was concluded that the cogeneration system could have a much higher refrigeration performance than that of Goswami cycle [16]. On basis of this resorption cycle, Lu et al. [17] investigated this cogeneration cycle by using mass and heat recovery. Nonetheless, the limited improvement of energy efficiency could be achieved, which was no more than 20%. Hereafter, Bao et al. [18] optimized resorption power generation cycle to gain the maximum power output, and an advanced cycle with optimal arrangement was proposed despite the loss of cooling effect. Except for ammonia-based sorption cycle, Al Mousawi et al. [19] investigated cogeneration potential of an integrated system by using working pair of metal organic framework (MOF) and water. Later, several sorbents i.e. silica gel, zeolite and MOF were adopted and compared in terms of power and refrigeration performance by incorporating an radial inflow turbine between desorber and condenser [20]. In fact, physisorption systems are relatively difficult for real application since water and methanol-based systems normally work at low pressure, which is lower than atmospheric level or even close to vacuum. For improving stability and continuity of power generation, multi-stage is considered as a good solution for optimization, which is able to be applied to both chemisorption cycles [21] and physisorption cycles [22]. Some lab-scale chemisorption cogeneration systems were established to investigate real experimental performance. The first lab prototype ammonia-based sorption cogeneration machine was established by Bao et al. [23], and results demonstrated that selection of expander for matching sorption system could be a key factor for real electricity output. Our previous work investigated a resorption system for electricity and refrigeration cogeneration. Results indicated that total system efficiency wasn't desirable due to the limitation of cycle efficiency by using a certain kind of working pair [24].

In order to further improve thermal efficiency, a novel resorption cycle for power and refrigeration cogeneration is proposed. Internal heat recovery between two different sorption reactors are first adopted for cogeneration cycle, which is rare reported. Theoretical evaluation of energy and exergy efficiency for power and refrigeration cogeneration is conducted. To avoid swelling and agglomeration, six composite metal halides are employed with expanded natural graphite (ENG), which is commonly used for real sorption reactors.

2. Working principle of resorption cogeneration cycles

For better elaborating resorption cycle with internal heat recovery, a basic resorption cycle for power and refrigeration cogeneration will be first introduced. For chemisorption reaction process, working pressure is determined by working temperature, which can refer to Eq. (1). When reaction enthalpy and entropy of a chemical working pair are

Download English Version:

https://daneshyari.com/en/article/6680373

Download Persian Version:

https://daneshyari.com/article/6680373

Daneshyari.com