



Exploration of ammonia resorption cycle for power generation by using novel composite sorbent



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HIGHLIGHTS

- An improved performance of resorption cycle for power generation is accomplished.
- Novel composite sorbent is developed with both ENG and Ni@C as the additives.
- Energy density is increased by up to 20% by using novel SrCl₂-ENG&Ni@C.
- Performance of basic resorption cycle is improved by 3–5 times through reheating process.
- Improved resorption cycle may be an alternative method for lower temperature heat utilization.

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ABSTRACT

Expanded natural graphite and carbon coated nickel are selected as the additives in the development of novel composite sorbent. Improved thermo-physical properties of composite strontium chloride result in a faster sorption reaction rate than that without using carbon coated metal. A case study of ammonia-based resorption power generation cycle with two identical reactors is analyzed in terms of sorption characteristics of composite sorbents. Power could be generated in both half cycles, which greatly enhances working versatility and thermal efficiency. It is indicated that additive of carbon coated nickel has a positive influence on performance of resorption power generation cycles. Energy and exergy efficiency of basic resorption cycle range from 0.072 to 0.116 and from 0.402 to 0.737, respectively. Basis resorption cycle for power generation is also compared with improved resorption cycle by using different composite sorbents. Increment between improved and basic resorption cycle by using the sorbent without carbon coated nickel is larger than that using that with carbon coated nickel. Energy density by using novel composite sorbent is improved by up to 20% based on mass and volume of sorption reactor. Through reheating process, performance of basic resorption cycle is further improved by 3–5 times.

1. Introduction

Characterized as sustainable feature and environmental protection, energy conversion technology is gathering the momentum, which could efficiently harness different low grade heat e.g. industrial waste heat, solar energy and geothermal energy [1]. As one of the most promising energy conversion methods, sorption cycle could play various roles of air conditioning and freezing [2], heat pump and energy storage [3], desiccant and desalination [4], CO₂ capture and storage [5], which has aroused a burgeoning number of attentions [6]. In recent decades, integration of sorption cycle with a turbine/expand has opened a new chapter of power generation, which also comes along challenges and opportunities [7]. Thus sorption cycle is able to meet energy demands

not only for heat and cold but also for electricity with higher energy grade.

Sorption is generally classified into liquid-gas absorption and solid-gas sorption technology. Liquid-gas absorption power generation cycles have been investigated for several decades. Water-ammonia working pair was first adopted as a pioneer in the 1950s, which verified the possibility of absorption power generation technology [8]. Afterward, Kalina cycle was proposed for power generation by Dr. Alexander Kalina in 1984 [9]. Different configurations of Kalina cycles were successively introduced to optimize the performance [10]. Also a series of demonstration projects throughout the world has been established based on Kalina cycles. With some modifications of Kalina cycle, Goswami cycle was proposed in 1998 for power and refrigeration

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Nomenclature		Subscripts	
c_p	specific heat capacity ($\text{kJ kg}^{-1} \text{K}^{-1}$)	a	ambient
Ni@C	carbon coated nickel	con	condensation
Q	heat (kJ)	d	desorption
R	gas constant ($\text{kJ kmol}^{-1} \text{K}^{-1}$)	en	energy
SrCl_2	strontium chloride	eq	equilibrium
ν	sorption rate ($\text{kg kg}^{-1} \text{s}^{-1}$)	ex	exergy
W	power (kJ)	ENG	expanded natural graphite
x	sorption capacity (kg kg^{-1})	h	heat
Abbreviations		in	inlet
COP	coefficient of performance	m	mass
E	exergy (kJ)	NH_3	ammonia
ED	energy density	out	outlet
ENG	expanded natural graphite	R	reaction
m	mass (kg)	re	reactor
P	pressure (Pa)	ref	refrigeration
T	temperature ($^{\circ}\text{C}$)	reh	reheating
t	time (s)	s	sorption
Greek letters		salt	sorbent
ΔH	reaction enthalpy of sorbent (kJ kmol^{-1})	sat	saturation
ΔS	reaction entropy of sorbent ($\text{kJ kmol}^{-1} \text{K}^{-1}$)	sen	sensible
η	efficiency	v	volume
		w	power generation
		x	sorption capacity

cogeneration [11]. In addition to water-ammonia working pair, similar absorption power generation cycle by using LiBr-water working pair was proposed [12,13]. A variety of advantages e.g. high exergy efficiency could be obtained when compared with conventional Rankine cycle [14]. But this concept was not suitable for small systems due to high volumetric flow rate [15]. Compared to these absorption cycles, solid-gas chemisorption cycles have complementary advantages e.g. large temperature and pressure difference due to its monovariant sorption characteristic, which reveal vast potentials of productive mechanical power generation [16]. Heat and mass transfer enhancement of the sorbent [17] and cycle innovation and optimization [18] are main research fields to accomplish high efficient power generation cycles.

With regard to performance of sorbents, thermos-physical properties e.g. thermal conductivity, permeability and sorption reaction rate are required to be evaluated comprehensively since these parameters are often interdependent. Due to severe swelling and agglomeration phenomenon, granular salts usually display poor heat and mass performance, which will inevitably have a negative influence on sorption and desorption kinetics [19]. Various matrices e.g. expanded natural graphite (ENG) [20], vermiculite [21] and carbon nanoparticle [22] have been attempted as additives in developing composite sorbents, which are considered to be a feasible solution. Among them, ENG is a most investigated material, which is verified as a good additive to improve heat transfer of the sorbent. In most cases, heat transfer and mass transfer are mutually restraint. Mass transfer is slightly weakened by adding ENG. It is worth noting that mass transfer is also a key parameter for thermal performance on some occasions when temperature potential is sufficient for heat transfer of the sorbent. Recently carbon coated metal has proved to be a good matrix for mass transfer enhancement, which could be jointly used with ENG [23]. It was demonstrated that large improvement of sorption cycle in freezing conditions could be achieved for combined heat and cold storage by using carbon coated metal [24]. Thus novel composite sorbent with carbon coated metal is also expected to have a remarkable improvement on sorption power generation cycle.

Additionally, power generation performance could be improved by various advanced cycles such as sorption cycle [25], resorption cycle [26,27], advanced resorption cycle [28] and multi-stage resorption cycle [29]. These sorption cycles could be applied for both physisorption and chemisorption, which generate the power or achieve cooling and power cogeneration by means of interval heating source, heat and mass transfer recovery, superheating and reheating process [30]. Similar with LiBr-water absorption cycle, physisorption cycles for power generation are relatively difficult for real application since water and methanol-based cycles often work at vacuum pressure, which result in high requirements for the expander [31]. Comparably, several lab-scale ammonia-based sorption systems were established to investigate their cogeneration performance [32,33]. Except for experimental investigation, theoretical analysis of these power generation cycles all lies in power output and thermal efficiency by using the first and second law of thermodynamics. Nevertheless, power is generally not only related with capacity but also with the time. In some cases, a high power generation rate is also required. It is quite difficult to predict real power output when an expander is integrated into a basic sorption cycle. The main reason is that mass flow rate of working fluid could not be ensured since the expander plays a role as resistance. Sorption or desorption reaction rate will be greatly varied, thus the typical reaction kinetic could not be further utilized.

In this study, sorption and resorption cycle for power generation are presented, and improved resorption cycle is then introduced. ENG and carbon coated nickel (Ni@C) are selected in developing novel composite strontium chloride (SrCl_2), which are conducive to heat and mass transfer performance. Under different working conditions, sorption rate of composite sorbent using Ni@C is accelerated and global conversion rate is increased to some extent when compared with the sorbent not using Ni@C. Thus an improved thermal performance of resorption power generation cycle is assessed in terms of energy output quantity, energy output rate, energy efficiency and energy density. In order to further elaborate the advantages in real application, performance of basic and improved resorption power generation cycle are further compared based on the properties of composite sorbents.

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