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Thermal analysis for the evaporation concentrating process with high boiling point elevation based exhaust waste heat recovery

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ABSTRACT

In order to reduce energy consumption of the solution evaporation concentrating process with high boiling point elevation (BPE), a novel cogeneration system is proposed to integrate the solution evaporation concentrating and power generation processes using the exhaust waste heat as heat source. Through compared with the conventional three-effect and mechanical vapor recompression evaporation processes, influences from the key operation parameters, including the evaporation temperature and BPE of the solution on overall thermal performance of the proposed system have been investigated. The results showed the overall thermal performance of the three schemes became worse with the rise of the BPE, but the proposed cogeneration system showed prominent thermal performance when dealing solutions with high BPE compared to those of the conventional three-effect and MVR evaporating processes. Moreover, through harmonizing the vacuum evaporation concentrating process and net power output, the optimal evaporating temperatures to achieve the maximal energy saving potential are obtained under different BPE working conditions for the proposed cogeneration system.

1. Introduction

Evaporation concentrating process is widely used to remove water from the dilute solution in chemical and pharmaceutical industries [1,2]. A large amount of thermal energy is required to evaporate the excess water, and the waste heat in the effluent stream is difficult to be recovered completely. In order to decrease the overall energy consumption, many different energy saving methods for solution concentration have been proposed, including the multi-effect evaporation (MEE) [3,4], multi-stage flash (MSF) [5,6], and mechanical vapor compression/recompression (MVC/MVR) [7–9].

In these days, some schemes based on the self-heat recovery technologies (SHRT) have been proposed to save energy [10–12]. Through compression of the effluent stream and optimal heat pairing, the sensible and latent heat in the process is recycled, and thus no extra heater is required for these schemes based on SHRT. However, using above schemes based on SHRT to deal with the solution at high boiling point elevation (BPE), the steam generated from the evaporation concentrating process is often at superheated condition, and the superheated degree increases as its BPE is increased [13–15]. In order to recover the effluent stream's waste heat, including the latent and sensible heat, high compression ratio of the compressor is required, and overall energy consumption of these schemes based on SHRT are still very high. Han et al. [16] studied the evaporation concentrating process of the calcium chloride solution with high BPE, and found the MVR system based on SHRT is energy saving compared to the conventional MSF or MEE evaporating systems with low BPE. While, they found overall compression work consumption of the single-stage MVR system based on SHRT increases obviously when dealing with the solution at high BPE, and its overall energy consumption is even higher than that of the MEE evaporation scheme with BPE over 20 K.

From above literature reviews, it is known overall energy consumption is still very high when dealing with solution at high BPE through above methods. Therefore, it is very necessary to investigate the energy saving problem for the evaporation concentrating process of the solution with high BPE in the future. In this study, through using the low-temperature exhaust waste heat as heat source, a novel cogeneration system is proposed. In evaporation concentrating process of proposed the cogeneration system, extra power is generated by the effluent steam through the turbine. The thermal performance of the cogeneration system is analyzed through comparing to the conventional three-effect and the MVR evaporation concentrating processes. The energy saving performance of the proposed system is investigated through analyzing influences from the key parameters, including the evaporating temperature, the initial solution concentration, x_i, and the final solution concentration, x_o, on the overall thermal performance indices.

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Nomenclature

1,2,3,…	stream number
a_o	BPE calculation parameter
b_o	BPE calculation parameter
BPE	boiling point elevation, K
m	mass flow rate, kg/s
p	pressure, kPa
Pt	power output of turbine, kW
Pp1	power consumption of pump1, kW
Pp2	power consumption of pump2, kW
P_e	net power output, kW
Q	heat transferred, kW
R_c	mass ratio of m_9 to m_{10}
RPER	relative primary energy ratio
T	temperature, K
x	solute mass fraction in solution
Δt	temperature difference, K
$\varepsilon_1, \varepsilon_2, \varepsilon_3$	the calculation precision, 1×10^{-4}
γ	latent heat, kJ/kg

Abbreviation

BPE	boiling point elevation
MSF	multi-effect flash
MHTTD	minimal heat transfer temperature difference
MVR/MCR	mechanical vapor compression/recompression
RPER	relative primary energy ratio
SHRT	self-heat recovery technology

Subscript

carnot	carnot cycle
_c	calculated value during iterative process
Con	condenser
He	heat exchanger
I	inlet
in	overall thermal energy transferred through the heat exchanger
min	the minimal value
o	outlet
p1	pump1
p2	pump2
Pr	preheater
qe	the equivalent thermal energy obtained
_s	isentropic process
_sat	saturated condition
t	turbine
w	water

2. System description

Fig. 1 shows flow diagram of the evaporation concentrating and power cogeneration system. The initial dilute solution of stream 3 is preheated by the concentrated solution of stream 10 through the preheater. Then the preheated dilute solution of stream 4 is mixed with the recycled concentrated solution of stream 9 leaving the recycle pump, and then the mixtures of stream 5 flow through the heat exchanger, where the exhaust waste heat is recovered and absorbed by the mixtures of stream 5. Temperature of stream 6 leaving the heat exchanger is increased, and then flows through the adiabatic flashing tank, where the steam of stream 7 and rich solution of stream 8 are separated.

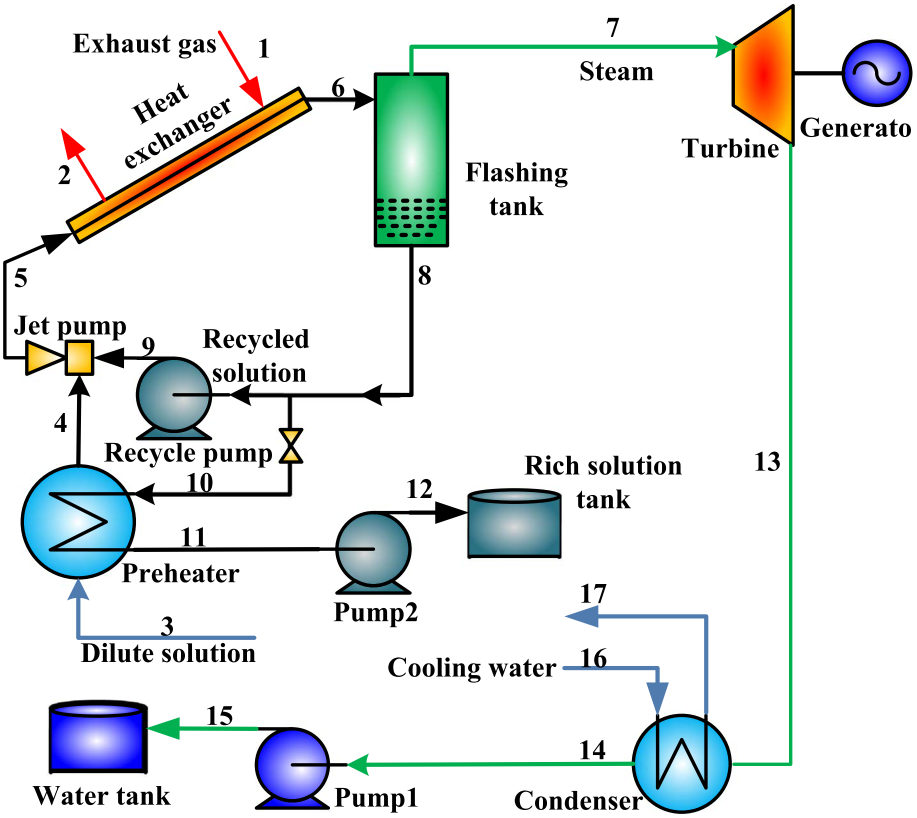

Fig. 1. The evaporation concentrating and power cogeneration system diagram.