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Performance analysis on a new multi-effect distillation combined with an open absorption heat transformer driven by waste heat

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HIGHLIGHTS

- A new absorption vapor compression distillation was proposed in present research.
- An open absorption heat transformer has a coupled thermally evaporator and absorber.
- Distillation of waste water with high content of SiO_2 from heavy oil production.
- The waste heat of 70 °C can be elevated up to 125 °C and generate steam of 120 °C.
- The waste heat is able to drive four-effect distillation to produce distilled water.

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ABSTRACT

In this paper, a new water distillation system, which consists of either a single- or multi-effect distiller combined with an open absorption heat transformer (OAHT), has been proposed.

The new integrated system can be used for distilling waste water with high amounts of SiO_2 from heavy oil production, and the resultant distilled water can be supplied to steam boilers to produce high quality steam which in turn is injected into oil reservoirs to assist with heavy oil recovery. The thermodynamic cycle performances for these new integrated distillation systems were simulated based on the thermodynamic properties of the aqueous solution of LiBr as well as the mass and energy balance of the system. The results indicate that combined with OAHT, the waste heat at 70 °C can be elevated to 125 °C and thereby produce steam at 120 °C in the absorber, which is able to drive a four-effect distiller to produce distilled water. For a single-effect and four-effect distiller, the coefficients of performance (COP) are approximately 1.02 while the performance ratios are 2.19 and 5.72, respectively. Therefore, the four-effect distillation system combined with an OAHT is more thermally effective and is an ideal option to process the waste water in oilfields.

1. Introduction

Steam injection is becoming a common method for enhancing oil recovery efficiency. 100% quality steam is required to be injected into the oil reservoir, to heat heavy oil and thereby to reduce its viscosity. Meanwhile, a lot of hot waste water with high amounts of SiO_2 will be produced in the separating process of crude oil from the oil–water mixture. In order to remove SiO_2 and other salts or contaminants from the produced waste water and meet the quality standards for feed water of steam boilers, some common physical and chemical technology of waste water processes are employed in heavy oil production. Recently the mechanical vapor compression (MVC) distillers, which mainly consist of a compressor and a distiller (or evaporator) were proposed [1].

In order to enhance the thermo-economy of the water purification process or desalination process, a common closed absorption heat pump (AHP) or an absorption heat transformer (AHT) are combined into a single-effect or multi-effect desalination [2–9]. The multi-effect thermal desalination system which is coupled with an open absorption heat pump driven by a high temperature heat source was analyzed recently [10]. The multi-effect thermal desalination system coupled with the absorption-compression heat pump was also analyzed [11].

In this paper a new thermal distiller, which is combined with an open absorption heat transformer (OAHT) and driven by low grade waste heat, is proposed. The OAHT has the coupled thermal absorber and evaporator. Compared with the MVC thermal distiller, the electric consumption of this new thermal distiller is much

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Nomenclature

COP	coefficient of performance
D	total amount of distilled water produced (kg/s)
E, E1, E2, E3, E4	evaporator
F	flow rate ratio
h	enthalpy (kJ/kg)
HE	solution heat exchanger
m	mass flow rate (kg/s)
P	pressure (MPa)
PR	performance ratio
Q	heat flow rate (kW)
r	vaporization latent heat of water (kJ/kg)
S	separator
t	temperature (°C)
x	mass fraction of lithium bromide in solution (%)

Subscripts

A	absorber
C	condenser
E	evaporator
G	generator
1,2,3… 22	the series number of streams

smaller because it is mainly driven by waste heat rather than electric power.

Up till now the articles or reports on this new integrated thermal distiller have not been found. In order to further develop this thermal distillation method and to optimize the operating parameters, it is necessary to analyze its thermodynamic cycle performance based on the thermodynamic properties of the aqueous solution of lithium bromide and on the mass and energy balance for each component in the system.

2. Configuration of integrated thermal distillation system

The configurations of either single-effect or multi-effect thermal distiller combined with an OAHT are schematically shown in Figs. 1 and 2. As shown in Fig. 1 the evaporator and absorber are coupled thermally in this new thermal distiller which has the same components as the common closed absorption heat transformer, such as: evaporator, absorber, generator, condenser, solution heat exchanger and a strong solution pump.

Unlike the common closed AHT, the condensed water in the condenser (stream 15) is not pumped into the evaporator (distiller) for further vaporization but instead withdraws continuously as the product (distilled water). This is the reason why the system can also be called an open AHT. Compared to the common closed AHT, another main difference is that the evaporator is strongly coupled with the absorber by waste water streams (stream 1–6). In fact, the evaporator is heated by the high-temperature heat released in the absorber rather than by the low-grade waste heat as used in the generator, and thus a higher evaporation temperature and pressure can be obtained in the evaporator, which leads to a higher absorption temperature and pressure in return.

As shown in Fig. 2, the high-temperature heat released from the absorber can be reused for many times in a multi-effect distillation, and thus a higher thermal efficiency and performance ratio can be obtained in this integrated system.

3. Theoretical analysis on the cycle

In order to analyze the performance of the new thermal distillation system, the following assumptions are made.

(1) The analysis is carried out under steady state conditions;
(2) The solution leaving the generator or the absorber is at a vapor–liquid equilibrium state;
(3) The condensate leaving the condenser or the evaporator is not sub-cooled;
(4) Thermal and pressure losses are neglected;
(5) The expanding process in the throttling valve is isoenthalpic;
(6) The energy consumed by the pump is neglected;
(7) The waste water fed to the absorber is a saturated liquid and its temperature is lower than the absorbing temperature by 5 °C;
(8) Boiling-point elevation (BPE) of waste water is neglected.

In order to fully analyze the thermodynamic performance, it is necessary to solve the mass and energy balance equations as well as the corresponding phase balance equations for each component in the new integrated thermal distillation system.

Mass balance equations are as follows

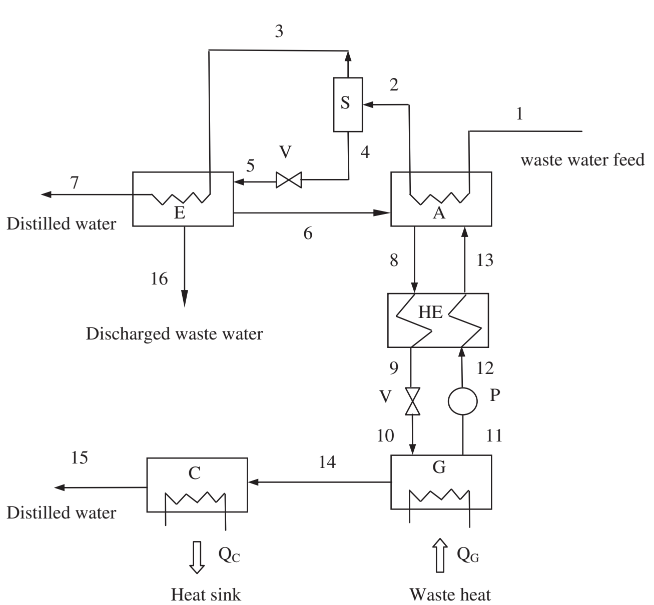

Fig. 1. Schematic diagram of a single-effect distillation integrated with an open AHT.

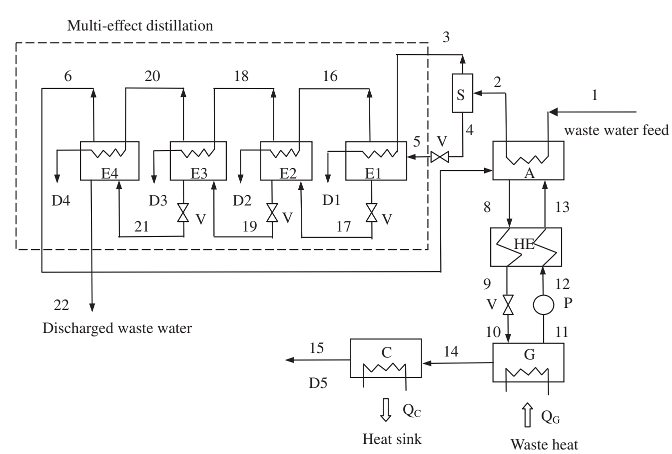

Fig. 2. Schematic diagram of a multi-effect distillation integrated with an open AHT.