APPLICATION OF OPEN CYCLE MECHANICAL VAPOUR COMPRESSION HEAT PUMP IN INDUSTRIAL FACILITIES.
PART 2. DESALINATION AND WASTEWATER PLANTS

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Abstract

A review and analysis of application of open cycle heat pumps with mechanical compression in industrial facilities are performed. The principle of operation of a mechanical heat pump, main elements and operation specifics are considered. Characteristics for energy efficiency of open cycle heat pump systems are given.

Keywords: *mechanical vapour recompression, coefficient of performance, energy cost, open cycle heat pump*

Introduction

Mechanical vapor recompression (MVR) heat pump are systems that are widely used in seawater desalination and industrial wastewater treatment plants. In process of desalination (water treatment), MVR heat pump system separates by thermal metod salted water (wastewater) to two components – clean distilled water and salt (concentrate sludge). Produced water can be reused in various industrial processes, where a clean water with high temperature is needed. Receiving of clean hot water by this method is made by low energy cost, because MVR heat pump system use secondary vapour of boiling process as a primary steam [6].

Material and method

MVR heat pump system used for desalination and wastewater treatment work in operating mode where wastewater in evaporator (heat exchanger) is in state "free boiling" (Fig.1) or "suppressed boiling" (Fig.2).

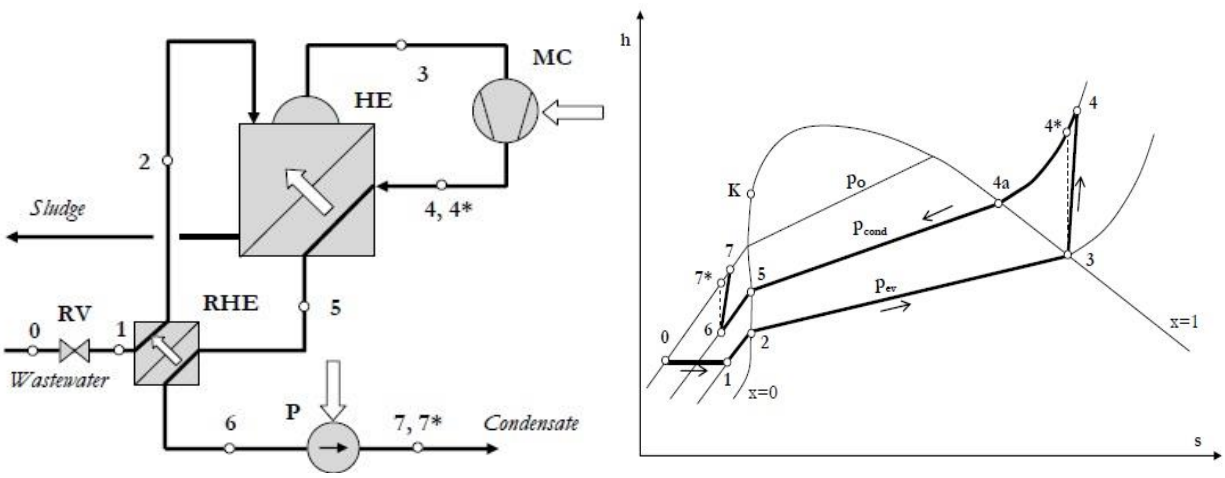

Figure 1. Schematic diagrams and open cycle for MVR heat pump with "free boiling''

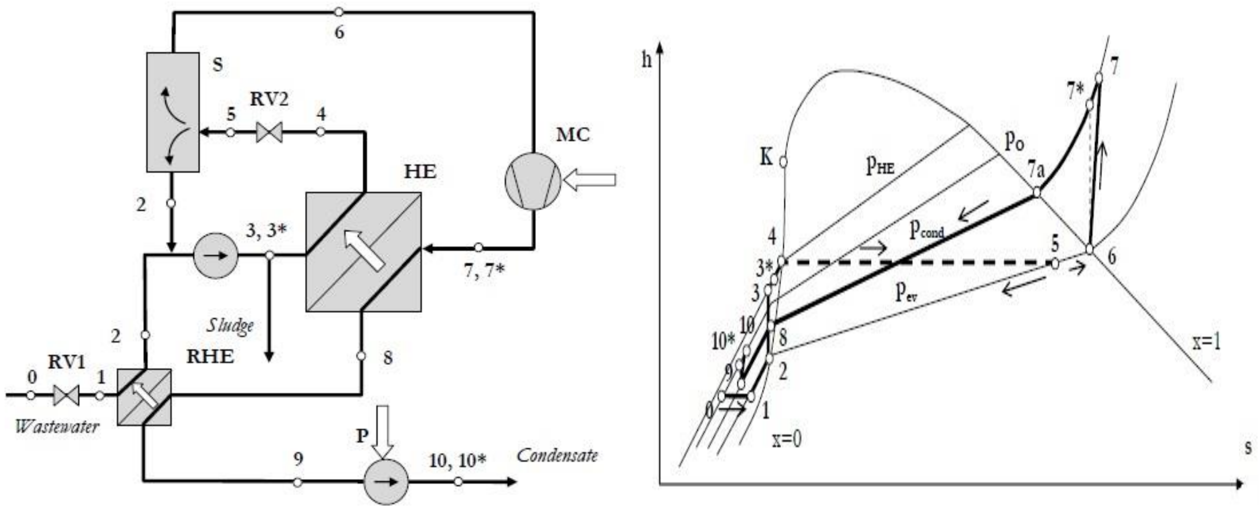

Figure 2. Schematic diagrams and open cycle for MVR heat pump with "suppressed boiling''

Results

Open cycle mechanical heat pump in desalination plants

In desalination plant with MVR heat pump most efficient processes of thermal single-stage distillation along with the method of reverse osmosis with energy recovery is performed [8,12]. Specific energy consumption of those systems is from 8 to 17 Wh/kg. This includes energy consumption of circulating pumps and compressor of the system. To use this method there is a limitation of daily performance of a single-stage installation - up to 300 m^3/day [1,2]. Highest efficiency has achieved in desalination plants with MVR heat pump with high daily performace - over 5000 m^3/day. Main disadvantages of MVR method are that it has to be used for water with temperature 60 - 70 °C, which means large heat exchange surfaces and high capital costs. Capital costs of those systems are higher, compared to capital cost for desalination installations, operating on principle of reverse osmosis. This requires improving efficiency of mechanical compressor, heat exchanger and other equipment of MVR heat pump to make system financially attractive. Temperatures of evaporation of boiling salt water and condensation of compressed water vapour are close in values - usually the difference between them is not more than 10 K. This determines high values of coefficient of performance of MVR heat pump (over 25) [11].

Open cycle mechanical heat pump in wastewater plants

Wastewater treatment with MVR heat pump is used to separate and remove undissolved substances from industrial wastewater. This method is usually preliminary. With it, the water is prepared for final treatment by chemical, biochemical or other method of treatment . As a stand alone method for treatment it is used very rarely. Wastewater subjected to this method significantly improve their qualities because up to 90% of undissolved substances are removed [17]. In catalogs of companies-manufacturers of MVR heat pumps for wastewater treatment there are data on specific energy consumption for treatment of one kilogram of water (from 10 to 85 Wh/kg) [3, 7, 9, 14, 16]. Main factors that are taken into account to improve efficiency of those systems are: volume flow of wastewater, boiling water temperature in evaporator, evaporator performance, required compression ratio, capital and energy cost of mechanical compressor. Wastewater MVR heat pump consumes 50% less energy compared to a conventional 3-stage evaporation system and 40% less than a 4-stage evaporation system [5, 10, 13]. In economic evaluation of such projects it is necessary to make an analysis of increase in capital costs at the expense of reducing energy ones. For medium to large evaporators with a performance of 20 to 100 t/h, the additional costs for MVR heat pump systems are paid at expense of reduced energy costs from 3 months to 2 years compared to a multi-stage system or evaporation system with a steam jet compressor. In wastewater heat pumps temperature difference between temperature of boiling wastewater and temperature of compressed vapour is very small, which determines a high value of coefficient of performance of MVR heat pump (from 10 to 30) [4, 15].

Discussion

The main advantages of using mechanical open cycle heat pumps in desalination plants are:

- low specific energy consumption for desalination systems with high daily performance;
- high values of coefficient of performance of MVR heat pump;
- zero waste technology – after thermal separation of desalination water as output products there are distilled water and salt.
- positive environmental effect - reducing carbon dioxide emissions in atmosphere.

The main advantages of using mechanical open cycle heat pumps in wastewater plants are:

- low specific energy consumption for wastewater systems for pleminary treatment;
- high values of coefficient of performance of MVR heat pump;
- high purification rate of wastewater MVR heat pump system;
- zero waste technology – after thermal separation of wastewater as output products
- there are distilled water and organic waste. Organic waste can be used as raw material for compost, fertilizers or biogas;
- positive environmental effect - reducing carbon dioxide emissions in atmosphere.

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Legend Figure 1:
RV – reducing valve
HE – heat exchanger
RHE – regenerative heat exchanger
P – pump
MC – mechanical compressor
S – separator
0 – not boiling wastewater at atmospheric pressure p_o;
1 – not boiling wastewater at evaporation pressure p_{ev};
2 – boiling wastewater at evaporation pressure p_{ev};
3 – dry saturated water vapour at evaporation pressure p_{ev};
4* – compressed water vapour at condensation pressure p_{cond} (ideal process);
4 – compressed water vapour at condensation pressure p_{cond} (real process);
4a – dry saturated water vapour at condensation pressure p_{cond};
5 – boiling condensate at condensation pressure p_{cond};
6 – subcooled (not boiling) condensate at condensation pressure p_{cond};
7* - condensate (ideal process);
7 – condensate (real process).

Legend Figure 2:
RV – reducing valve
HE – heat exchanger
RHE – regenerative heat exchanger
P – pump
MC – mechanical compressor
S – separator
0 – not boiling wastewater at atmospheric pressure p_o;
1 – not boiling wastewater at evaporation pressure p_{ev};
2 – boiling wastewater at evaporation pressure p_{ev};
3 – boiling wastewater at pressure p_{HE};
3* – not boiling wastewater at pressure p_{HE};
4 – preheated not boiling wastewater at pressure p_{HE};
5 – boiling wastewater at evaporation pressure p_{ev};
6 – dry saturated water vapour at evaporation pressure p_{ev};
7* – compressed superheated steam at condensation pressure p_{cond} (ideal process);
7 – compressed superheated steam at condensation pressure p_{cond} (real process);
7a – dry saturated water vapour at condensation pressure p_{cond};
8 – boiling condensate at condensation pressure p_{cond};
9 – not boiling condensate at condensation pressure p_{cond};
10* - condensate (ideal process);
10 – condensate (real process)