APPLICATION OF OPEN CYCLE MECHANICAL VAPOUR COMPRESSION HEAT PUMP IN INDUSTRIAL FACILITIES. PART 1. DISTILLATION AND EVAPORATION PLANTS

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Abstract

A review and analysis of application of open cycle heat pumps with mechanical compression in distillation and evaporation plants are performed. Main elements and specifics of operation of heat pump system are considered. Characteristics for energy efficiency assessment of heat pump systems are given.

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

Introduction

Heat pump is a device that transfer heat from a body with a low temperature to a body with high temperature. According to the second law of thermodynamics, this process is negative. In order for it to be possible, process must be accompanied with compensatory energy. The essence of heat pump requires the presence of a source and receiver of heat [31]. These can be atmospheric air, exhaust air from ventilation systems, water, soil, solar radiation and waste heat from industrial processes [21]. The choice of heat pump depends on the type of waste heat flow (source) and its temperature, as well as the type of heat receiver. To perform process of heat transfer for compensatory energy we can use mechanical work (compressor heat pump) or heat (absorption heat pump, thermal compressor heat pump) [2,4,26]. Efficiency of mechanical compressor heat pump depends of type of working body, energy costs of mechanical compressor, values of evaporation and condensation pressures of heat pump cycle [5,10,14,32]. Operation cycle in which mechanical compressor heat pump operates can be open or closed.

Material and method

Mechanical vapour recompression heat pump are systems that are widely used in the industry - in evaporator and distillation installations, in seawater desalination and industrial wastewater treatment plants.

Heat pump systems using mechanical vapour compression consist of a single-stage evaporator system in which wastewater is completely concentrated to final concentration of dry matters, usually at realization of repeated recirculation through the evaporator. Secondary vapour, separated by boiling wastewater is compressed to high pressure by mechanical compressor and this is reused as a heating steam for boiling process. This method is called Mechanical Vapour Compression (Recompression) and is abbreviated as the MVC (MVR) method. MVR heat pump system operates on open cycle – Fig.1.

Water is used in high-temperature heat pumps operating with open or closed cycle. Temperature range of water in those installations is from 80 to 150 °C. Water is becoming more and more popular working fluid in industrial heat pump systems because of excellent properties like non-flammability and non-toxic properties. Main disadvantage of water are low values of specific volume, which means large and expensive compressors, especially at lower water temperatures [3, 12, 22].

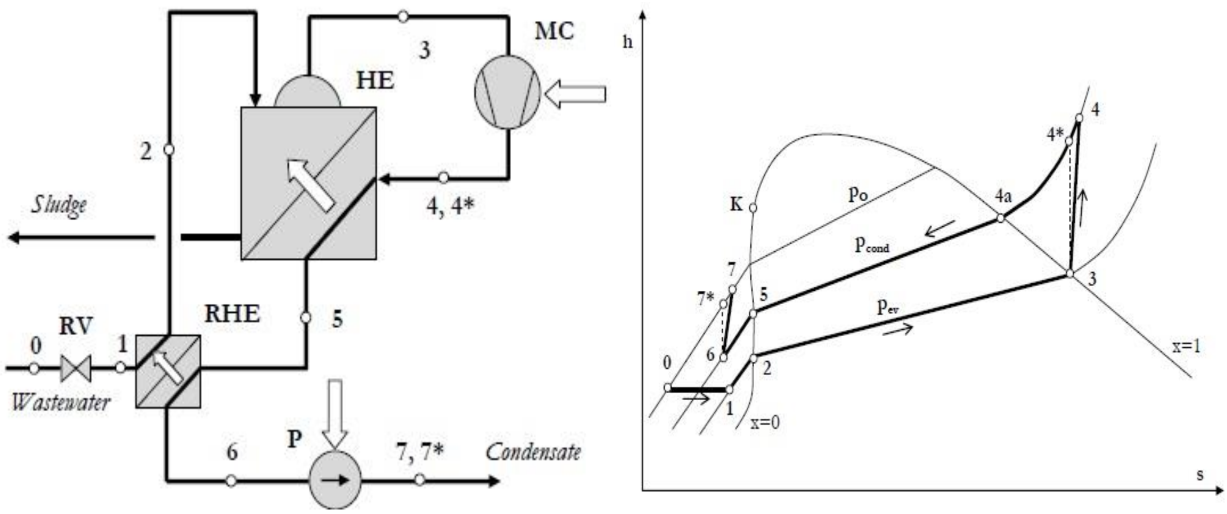

Figure 1. MVR heat pump system and performance open cycle

Assessment of energy efficiency and economic benefit of MVR heat pump systems is carried out through the following indicators:

- *Specific energy consumption of MVR system* is calculated as:

$$n = \frac{N}{D},$$

where: - N – consumed electrical power by the motor of mechanical compressor , W
D – mass flow of evaporated water, kg/h ;

- *Coefficient of performance of MVR system* is determined as follows:

$$COP = \frac{\dot{Q}}{|N|},$$

where: - $\dot{Q}$ – heat flux, exchanged in evaporator, W.

Payback period of those type installations, which is an economic evaluation for implementation of an MVR system in some industrial facility is calculated by the equation:

$$PB = \frac{I_o}{B},$$

where: - I_o – capital cost of MVR system, €;
B – net cost savings for year, €.

Efficiency of MVR heat pump is represented by following estimate quantities: low values of specific energy consumption, high values of coefficient of performance and low values of payback period.

Results

Open cycle heat pump in distillation plants

Distillation plants are used in oil, chemical, pharmaceutical and food factories not only to obtain distillates, but also to recycle and reuse waste products (water) obtained from technological processes. Distillation process in industry is associated with high energy costs, so it is important to look for ways to reduce them [19,25,28]. Production of distilled water requires energy of 2326 kJ/kg (650 Wh/kg). In this case, a low-cost compressor or fan can be used to compress vapour, which reduces the capital cost for heat pump system [13]. This type distillation plant does not need a condenser - cooler, as well as cooling water for the process. MVR method in distillation systems is preferred if components of wastewater have close temperature boiling points (ΔT <20 °C). By using a MVR heat pump in distillation plants, solutions with a much higher concentration can be obtained compared to plants using other concentration methods. For example, in a distillation plant with MVR heat pump, wastewater can be concentrated at concentration from 5 to 10 times higher than wastewater in concentrators, operating on the principle of reverse osmosis or membranes. In this case distillation plants achieve over 90% energy savings for water evaporation. Energy consumption for production of distilled water can be reduced to 58 - 65 kJ/kg (16 - 18 Wh/kg) [29,30]. Coefficient of performance of MVR heat pump system in distillation plants has values from 5 to 7. Payback period for such type of installations depends on their performance value and is from 1 to 2 years [7,24].

Open cycle heat pump in evaporation plants

MVR method has been used in evaporating plants for concentrating different brines. Described systems are successfully attached in food and chemical industry to reduce energy costs in evaporating plants, e.g. in production of milk powder and processing of whey, fruit and vegetable concentrates, protein products, various chemical compounds [8,11,17,18,23]. This modern trend is manifested in production ranges of leading global companies for evaporating installations - Gea Wiegand, SPX Anhydro, Epcon, Alfa Laval and others. The addition of MVR heat pump to a single-stage evaporator installation can lead to lower specific energy costs compared to a multi-stage evaporator installation. When using a MVR heat pump system in evaporation plants, the heat given off in a condenser is drastically reduced or completely eliminated. As a result, theoretical efficiency of evaporator plant with MVR heat pump corresponds to multistage evaporation system with over 100 stages. In practice, a number of limitations such as compressor and gear efficiency significantly reduce actual efficiency of those systems. An analysis of energy costs shows that an evaporator with MVR heat pump consumes 2 times less energy per day compared to a 5-stage evaporator system with steam jet compressor [15,16]. In all cases MVR heat pump systems are performed as single-stage evaporation systems. In order to achieve heat balance, constant compression ratios and stable operating parameters, it is possible to add or remove small amounts of additional energy. Specific energy consumption of MVR system for evaporation plant with MVR heat pump is from 20 to 80 Wh/kg [1,6,9,27]. Coefficient of performance of these systems is in range from 10 to 30 [20]. In addition to saving energy costs, use of a mechanical heat pump an evaporator installation also has a positive environmental effect - reducing carbon dioxide emissions in environment.

Discussion

Main advantages of using mechanical open cycle heat pumps in distillation and evaporation plants are:

- low specific energy consumption;
- small temperature difference between temperatures of boiling brines and compressed heating steam in the evaporator – low cost compressors and fans;
- short residence time of product in installation, as single stage installations are usually used - preserving useful elements of wastewater (brine);
- simple installations – low capital cost;
- excellent installation work in partial load mode;
- low installation energy costs;
- 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).