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LOW POTENTIAL HEAT RECOVERY USING HEAT PUMPS

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ABSTRACT

This paper presents a study on the possibility of recovering low thermal potential heat from the cooling technological water of industrial processes. The analysed solution consists in the use of a heat pump which would send the recovered heat to a hot water flow. We started from a technological water flow which was taken over by a 350 m^3/h cooling tower and we determined the performances of a heat pump when using various refrigeration agents, for a range of values of the temperature of hot water and the temperature of the return of technological water which varies according to season.

KEYWORDS: heat recovery, technological water, heat pump, Carnot efficiency, exergy output

1. Introduction

Many industrial processes require the release of heat flows into the environment, in order to maintain the parameters of those processes within normal operation limits. In the case of high capacity industrial equipment, this heat release is generally performed by means of a flow of cooling water, also called technological water, which takes over the heat from the concerned industrial equipment and, subsequently, releases it into the environment. This release of the heat taken over from the industrial process is generally performed by means of a cooling tower.

Cooling towers, with natural air circulation or with forced air circulation, are based on the operating principle of cooling by evaporation of a certain amount of technological water. This means that the formed water vapours taken from the air which circulates through the cooling tower contain the cooling heat of the technological water under the form of latent evaporation heat. Given the present wishes to increase the use efficiency of energy resources and to decrease fuel consumption, we must analyse all the possibilities of recovering low potential energy resources [1], [2].

We can include here the heat obtained from technological water, released into the atmosphere by cooling towers. Any solution to recover and to use heat from technological water must take into account that, even if heat flows can be very high, the temperature level is, generally, fairly low. This is the case if any user of recovered heat requires a certain value of input temperature.

In this paper, we mean to prove the possibility of recovering heat from technological water by means of a heat pump.

This heat pump shall take over the heat from the low temperature technological water and shall send it to a circuit of hot water which can be used by domestic or industrial consumers [3]. Obviously, the concrete application with heat pump sizing must take into account the heat requirement of consumers and the flow of available industrial technological water.

2. Heat recovery by means of a heat pump

For the purposes of this study, we have considered a flow of technological water cooled by means of a 350m^3/h cooling tower. The operating parameters of the cooling circuit of the technological equipment, as well as its composition, have not been modified, so that the goal of the technological cooling process may be achieved when heat recovery does not occur.

Consequently, for the recovery of heat from technological water, a heat pump has been introduced in the cooling circuit (Fig.1) which, by means of the vaporiser, takes heat from the technological water and, by means of the condenser, transfers it to the flow of hot water which is then sent to consumers [4].

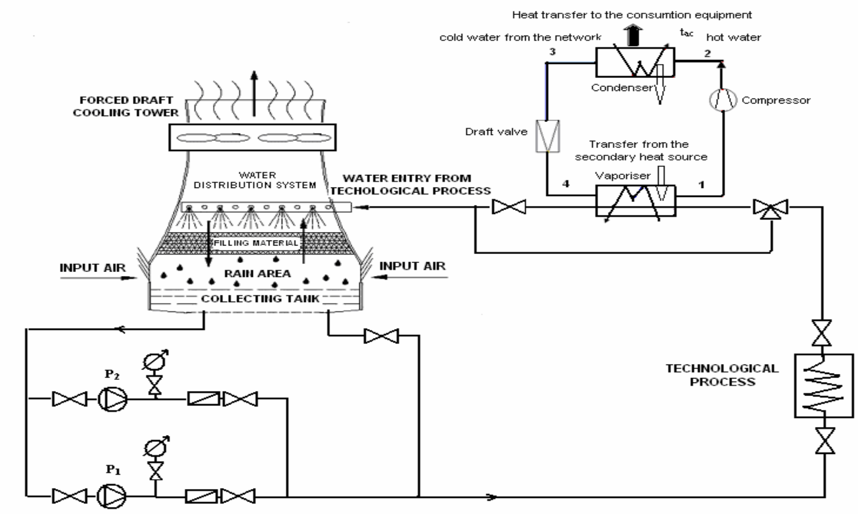

Fig. 1. *Cooling technological equipment with heat recovery*

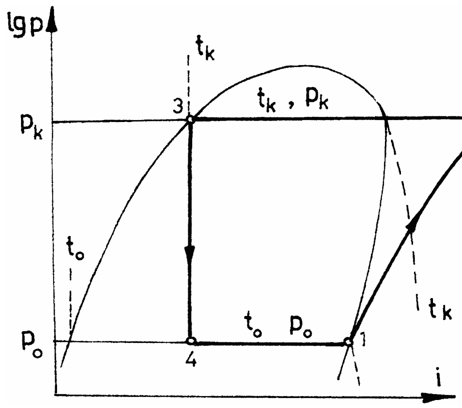

Fig. 2. *Theoretical cycle of the heat pump*

In order to determine the operating parameters of the recovery equipment, we have used the Engineering Equation Solver (EES) programme, able to solve the equations of the mathematical model of the processes taking place in heat pumps, consonant with the structure of the equipment and with the type of the working agent which evolves in it. The programme calculates the following performance measures for the heat pump: Carnot efficiency, η_c; exergy output, η_{expc}; coefficient of performance, COP; obtained hot water flow: $\dot{m}_{ac}$ [kg/s].

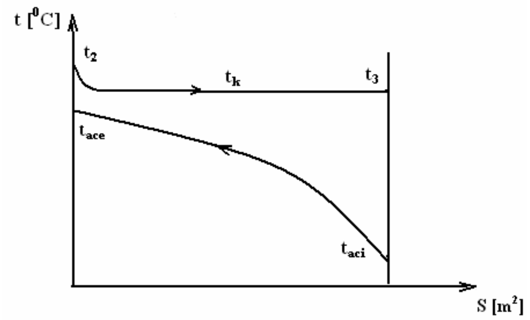

Fig. 3. *Diagram of fluid temperature variation along the heat - condenser transfer area*

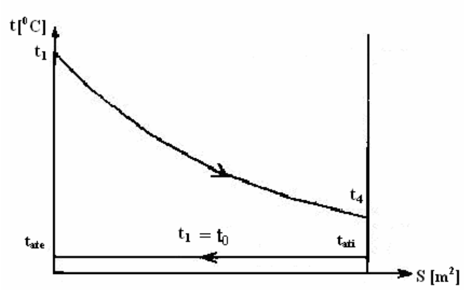

Fig. 4. *Diagram of fluid temperature variation along the heat - vaporiser transfer area*

The hot water flow is calculated on:

$$\dot{m}_{ac} = \frac{\phi_K}{c_a \cdot \Delta t_k} \ [kg/s] \quad (1)$$

where: c_a = 4.18kJ/kg.K - specific water heat; Δt_k = 40°C - temperature increase of the obtained hot water; ϕ_K $[kW]$ - heat flow yielded to hot water in the heat pump condenser.

Given the temperature - heat transfer area representations in the heat pump vaporiser (Fig. 3), or in the condenser (Fig. 4), Carnot efficiency, the exergy output of the recovery equipment, as well as the coefficient of performance of the heat pump, are expressed by means of the following relations [5], [6]:

$$\eta_{C1} = 1 - \frac{(t_{mat} + 273.15)}{t_{mac} + 273.15} \quad (2)$$

$$\eta_{expc} = \frac{\phi_K \cdot \eta_{C1}}{P_{C1}} \cdot 100 \ [\%] \quad (3)$$

$$COP = \frac{\phi_K}{P_{C1}} \quad (4)$$

where: $t_{mat} = \frac{t_{ati} + t_{ate}}{2}$ [°C] - average temperature of the technological water which entering the heat pump vaporiser with temperature t_{ati} and exiting it with temperature t_{ate}; $t_{mac} = \frac{t_{aci} + t_{ace}}{2}$ [°C] - average temperature of the water which entering the heat pump condenser with temperature t_{aci} and exiting it with temperature t_{ace}; P_{C1} [kW] – power of the heat pump compressor.

We mention that the adoption of the value for the temperature increase of the obtained hot water (Δt_k = 40°C) covers all the possible situations requested by heat consumers. For instance, in the presented application we focused solely on the supply of domestic hot water, which undergoes heating from 25°C to 65°C.

However, if the recovered heat flow is used for heating buildings, with the need of increasing hot water temperature to 95°C, then the same temperature increase can be preserved, as a hot water closed circuit is presupposed, with return to 55°C.

By means of the EES programme, we have made a comparative study on the performance of the recovery equipment with a heat pump, when using different refrigeration agents. This, given that the thermodynamic properties of the refrigeration agent which evolves in a heat pump directly influence the compression, drafting and heat transfer processes.

As main thermodynamic conditions of these refrigerating agents we mention: boiling point under cooling temperature of technological water, vapour pressure as close as possible to atmospheric pressure, condensation pressure as low as possible in order to achieve low energy consumption, latent evaporation heat as high as possible in order to ensure reduced flows and an as small as possible vapour specific volume.

The use of certain inappropriate refrigerating agents can lead to a decrease in the efficiency of the recovery equipment or to the oversize of the heat pump components, these leading to an increase of the recovery costs. Consequently, the following refrigerating agents have been selected: R152a, R500, R600, R114, R717.

3. Results and conclusions

For the analysis of the performances of the equipment for heat recovery from technological water, we considered the following variable measures: t_{ati} - temperature of technological water on entering the heat pump vaporiser; t_{ace} - temperature of hot water on exiting the heat pump condenser; $\dot{m}_{at}$ - flow water of the technological process.

Given the conditions above, we present below the graphical representation of the results.

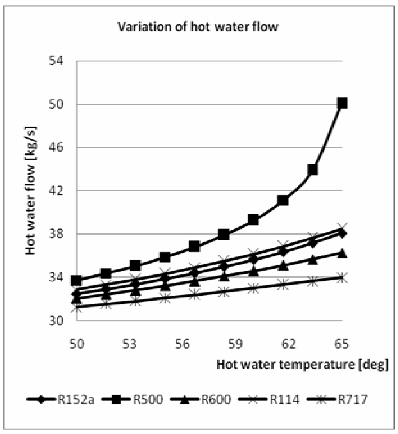

Fig. 5. *Variation of hot water flow*

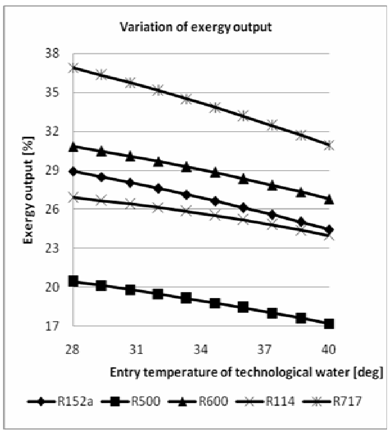

Fig. 6. *Variation of exergy output f(t_{ati})*

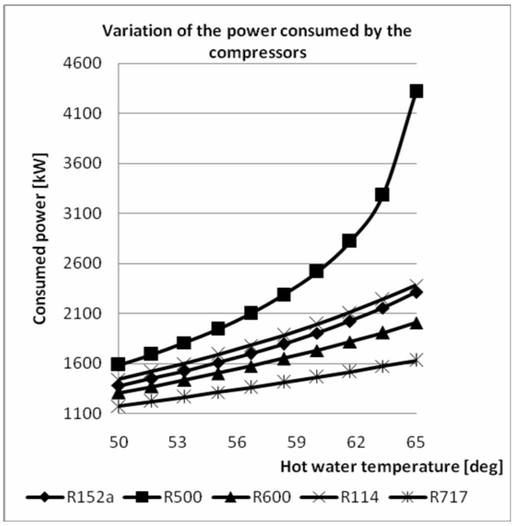

Fig. 7. *Variation of the power consumed by the compressor*

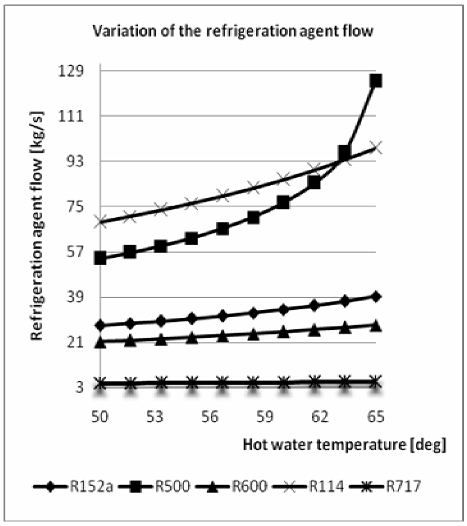

Fig. 8. *Variation of the refrigeration agent flow*

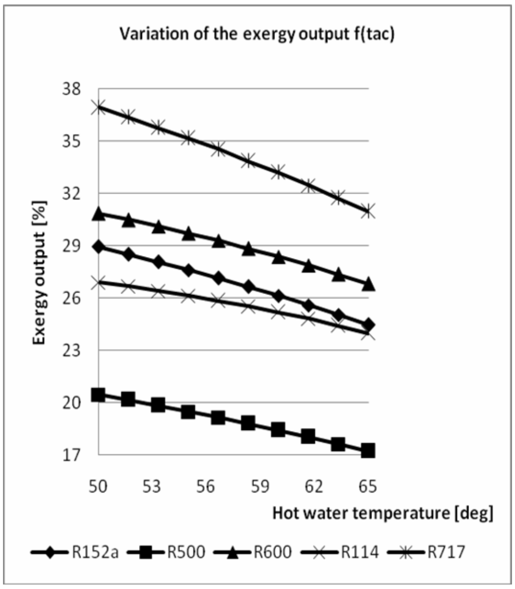

Fig. 10. *Variation of the exergy output $f(t_{ac})$*

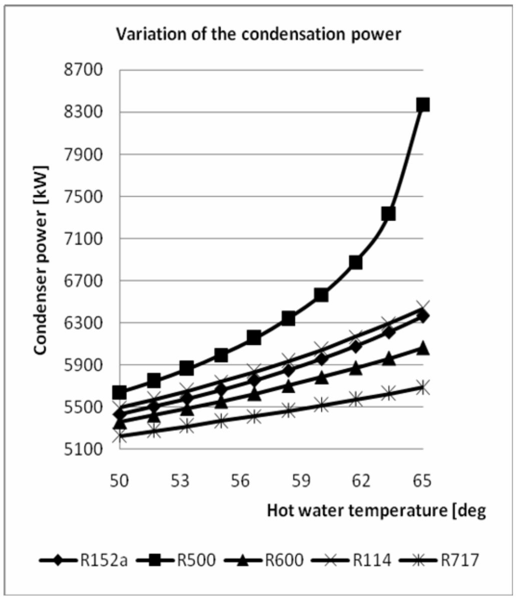

Fig. 9. *Variation of the condensation power*

The values obtained and graphically presented prove the possibility of the proper operation of a heat pump which would ensure the recovery of heat from the cooling water of the technological processes. Thus, we can discuss two important aspects:

1. The temperature of the hot water on exiting the heat pump condenser directly influences the performances of the recovery equipment. This happens because, for the increase of hot water temperature, the condensation temperature must increase, involving the increase of compression pressure with the increase of the power consumed by the compressor (Fig. 7). In this case, the increase of the flow of obtained hot water (Fig. 5) is explained by the fact that it will increase condenser power (Fig. 9), on the basis of the increase of compressor consumption, not due to the increase of the flow of recovered heat.

Nevertheless, in the conditions of the increase of hot water on exiting the heat pump condenser, one can notice an increase of the refrigeration agent flow (Fig. 8). This is explained by maintaining the same minimum temperature differences in the condenser, between the condensation temperature and the exit temperature of hot water if the flow sent into the condenser increases.

2. The exergy output, considered a main coefficient of performance of the heat recovery

equipment, is influenced both by the temperature of the hot water on exiting the heat pump condenser and by the temperature of the technological water on entering the vaporiser. Thus, in the first case, exergy output decreases (Fig. 10) because by the increase of the temperature of the hot water on exiting the heat pump condenser and the increase of the power consumed by the compressor, the coefficient of performance of the heat pump (COP) shall decrease. In the second case, the decrease of the exergy output, with the increase of the temperature of technological water on entering the vaporiser is due to the increase of the average temperature in the cold source.

The two aspects are specific to any heat recovery equipment which uses heat pumps, irrespective of the type of refrigeration agent it operates on. We find, however, that there are fairly significant differences in performance values according to the type of refrigeration agent, which allows the selection of the most adequate agent. Based on this simulation, it clearly results that for the recovery of heat from technological water by means of heat pumps the most appropriate working agents are R600 and R717, with the best values for exergy output and the lowest compression consumptions.

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