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UTILIZATION OF SECONDARY ENERGY RESOURCES OF METALLURGICAL ENTERPRISES USING HEAT PUMP

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ABSTRACT

Thermal secondary energy resources (SER)in metallurgical production can be divided into high-temperature and low-potential energy sources (with temperatures below 50 C). We have considered the ways of using low-potential thermal SER of a metallurgical plant. According to the traditional scheme, the circulating water is cooled in a cooling tower with the return of the heat of cooling to the environment.We propose to use a heat pump driven by a heat engine instead of a cooling tower. The scheme consists of a compression heat pump with a heat output of 4200 kW, a working agent R 600, a source of low-potential heat-circulating water: a 460 kW gas engine. The proposed scheme showed high efficiency of power supply of the town in comparison with the gas boiler.

Keywords: heat pump; internal combustion engine; metallurgical plant; energy efficiency.

1. INTRODUCTION

1.1. First Subtitle

The problems of climate warming on the planet are directly related to the amount of consumed organic fuel and, correspondingly, to the increase of carbon dioxide emission.

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Various industries, including metallurgy, consume a significant part of the fuel produced, so energy conservation issues are paramount. Rational use of fuel and energy resources is one of the topical problems of Russia.

Due to the geographical location of the main industrial centers of Russia, the specific energy inputs per unit of industrial output are higher than in European and Asian countries. Nevertheless, there is a significant potential for the use of waste heatin industry.

At the same time, there is a need to cool technological coolants (water of a circulating water supply system, process gases, etc.).

Heat pumps can be used to convert low-potential thermal energy into a high-potential thermal energy used in heating and hot water supply systems.

1.2 Second Subtitle

Heat pumps are widely used for heat supply [1-5]and in various industries [6-9].Working agents of heat pumps must satisfy the Montreal Protocol and the Kyoto Protocol. The Montreal Protocol requires working agents with zero ozone damage potential. The Kyoto Protocol requires the limitation of working agents with high global warming potential. At present, it is extremely necessary to find refrigerants that could meet the requirements of both the Montreal Protocol and the Kyoto Protocol. Analysis of the properties of new working agents has shown that similar reagents already exist.

There are some papers offering new more effective schemes for improving heat pumps in order to increase coefficient of performance (COP)[10-17].

Some reserchers[18]investigated a diversity of refrigerant choice, and noted that R32 is a quick-action refrigerant against global warming. Others [19] compared the performance using R32 and R410A in a thermodynamic model and made experiments at different operating conditions in a 3.2 kW residential heat pump unit.

2. RESULTS AND DISCUSSION

In our study the scheme of the heat pump providing the heating system for hot water supply is given in Fig. 1.

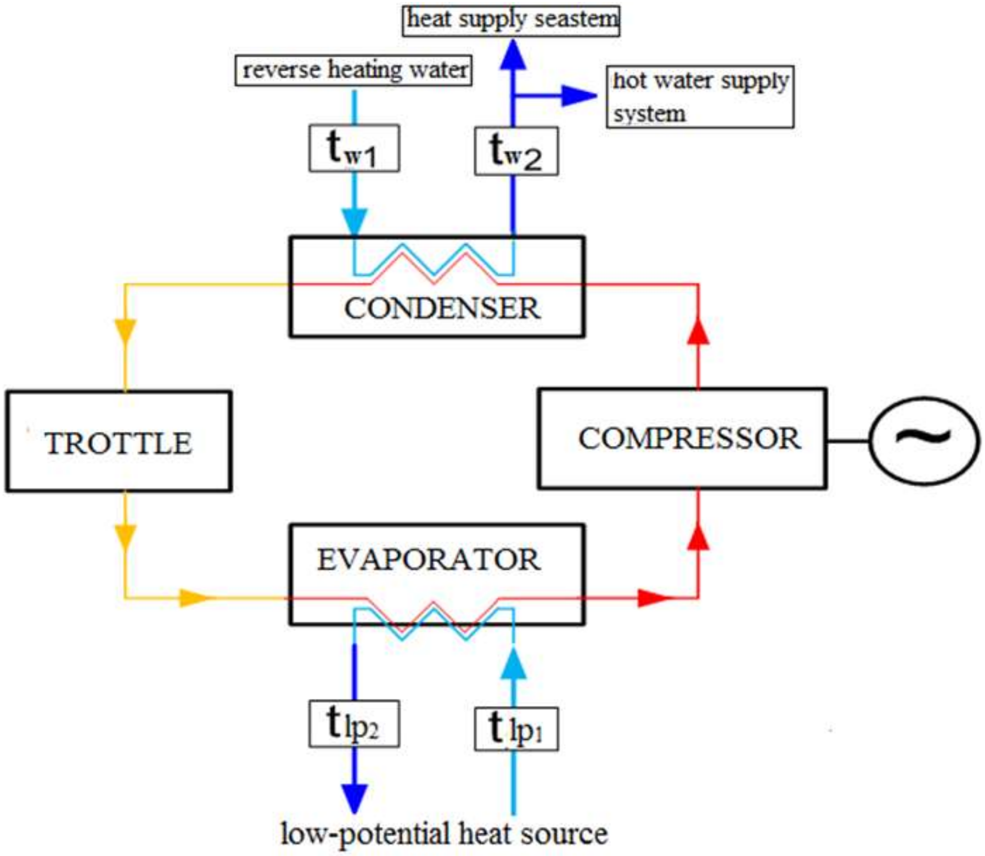

Fig.1. Heat pump for heat and hot water supply

Heat carrier of low-protentional heat (e.g. water) flows into evaporator with temperature $t_{lp1}$where it is cooled to a temperature t_{lp2} transferring its heat to the working fluid of heat pump.Heat affects therefrigerant, which causes it to boil and turn into steam.The refrigerant is transferred to the condenser with required pressure by the compressor, where its heat is being transferred after cooling to the hot water supply system or heat supply system.

The value COP μ is the ratio of the heat output (heat flux) Q generated by the HP to the power N spent on the compressor drive:

$$\mu = \frac{Q}{N} = \frac{G_w(t_{w_2} - t_{w_1})C_{pw}}{G(i_{2ad} - i_1)\cdot\eta_c} \quad , \qquad (1)$$

here Gw and G are the rate of water cooling the condenser and the working agent of the HP;

$t_{w1}$and t_{w2} - cooling water temperatures at the inlet and outlet of the condenser;

i_1- the enthalpy of the working body of the HP at the inlet to the compressor;

i_{2ad} — - the enthalpy of the working agent under adiabatic compression at the compressor outlet;

$\eta_c = \eta_i \eta_м$ - compressor efficiency;

$\eta_i \eta_м$ - internal and mechanical efficiency of the compressor.

For qualitative analysis of μ, it is convenient to use the approximate relation based on the inverse Carnot cycle of HP:

$$\mu = k\mu t = k\frac{T_c}{T_c - T_e}, \qquad (2)$$

here $k = 0{,}5 \div 0{,}6$ – experimental coefficient, μt - the theoretical COP; T_c и T_e- condensation and evaporation temperatures, i.e. temperature of the working agent at the compressor outlet and inlet under adiabatic compression.

As follows from (2), for a given value of T_c,, the theoretical COP depends only on the value ofT_e, the value of which is directly related to the temperature of the low-potential heat source (LPHS).

Thus, the increase of LPHS energy causes the growth of T_e and μ.

As follows from Fig. 2 and Fig. 3 the temperatures of high and low heat sources highly affect conversion ratio μ. To increase μ it is obvious to seek for a temperature 20°C or higher and also t_{lp1} heat consumer has to have low temperature level. A single industry-city based near the metallurgical plant with high-temperature LPHS matches these requirements.

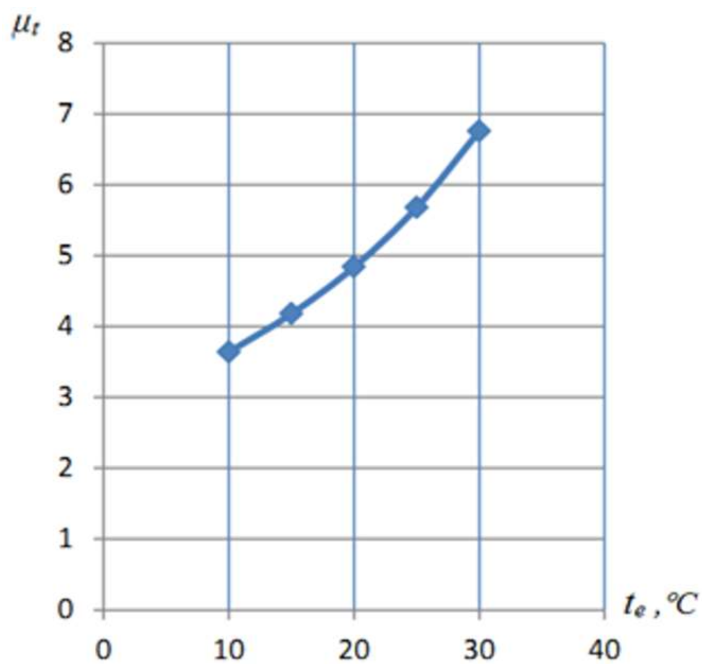

Fig.2. Dependence of performance coefficient μt on evaporation temperature T_e

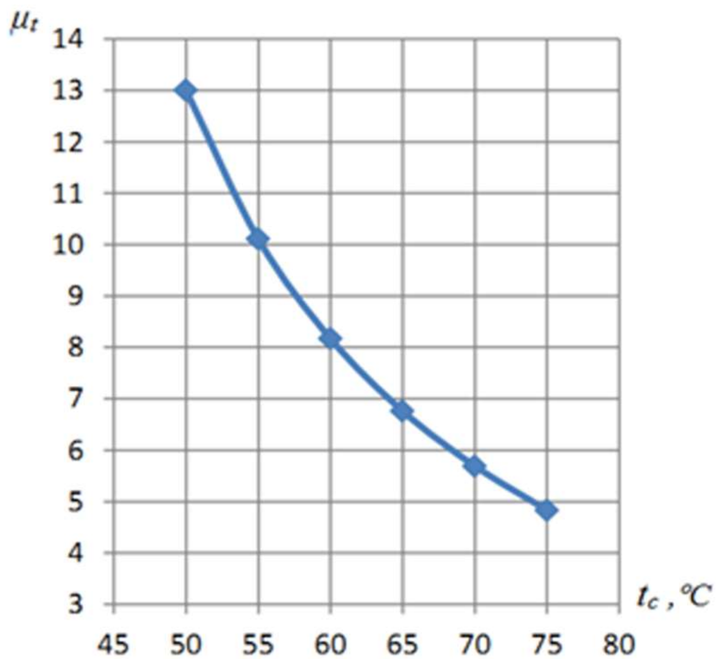

Fig.3. Dependenceof performance coefficienton$\mu_t$condensation temperature T_c

Below, in the example of a metallurgical plant, the feasibility of using a HP for recycling of SER of this enterprise is considered. The main suppliers of SER at modern metallurgical plants are electric steel smelting and oxygen-compressor shops. Recirculating water supply systems at metallurgical plants features very high temperature of the cooling water outlet (up to 45 ° C). Cooling water can serve as a source of low-potential heat (LPHS) for HP, on the other hand there is a consumer of thermal energy produced by HP.

These are the heating and hot water supply systems of the plant and its servicing village (the single-industry town).

According to the traditional scheme, the circulating water is cooled in a cooling tower with the return of the heat of cooling to the environment.

In the actual scheme, the circulating water is cooled in a cooling tower with the return of the heat of cooling to the environment. Instead of a cooling tower, we can propose an alternative scheme - a heat pump driven by a heat engine, Fig. 4. Cooling water from thecirculating water supply system with a temperature of 45 C enters the evaporator HP, where its temperature drops to 35 C. The heat of cooling is evaporated by the working agent in the evaporator. The working agent vapor is compressed in the compressor and enters the condenser, where they condense with the return of heat to the network water. Drive compressor HP is carried out from the gas engine. Reverse network water from the heat consumer is heated in the subcooler and the VT condenser. Further heating of the network water is due to the use of the thermal energy engine (heat of exhaust gases, heat of coolant and oil).

Prices for energy and electricity are not constant, therefore it is more convenient to make economic comparison of various power supply schemes using the concept of conventional fuel**.** Conventional fuel is a universal measure of fuel and energy consumption. In Russia, as a conventional fuel is accepted, having a lower calorific value of 29300 KJ / kg. In some countries, a fuel equivalent is used for fuel equivalent (1 t of fuel with a heat of combustion of 41,900 KJ / kg).

In our case, we conducted a study on energy efficiency by fuel consumption.

The thermal calculation of the circuit is carried out according to the procedure Shatalov [20].

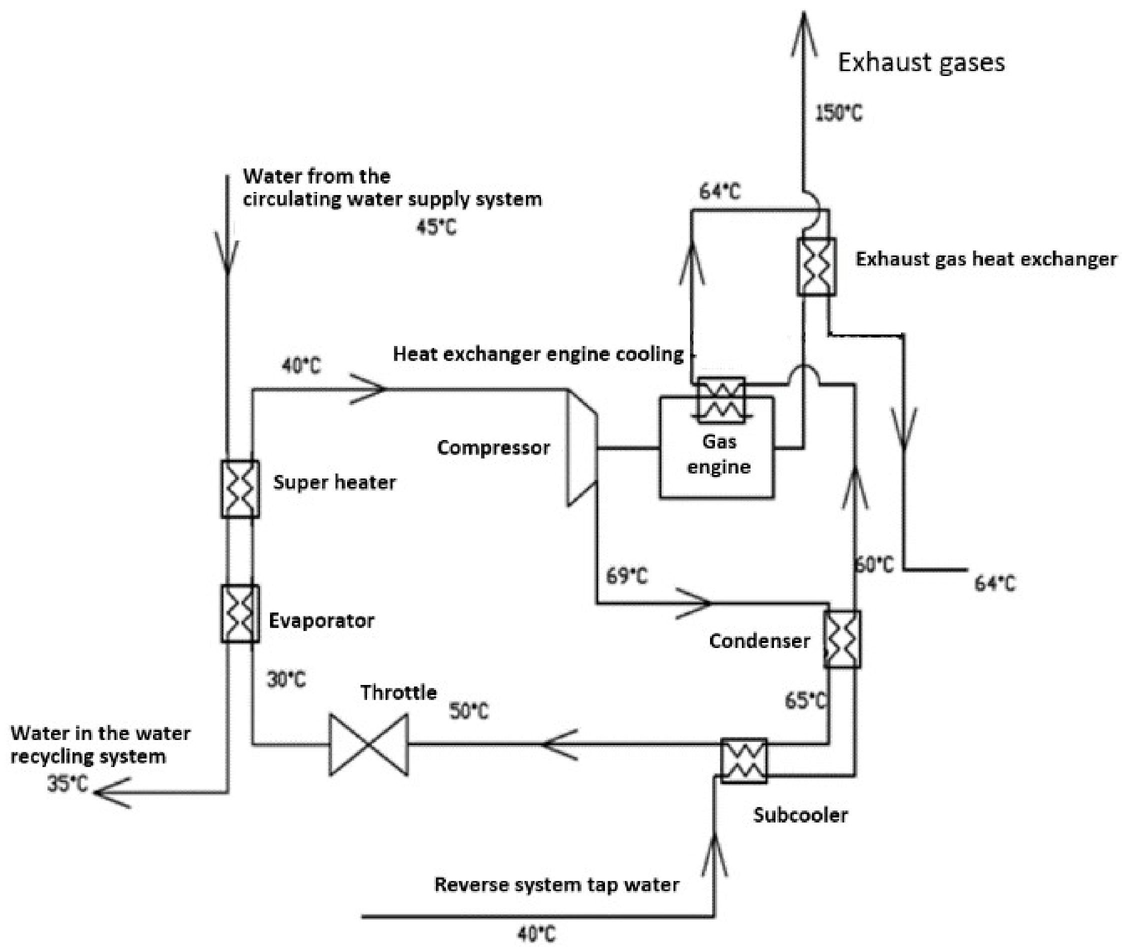

Fig.4. Gas engine driven heat pump system providing heat and hot water supply

The COP of the heat pump included in the power supply scheme (Fig. 4) was 7.69 according to our caclulation. The calculation was done for the following initial conditions: refrigerant R600a; compressor efficiency η_c = 0,9; water temperature at the evaporator inlet HP (circulating water) 45 °C; water temperature at the outlet of the heat pump condenser 60 °C.

To drive the HP compressor, a gas engine with following technical data was chosen: fuel - natural gas; engine power$N_e = 460\ kW = 0{,}46\ MW$;$\eta_e = 0{,}37$ effective efficiency; exhaust gas flow rate = 0,097 kg/ s exhaust temperature $t_{г} = 555\ °C$; flue gas temperature 150 $°C$; relative amount of heat transferred to water $g_w = 0{,}22$; the relative amount of heat transferred to the oil $g_{м} = 0{,}07$.

Prices for energy and electricity are not constant, therefore it is more convenient to make economic comparison of various power supply schemes using the concept of conventional fuel. Conventional fuel is universal measure of fuel and energy consumption. In Russia fuel, having a lower calorific value of 29300 kJ/ kg, is accepted as conventional fuel.

The heat balance of the gas engine can be presented as:

$$Q_F = \frac{G_h * H_u}{3600} = Q_{Ne} + Q_g + Q_W + Q_m$$

Q_F – chemical fuel heat;

G_h - fuel consumption per hour;

H_u – net calorific value of fuel;

Q_g – heat flow of exhaust gases;

Q_w– heat transferred to the cooling water;

Q_{Ne}- heat flow of effective engine capacity;

Q_m - heat transferred to the cooling oil.

Total heat of HP and utilization of gas engine Q_Σ:

$$Q_\Sigma = \mu \cdot Q_{N_e} + Q_2 + Q_g + Q_m + Q_w$$

$$Q_\Sigma = 3337 + 313 + 269.3 + 85.8 = 4205\ kW$$

So, Q_Σ = 4205 kW, and the fuel is spent only in the gas engine.

Specific consumption of conventional fuel in the gas engine g_e:

g_e= 0,123 /η_e = 0,123 / 0,37 = 0,322 kg of cf / kW.

Hourly fuel consumption in gas engine G_h:

$G_h = g_e \cdot N_e = 0.332 \cdot 460 = 152.7$ kg·cf/h.

To obtain 4205 kW of heat in a gas boiler, it is necessary:

$G_{gb} = \frac{3600 \cdot Q_\Sigma}{\eta_{gb} \cdot \text{Hc}}$ = 3600· 4205/0.8 29300 = 645 kg of cf/h,

here:

G_{gb} – hourly fuel consumption in a gas boiler;

η_{gb} – efficiency gas boiler equal to 0,8;

Hcf– calorific value of the conventional fuel, equal to 29300 kJ / kg.

Thus, in order to obtain the same amount of heat by burning in a gas boiler or using a heat pump driven by a heat engine, 645 kg of cf/h and 152.7 kg of cf/h,were neededrespectively. That is, fuel requirements in an alternative heating and hot water supply scheme is4,2 times less.

3. EXPERIMENTAL

We used the experimental data of a real metallurgical plant (located in Siberia) to conduct a study and calculate the efficiency of the proposed scheme.

4. CONCLUSION

The task of energy saving is the effective use of primary and secondary energy resources (SER). We have considered the ways of using low-potential thermal SER using the example of a metallurgical plant. In the technological process of steel production, the equipment of the electric steel-smelting and oxygen-compressor shops are cooled by water at the inlet temperature of 35 C with the outlet temperature of 45 C. According to the traditional scheme, the circulating water is cooled in a cooling tower with the return of the heat of cooling to the environment. We propose to use a heat pump driven by a heat engine instead of a cooling tower. The scheme consists of a compression heat pump with a heat output of 4200 kW, a working agent R 600, a source of low-potential heat-circulating water: a 460 kW gas engine. Thermal power is used for heating and hot water supply of residential and industrial buildings of the town and the plant. The proposed scheme showed high efficiency of power supply of the town in comparison with the gas boiler. The usage of heat pumps working on SER of metallurgical plant (e.g. circulation water) leads to lowering costs of heating and hot water supply more than 4 times per unit of estimated power.

5. ACKNOWLEDGEMENTS

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