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RECOVERY OF WASTE HEAT RESULTING FROM TURBOCOMPRESSOR COOLING

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Abstract

The high efficiency of turbocompressors makes them ideal for supplying larger mines with com-pressed air. As the gas flows through the compressor, the pressure increases, generating a large amount of heat. This heat needs to be removed, and this is usually achieved through cooling towers and it ultimately escapes into the surroundings as waste heat. This article aims to study the recovery and possible use of this waste heat.

Keywords: *turbocompressor, waste heat, heat recovery.*

1. Introduction

As the modern world struggles with energy shortages, energy saving and waste heat recovery have become topical issues worldwide.

The importance of energy efficiency and waste heat recovery is emphasized by the fact that the European Union pays special attention to this topic [1], and it is also an important topic in the United States [2]. Furthermore, it is treated in the same category as environmental protection, and almost every country has developed strategies in this area [3, 4].

The use of waste heat has also received considerable attention in other countries, and guides have been developed [5, 6] to help those who take energy conservation and waste heat seriously.

These guides classify waste heat according to temperature, but there are also different industry classifications and, based on different experiences, these guides suggest the most efficient recovery methods [7].

Referring to the sources mentioned above, underground mines can be classified as low-temperature waste heat sources, so the most efficient way to recover heat is to use heat pumps.

2. Use of turbocompressor in the mining industry

Although compressors employed today are rotary-screw compressors, turbocompressors are also used due to their high compressed air yields, in industries where compressed air requirements are high and uninterrupted production is needed.

In addition, the turbocharger adapts well to the changing compressed air demand since the operating point of the turbocompressor moves, as for any such machine or pump, so no control is required if there is no major variation in the compressed air demand.

Because mining is cyclical and many things affect compressed air demand, this is constantly changing.

In the heyday of mining, the mines in Jiu Valley were usually equipped with a turbocompressor. Depending on their size, there were underground mines commissioning up to three turbocompressors.

Two of these were usually working when the demand for compressed air was high, but only one of them on weekends, when not as many people worked underground.

These were usually Russian-made turbocompressors. This type of turbocharger consists of seven stages, arranged in three bodies, the first two bodies having two rotors and the last having three. Cooling is performed by means of two intercoolers (**Figure 1.**) and a final cooler, each of which is interchangeable.

Rated characteristics according to operation manual **[8]**:

Inlet air flow rate	16000 m^3/h;
Inlet pressure	1 bar;
Inlet temperature	20 °C;
Outlet pressure	8 bar;
Turbocompressor speed	9980 rpm;
Motor speed	1500 rpm;
Air temperature at final cooler outlet	40 °C;
Cooling water temperature at inlet	25 °C;
Cooling water flow rates:	
– through final cooler	55 m^3/h;
– through intercoolers	95 m^3/h;
– through oil cooler	20 m^3/h;
Rated motor power	1800 kW;
Motor efficiency	0.9;
Gear efficiency	0.95.

Measurements made by manufacturer before shipment (**Table 1.**) made it possible to plot the two characteristic curves of the turbocompressor, the throttle curve p = f (Q) in **Figure 2. a)**, and the power characteristic P = f (Q) in **Figure 2. b)**.

Table 1. *Measurements made by manufacturer* **[1]**

Inlet air flow rate [m^3/h]	Outlet pressure [bar]	Actual power [kW]
12 150	10.3399	1325
14 000	10	1525
16 100	8.45	1570
17 000	7.35	1555
17 600	6.05	1510
18 075	4.475	1442.5

The cooling water enters a cooling tower where it is cooled by air and then returned to the turbocompressor coolers. This process, usually in summer, affects the efficiency of cooling and reduces the turbocompressor efficiency, and in addition the com-pressed air gets into the mine at too high a temperature.

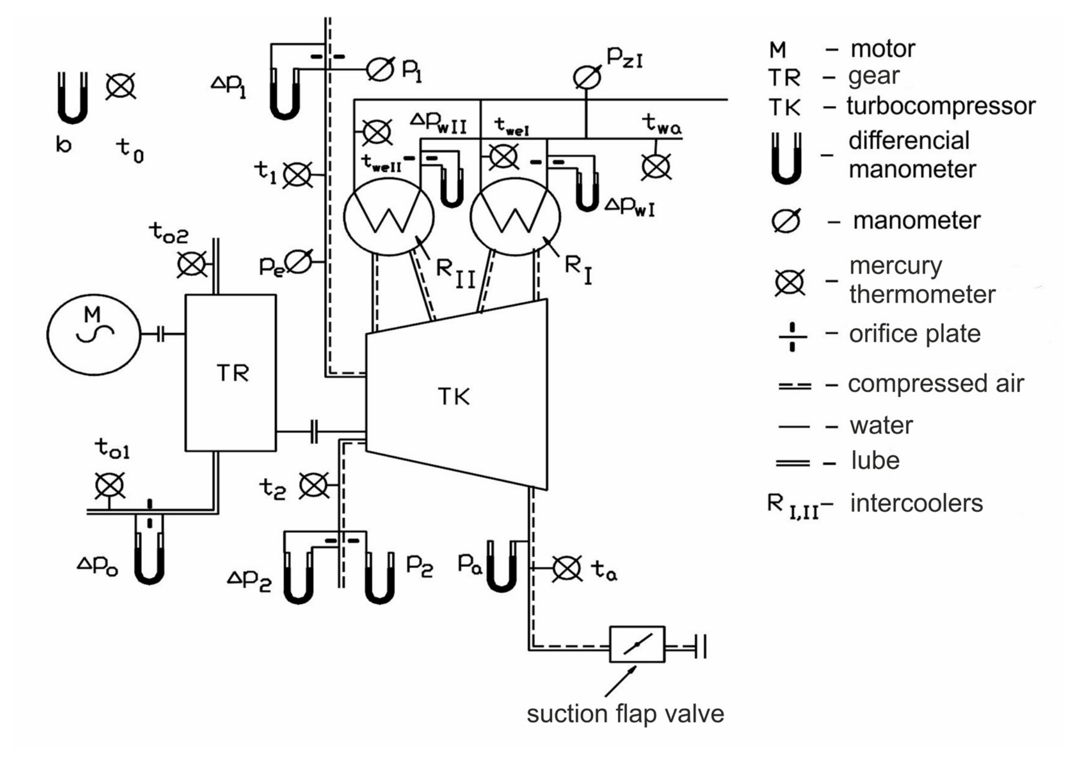

Figure 1. *Schematic of the turbocompressor* **[8]**

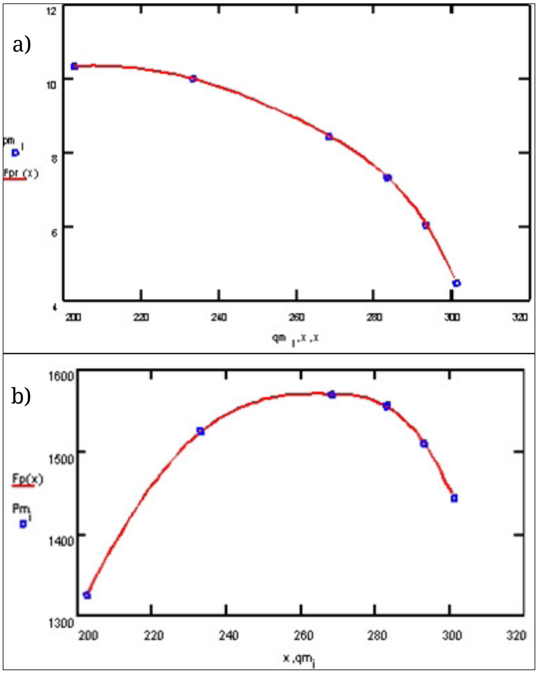

Figure 2. *Characteristic curves of the turbocompressor*

3. Calculating the amount of waste heat

In order to accurately calculate the amount of waste heat, 124 measurements were made **[8]**.

Measurement data is presented in **Figure 3.**

In the colder months, in this case in March, the water inlet temperature is 15 °C, while in the summer months it can reach 28 °C-t.

The temperature increase is 2-4 °C and depends on the motor power, which is directly proportional to the change in compressed air demand. The average temperature increase is 2.75 °C.

The inlet temperature of cooling water was measured at the outlet of the cooling tower, while the outlet temperature of the cooling water was measured at the inlet of the cooling tower and according to this the flow rate of the cooling water was 170 m^3/h.

The amount of received heat:

$$Q = m \cdot c \cdot \Delta t = \rho \cdot V \cdot c \cdot \Delta t = \\ = \frac{997,05 \cdot 170 \cdot 4,1816 \cdot 2,75}{3600} = 541,43 \quad kW \tag{1}$$

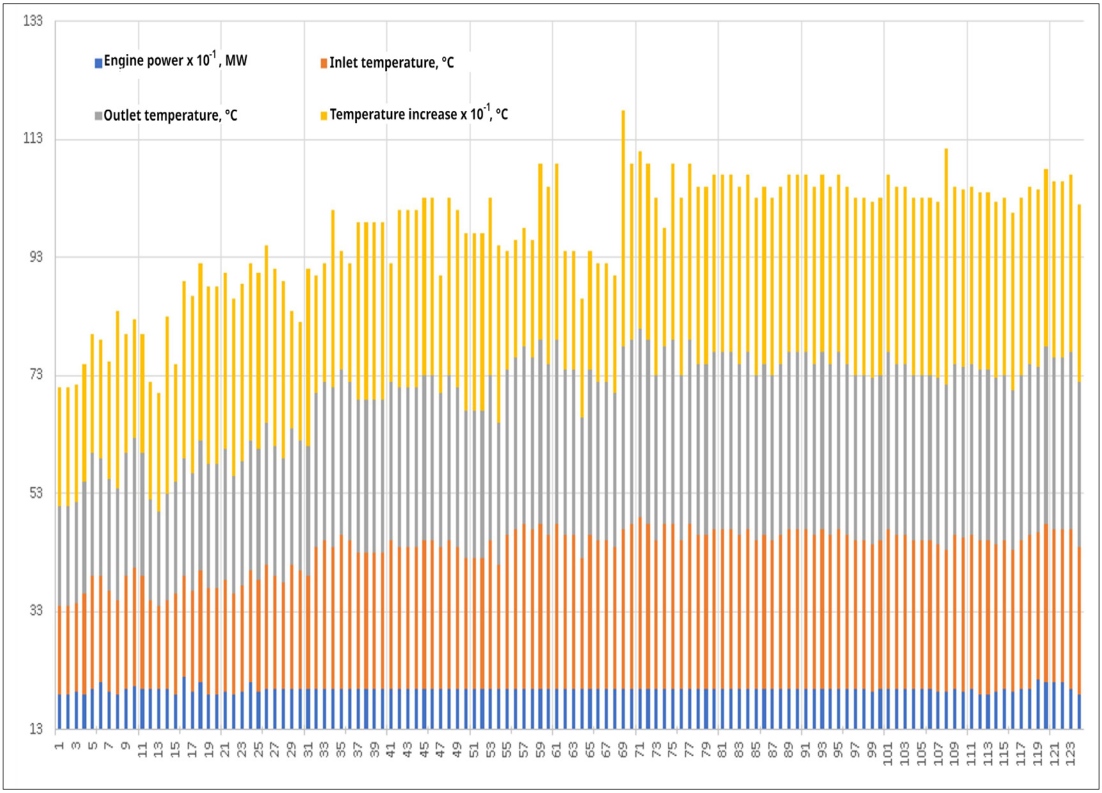

Figure 3. *Measured data*

where:

Q – amount of heat, kW;
V – volumetric flow rate, m^3/h;
Δt – temperature difference, °C;
c – specific heat capacity of water at 25 °C, kJ/kg·K,
ρ – density of water, kg/m^3.

As can be seen, the amount of waste heat is very high, 541.43 kW, and all this is released into the environment.

In addition, high cooling water temperatures during the summer period result in inadequate cooling of the turbocompressor, which negatively affects its efficiency, and hot compressed air raises the temperature in the quarry, which has a negative effect on humans.

Thus, two tasks have to be solved, on the one hand the use of the waste heat and on the other hand the proper cooling of the turbocompressor. Both of these can bring huge energy savings if solved.

The biggest challenge in this case, in terms of waste heat usage, is that the temperature of the water is very low, so that it cannot be used as it is in other technological processes.

4. Employing heat pumps

The biggest challenge in the process of waste heat recovery is finding out what the recovered heat will be used for.

For an underground mine where a large amount of domestic hot water is required, its production can be economical by using waste heat.

Heat pumps suitable for exploiting low-heat energy sources are steam-compression water-to-water systems [9]. This type of heat pump is suitable for recovering waste heat from water below 40 °C by heating domestic hot water to 50-80 °C.

The mathematical model of such a heat pump was presented in the literature [10] so in the following we calculate the thermal characteristics of the heat pump based on that model.

The thermal characteristics of the heat pump will be calculated using the following initial data: the required heat delivery Q must be at least the amount of heat acquired by the cooling water Q = 541.43 kW; T_i = 65 °C - domestic hot water temperature; T_a - ambient temperature (heat source); ΔT_c = 5 °C - temperature difference required for heat transfer in condenser (heat delivery); ΔT_0 = 5 °C - temperature difference required for heat transfer in the evaporator; T_{sr} = 10 °C - temperature difference for sub-cooling; the refrigerant used was R717 (ammonia).

The heat source is the water heated in the turbo-compressors cooling system, so calculations are made for the minimum, average and maximum water temperatures namely 16, 26, and 32 °C.

In addition, calculations must be made at 5 °C to provide a basis for comparison.

The data in Table 2. are shown in Figure 5., 6. and 7.

It is clear from these figures that, as the temperature increases, the mechanical work of the cycle and the amount of mechanical work sup-plied to compressor decrease (Figure 5.).

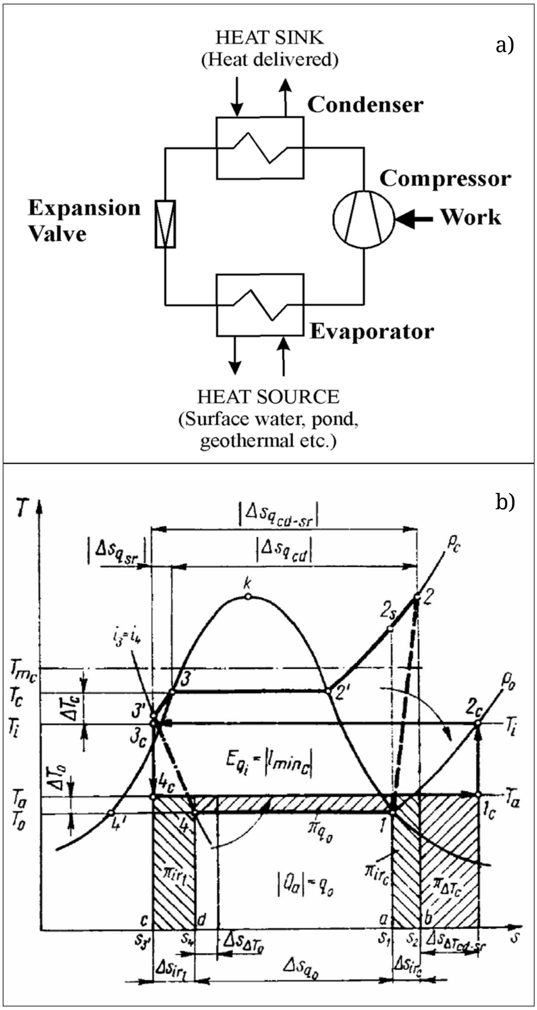

Figure 4. *Schematic of heat pump a) and temperature-entropy diagram b)* [9]

Table 2. *Thermal characteristics of the heat pump*

	Basis for comparison	**Minimum value**	**Mean value**	**Maximum value**
Ambient temperature (of heat source), T_a [°C]	5	16	26	32
Cycle compression work, l [kJ·kg-1]	375.24	346.64	324.42	312.67
Work supplied to compressor, P_e [kW]	170.67	159.73	151.04	146.39
Heat transferred in evaporator (from heat source), q_0 [kJ·kg-1]	947.41	958.89	967.71	972.25
Heat transferred in condenser (delivered heat), q_c [kJ·kg-1]	1322.65	1305.54	1292.13	1284.92
Ideal (Carnot) coefficient of performance $COP_{\mu C}$	5.64	6.9	8.67	10.25
Theoretical coefficient of performance COP_{μ}	3.52	3.76	3.98	4.11
Practical coefficient of performance $COP_{\mu e}$	3.17	3.38	3.58	3.70

Figure 6. shows the same dependence between the heat transferred in evaporator (acquired from the heat source) q_0 and temperature, while the delivered heat at the upper temperature level q_c increases with increasing temperature. The most important thermal characteristic of the heat pump, the ideal (Carnot) coefficient of performance $COP_{\mu C}$, the theoretical COP_{μ} and the actual $COP_{\mu e}$, also increase with increasing temperature

5. Conclusions

The study investigated the amount and quality of heat recovered from the cooling water of the turbocompressor.

The biggest issue is that the waste heat available in the turbocompressor cooling water is of very low quality (low temperature) and therefore cannot be used directly.

The literature recommends the use of heat pumps for this type of waste heat [9].

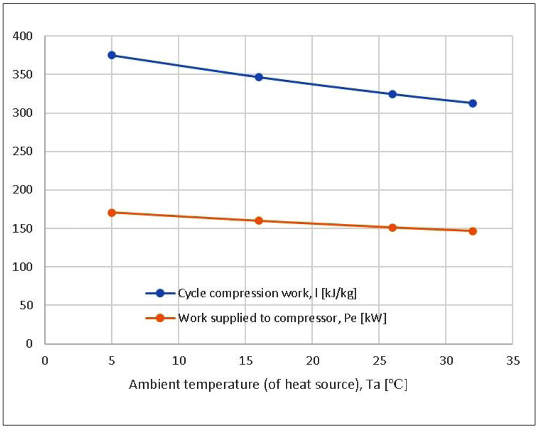

Figure 5. *The mechanical work of the cycle and the mechanical work supplied to the compressor*

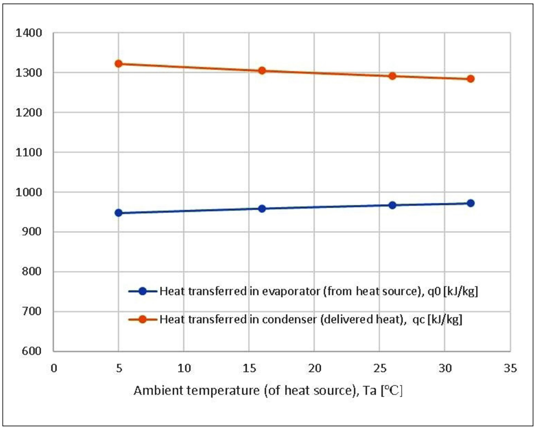

Figure 6. *Heat transferred in evaporator q_0 and in the condenser q_c.*

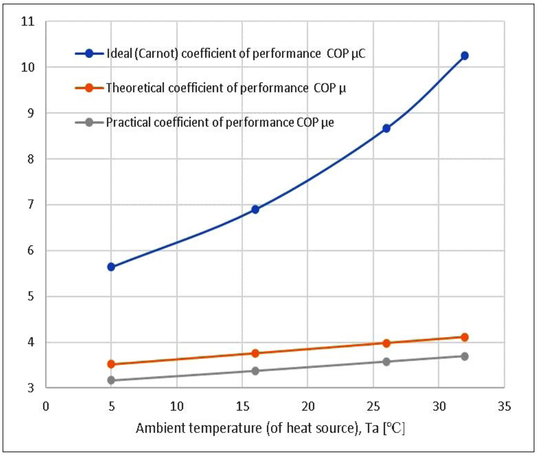

Figure 7. *Ideal Carnot COP (coefficient of performance) μC, theoretical COP_{μ} and practical $COP_{\mu e}$*

There are many types of heat pump, both from a construction and refrigerant point of view, so it would be difficult to compare them. Therefore, the basic constructive model, the vapor-compression water-to-water heat pump using ammonia as refrigerant, was chosen to facilitate comparison.

The amount of waste heat is very high, 541.43 kW, although it is only the heat produced by a single turbocompressor.

Multiplying these values by ten (as the average number of turbocompressors operating in the local mining industry) numbers are even higher, it would be enough to heat a small settlement, so it is worthwhile recovering that waste heat.

Although the recovery of large amounts of waste heat is not technically problematic, it may not be economically viable, as it is necessary to find a consumer who will use this continuously generated amount of heat.

Storage of this amount of heat is also not very economical and may be challenging from a technical point of view. There is also a problem with the transportation, as usually the under-ground mines are located outside the settlements, preferably at the edge of the villages or towns.

Heat could be delivered via pipelines using water as a heat transfer medium, although it would be expensive to build.

A solution could be to connect the existing district heating pipe system, but in this case several technical problems may arise because the temperature and pressure of the heat carrier must be at a level that does not disturb the existing district heating system.

The final conclusion is that while there is a large amount of waste heat that is technically easy to recover, its subsequent use is problematic as it is difficult to find the right user.

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