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Intensification of the cooling process in air cooling apparatus for booster compressor stations

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ABSTRACT: Since the process of gas compression is always accompanied by heating, when transporting gas through gas pipelines, it is necessary to provide conditions for its cooling. The authors present experimental data on the intensification of the cooling process in air coolers in a wide range of regime parameters. Criteria formulas for the coefficients of heat transfer and heat removal from the heat exchange surface are obtained.

KEYWORDS: ACU - air coolers, heat transfer coefficient, air side heat transfer, heat transfer coefficient, moisture content, relative air humidity

I. INTRODUCTION

Increasing the energy efficiency of booster compressor stations (BCS) is an urgent problem in the gas industry. Analysis and calculation of the technological modes of operation of the CS is an integral part of solving the problem of ensuring energy efficiency and optimizing the operation of the BCS and the entire gas transmission system (GTS) as a whole.

System energy efficiency characterizes the energy efficiency of the gas transmission system, taking into account the energy interdependence of its constituent objects, takes into account the mode of their joint operation (the energy contribution of each object to the system operation) [1].

To optimize the operating mode of the compressor station [2], the regulation of thermodynamic parameters occurs depending on the change:
- the number of operating superchargers at the compressor station;
- the actual number of revolutions of the rotor of each supercharger;
- the number of switched on fans in the ACU gas.

The number of air coolers is determined based on the data of the thermal and hydraulic calculation of the gas pipeline according to the throughput mode. All cumulative data are taken into account: air and ground temperature (average annual), as well as average annual gas temperatures.

When designing a compressor station, the number of air coolers is selected in accordance with industry standards, and based on these standards, the temperature of the process gas at the outlet of the air cooler should not be higher than 15-20 ° C of the average outdoor air temperature.

A decrease in the temperature of the process gas entering the gas pipeline after its cooling in the ACU leads to a decrease in the average gas temperature in the linear section of the pipeline and, as a result, to a decrease in temperature and an increase in gas pressure at the inlet to the subsequent BCS and, as a rule, leads to a decrease in the compression

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ratio by the next station (while maintaining the pressure at its outlet) and energy consumption for gas compression through the station.

II. EXPERIMENTAL INVESTIGATION OF THE PROCESS OF AIR-WATER EVAPORATION COOLING IN ACU.

A. Intensification of heat transfer during air-water evaporation cooling.

To conduct the study, a universal experimental stand was developed that simulates the operation of air coolers [6]. The authors carried out experiments to study the intensification of heat transfer in air coolers using air-water evaporative cooling [7, 8]. To do this, water was dispersed into the cooling air flow, in the summer period, by a nozzle, which, due to the adiabatic cooling of the air, completely evaporated. The experiments were carried out in the range of parameters change: Reynolds number of cooling air Rev=1700÷9000, Reynolds number (20%, 30%) an aqueous solution of monoethanolamine Rem=1000÷8500; initial temperature of the amine solution at the inlet t = 40oC, 60oC, 80oC; pressure of the water sprayed by the nozzle P = 0-20 kgf/sm2; air speed W = 0,5 - 6,13 m/s; degree of air irrigation ρ = 0,0013-0,004 kg/kg.

On fig. 1 and 2 shows the dependence of heat transfer from the air side during cooling of the amine solution, depending on the Reynolds number and the degree of irrigation of the cooling air, as well as on the temperature of the amine solution at the inlet to the heat exchange sections of the air cooler in the form

$$\alpha_v = f\,(Re_v, \rho, t).$$

It can be seen from the figures that the value of the heat transfer coefficient of air α_v significantly depends on such parameters as: Re_v, ρ, t and Re_m. From the analysis of the graphs in Fig. 1, which characterize air cooling, without the use of humidification, it follows that with an increase in the values t, Re_m and Re_v, magnitude α_v increases.

In Figs. 1 and 2, the lower curves (passing through triangles) characterize the cooling of the amine solution by the temperature t = 40^{o}C; curves passing in the middle (through the squares) refer to the solution with t = 60^{o}C; the upper curves (passing through the rhombuses) refer to the amine solution with the temperature at the inlet to the heat exchange sections of the air cooler t = 80^{o}C. Thus, with “dry” air cooling, the value of α_v changed in the interval 15 – 70 W/m^2 C, for amine solution with temperature t = 40^{o}C For solution c t = 60^{o}C and t = 80^{o}C magnitude α_v amounted to 19-80 W/m^2 C and 21-86 W/m^2 C respectively.

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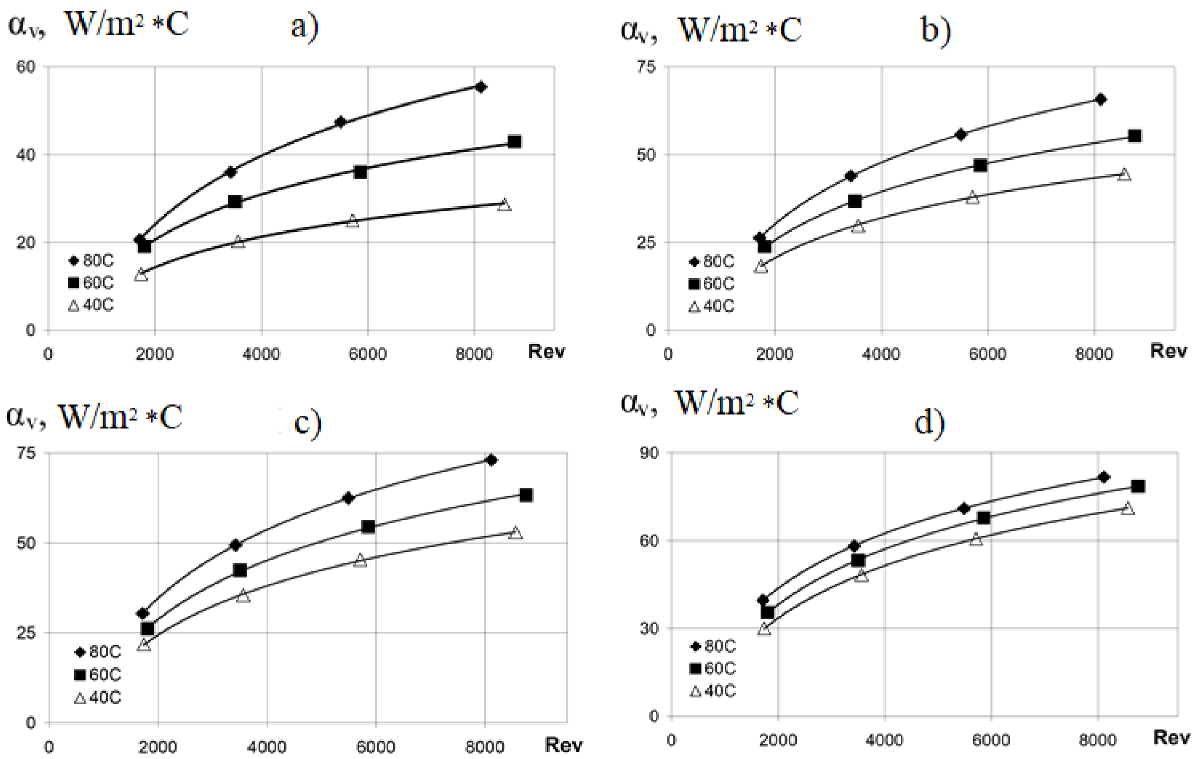

Fig.1. The dependence of the heat transfer coefficient of air in the form:
α_v = f (Rev), c_p = 30% "dry" air cooling.
a) $Re_m \approx 2200$; b) $Re_m \approx 3700$; c) $Re_m \approx 5600$; d) $Re_m \approx 8000$

Fig. 2 characterizes the dependence of the intensity of heat transfer of air during air-evaporative cooling and the degree of irrigation of the air flow ρ = 0,004 kg/kg. It can be seen from the figures that at $Re_v = 6000$ and $Re_m = 5600$ (fig.2 -c), the value of the heat transfer coefficient of air was α_v = 85 W/m^2 °C, 105 W/m^2 °C, 145 W/m^2 °C at solution temperature t = 40^{o}C, 60^{o}C and 80^{o}C respectively. With an increase in the Reynolds number of the amine solution to $Re_m = 8000$ (fig.2 -d), the value of the heat transfer coefficient of air also increases, which amounted to α_v = 115 W/m^2 °C, α_v = 135 W/m^2 °C and α_v = 175 W/m^2 °C, with the same Rev= 6000. A further increase in the Reynolds number of the cooling air to Rev= 8000 also intensified the heat transfer, the values of α_v were 130 W/m^2 ^{o}C, 155 W/m^2 ^{o}C and 190 W/m^2 ^{o}C. In comparison with "dry" air cooling, the intensity of heat transfer increased by 1.8 - 2.6 times.

B. Intensification of heat removal during air-water evaporation cooling.

On fig. Figure 3 shows the change in air heat removal depending on the Reynolds numbers of the air and the degree of irrigation of the air flow in the form: Qv = f (Rev, ρ). Accepted designations: 1 - "dry" cooling; 2 – ρ = 0.0013 kg/kg; 3 – ρ = 0.0027 kg/kg; 4 - ρ = 0.0033 kg/kg; 5 - ρ = 0.004 kg/kg.

The results show that the value of heat removal Qv significantly depends on such parameters Rem, Rev and ρ. As Rem and Rev increase, the heat removal from the air side increases. For any of the considered values of ρ, the values of Qv are higher than for "dry" air cooling.

Dependence plots for various values of ρ are plotted as Qv =f(Rev). The graphic dependences summarize the results of adiabatic air cooling at fixed coolant temperatures inside the ACU heat exchange tubes t = 40 °C, 60 °C and 80 °C. As in Fig. 3, a change in the flow regime of the cooling air and coolant affects the intensity of cooling. When the cooling air is humidified to a certain value, a significant increase in the Qv value is observed. For example, when cooling a 30% amine solution with temperature t = 80 degrees Celsius, the Qv values were 24000-28000 W for air-evaporative

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cooling and 14000 W for "dry" air cooling. It should be noted that a further increase in the degree of irrigation of the cooling air did not give a significant effect, perhaps this is due to supersaturation with water vapor at the time of the experiments.

As a result of experimental data processing, a criterion equation was obtained for calculating the efficiency of heat removal during air-water evaporation cooling of an amine solution:

$$\boldsymbol{Q}' = \left[\frac{8020}{Re\,m}\cdot\left(1+\frac{Re\,v}{8553}\right)\right]^{0,5}\cdot\left[\left(0,2+\frac{2}{\mathrm{p}}\right)\cdot\left(1+\frac{t}{80}\right)\right]^{0,2}\cdot\left(\frac{c_p}{30}\right)^{0,7}$$

where Rem is the Reynolds number of the amine solution; Rev is the Reynolds number of the cooling air; p is the pressure of water supplied to the nozzle, kgf/cm^2; t is the temperature of the amine solution inside the ACU heat exchange tubes; Cp is the concentration of the amine solution, %.

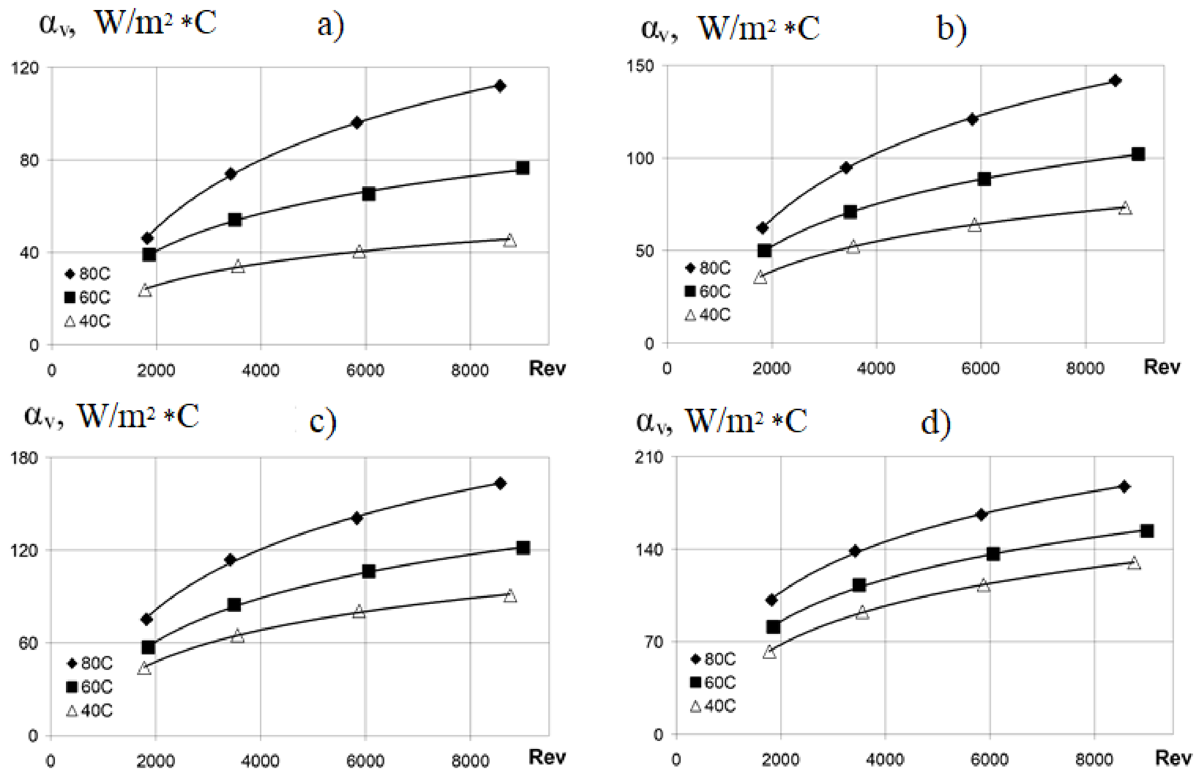

Fig.2. The dependence of the heat transfer coefficient of air in the form:
$\alpha_v = f(Rev)$, cp = 30%. ρ = 0,004 kg/kg.
a) $Re_m \approx 2200$; b) $Re_m \approx 3700$; c) $Re_m \approx 5600$; d) $Re_m \approx 8000$

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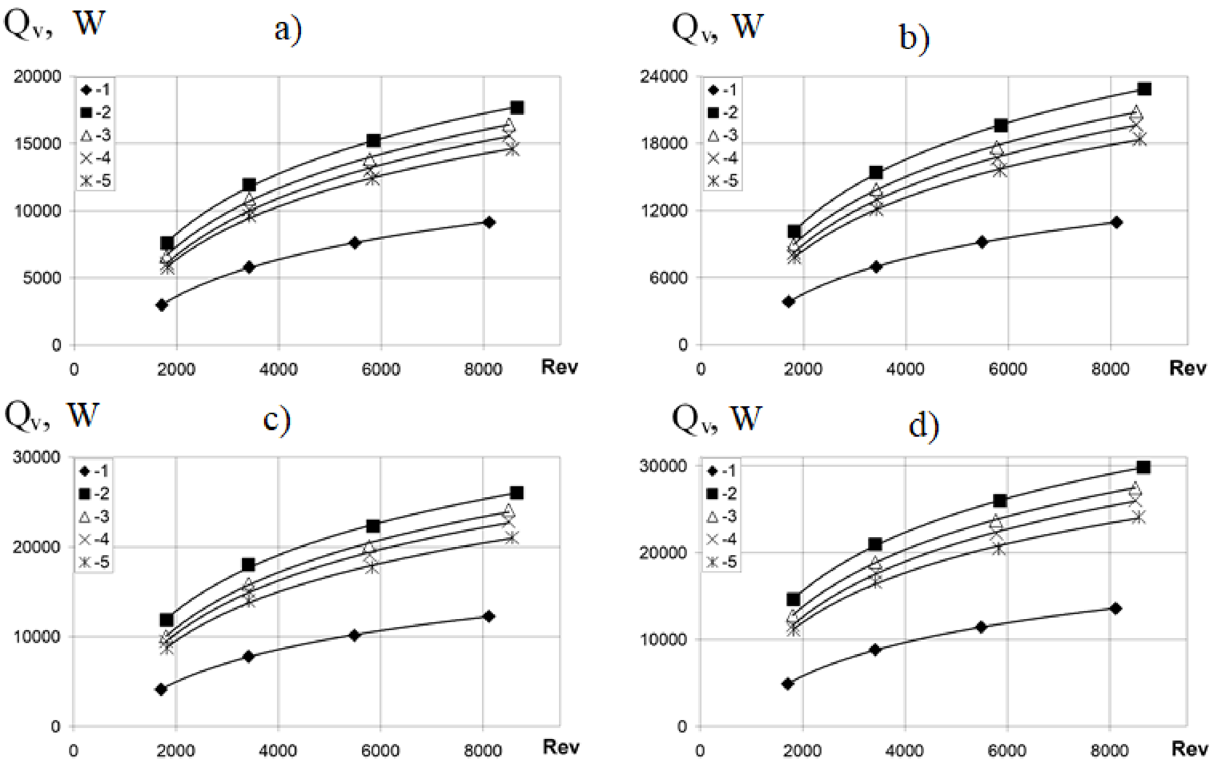

Fig. 3 Dependence of the coefficient of heat removal of air in the form: $Q_v = f\ (Rev)$.
c_p = 30%. a) Re_m = ≈ 2200; b) Re_m ≈ 3700; c) Re_m ≈ 5600; d) Re_m ≈ 8000; t = 80°C

C. Intensification of heat transfer during air-water evaporative cooling

Based on the generalization of experimental data, a criterion formula was obtained for calculating the heat transfer coefficient during air-water evaporation cooling of an amine solution:

$$k^{/} = \left(\left(\frac{W}{3,5} \cdot \frac{0.0028}{\rho} \cdot \frac{25}{C_p} \cdot \frac{273+t}{293} \right)^{0,1} \cdot (1,57 - 0,032 \cdot \ln(\mathrm{Re}\ m) \right)$$

Where $k^{/} = K / K_0$;
K_0 - heat transfer coefficient for "dry" air cooling;
K is the heat transfer coefficient for air-water evaporative cooling.

III. CONCLUSION

Experimental studies of the effect of air-water evaporative cooling on the efficiency of air coolers have been carried out.
Depending on the degree of irrigation, the temperature of the cooling air decreases by 8-19 °C in comparison with "dry" air cooling, the heat transfer intensity increased by 1.8 - 2.6 times, and the heat transfer rate by 1.2-1.5 times.

Intensification of heat transfer is observed during cooling of gas and other technological media in air coolers, which makes it possible to recommend equipping industrial air coolers located in regions with arid climates with a humidification system based on the developed nozzle design to intensify their work.

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Criteria dependencies are obtained for calculating the intensity of heat removal and the heat transfer coefficient during cooling of amine solutions in a wide range of changes in cooling regime conditions.

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