# Cooling of air entering a gas turbine compressor using heat exchangers

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**Abstract.** The article presents an analysis of reducing the inlet air temperature supplied to the compressor of a 28,6 MW gas turbine unit operating at the "Tashkent thermal power center" branch of JSC "IES" through the application of a heat-exchange system. In contemporary power engineering, combined cycle gaz turbine units have become prevalent due to their superior economic and operational performance. The output of a gas turbine is highly sensitive to the temperature of the ambient air entering the compressor. In Uzbekistan, average annual outdoor air temperatures range from approximately +5 $^0$C to +33 $^0$C. When the compressor is supplied with air at elevated temperatures of 40-45 $^0$C, the power output of gas turbine units may decline by as much as 30%, accompanied by a notable increase in specific fuel consumption. The findings of the study demonstrate that lowering the compressor inlet air temperature by up to 20 $^0$C using a heat exchanger can significantly enhance the performance and efficiency of the gas turbine unit.

## INTRODUCTION

Gas turbines are widely employed both for electricity generation and as propulsion systems in aviation [1,2,3]. A conventional gas turbine engine comprises a compressor that elevates the pressure of the incoming air, a combustion chamber in which a fuel-air mixture is ignited, and a turbine that extracts mechanical energy from the high-temperature combustion products [4,5]. The thermodynamic processes governing these engines follow the open Brayton cycle [3,6]. Power units operating in combined-cycle configurations exhibit notably high economic and operational efficiency. The electrical output of a gas turbine is strongly influenced by the temperature of the ambient air entering the compressor. In Uzbekistan, average annual outdoor air temperatures typically range from approximately +5 $^0$C to +33 $^0$C. When the compressor intake air temperature rises to 40-45 $^0$C, the power output of gas turbine units can decrease by as much as 30%, accompanied by a corresponding increase in specific fuel consumption [7].

Typically, the rated capacity of gas turbines is determined under standardized ambient conditions, assuming zero inlet and outlet pressure losses, in accordance with International Organization for Standardization (ISO) guidelines [2]. These reference conditions specify a compressor inlet air temperature of +15 $^0$C, a relative humidity of 60%, and an atmospheric pressure of 101,325 kPa.

Numerous researchers have investigated various inlet-air cooling techniques aimed at improving the performance of gas turbine plants operating under high-temperature ambient conditions. The most commonly examined methods include evaporative cooling, spray-type or fogging systems, and mechanical refrigeration using chillers [7].

Internal combustion gas turbines operate as constant-pressure engines, and their power output is fundamentally constrained by the mass flow rate of air entering the system. Because the compressor delivers a nearly fixed volumetric airflow at a given rotational speed, its volumetric capacity remains essentially constant. However, the mass flow rate of the air admitted to the gas turbine varies as a function of ambient temperature and relative humidity, resulting in corresponding changes in turbine performance [8, 9].

## EXPERIMENTAL RESEARCH

A computational methodology was developed for the proposed heat exchanger intended to reduce the temperature of the air supplied to the compressor of the 28.6 MW gas turbine unit at the "Tashkent thermal power center" branch of the "Heat Power Plants" Joint-Stock Company to a target value of $t''_1 = 20$ $^0$C [7, 9]. The compressor of this unit continuously ingests air at a volumetric flow rate of $V_1 = 90000\ m^3/soat$. According to meteorological data, the average outdoor air temperature at 13:00 during the hottest month (July) in Tashkent is $t'_1 = 33{,}3$ $^0$C [9, 10]. Technical water (river water) serves as the cooling medium in the heat exchanger; measurements indicate that at an ambient temperature of $t'_1 = 33{,}3$ $^0$C the temperature of the cooling water entering the system is $t'_2 = 18$ $^0$C The geometric characteristics of the designed heat exchanger layout are as follows: pipe width $l_1 = 3\ m$, height $l_2 = 2\ m$, and length in the range of 6-6.5 meters [11, 12].

The proposed configuration of the external-air cooling system supplying the 28.6 MW gas turbine compressor is illustrated in Figure 1.

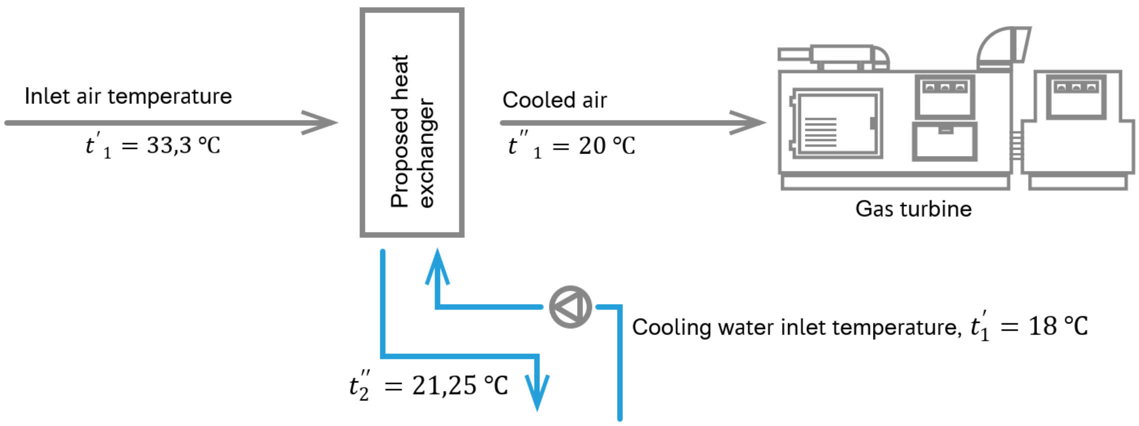


**FIGURE 1.** Cooling scheme of air supplied to the gas turbine compressor.

The technical characteristics of the gas turbine plant of the "Tashkent thermal power center" branch with a capacity of 28,6 MW for calculating thermodynamic processes are presented in Table 1.

**TABLE 1.** The technical characteristics of the gas turbine of the "Tashkent thermal power center" branch.

| Gas turbine (Hitachi-5) | | Air compressor | |
|---|---|---|---|
| Equipment | Technical characteristics | Equipment | Technical characteristics |
| Model Description | Open, single-shaft, simple cycle | Model | BK75-8GH |
| Power | 28670 kWt*h (under ISO conditions) | Number of stages | 1 |
| Calculated atmospheric temperature | 15 $^0$C | Air discharge pressure, (MPa) | 0,8 |
| Exhaust gas temperature | 557 $^0$C | Capacity, $(m^3/minute)$ | 13 |
| Working atmospheric temperature | Min: -30 $^0$C, Max: +45 $^0$C | Supply voltage, V | 380 |
| Turbine rotor speed | $7255\ rpm$ | Voltage frequency, Hz | 50 |

## RESEARCH RESULTS

The proposed cooling system-namely, the heat exchanger-is positioned upstream of the air filtration unit and utilizes technical river water as the cooling medium. The results of the thermal performance calculations for the heat exchanger installed prior to the air filter are summarized in Table 2.

**TABLE 2.** Heat calculation of the proposed heat exchange device.

| The quantities being calculated | Formulas | Result values | |
|---|---|---|---|
| | | Air | Cooling water |
| Average temperature, $^0$C | $\bar{t} = (t_1' + t_1'')$ | 32,5 | 20,2 |
| Heat balance, kW | $Q = G_1 \cdot Cp_1 \cdot (t_1' - t_1'') = G_2 \cdot Cp_2 \cdot (t_2'' - t_2')$ | 394,6 | 394,6 |
| Water consumption, kg/sec | $G_2 = \pi \cdot \left(\frac{d_{in}}{4}\right)^2 \cdot w_2 \cdot \rho_2 \cdot n$ | | 29 |
| Air consumption, kg/sec | $G_1 = V_1 * \rho_1$ | 29,5 | |
| Water outlet temperature, $^0$C | $t_2'' = t_2' + \frac{Q}{G_2 \cdot Cp_2}$ | | 21,25 |
| Average temperature difference, $^0$C | $\overline{\Delta t}_{aver.} = \frac{\Delta t_{big} - \Delta t_{small}}{ln \frac{\Delta t_{big}}{\Delta t_{small}}}$ | 5,6 | |
| Reynolds number | $Re_x = w_x \cdot d_x / \gamma_x$ | 2610 | 9843,5 |
| Nusselt criterion | $Nu_x = 0{,}021 \cdot Re_x^{0,8} \cdot Pr_x^{0,43} \cdot \left(\frac{Pr_x}{Pr_{wall}}\right)^{0,25}$ | | 78 |
| | $Nu_x = 0{,}215 * Re_1^{0,65} * Pr_1^{0,33} \left(\frac{s}{D_{out} + 2 * q_2}\right)^{0,54} * \left(\frac{s}{h_p}\right)^{0,14}$ | 8,6 | |
| Heat transfer coefficient, $\frac{W}{(m^2 \cdot {}^\circ C)}$ | $\alpha_x = \frac{Nu_x \cdot \lambda_x}{d_x}$ | 64,8 | 1866 |
| The overall heat transfer coefficient, $\frac{W}{(m^2 \cdot {}^\circ C)}$ | $k = \frac{1}{\frac{1}{\alpha_2} * \varphi + \frac{q_1}{\lambda_1} + \frac{1}{\alpha_1} + \frac{q_2}{\lambda_2}}$ | 47,32 | |
| Heat exchange surface, m$^2$ | $F = \frac{Q}{k \cdot \overline{\Delta t}_{aver.}}$ | 1490 | |

The heat exchanger underwent operational testing at the “Tashkent thermal power center” branch during the period from April to September 2024. The results of these performance evaluations are summarized in Table 3.

**TABLE 3.** Average annual production figures of a gas turbine plant.

| Months | Average outdoor temperature, $^0C$ | Generated power, MWt | Average outdoor temperature, $^0$C | The power generated by the heat exchanger when installed, MW |
|---|---|---|---|---|
| January | 4,5 | 31,2 | 4,5 | 31,2 |
| February | 5,5 | 31,2 | 5,5 | 31,2 |
| March | 12 | 29,45 | 12 | 29,45 |
| April | **18,5** | **27,6** | **20** | **27,61** |
| May | **25** | **25,8** | **20** | **27,01** |
| June | **29,5** | **24,6** | **20** | **27,01** |
| July | **32** | **23,96** | **20** | **27,01** |
| August | **30,5** | **24,4** | **20** | **27,01** |
| September | **25** | **25,8** | **20** | **27,01** |
| October | **17** | **28,03** | **17** | **28,03** |
| November | 9 | 30,32 | 9 | 30,32 |
| December | 5 | 31,2 | 5 | 31,2 |

## CONCLUSIONS

The performance of a 28,6 MW gas turbine unit at the “Tashkent thermal power center” branch was evaluated by calculating and experimentally verifying the effect of cooling the compressor inlet air using a heat exchanger. The investigation demonstrated that, with seasonal outdoor air temperatures ranging on average from +5 $^0$C to +33 $^0$C, the turbine's power output may decline by as much as 17%. At an ambient temperature of 33,3 $^{0}$C, reducing the compressor inlet air temperature to 20 $^{0}$C prevents a power loss of 5,97 MW. Consequently, the application of the cooling system enables an annual additional electricity generation of approximately 7,929,000 kW·h.

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