Секція № 5. ХОЛОД НА ТРАНСПОРТІ, В ЕНЕРГЕТИЦІ ТА АГРОПРОМИСЛОВОМУ КОМПЛЕКСІ

UDK 621.517: 62-717

EFFICIENCY ANALYSIS OF MULTISTAGE COMPRESSOR INTERCOOLING BY USING THERMOPRESSOR

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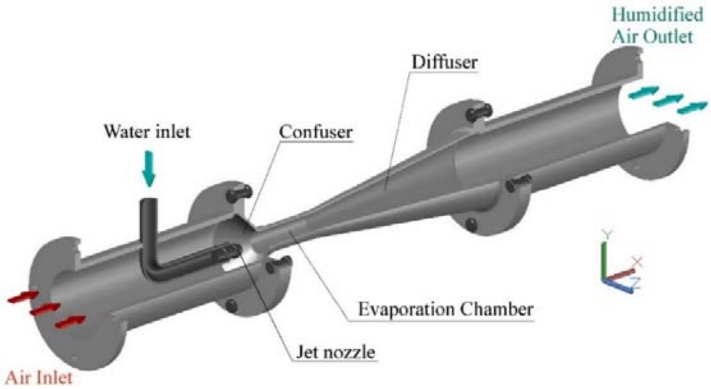
Abstract: A study of the thermopressor operation for air intercooling between the stages of a multistage compressor as part of a modern gas turbine was carried out. A calculation method has been developed using numerical modeling for the evaporation of fine water droplets in the air flow. The main characteristics of the two-phase flow at the thermopressor outlet have been determined. It has been found that the thermopressor applying allowed to reduce the temperature of the compressed air between the compressor stages to 50–70 °C. A decrease in pressure at the thermopressor outlet is up to 12–28 kPa (4-9%).

Keywords: Water Droplet Diameter, Two-Phase Flow, CFD simulation.

There are a number of technologies available to improve the efficiency of the air compression process in multistage compressors. Particular attention is paid to cycles with water or steam injection along the path of the compressor section of gas turbine engines to humidify the working fluid [1, 2] and reduce the temperature. An alternative way to inject water into the air flow between the compressors is to use a thermopressor (Fig. 1a). If the optimal geometric parameters were selected, the rational organization of thermophysical processes in the flow path of the thermopressor could be possible. The correct selection of these parameters will ensure the evaporation of the water amount (80–85%) in the thermopressor and the additional evaporation of remaining water (15–20%) in the flow path of the high-pressure compressor. In this case, the water droplets diameter entering the compressor will not exceed 20 μm [3].



Parameter	Value
Continuous phase (air flow)	
Inlet air pressure P_1, Pa	301325
Inlet air temperature T_{air1}, K	473
Inlet air velocity w_{air1}, m/s	55
Air mass flow G_{air}, kg/s	1.56
Mach number at the inlet evaporation chamber M	0.55
Discrete phase (water drops)	
Diameter of drop δ, μm	3-30
Water temperature T_w, K	300
Water velocity w_w, m/s	100
Water mass flow G_w, kg/s	0.031; 0.062; 0.156

(a) (b)

Fig. 1. 3D model of the thermopressor (a) and the main inlet parameters of the airflow and water injection (b)

The choice of such optimal geometric parameters of the thermopressor, as well as the determination of the characteristics and injection mode (flow velocity; average, maximum and minimum droplet diameters; inlet air temperature; relative water flow rate, air pressure and air flow rate) (Fig. 1b) should be carried out according to the results of an experimental study of working processes and in numerical modeling [2, 3].

To carry out numerical modeling, the finite volume method was applied, which is implemented in the ANSYS Fluent software package. The Eulerian-Lagrangian approach was used to simulate the interaction of injected water droplets and air flow. A two-parameter k-ε Realizable turbulence model from the RANS group of models was used to investigate the behavior of the air flow [4, 5]. Discrete Phase Model was used to simulate the movement of water droplets.

To analyze the gas turbine cycle, the well-known calculation methods were used [6, 7]. The calculation of the gas turbine cycles was carried out for the degrees of pressure increase π_c = 12–40.

The increase in total pressure as a result of thermogasdynamic compression (Fig. 2) was ΔP_{tp} = 2.8 kPa (2.1 %) relative to the inlet pressure. It should be noted that the cyclic air cooling in the thermopressor is ΔT_{tp} = 135 K (Fig. 2), from the initial temperature T_{tp1} = 473 K (200 °C) to the outlet temperature T_{tp2} = 340 K (67 °C).

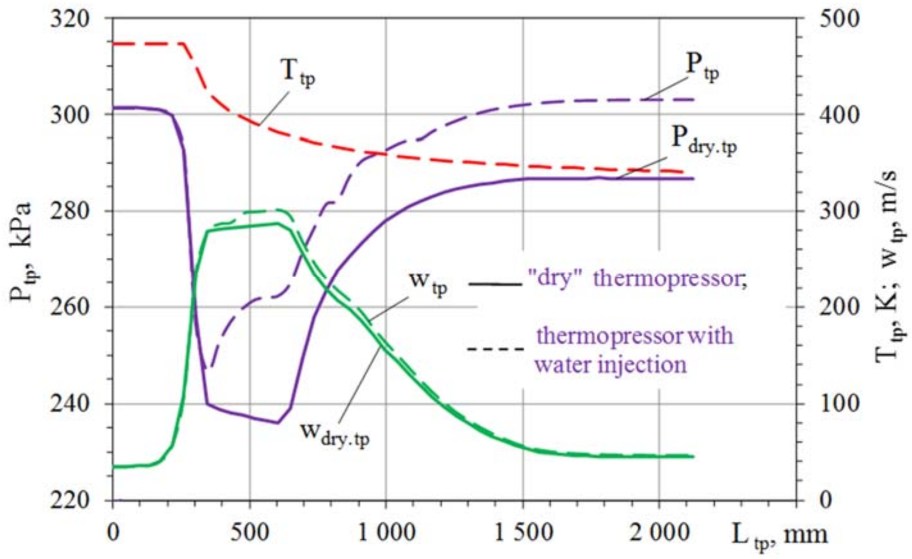


Fig. 2. Dependences of the flow main characteristics: total pressure P_{tp}, flow velocity w_{tp}, flow temperature T_{tp} on the length of the thermopressor flow part L_{tp}

The dispersion of water droplets at the evaporation chamber inlet was δ_d =3–30 μm. The distribution of sprayed water droplets in the flowing part of the thermopressor has been given: for incomplete evaporation, with obtaining smaller droplets at the outlet of the diffuser part of the thermopressor (G_w = 0.156 kg/s) (Fig. 3).

The use of the thermopressor made it possible to reduce the air temperature between the compressor stages by t_{2tp} = 50–70 °C, that is, up to 50–110 °C.

Such a decrease in temperature under thermo-gas-dynamic compression conditions made it possible to increase the pressure by ΔP_{tp} = 12–28 kPa, that is, up to 4–9%. Contact air cooling by using the thermopressor allowed to reduce the compressor compression work by 2.5–3.0%.

A decrease in the compressor operation and a simultaneous increase in the amount of the working fluid in the cycle makes it possible to increase the efficiency GTP by $\Delta\eta_e$ = 0.01–0.02 (1–2 %). In this case, the specific fuel consumption will decrease by Δg_e = 5–10 g/(kW·h). At the same time, the gas turbine specific power is increased by ΔN_s = 5–30 kW/(kg/s), which is 3–10 % (Fig. 4). The simulation of the gas turbine operation was carried out for the range of degrees of pressure increase in compressor stages of the gas turbine π_c = 12–42, which are typical for the operation mode according to the classical cycle.

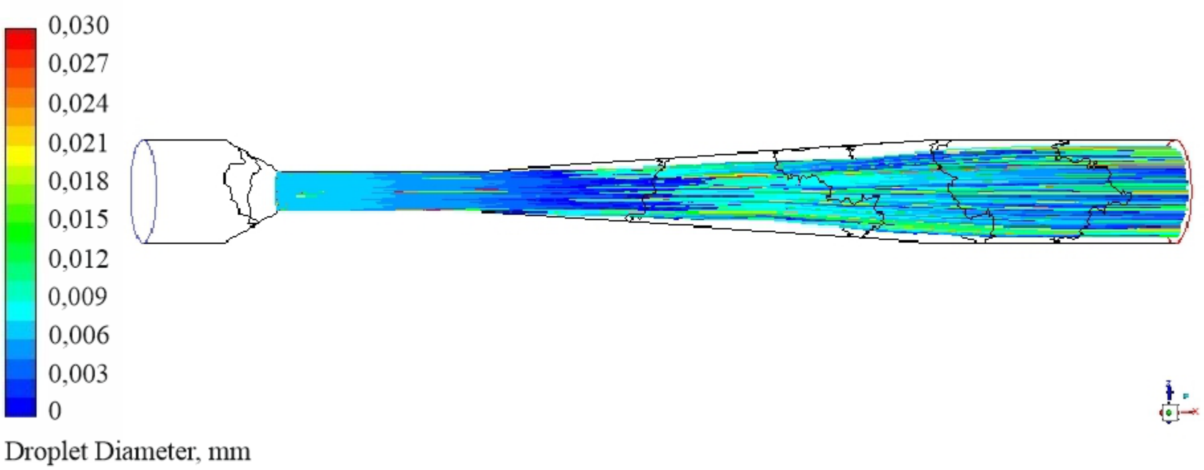


Fig. 3. Dispersion distribution of sprayed water δ_p in the flow path of the thermopressor for incomplete evaporation, with obtaining smaller droplets at the outlet of the diffuser part of the apparatus (g_w = 10%)

Conclusion. The paper analyzes the efficiency of using a thermopressor for contact cooling of compressed air in the LMS100 gas turbine circuits. Thermopressor provides effective fine atomization of water, and hence, a more efficient compression process in the high-pressure compressor.

It has been determined that the thermopressor allows to increase the air pressure between the compressor stages by 4–9%, as a result of which the compression work in the compressor stages decreases; increase the amount of the working fluid in the cycle by g_w = 2–4%, and, as a consequence, increase the specific power of the gas turbine by 3–10%.

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