Simulation and efficiency evaluation of the operating cycle of the stationary GT

K NTECH
L A B O R A T O R Y

Abstract

The paper shows the use of **Chemical Workbench** to calculate the thermodynamic cycles of power and propulsion systems by the example of a gas turbine (GT), operating on mixture of air and methane.

Introduction

Workflows of turbine, turbojet and ramjet combustion engines and gas turbine engines of the external combustion engine with closed-loop gas (single-phase) working fluid are described by the Brayton thermodynamic cycle, which consists of the processes:

1 Isentropic compression. (Compressor)
2 Isobaric heat input. (Province of combustion)
3 Isentropic expansion. (Turbine)
4 Isobaric heat removal.

It is known that the increase of the gas temperature before the turbine can significantly increase the power density and thus reduce the size and weight of the gas turbine plant. The simultaneous increase in temperature and the degree of compression is most effective way to increase the specific work cycle and efficiency.

Chemical Workbench is a handy tool for calculating the thermodynamic characteristics of complex systems.

Formulation of problem

Objective: To evaluate the efficiency of the gas turbine plant. To do this, we calculate the gas temperature at all stages of the process, and calculate the efficiency of the thermodynamic cycle system.

Conditions of calculation:
the ratio of fuel to oxidizer (alpha) varies in the range from 2 to 4;
the compression ratio of the compressor varies from 5 to 40

Teurbine model

In the software package **Chemical Workbench** GT model is constructed by a sequence of elementary reactors, describing processes in various areas of the installation (stage Brayton cycle). Model turbine consists of the following areas:

The area of the outer atmosphere, where air is supplied - for the calculation of the *initial enthalpy* **H1** of air, this region is modeled by the *thermodynamic reactor with constant pressure and temperature* **RT**

Compressor - adiabatically compresses air – modeled by the *thermodynamic reactor with constant pressure and entropy* **PS**. The reactor will calculate the *enthalpy of air after compression* **H2**.

Combustion area – modeled by the *thermodynamic reactor* **PH**. This reactor calculates the *enthalpy of gas after combustion* **H3**, *temperature* **T3**, and *heat capacity* **C3** of the gas mixture.

Turbine - it expands the gas mixture adiabatically to 1 atm – it is modeled by the *thermodynamic reactor with constant pressure and entropy* **PS**. The reactor calculates the *enthalpy of air after the expansion* **H4**, and the *final temperature* **T4**.

Atmosphere   Compressor   Flame   Turbine

Application notes: Chemical Workbench
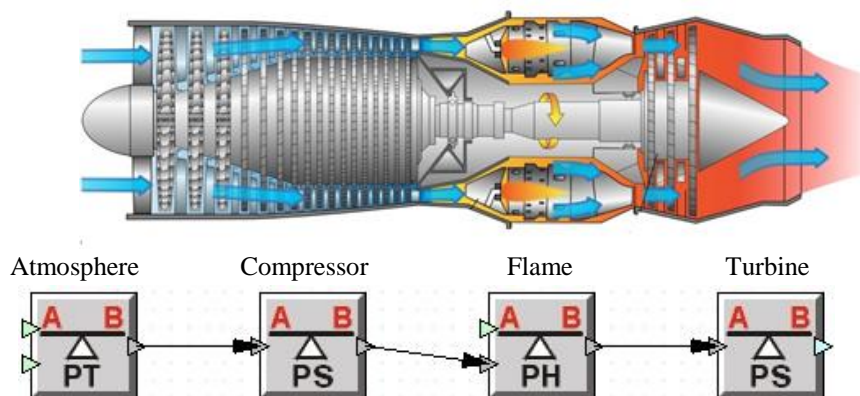
Calculating of the simple gas turbine plant (GT) of open type by Brayton cycle is performed according to the conventional algorithm, in which the first step is to define the parameters of the air compression process in compressor, such as the temperature of the compressor, the enthalpy of air at the beginning and the end of the the compression process.

Then, using the temperature value we determine the values of enthalpy of air, flue gas and the gas mixture after the turbine.

Work of gas expansion in the turbine is determined by the formula: *Hm=H2-H3*

The work spent on compressing the air in the compressor: *Hκ=H1-H0*

So, the work on the GT's shaft is found by the formula: *He=Hm-Hκ=(H2 – H3) – (H1 – H0)*

Heat generated from combustion of methane: *Q=C2·T2 – C1·T1*

Finally, the efficiency of the gas turbine is calculated as follows:

$$\eta = \frac{(H3-H4)-(H2-H1)}{Cp2 \cdot T2 - Cp3 \cdot T3} \cdot 100\%$$

The methodology of calculation in Chemical Workbench

Installation parameters are calculated as follows.

1. Using a library of models construct on the desktop a sequence of reactors (shown in the figure)
2. Set the parameters of the input streams of air and methane flow, temperature, pressure
3. Input the working pressures in the reactors (depending on a given degree compression of from 5 to 40 atm)
4. Set CH4, N2, O2 as the compressor working gas mixture, as the chemical transformations do not occur. List the possible combustion products (chemical mechanism)
5. Run the calculation

After entering substances the software is automatically loads from the built-in database recommended values of polynomial functions and the thermodynamic properties of substances, taking into account non-ideal gas.

GT modeling results
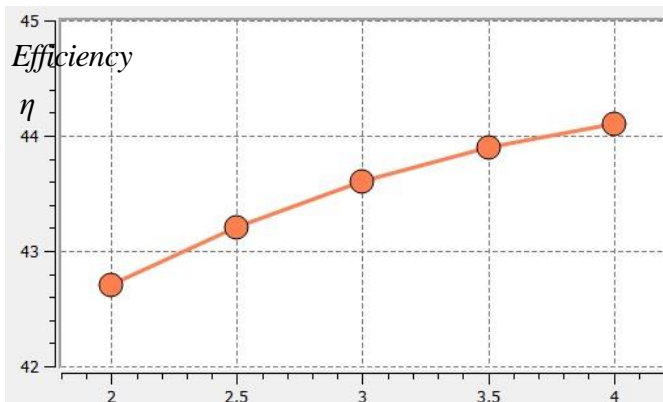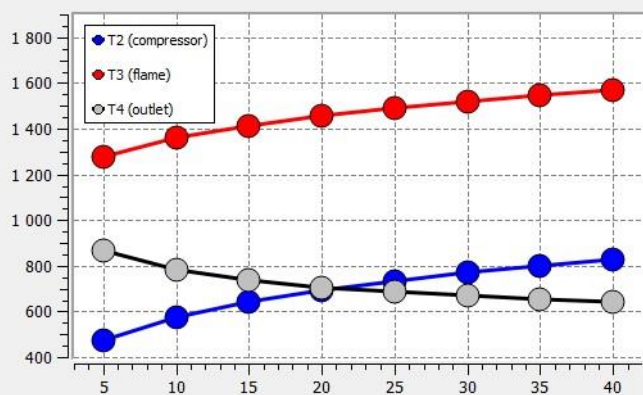
The figure shows the temperature of the gas before the combustion chamber **T2**, before the turbine blades **T3** and the turbine outlet **T4**. These parameters may be used in the selection of operating modes, and for calculating parameters necessary for hydrodynamic simulation.

In contrast to the classical formulas, calculation on Chemical Workbench gives a nonconstant value efficiency - due to the fact that the program automatically takes into account the nonideal gas effects.

Conclusions

On the example of the gas turbine simulation the possibilities of the software package **Chemical Workbench** for the calculation of thermodynamic cycles and finding the characteristics of the installation are demonstrated.

Advantages of **Chemical Workbench** in simulation of systems lies in the fact that the complex multi-step process presented as a sequence of simple reactors. All necessary information is passed between the reactors themselves. In addition, the thermodynamic parameters of materials, including their temperature dependence are automatically loaded from the built-in database.

The described approach to modeling gas turbines can be applied for a wide range of processes and installations using combustion to generate energy.