Complex of virtual works on Thermodynamics. Section «Processes of ideal gases and humid air»

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Abstract. Two virtual laboratory works are presented in the developed complex: “Measurement of the heat capacity of air” and “Processes in moist air” performed in the Excel 2010 spreadsheet. The works are devoted to the study of processes in ideal gases, in particular in humid air, and are virtual analogues of physical work, on existing stands in the laboratory of technical thermodynamics of the Department of Theoretical Foundations of Heat Engineering MPEI, corresponding to the bachelor's program in the disciplines "Thermodynamics" and "Technical Thermodynamics". The presented material is intended to be included in the educational process in case of repair of existing laboratory stands, as well as for distance learning of students

1. Introduction
The presented material contains two virtual laboratory works that are analogues of physical work performed at the stands in the laboratory of technical thermodynamics under the undergraduate programs in the areas of "Thermoelectric and heat engineering" (03/13/01), "Power engineering" (03/13/03).

The purpose of the development is the replacement of physical work for the period of repair in case of failure, as well as for distance learning.

To build programs, along with the Excel 2010 spreadsheet, we used property calculations in the Mathematica-8 software package, which provide polynomial dependencies for tabular reference data [1,2] recommended for students in the training course. Schemes and other graphic constructions are made using available graphic editors (Paint, Photoshop). The software products are installed on computers with a configuration that allows the use of the Office 2010 - 2016 software package installed previously. Table cells not filled by students are protected from changes. Access to external connections to computers is password protected.

2. Laboratory work no.4 «Determination of isobar heat capacity and thermodynamics properties of air»
Measurement of the isobaric heat capacity of air is carried out on an existing bench using the flow calorimeter method [2,3]. The experimental setup is shown in figure 1.
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Figure 1. Schematic of an experimental setup for measuring the isobaric heat capacity of air

Atmospheric air is pumped through a flow calorimeter by a vacuum pump. In the calorimeter, heat equal to the electric power of the heater is supplied to the air flow. The labyrinth device of the calorimeter provides almost complete absorption of the supplied heat by the air flow. Measured values are: voltage drop across the heater, heater current, temperature at the inlet to the calorimeter, temperature at the outlet of the calorimeter, air volumetric flow rate, as well as the temperature of the “wet” thermocouple. The isobaric heat capacity of atmospheric air is calculated as:

\[ c_p = \frac{Q_t}{m(t_2 - t_1)} \]

\[ Q_t = U \cdot I \]

\[ m_t = \frac{p \cdot V_{T1}}{R_{wet} T_1} \]

\[ R_{wet} = \frac{(R_{air} + R_{water} d)}{1 + d} \]

where \( V_t \) – volumetric air flow at the inlet to the calorimeter, \( m \) – mass flow, \( R_{wet} \) – wet gas constant, \( R_{air} \) – dry air gas constant, \( R_{water} \) – water steam gas constant, \( d \) – moisture content.

In virtual work, the voltage on the heater (U) and volumetric flow rate (V) are set according to an empirical formula depending on the group number and the number of the team performing the work. Heater current is calculated as a function of resistance and voltage. Temperature \( T_1 \) and \( T_3 \) - are measured by a psychrometer, and atmospheric pressure - by a barometer located in the computer class (real values). Of these, the moisture content \( d \) is determined by the \( h-d \) diagram. The heat capacity of moist air is calculated in the Excel 2010 spreadsheet as a function of temperature and the gas constant of moist air according to the equation obtained when describing the dependence on these values in the Mathematica software environment 8. As a result, the last calculated value in the program is the temperature at the exit of the calorimeter \( T_2 \). The whole calculation mechanism is in hidden cells, and cells with formulas and the necessary information for the protocol are protected. The cells available for change are highlighted in light green. The working interface of the program is shown in figure 2.
3. Laboratory work no.8 «Process study in humid air»

The laboratory work interface is performed on two sheets. The first sheet shows the experimental setup scheme, the specification for the scheme, instructions on the order of the work and the data of the students involved in its implementation (study group, team). On the second sheet - a working table of the experience.

The experimental data obtained in a virtual experiment correspond to the results of measurements in work on a physical experimental setup. The essence of the work is to measure the state parameters in various points of a flow dryer. The layout of the experimental setup is shown in figure 3.

The air from the room with the temperature measured by thermocouple 4 and passing through the flow meter 6, enters the heater 1, where it is heated by an electric heater 3. The temperature of the hot air is measured by the thermocouple 8. Next, the hot air enters the drying chamber 2, where the wick
element 11 wetted by water is drained from the reservoir 9. During the drying process, the vaporized vapor increases the moisture content of the air, and its temperature decreases. The temperature at the outlet of the drying chamber is measured by a thermocouple 12, and its relative humidity is measured by a humidity sensor 13. All data on the states during the drying process are sequentially displayed on the display of the eight-channel meter-controller OVEN of TRM-138.

The data for modeling processes in humid air are described by polynomial equations in Mathematica 8. For the description, information from the psychometric table, as well as data from the h-d diagram of moist air, are used. The voltage drop, the current in the heater coil circuit, which determines the supplied heat flux, as well as the volumetric air flow rate, are given by the empirical formula by the number of the brigade and group. Cells of the spreadsheet with the program being executed are hidden, and cells with readings that simulate the results of measurements are protected and highlighted in yellow. Cells for filling by students are highlighted with green color filling. Students receive data on atmospheric pressure, inlet temperature, and the temperature of the “wet” thermometer (4) using instruments installed in a computer class. The interface of the working table is presented in figure 4.

| No measurement | Measured value | Instrument readings |
|---------------|---------------|---------------------|
| 1             | $t_{dry}$ °C  | 20.0                |
| 2             | $t_{wet}$ °C  | 18.0                |
| 3             | $V\tau$ m$^3$/h | 8.00               |
| 4             | $t_{in}$ °C   | 93.1                |
| 5             | $t_{out}$ °C  | 45.4                |
| 6             | $\varphi_{out}$ % | 39.00            |
| 7             | I$_{heat}$ A   | 2.08                |
| 8             | U$_{heat}$ B   | 101.0               |

**Figure 4. Worksheet "Study of processes in moist air"**

Based on the measurement results, students enter the states and lines of processes at the nodal points in the distribution form of the h-d diagram attached to the work report. An example of an h-d diagram with applied processes is shown in figure 5.
4. Conclusion

Using the described virtual laboratory work allows you to successfully replace the physical work performed on the stands in the laboratory of technical thermodynamics in case of failure, repair, as well as for distance learning. Using an accessible Excel environment does not require the installation of special licensed software. In the future, it is planned to improve virtual laboratory work and add animation of physical processes for a more visual demonstration.

References

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