Calculations of Thermodynamic Cycles via Internet

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Abstract—Information is provided regarding a website where calculations of thermodynamic cycles can be carried out in an interactive mode.

At present, we are witnessing a growing number of informational projects being implemented, as they used to say, on a voluntary basis, i.e., not on the basis of specially earmarked budgetary or private money (investments), but at the expense of the resources of an informal team of scientists and researchers.[1]

One salient example of such a project is the Wikipedia e-portal, an interactive network encyclopedia, the website of which (www.wikipedia.org) is organized so that any visitor can edit and extend existing articles and create new ones. The newly created information is then subjected to scientific editing and sometimes even censorship, e.g., to make it politically correct. A team of enthusiastic specialists, who work on the same voluntary basis, carry out these activities. With interaction organized in this way, it is relatively simple to automate routine work, such as making page layouts, proofreading, making illustrations, and programming calculations, thus opening the field for free creative work of an informal team of specialists, the composition of which changes continuously.

Many analysts believe that such open budgetless projects will have an increasingly important influence on the vector along which the world's economy develops, at least as regards information technologies, which are among its rapidly developing branches [1–3].

One example of such a project is the website http://twt.mpei.ac.ru/TTHB/2/ThermCycle.html, an e-portal for calculating the thermodynamic cycles of thermal power installations [4]. The following factors helped bring it about.

(1) The use of mathematical packages, such as Mathcad, Matlab, Mathematica, Maple, and others, which came to take the place of programming languages, enabled engineers specializing in thermal power engineering to solve problems in a quick and efficient manner without the need to resort to the aid of third-party programmers, who very seldom work on a voluntary basis [5].

(2) Specialized sets of functions have become available that can be connected to mathematical programs to return the properties of working fluids used in thermodynamic cycles. The computer program WaterSteamPro (www.wsp.ru) [6, 7] is an example of such functional sets.

(3) Calculations carried out in an environment of mathematical computer programs with connected functions for the properties of working fluids and heat carriers can now be done interactively on the Internet. For example, the Mathcad Calculation Server serves as such a network publisher of the Mathcad package.

All these factors have enabled specialists who work in the field of carrying out calculations of thermodynamic cycles and optimizing them to promptly publish them on the site and make them open for different purposes, which may include their being analyzed and criticized, corrected for removing assumptions, extended for a wider range of applications, etc.

The website with calculations of thermodynamic cycles is connected with another one, http://twt.mpei.ac.ru/ochkov/WSPHB, a site on the properties of working fluids and heat carriers in power engineering, which was also created on a voluntary basis. If the numerical value of a certain property of working fluid and heat carrier used in power engineering has to be determined in the course of a thermal engineering calculation, the user can open a handbook from which the answer can be obtained either immediately or after some interpolation of tabulated data. However, it is also possible to access the appropriate site via the Internet and receive an answer, not only as a numerical value with the chosen unit of measurement, but also in graphical form as a family of curves or a surface on which the calculated point, isobars, isotherms, and other curves can be highlighted. In addition, the range in which combinations of input parameters are available on the site is much wider than that available on paper printouts. Handbooks usually give pressure and temperature as

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[1] The publication of scientific–technical books and journals the fee for which is the last thing the authors think of should be regarded as a sort of scientific project carried out on a voluntary basis. Most editorial offices in Russia and abroad pay symbolic fees or do not pay them at all. Many journals are published in online form, the use of which also helps reduce the cost of such projects.
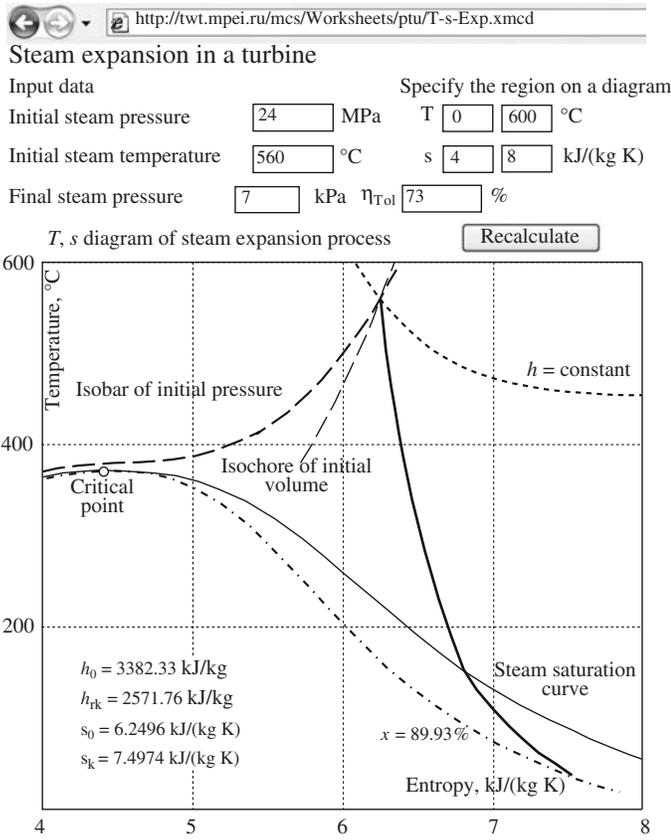
Fig. 1. Calculation and graphic representation of the steam expansion process in a turbine.

Fig. 2. Optimization of a steam turbine cycle with two extractions.

input parameters, whereas the tools available on the site allow other pairs of input quantities to be specified: pressure and enthalpy, temperature and entropy, enthalpy and entropy, and so on. A user working on the site can enter input data not only as discrete values, as in the tables of handbooks, but as any value from a permissible range. Appropriate functions can also be copied from the Internet for embedding them into the programming environment in which a user or programmer is working.

Figure 1 shows one page of the site located at http://twt.mpei.ac.ru/mcs/Worksheets/ptu/T-s-Exp.xmcd, on which the steam expansion process in a turbine is calculated and depicted on the T, s diagram.[2] The pressure and temperature of steam at the initial point, the pressure at the final point, and the relative internal efficiency of the steam turbine are used as initial parameters for this calculation. In addition, the user specifies the region of the T, s diagram in which the process will be depicted. The parameters of steam at the initial and

final points of the expansion process and the appropriate curves characterizing this process are displayed as a result of calculation on the site. Unlike diagrams printed out on paper, those displayed on the site are not crowded with "extra" isobars, isochores, or other curves, so that they are easier to read. The obtained figures (diagrams) can be easily transferred into another document, for example, a report on the calculation of any thermal power installation.

The software packages mentioned above and, in particular, Mathcad, contain powerful tools for solving standard mathematical problems, such as finding roots of equations, solving optimization tasks, displaying functional dependences in graphic form, and many other things. Figure 2 shows the page of this site with a calculation in which all these tools are used. A standard thermal engineering problem of optimizing a steam turbine cycle is solved here: the parameters of steam extractions to two direct-contact heaters at which the maximum thermal efficiency of the cycle is achieved need to be determined. The solution of this problem involves the following operations: the roots of a system of equations describing the balance of flowrates and energies of the working fluids used in the heaters of the "internal cogeneration system" are analytically deter-

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[2] References are available on the site to calculated network documents that show processes in other systems of coordinates, such as h, s, p, s, T, h diagrams, and others. Network calculations are also available that allow processes to be displayed on 3D diagrams, e.g., an h, s, p diagram.
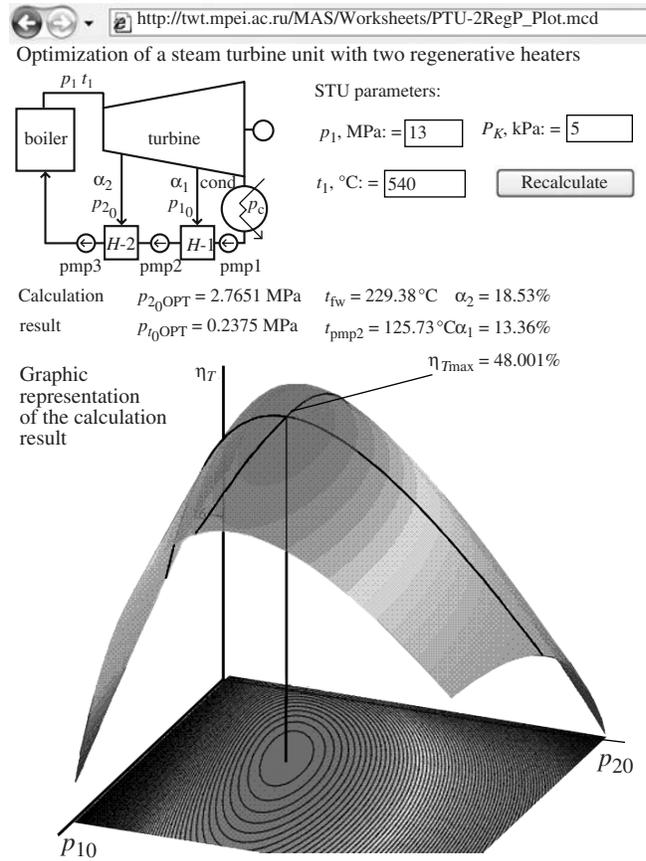
http://twt.mpei.ac.ru/MCS/Worksheets/PTU/VOL-13.xmcd

Calculation of fuel savings at a GTU-based cogeneration station as compared with separate production of heat and electricity

Working fluid [air]

t_3 [1100] °C p_1 [0.1] MPa

t_1 [15] °C p_2 [1] MPa

Relative int. efficiency of the compressor [85] %

Relative efficiency of the gas turbine [86] %

Regeneration ratio [0.5]

Separate production of electricity and heat using a GTU and HWB house

Combined production of electricity and heat at a GTU-based cogeneration station

Temperature difference at the outlet of flue gases from the cogeneration heater [50] K

Temperature of water at the inlet to the cogeneration heater [60] °C

Efficiency of the GTU combustion chamber [98] %

Efficiency of the cogeneration heater [85] %

Efficiency of the hot-water boiler house [85] %

Cycle of the GTU-based cogeneration station

[Recalculate]

Legend:
- - - - Ideal GTU cycle
—— Real GTU cycle
◆ Air upstream of the compressor
● Air downstream of the compressor
□ Air downstream of the regenerator
◇ Gas upstream of the turbine
○ Gas downstream of the turbine
△ Gas downstream of the regenerator
■ Gas downstream of the regenerative heater

T, °C (vertical axis: 120 to 1200)
S, kJ/(kg K) (horizontal axis: 6.8 to 8)

GTU efficiency for electricity production without a cogeneration heater = 37.151%

Efficiency of the GTU-based cogeneration station for electricity production = 73%

Specific consumption of standard fuel for the production of electricity at the GTU-based cogeneration station = 168.258 g/(kW h)

Specific consumption of standard fuel for the production of heat at the GTU-based cogeneration station = 40.961 kg/GJ

Specific consumption of standard fuel for the production of electricity at the GTU without a cogeneration heater = 330.639 g/(kW h)

Specific consumption of standard fuel for the production of heat at the hot-water boiler house = 40.142 kg/GJ

Saving of standard fuel for the production of electricity at the GTU-based cogeneration station as compared with the GTU without a cogeneration heater = 45.106 kg/GJ
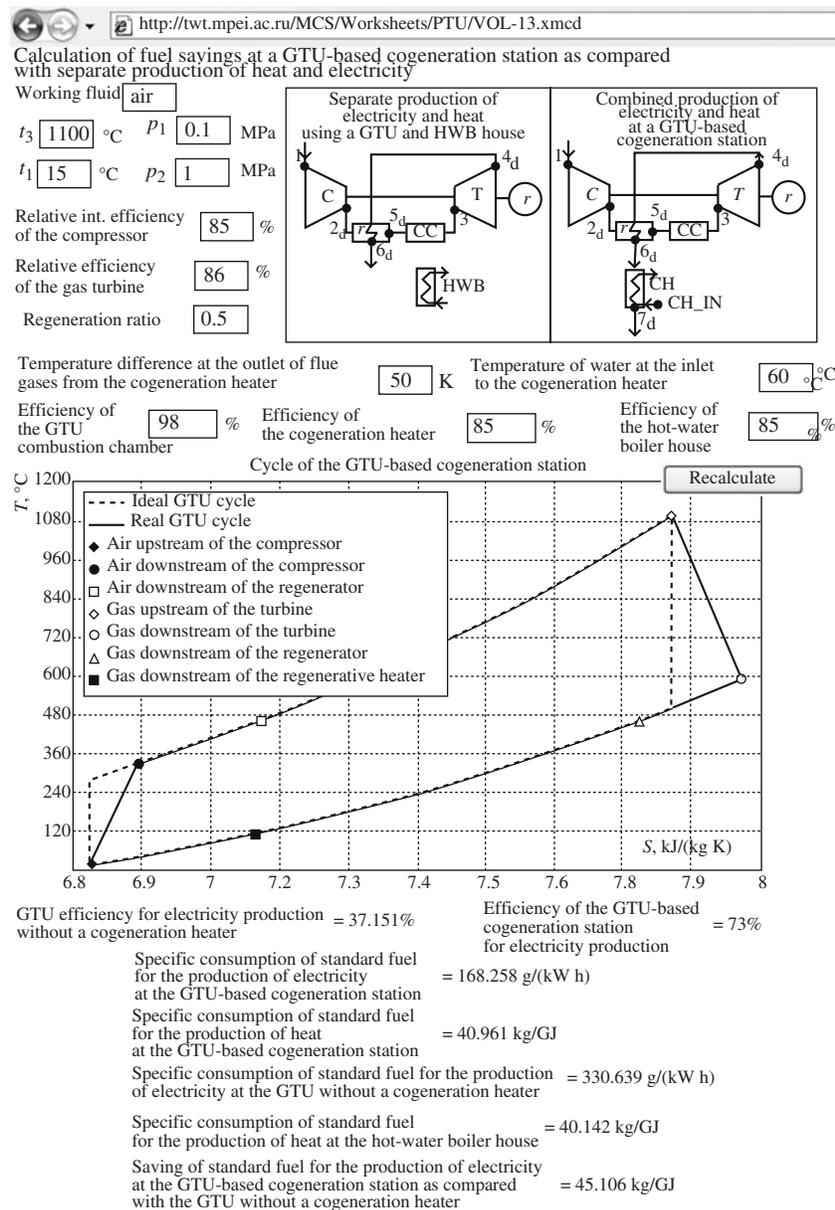
Fig. 3. Calculation and comparison of two power supply arrangements.

mined, the parameters of the cycle are optimized, and an answer is generated not only in numerical form, but also in the form of curves and points on a 3D graph depicting a surface and curves corresponding to certain levels. Once a site visitor changes the input data (the pressure and temperature of live steam or the pressure in the condenser) and clicks on the Recalculate button, the optimal point will shift to a new location.

The site page shown in Fig. 3 depicts calculations on two thermal power facilities at once, thus making it possible to compare two solutions for supplying heat and electricity. In particular, the saving of fuel as a result of shifting from separate to combined production of heat and electricity (from the use of a gas turbine and a hot-water boiler house to the use of a gas turbine operating jointly with a heat-recovery boiler). Different processes and cycles can also be calculated at this site.

(1) *Cycles*: Carnot, Otto, Diesel, Miller, Trinkler, and Stirling's.

(2) *Gas turbine cycles*: A gas turbine unit (GTU) (construction of diagrams and calculation of thermal efficiency); calculations of a GTU's effective efficiency, a real gas turbine unit, the efficiency of a GTU with regeneration, the efficiency of a GTU with regeneration and two-stage air compression, a GTU with two-stage expansion of gases and regeneration, and a steam-injection gas turbine.

(3) *Steam turbine cycles at thermal power stations*:

carrying out calculations of the following processes:

isentropic expansion of steam,

steam throttling,

throttling of steam from a two-phase region,

Rankine cycles with 2D and 3D diagrams,

the cycle of a steam turbine unit (STU) with reheating

the cycle of an STU with two reheating stages;

optimizing the STU cycle with two reheating stages;

the cycle of an STU:

with a regenerative steam extraction,

with two regenerative steam extractions;

assessing the effect the reheat pressure has on the efficiency of the STU cycle;

optimizing the STU cycle with two regenerative steam extractions (see Fig. 2);

carrying out calculations of steam expansion processes in different turbines:

K-300-240 and

K-200-130.

(4) *Steam turbine cycles at nuclear power stations*:

Rankine's cycle with saturated steam,

Rankine's actual cycle with saturated steam,

calculating the thermal circuit of a steam-turbine unit at a nuclear power station equipped with RBMK-1000 reactors.

(5) *Steam turbine cycles at cogeneration stations*:

calculating specific consumption of standard fuel in the cogeneration mode using an R-type turbine;

determining specific savings of standard fuel:

in the cogeneration mode using an R-type turbine as compared with separate production of heat and electricity,

in the cogeneration mode using an R-type turbine as compared with separate production of heat and electricity (a condensing turbine incorporates regenerative heating of feedwater),

in the cogeneration mode using an R-type turbine as compared with separate production of heat and electricity (a condensing turbine incorporates reheating and regenerative heating of feedwater);

determining the consumption of standard fuel at cogeneration stations equipped with PT and T turbines, PT turbines as compared with separate production of

heat and electricity, and T turbines as compared with separate production of heat and electricity; and

determining the saving of standard fuel in case of using a GTU-based cogeneration station as compared with separate production of heat and electricity.

(6) *Calculation of binary cycles*:

the simplest one,

with reheating of gases in a gas turbine,

with a high-pressure heat recovery boiler,

and others.

This work on creating a site for calculating thermodynamic cycles commenced on a voluntary basis (see above), but at present it is part of an innovation program (http://inedu.mpei.ru) conducted by MEI researchers (www.mpei.ru) for the development of the Electronic Encyclopedia of Power Engineering ([1], www.trie.ru).

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