INVESTIGATIONS OF HEAT ENGINES CYCLES WITH THE HELP OF MODERN INFORMATION TECHNOLOGIES

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On the base of mathematical simulation, with the use of Mathcad Calculation Server technology the examples of investigations of some cycles of heat pumps are given in the work.

Keywords: information technologies, Mathcad Calculation Server, heat pump cycles, simulation

Introduction

Results of investigations and analysis of cycles of heat engines are widely spread and can be found in specialized literature and other sources. But such sources as a rule are not always easily accessible and they often give only partial information. Moreover further studies are still in progress because of additional conditions, new applications, new types of heat engines, etc.

Mathematical simulation is a quite powerful instrument for investigations in thermal power engineering. But if even a simulation program is created it is often quite expensive and as a rule it is very difficult to understand or to see calculation methods.

Due to wide use of mathematical packages, such as Mathcad, Matlab, Mathematica, Maple, and others, which came to take place of programming languages, engineers specializing in thermal power engineering can solve problems in a quick and efficient manner without the need to resort to the aid of third-party programmers.

The first place in the list of the most important “IT-revolutions” belongs to development of so-called “cloud computing” – providing of remote computing ability, footprint (“clouds”) and communication channels for customers. The reason which begets using of “cloud computing” is high cost for program licenses for detached workstations, rent of space, electricity and control of software piracy. By “clouds” we mean computing centers which are significantly more powerful than user’s stationary infrastructure. Instead of physical servers customers use virtual servers which are spread in allocated net of computers with industrial ability.

Specialists of Moscow Power Engineering Institute (Technical University) with participation of research workers of other organizations have created a website located at www.vpu.ru/mas which can be useful for all who need to determine properties of working fluids or heat carriers and mathematical simulations or visualization of processes in power engineering [1 - 3].

1. Task setting

Therefore the given paper on example of heat pumps (HP) cycles provides information regarding investigation and analysis of such cycles via the website http://twt.mpei.ru/ochkov/VPU_Book_New/mas/index.html in an interactive mode.

In [1, 2] there are results of optimizing investigation of exemplary thermodynamics cycles of some schemes of gas turbine power plant and gas-steam combined power plant with the purpose of increasing inner efficiency which were made on the base of the presented IT.

2. Presentation of the main material

Figure 1 shows the page of the website http://twt.mpei.ru/ochkov/VPU_Book_New/mas/index.html where a user can see a list of types of power units which can be numerically investigated in an interactive mode.

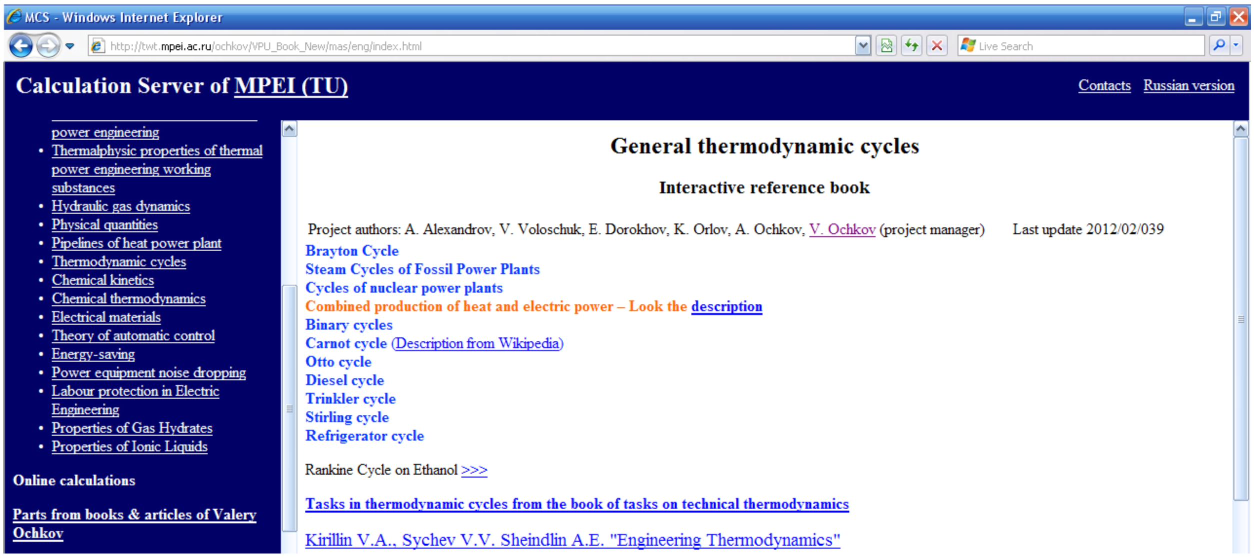

Fig. 1: Fragment from a website http://twt.mpei.ru/ochkov/VPU_Book_New/mas/index.html where it is possible to do numerical investigation of thermodynamic cycles of power units in an interactive mode

An example of input data block for one of the HP cycle which is prepared according to the technology of Mathcad Calculation Server – technology which allows to post Mathcad worksheets in Internet so that a user can fill in interactive math calculation forms without having to know or own Mathcad – is shown in Figure 2.

Therefore, a user of the site http://twt.mpei.ru/ochkov/VPU_Book_New/mas/index.html chooses a required source from the list, fills in input data which are located in special “live” cells, presses button “Recalculate” and receives calculated data about characteristics of the chosen thermodynamic cycle.

In the figure 3 an example of numerical simulation results made for a HP cycle with help of the given IT is presented (location at http://twt.mpei.ac.ru/MCS/Worksheets/PTU/Vv-29.xmcd). Moreover such technology gives a possibility to see calculations methods which were used for simulation (see figure 3).

So, filling in input data a user can receive a wide variety of final and intermediate calculation results. These results can be displayed graphically, in table, etc.

In the figure 4 we can see results of numerical simulation of influence of the temperature of low potential heat source and outlet heating temperature on the coefficient of perfomance of simple HP cycle (location at http://twt.mpei.ac.ru/MCS/Worksheets/PTU/Vv-27.xmcd).

Such dependences are widely spread in literature. But with the help of the introduced recourses it is possible to investigate a quite wide variety of input conditions (temperature of low potential heat source, outlet heating temperature, compressor efficiency, pressure losses etc.) and, for example, to determine numericcaly the most irreversibilities taking place in a HP cycles and so on.

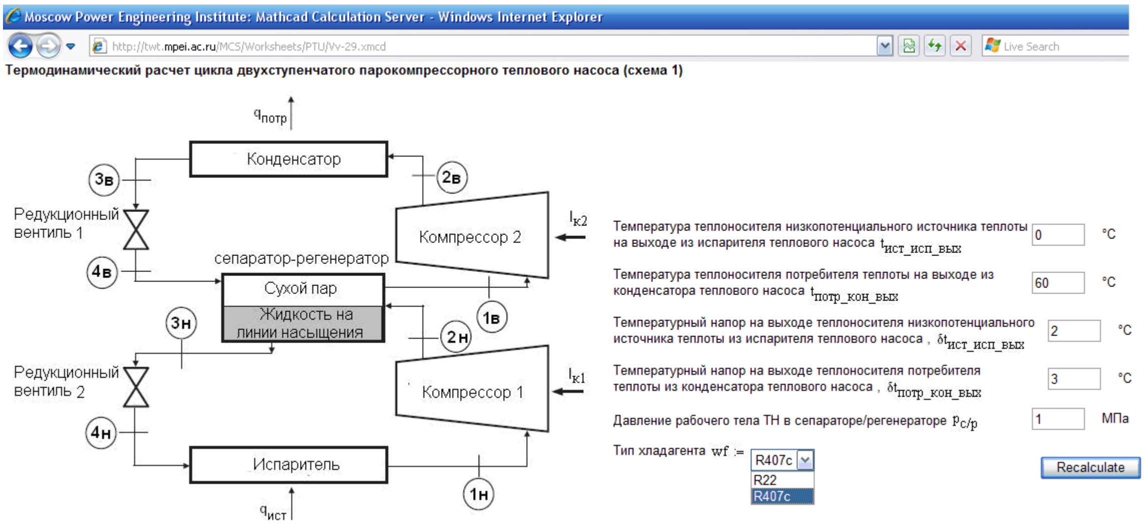

Fig. 2: Input data block prepared on technology of Mathcad Calculation Server for numerical simulation of HP cycle

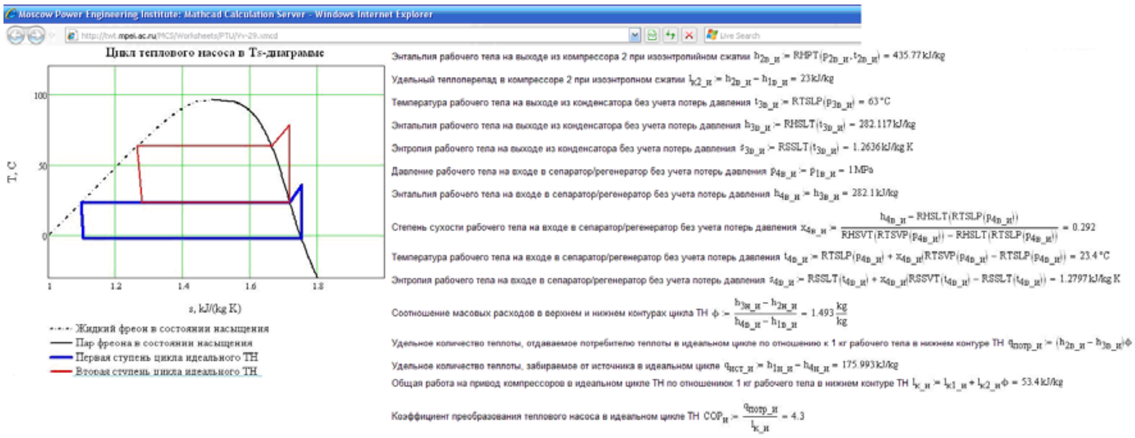

Fig. 3: An example of numerical simulation results made for a HP cycle

For the purpose to suit an application in a better way (including to get a higher COP but not always) some certain changes to the basic simple HP cycle are made. For example, HP cycles with internal heat exchanger (regenerator) or with multistage vapor compression can be recommended.

In the first type of HP cycle the specific enthalpy (and temperature) of the pre-expansion state are reduced and conversely the specific enthalpy (and temperature) of the pre-compression state are increased. These differences point out two intended benefits of this cycle modification. First, since the specific enthalpy remains constant during expansion, a reduction of the specific enthalpy prior to expansion results in a reduction of specific enthalpy prior to evaporation. Therefore the unit will have more evaporative heat transfer to provide more evaporator capacity. Second, the state prior to compression is further away from the saturated vapor line. For most compressors, it is imperative that the state of the refrigerant prior to compression does not have any liquid in the form of droplets or mist, since liquid entrained in a vapor undergoing compression tends to damage the fast moving parts of a compressor, seriously degrading the performance and working life span of the compressor. For this reason, it is usually desirable for the refrigerant to enter the compressor as a superheated vapor, several degrees above the saturation temperature at the pre-compression pressure. The internal heat exchanger, by increasing the enthalpy and temperature of the pre-compression refrigerant, assists in ensuring that a superheated vapor with no liquid droplets enters the compressor. In some cases, the internal heat exchanger (regenerator) will also serve to increase the COP of the cycle, but this depends on the refrigerant used.

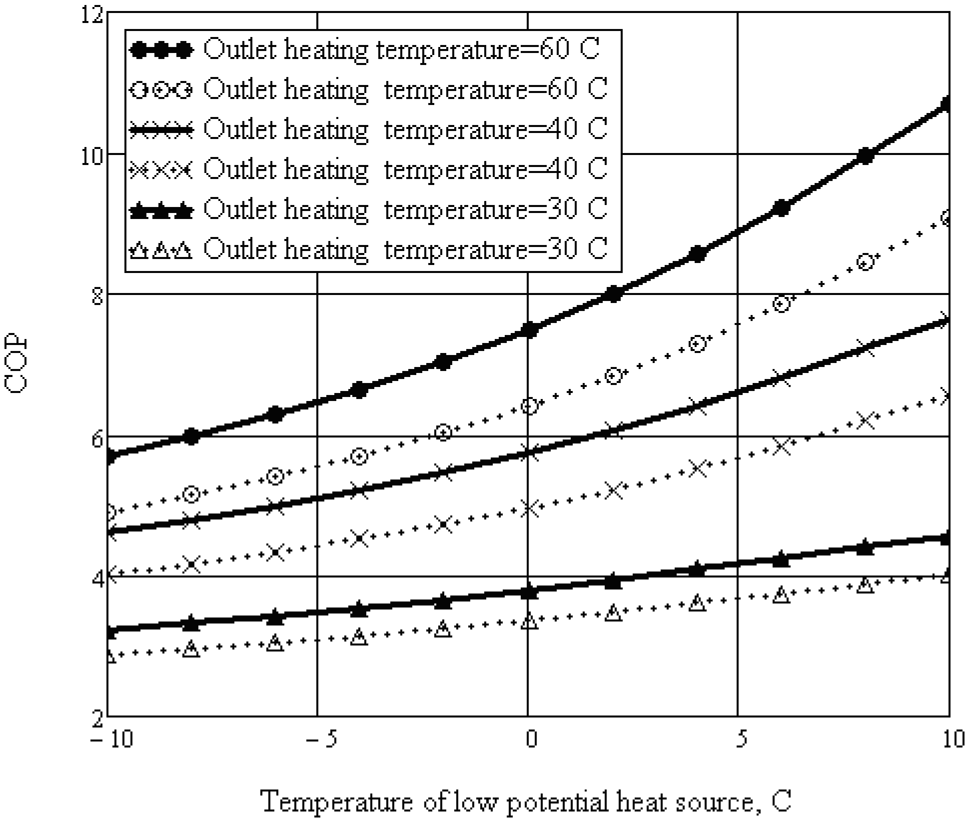

Fig. 4 Results of numerical simulation of influence of the temperature of low potential heat source and outlet heating temperature on the coefficient of perfomance of simple HP cycle: continuous lines – for ideal HP cycle; stroke lines – for actual HP cycle

Using of multistage vapor compression cycles is especially necessary when the pressure ratio between the heat rejection and heat absorption pressures is large (5 or more). Multistaging involves one or more intermediate pressures between the heat rejection and heat absorption pressures, and a series of compressors operating between successive pressure intervals. The primary benefit of a multistage compression cycle is the reduction in compressor work compared to that of a single stage compressor. Typically, the isentropic efficiency of most compressors used in refrigeration applications tends to decrease with increasing pressure ratio beyond a value of 3. So, for a high pressure ratio, the average isentropic efficiency for two successive compressors could be significantly higher than that of one compressor, reducing the total amount of work required.

One of the types of multi-compressor vapor compression HP cycle is the flash chamber/regenerative intercooling multistage vapor compression cycle. There are actually two sub-types. Both cycles involve compression of the same refrigerant in two or more stages; only two will be shown here for demonstration purposes. At the intermediate stage there is a flash chamber, into which the refrigerant expands from the condenser, and the saturated liquid and vapor at the intermediate pressure can be separated. The saturated liquid expands from the intermediate pressure to the evaporation pressure. These aspects are common to both subtypes.

One of the subtypes also includes a mixing chamber where saturated vapor from the flash chamber mixes with the vapor leaving the low pressure stage compressor. This vapor-mixing chamber acts as a regenerative intercooler since it cools the superheated vapor leaving the low-pressure stage compressor using lower temperature saturated refrigerant, mixing the two prior to the next stage of compression.

Typically, the intermediate pressure chosen for the flash chamber/regenerative intercooling multistage vapor compression cycles is the geometric mean of the evaporation and condensation pressures but not always.

In the other flash chamber/regenerative intercooling multistage subtype, there is no separate mixing chamber (see Figure 2). The flash chamber combines the fluid exiting the expansion device following the condenser with the vapor leaving the low pressure stage compressor into one two-phase mixture. From the flash chamber/regenerative intercooler (sometimes simply referred to as a flash intercooler), the saturated vapor is separated and enters the higher pressure stage compressor.

So, some results of numerical simulations of the presented HP cycles which were made with the help of introduced IT are given in figures 5 and 6.

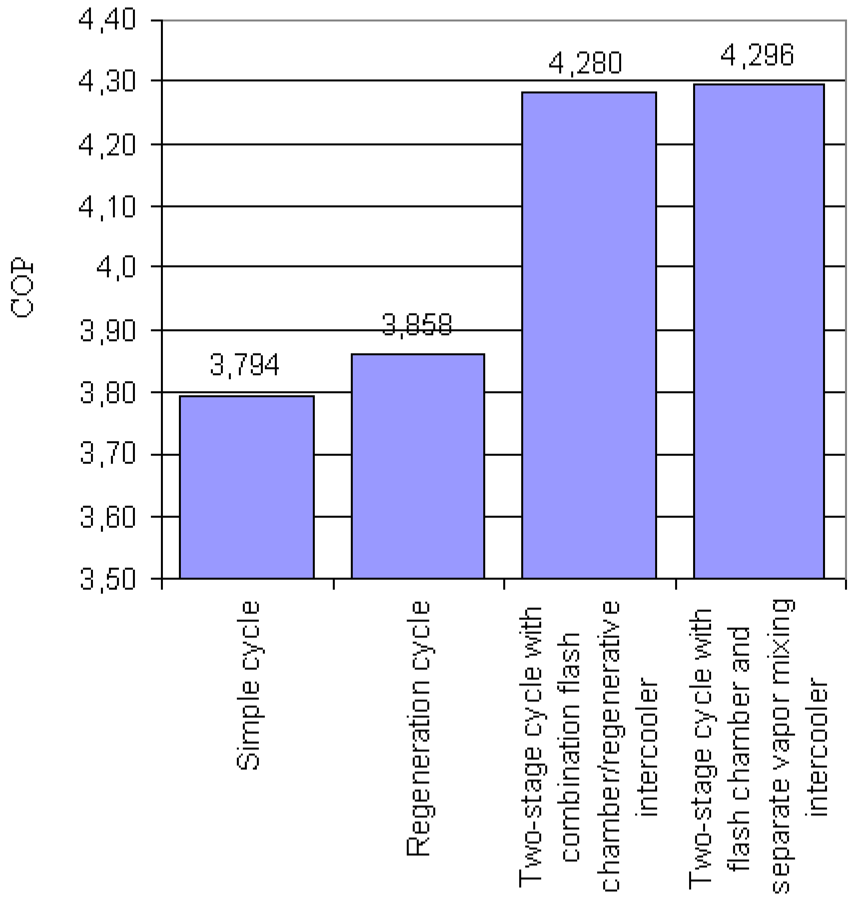

Fig. 5: Results of numerical simulations of influence of HP cycle type on the coefficient of perfomance

It is shown in figure 5 that for the same input conditions using internal heat exchanger (regenerator) or two-stage vapor compression in HP cycle gives some increasing of COP in comparison with simple HP cycle. At the same time it can be seen that two-stage vapor compression HP cycle results higher COP increasing than regeneration HP cycle.

Figure 6 shows the results of numerical simulations of influence of intermediate pressure in the flash chamber/regenerative intercooling on COP of HP. It can be seen that there is an optimum intermediate pressure for which COP of two-stage vapor compression HP cycle has the highest value.

As a rule heat pumps units are not dimensioned for managing the total heating needs. Some part of heating needs, the so-called peak heat load, usually constitutes of alternative solutions (an electrical cartridge, a boiler, and other peak load heaters). The peak load for heating occurs under very cold conditions and only for a limited time of the year – usually during short and very cold spells (see figure 7).

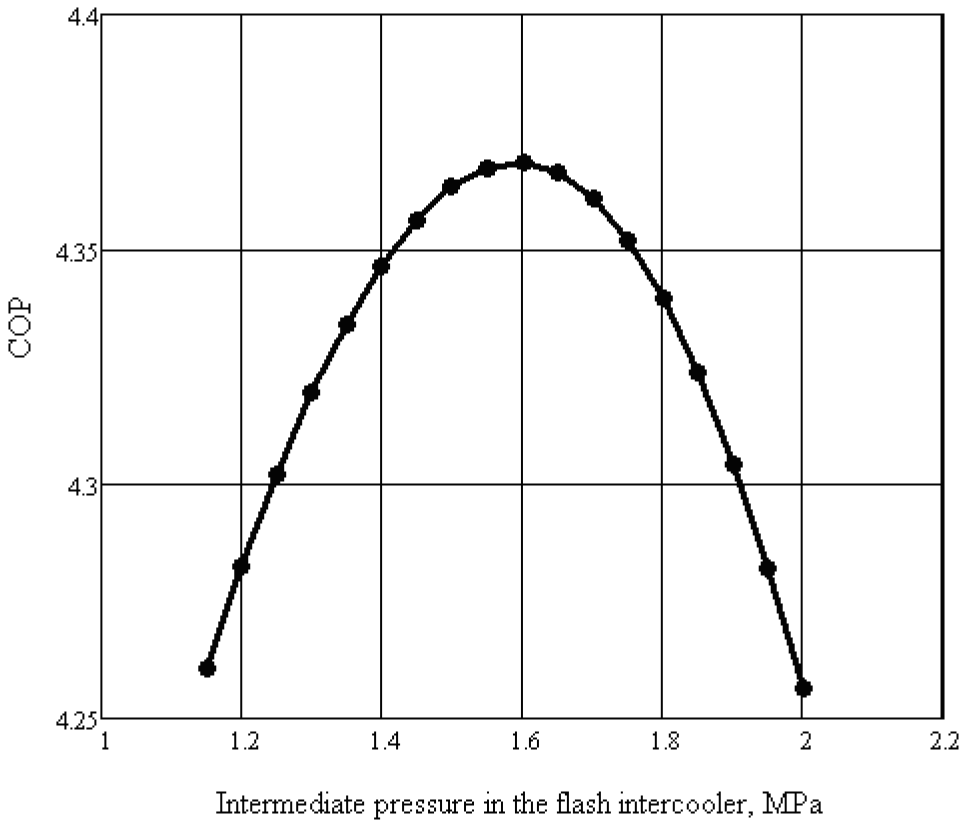

Fig. 6: Dependence of COP of two-stage vapor compression HP cycle on intermediate pressure in the flash chamber/regenerative intercooling

A distribution between base or HP load and peak load heater must be made for economic reasons. The task to determine HP heating coverage and alternative peak load heating coverage is an optimization task in which a wide variety of influence factors should be taken into account (climate conditions, technological parameters, prices etc.).

In the figure 8 there are two examples of determining rate of HP load made on the base of techno-economic optimization with the help of the webpage http://twt.mpei.ac.ru/MCS/Worksheets/PTU/Vv-31.xmcd.

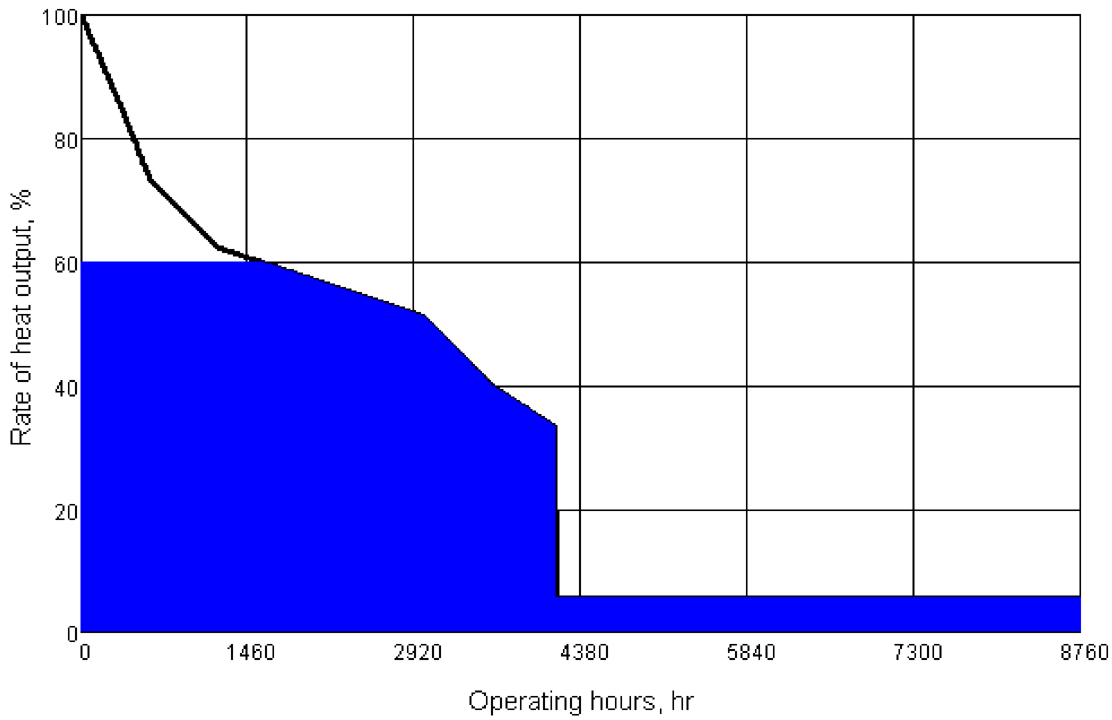

Fig. 7: Example of distribution between base and peak heating load

So, we can see two cases which differ from each other by climate conditions, technological parameters and prices. In case 1 the optimum rate of HP load is about 60 % because within this rate Net Present Value is the highest and Payback period is the lowest. In case 2 the optimum rate of heat pump load is about 40…50 % .

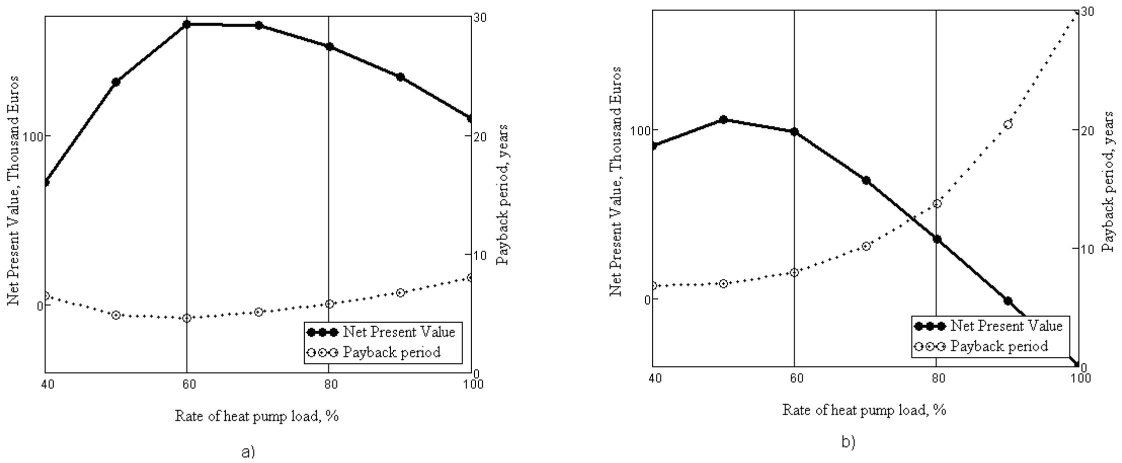

Fig. 8: Dependence of Net Present Value and Payback period on HP rate coverage received with the help of the introduced IT (location at http://twt.mpei.ac.ru/MCS/Worksheets/PTU/Vv-31.xmcd):
a) – case 1; b) – case 2

Conclusion

Using a mathematical package Mathcad for which a network publisher is Mathcad Calculation Server allowed to create a website http://twt.mpei.ru/ochkov/VPU_Book_New/mas/index.html that made possible to do interactively calculations of thermodynamics cycles of thermal power installation.

On example of heat pumps it was shown that with the help of such Internet resources a wide variety of tasks can be solved in an interactive mode with a possibility to change input data.

The website http://twt.mpei.ru/ochkov/VPU_Book_New/mas/index.html is open for different purposes, which may include it being analyzed and criticized, corrected for removing assumptions, extended for a wider range of application, etc.

Literature

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