
REFERENCE DATA

Application of the Cloud Technologies to Perform Heat Engineering Calculations

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Abstract—The technology of heat-engineering calculations using the cloud functions by the properties of the working substances of energy cycles as well as the type of cloud formulas and instructions on their application (formulations) for the calculations.

Keywords: heat-engineering calculations, Mathcad, heat-engineering properties of working bodies, thermodynamic cycles

DOI: 10.1134/S0040601513090085

The heat-engineering calculations require the knowledge of not only thermal-physics properties of the working bodies (water and/or water vapor, air, smoke gases, etc.) [1–4] and the power engineering materials but also the formulas for calculations. These formulas with formulations are taken from various handbooks, for example, from [5], or from the Internet; they are transferred into the corresponding calculations. Such a work is not very convenient since it retards the fulfillment of computational projects and increases the risk of appearance of errors. In connection with this, as well as taking into account the fact that currently the computers of almost all specialists that fulfill the thermal technical and other engineering calculations have a constant and high-speed output onto the Internet, we developed a new operational technology with formulas, which will be illustrated by simple type examples in the medium of the Mathcad engineering office (calculator) [6], which is very popular among students, engineers, and scientific-and-technical workers.

The cloud operational technology with the formulas is the continuation of the approach presented in [4] and associated with using the functions stored on the Internet for the calculation of the working bodies of power engineering. Let us explain simply the operation with these functions.

When designing any heat-engineering object, after the introduction of the starting data into the calculation, there is a reference to the Mathcad-document on the Internet (in “clouds”) at the address [h://tw.tpmpei.ac.ru/TTHB/H2O.xmcdz](http://tw.tpmpei.ac.ru/TTHB/H2O.xmcdz). After it, all the functions defined in the document, onto which the reference is done, become visible in the working document. This is not only the functions that return the thermal physical properties of water and the water

vapor such as specific enthalpy h , specific entropy s , temperature T , degree of dryness x , etc. [1], but also the functions that return the parameters of certain heat-engineering processes (throttling in the controlling valve or the vapor expansion in the vapor turbine), namely, the values of the specific enthalpy and the degree of vapor dryness in the end of these processes. The names of these two functions have a root in the name EXPANSIONPTPEFF:¹ expansion is the spread, PT is the vapor pressure in the initial point, P is the vapor pressure in the final point, and EFF (efficiency) is the internal process efficiency.

Such an approach is the alternative to using the specialized software means for the calculation of the properties of the working substances [7], for the operation with which, the program itself should be downloaded and implemented on the computer. When using the cloud functions, the necessity of the separate download and establishment of such programs is absent. A large plus is also the possibility of the operative renovation of the functions—the user always deals with only the latest version of the calculation.

Among the disadvantages of the cloud functions, the necessity of access to the Internet when performing the calculations should be mentioned. In this case, the exit can be the “transparent” passage to usual programs. For example, in the absence of access to the Internet, program [7] can be downloaded and the examples, which are presented in this article, will be in action. This is provided by identical names and argu-

¹ The names of all the functions have the prefix *wsp*. This is the abbreviation of the WaterSteamPro program, which can be downloaded from the www.wsp.ru site. The cloud functions, which are described in this article, are the small part of the WaterSteamPro package.

ments of the functions for the calculation of the properties of the working bodies.

The use of cloud technologies for the formulas and sets of formulas gives the user access to ready calculations, which he can use directly in his developments, and which are the solutions of concrete problems. In this article we will show several examples of such cloud calculations.

Example 1. Throttling processes of the steam in the controlling valve and its subsequent expansion in a steam turbine should be calculated. It is also required to reflect these processes in (h, s -) diagrams and ($T-s$) diagrams of water and steam. This calculation in the Mathcad medium is shown in Fig. 1.

The first operators of the calculation shown in Fig. 1 are the starting data; namely; pressure p_1 and temperature T_1 of the fresh steam; the pressure to which the vapor is throttled; p_2 is the end pressure in the steam expansion in the turbine (the condenser pressure is p_3). In addition, the relative internal efficiencies of these processes $\eta_{in,rel}$. If the efficiency is 100%, this is the ideal process of steam expansion in the turbine at which the steam entropy is invariable. If this efficiency is 0%, this is the ideal steam throttling at which the enthalpy remains constant. During the actual throttling (for example, upon passing the steam over the steam pipe), the steam enthalpy somewhat decreases, which determines the internal relative throttling efficiency differing from zero (5% in the calculation shown in Fig. 1).

Having ready functions in hand we can easily and unmistakably calculate all the required parameters of the steam expansion and reflect it in diagrams, in which the lines of saturation in regards to water and water steam as well as the line of the constant steam dryness (humidity), are additionally shown. It is rather easy to construct all these lines in the plots taking into account the corresponding functions visible in the calculation: $wspHSST$ is the specific enthalpy of the saturated steam depending on temperature and $wspHSWT$ is the same for water on the saturation line. If we replace letter H by letter S in the names of these functions, they will give the specific entropies of water and steam on the saturation line. To construct the line of the constant vapor humidity, two functions are used, namely, $wspHSTX$ and $wspSSTX$, which return the specific enthalpy and specific entropy of the wet steam depending on its temperature and degree of dryness. The parametric plots are constructed in the $h-s$ diagram, namely, parameter T is specified (this region is hidden in Fig. 1 and in Fig. 2, it is opened) in a range from the critical point of water to its ternary point (these constants also become visible in the calculation after the above-described reference), and three pairs of functions of T .

We specified a very large pressure drop (24–10 MPa) to exhibit this process in diagrams (Fig. 1). At the actual heat-power stations, the pressure loss in the

steam line from a boiler to a turbine is about 5%. If we introduce p_2 smaller than p_1 by 5%, points 1 and 2 will merge into one.

In the $T-s$ diagram, the argument is denoted at axis y (the temperature), and the functions are denoted at axis x . In the last versions of Mathcad, multiplier $/^{\circ}C$ is introduced, which makes it possible using the Celsius scale on the plot axes (Fig. 2). As the default, the temperature is in the Kelvin scale (the second plot in Fig. 1).

Example 2. The pump raises the water pressure from value p_1 (the saturation line of water) to value p_2 with the internal relative process efficiency $\eta_{in,rel}$. Then, water is isobarically heated to the boiling point. It is necessary to determine the parameters of these processes and reflect them in the $T-h$ diagram.

Figure 2 shows this calculation using the cloud functions. It differs from the calculation presented in Fig. 1 by two details only. First, to calculate the process of increasing the pressure, function EXPANSIONPT-PXEFE rather than function $wspEXPANSIONPTPEFF$ is used, which has an additional argument x of the degree of dryness. It is 0 for water and 1 for the saturated vapor. Second, points 1, 2, and 3 in Fig. 1 were connected by straight lines. In Fig. 2, the lines that reflect the processes of increasing the pressure in the pump and heating water in the economizer are shown in the plot in another manner, namely, we generated the vectors of pressure v_p , specific enthalpy v_h , temperature v_T , and specific entropy v_s for processes 1–2 and 2–3 (Fig. 2). We should act as if the line in the diagram is not straight or close to it. The plots in Figs. 1 and 2 should be constructed in the same manner (throttling with the efficiency of 5%) as 2–3 (the steam expansion in a turbine with the internal relative process efficiency of 75%), but it is rather difficult to determine the shape of these lines since the efficiency can be different for various segments of the process. Line 2–3 in Fig. 2 is not a straight line. We can be convinced in this fact by expanding the diagram region. Therefore, to construct this line, the vectors were required. The same was made with line 1–2.

The $T-h$ diagram rather than the $h-s$ or $T-s$ diagram was plotted in Fig. 2. The $T-h$ diagrams are rarely used to illustrate the steam-turbine cycles; however, it is used here for the following reason. Currently, heat engineering students, who are enthusiastic about computers, have begun to construct not only the conventional diagrams of heat-turbine cycles ($h-s$ and $T-s$ diagrams, Fig. 1) but also the three-dimensional volume diagrams, for example, $h-T-s$ diagrams [8]. Two planes of this volume diagram are shown in Fig. 1a, and the third one is shown in Fig. 2. Looking at it, we can erroneously assume that the process of increasing the water pressure should be imposed on the two-phase region, which should be arranged to the right of the saturated water line, but this is not the case. This region reflects two segments of the thermodynamic

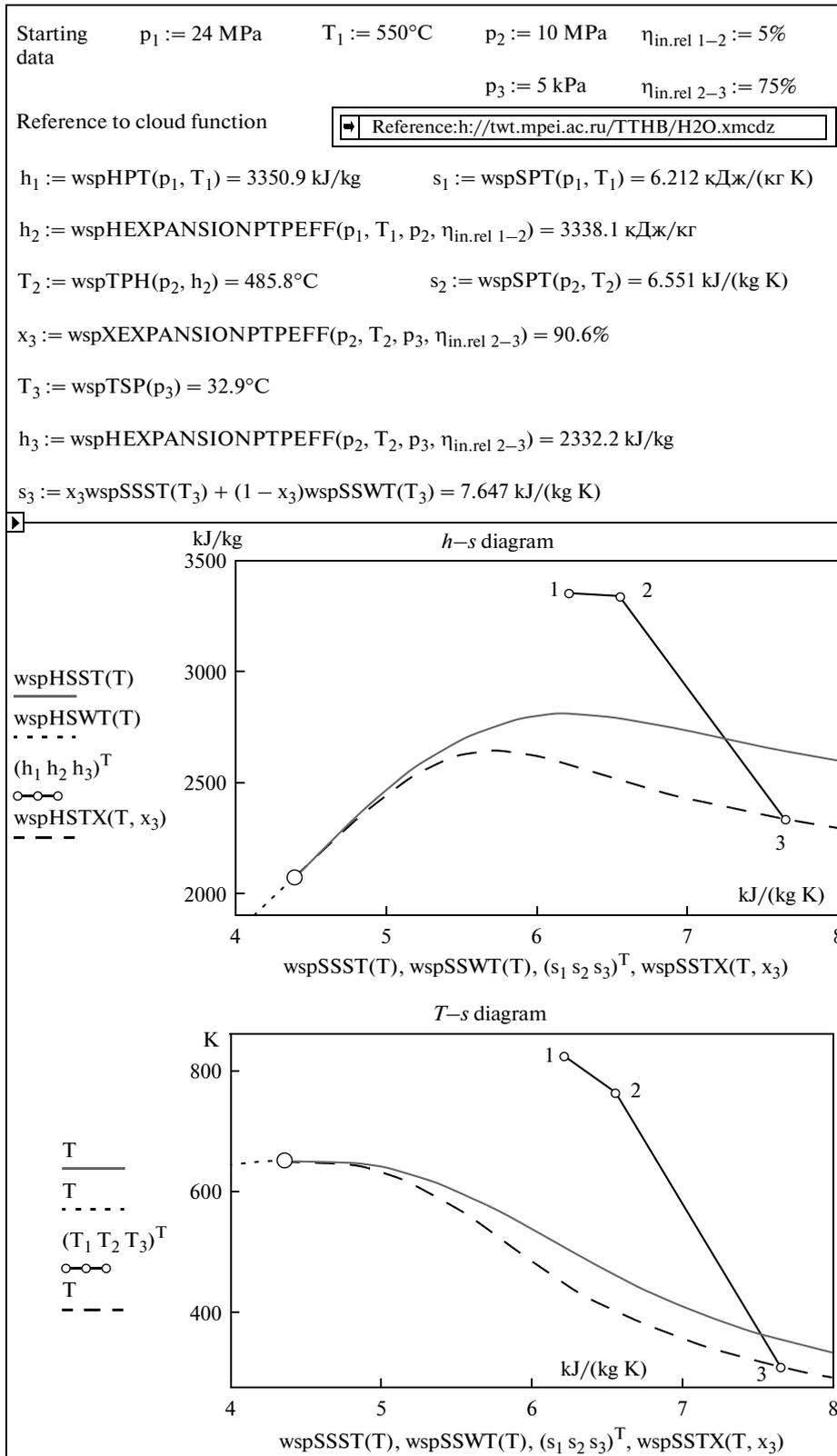


Fig. 1. Calculation of throttling and steam expansion in the turbine.

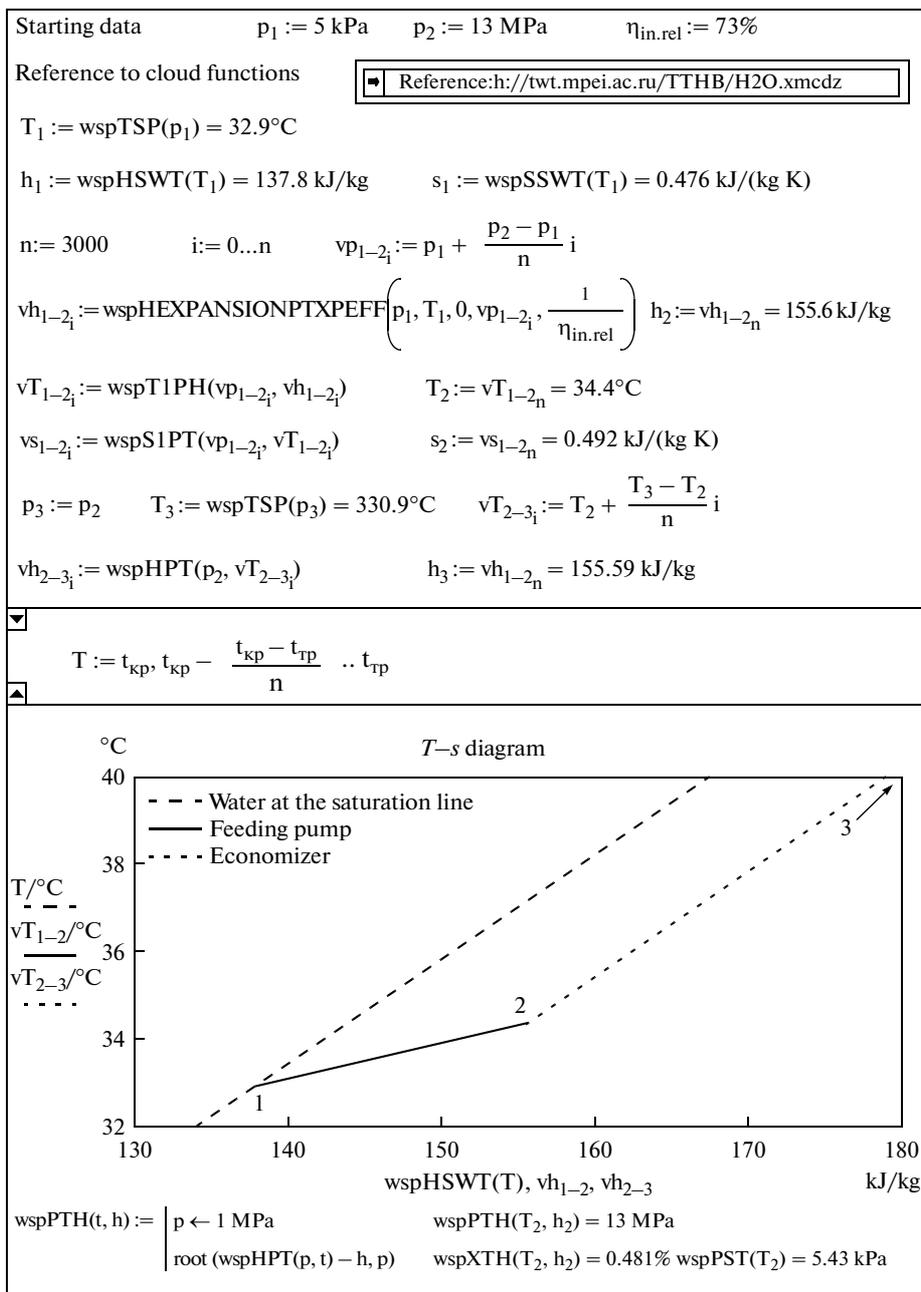


Fig. 2. Calculation of the pump operation.

surface of water in the $h-T-S$ coordinates. At point 2, water has parameters $p = 13 \text{ MPa}$, $t = 34.4^\circ\text{C}$, and $h = 156.6 \text{ kJ/kg}$. However, the analog of point 2, or the two-phase liquid, has the same parameters in regards to T and h . This two-phase liquid is water with the steam content of 0.481% and the temperature of 34.4°C , which is situated under a pressure of 5.34 kPa.

The Mathcad user can expand the list of cloud functions, which are stored in the document at the address [h://twt.mpei.ac.ru/TTHB/H2O.xmcdz](http://twt.mpei.ac.ru/TTHB/H2O.xmcdz),

using the tools for solving the equations and the systems and the search for function zeros. For example, the formation and call for function wspPTH , which returns the pressures of water and/or water vapor depending on temperature and specific enthalpy (one of two inverse functions of the wspHPT package of the cloud functions at the address [h://twt.mpei.ac.ru/TTHB/H2O.xmcdz](http://twt.mpei.ac.ru/TTHB/H2O.xmcdz) is shown at the bottom of Fig. 2). Formed function wspPTH uses function “root” inserted into Mathcad and returns the value of the pressure by the temperature and specific enthalpy near the first-approxima-

tion point over the pressure (1 MPa). We do not give the complete list of package functions since it is added to continuously.

Example 3. The pressure loss in the pipeline filled with the pumped water should be calculated (Fig. 3). To calculate the pressure loss in the pipeline, the engineer should remember or find in the paper or web handbooks the set of corresponding formulas and their application rules called formulations. In addition, the engineer should know certain water properties, particularly, its kinematic viscosity ν and density ρ . These values are presented in a form of the tables or the empirical formulas, which associate the water viscosity and density with the temperature. These data presented in various serious publications can substantially differ. In addition, the engineer, when transferring the numbers from the tables into the concrete calculation, can make an error associated with the erroneous interpolation or even with the inexact set of the digits on the computer keyboard and/or the incorrect interpretation of measurement units and multiplier of them. All these factors complicate and retard the calculation increasing the probability of the appearance of an error in them.

The dynamic viscosity of water is calculated according to the formulation developed and affirmed by the International Association on the Properties of Water and Steam (IAPWS—www.iapws.org), with which the two first authors of this article collaborate. Based on the IAPWS formulations, the handbooks with the tables containing the discrete parameters of water and steam depending on the temperature and pressure are published. Similar tables are also published in our country. The newest such handbook [1] is found at [h://twt.mpei.ac.ru/rbtp](http://twt.mpei.ac.ru/rbtp), which facilitates and accelerates the work with the handbook.

Kinematic viscosity ν is determined by the water density and its dynamic viscosity in the computation shown in Fig. 3. We previously introduced inner tube diameter d into the calculation and calculated the water velocity v in it. Using these three parameters (the velocity, the diameter, and the viscosity), a very important dimensionless criterion of the fluid in the tube, such as the Reynolds number, is determined. Along with the roughness of the inner pipe surface, it determines the desired value of the loss of the water pressure due to the friction at the pipe walls.

In handbooks, the dependence of the relative dimensionless resistance coefficient to the liquid friction in the round pipe λ is given in a form of either plots or a set of formulas. The interactive nomogram (“Nikuradze spoon”) is arranged on the site [h://twt.mpei.ac.ru/MCS/Worksheets/Hydro/La-De-Re.xmcd](http://twt.mpei.ac.ru/MCS/Worksheets/Hydro/La-De-Re.xmcd). It associates the consideration of coefficient λ with the Reynolds number Re and relative surface roughness Δ (the ratio of the average height of protuberances (roughness) of the inner pipe surface to its inner diameter). The visitor of this site can change

the values of Δ and Re , press the button “Recalculate” and obtain not only the result of the calculation but also the form of this dependence in the most “interesting” region, namely, in the region of the transition from the laminar flow to the turbulent flow, which cannot be recommended for the pipeline operation.

There is also the handbook on the hydro-and-gas dynamics at the computational portal of the National Research University Moscow Power Engineering Institute, where the sites described in the article are arranged. This handbook is located at [h://twt.mpi.ac.ru/GDHB/hgd.html](http://twt.mpi.ac.ru/GDHB/hgd.html), and in addition to the other function useful for hydrodynamic calculations, the cloud function is stored. It returns the friction coefficient depending on the Reynolds number in its broad range and the relative roughness of the inner surface of a round pipe. We can find various “named” functions for the calculation of the friction coefficient depending on Re and Δ in publications, namely, Blasius, Konakov, Al’tshul’, Nikuradze et al. We can select any function from this set not keeping in mind its roughness since the starting parameter itself, namely, the pipe roughness, is evaluated very roughly. We can measure the pipe roughness only approximately. This is usually done during the hydraulic tests of the tubes. In handbooks, this important parameter is given in certain limits depending on the pipe material’s (metal, plastic, ceramics, copper, etc.) method of production. In addition, the inner surface roughness of the pipe can vary during its downtime or during operation because of the corrosion–erosion processes or the formation of sediments. When calculating the pressure loss, it is required to introduce certain linguistic constants (“the seamless pipe,” “welded pipe,” “plastic pipe,” etc.), by which the value of Δ is evaluated by the fuzzy-set methods in a certain range, which determines the expected range of the possible variation in the calculated pressure loss along with other uncertainties such as the uncertainty range of the Reynolds numbers and the formulas themselves for the calculation of λ (Fig. 3), rather than the concrete values of relative roughness Δ .

The formula, which is the key formula for the calculation of the pressure loss (it is framed in Fig. 3), we always want to simplify it, for example, transfer constants 2 and g from the denominator into resistance coefficient λ . However, it cannot be done for some causes. First, the acceleration of gravity g ($9.81 \text{ m}^2/\text{s}$), is not a constant strictly speaking but the function of other quantities, firstly altitude above sea level and the geographic latitude of the land. If we do reference the cloud function in the Mathcad document located at [h://twt.mpei.ac.ru/TTHB/g-h-psi.xmcdz](http://twt.mpei.ac.ru/TTHB/g-h-psi.xmcdz), then constant g in the Mathcad medium will transform into the function $g(h, \varphi)$, where h is the altitude above sea level and φ is the geographic latitude of the land (0° is the equator and 90° are the earth’s poles). In addition, we should keep in mind that sometime in the future pipelines will be designed on the Moon or Mars, where g

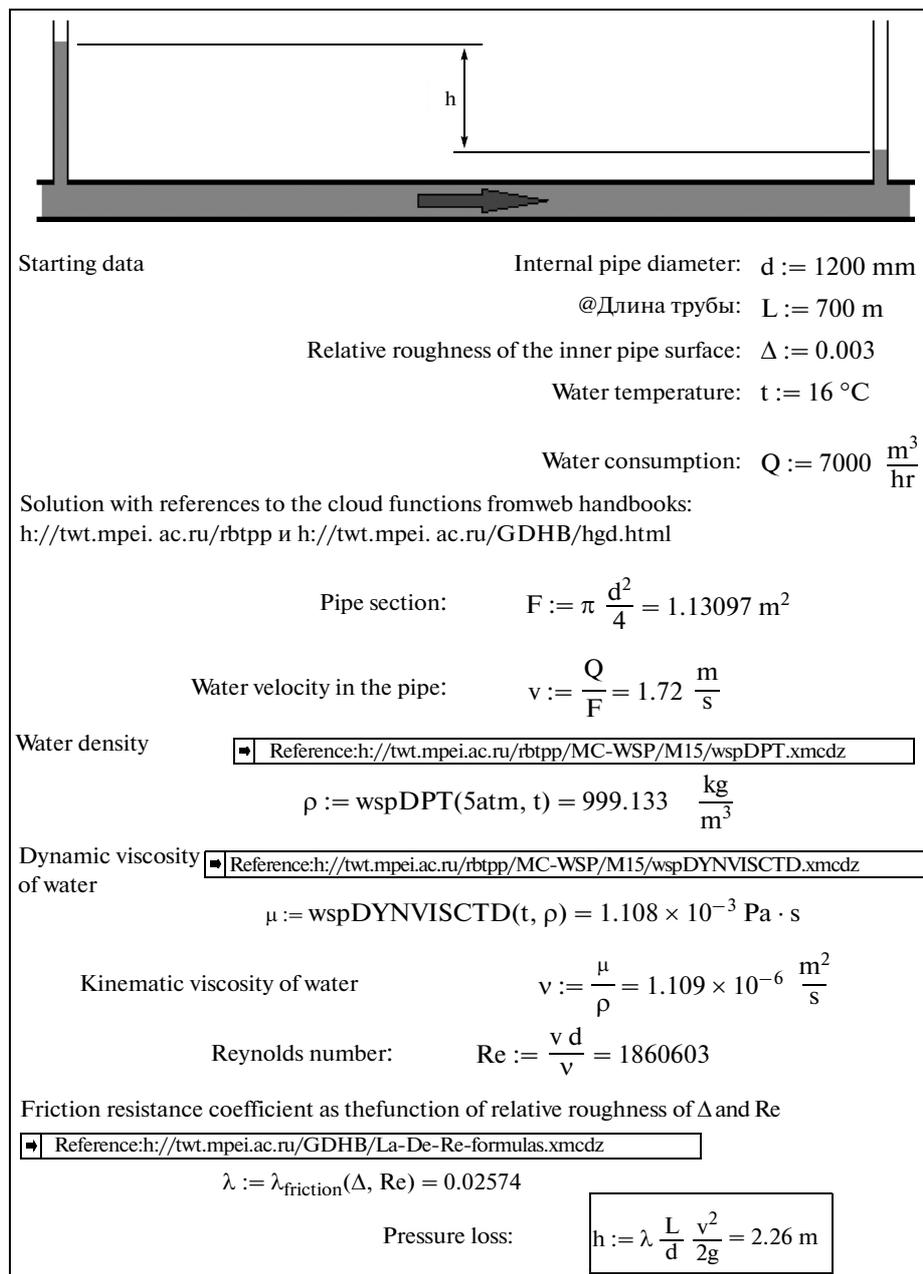


Fig. 3. Calculation of the pressure loss in the pipeline.

substantially differs from $9.81 \text{ m}^2/\text{s}$. It is interesting, is the suggested formula applicable to determine the pressure loss in the water pipeline or the fuel pipeline at the space station where $g = 0$? Yes, constant g cannot be removed in the formula for calculating the pressure loss in the pipeline and is transferred into coefficient λ . The digit “two” in the denominator also cannot be transferred into resistance coefficient λ , but due to other reasons. The formula of the pressure loss reflects the fundamental law of physics, which relates the variation in the potential and kinetic energy of the liquid flow because of the friction at the pipeline walls and

the transformation of these types of energy into less valuable thermal energy. In a horizontal pipeline (the simplified problem), the potential energy is invariable, while the kinetic one ($mV^2/2$) varies. So, digit two in the denominator in the formula for the pressure loss is quite correct since the physical sense of the problem will be less understandable without it.

The technology of the references and downloading described in this article has its own pluses and minuses. A compromise (the intermediate) information technology is the implementation of the Water-SteamPro [7] and its regular renovation. If the thermal

engineering calculations are performed using the computers reliably connected to the Internet, the technology of references described in this article can be used. The technology of the references to the internet-functions opens to the users access to a rich set of other functions useful for heat engineers, which are arranged at the computational server of Moscow Power Engineering Institute—Joint Institute for High Temperatures, Russian Academy of Sciences—OOO Trieru.

The article itself with the additional materials and operating hyperlinks is arranged at the author's site and located at [h://tw.t.mpei.ac.ru/ochkov/WSPHB/Cloud-Formulas.pdf](http://tw.t.mpei.ac.ru/ochkov/WSPHB/Cloud-Formulas.pdf).

ACKNOWLEDGMENTS

This study is supported by the project of the National Research University Moscow Power Engineering Institute “Information Support of Power Engineering, Energy Efficiency, and Energy Saving—the Formation of the Center on Thermal Physics Properties of Substances and Solutions for Power Engineering”. It makes it possible to provide the engineers who are busy with the design, construction, operation, repair, and output from the operation (the utilization) of the power engineering objects using the cloud database with the data on the properties of substances and the set of formulas for the calculations.

REFERENCES

1. A. A. Aleksandrov, K. A. Orlov, and V. F. Ochkov, *Thermal Physical Properties of Working Bodies of Thermal Engineering: Internet-Handbook* (MEI (National Research University “Moscow Power Engineering University) Moscow, 2009) (see [h://tw.t.mpei.ac.ru/rbtpp](http://tw.t.mpei.ac.ru/rbtpp)).
2. A. A. Aleksandrov, v. F. Ochkov, K. A. Orlov, and 2 A. V. Ochkov, “Thermal Physical Properties of Water and Water Vapor in the Internet,” *Industr. Energet.* No. 3 2 (2007) (see [h://tw.t.mpei.ac.ru/ochkov/WspIn](http://tw.t.mpei.ac.ru/ochkov/WspIn)).
3. A. A. Aleksandrov, V. F. Ochkov, and K. A. Orlov, 2 “Equations and programs for the calculation of the properties of gases and combustion products,” *Teploenergetika*, No. 3, 48 (2005).
4. V. F. Ochkov, K. A. Orlov, M. L. Frenkel, A. V. Ochkov, 2 and V. E. Znamenskiy, ““Cloud” service on the properties of working media for thermal engineering calculations”, *59* (7), 566 (2012).
5. A. A. Aleksandrov, *Thermodynamic Foundations of the Cycles of Thermal Engineering Installations* (MEI (National Research University “Moscow Power Institute”), Moscow, 2004).
6. V. F. Ochkov, V. F. Utenkov, and K. A. Orlov, “Thermal engineering calculations in the Matchcad medium,” *Therm. Eng.* No. 2, 73 (2000).
7. K. A. Orlov, A. A. Aleksandrov, V. F. Ochkov, et al., 2 “WaterSteamPro software complex for the calculation of thermal physics properties of water and steam, Abstracts of Papers, Presented at *10th All-Russia Conf. on Thermal Physical Properties of Substances* (Butlerovskie soobshcheniya (Butlerov Reports), Kazan, 2002), pp. 187–188.
8. V. F. Ochkov, “Construction of diagrams of thermodynamic cycles: step by step,” *Avtomatiz. IT Energet.* Nos. 2–3, 6 (2009).
9. V. F. Ochkov, K. A. Orlov, Ko Ko Chzho, and 2 D. A. Anokhin, *Vodosnabzh. Kanaliz.* No. 1, 68 (2013) (see [h://tw.t.mpei.ac.ru/GDHB/CloudFunction.pdf](http://tw.t.mpei.ac.ru/GDHB/CloudFunction.pdf)).

Translated by N. Korovin

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