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# "Cloud" Functions and Templates of Engineering Calculations for Nuclear Power Plants

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**Abstract**—The article deals with an important problem of setting up computer-aided design calculations of various circuit configurations and power equipment carried out using the templates and standard computer programs available in the Internet. Information about the developed Internet-based technology for carrying out such calculations using the templates accessible in the Mathcad Prime software package is given. The technology is considered taking as an example the solution of two problems relating to the field of nuclear power engineering.

*Keywords*: thermal engineering calculations, Mathcad, thermophysical properties of NPP working fluids and coolants

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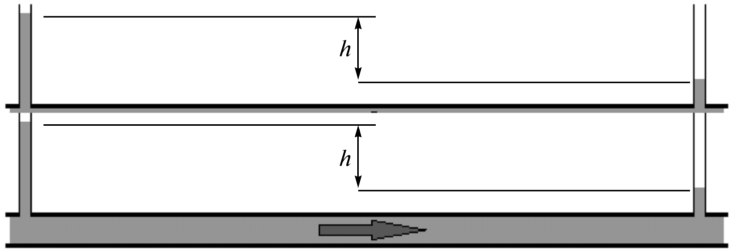
In dealing with scientific-technical and engineering problems, in particular, problems concerned with designing nuclear power plants (NPPs), it is necessary to know the properties of working fluids, coolants, and materials used at NPPs, as well as the parameters of the processes being analyzed [1]. At present, almost all calculations of this sort are carried out on computers using dedicated computer programs or various engineering calculators, and even with groundlessly frequent use of the Excel spreadsheet processor. As a rule, the computers on which these calculations are carried out have access to the Internet, and the specialist who carries out calculations consults not a relevant reference book on the shelf but the ... computer mouse. Indeed, at present, almost all scientific-technical information has been transferred from paper carriers to the Internet [2]. Below, it is shown how the "worldwide web" and the user enterprise's local area network can be efficiently applied for solving not very cumbersome but quite typical problems connected with calculations of some processes that take place at NPPs [3].

Powerful computer programs for carrying out calculations of power facilities have been developed, certified, and are being successfully used. These programs operate according to the "black box" principle, which looks figuratively speaking as follows: the user puts the arrays of input data into the box, closes the cover (presses the "Calculate" pushbutton), opens the box cover and retrieves the answer from it in the form of the sought parameters of the thermal engineering facility being designed. But one always wishes to have at least a general idea about the content of this "black box," to know whether these calculations are correct or not, and to see the intermediate results and all formulas by which the calculations are carried out. In addition, the possibility to open the cover of such box is useful for self-education purposes, namely, for studying the mathematical models according to which the calculations are carried out. One else important reason to look inside the "black box" is that recent years have seen more frequent cases when ready-made computation modules are incorrectly applied for solving particular engineering problems due to lack of open data on the applicability boundaries of the numerical mathematical methods used in the modules, with irremovable errors stemming from such incorrectness.

It should also be remembered that various sorts of powerful computer programs intended for thermal engineering calculations shall not be used for solving a nonstandard but quite important and operative problem, which can in principle be solved "with a pen on paper," but for speeding up calculations and excluding errors, these calculations are carried out on a computer. In addition, it should not be forgotten that "huge" computer programs are very expensive, that they are reliably protected from attempts to copy them, that they require intricate and expensive maintenance carried out by specialists from other companies, and that much time and effort (which are always scarce) are required to study them.

On the other hand, universal, cheap (and in some cases even free of charge) and simple in mastering computer programs for engineering and scientific-technical calculations have been developed for the same computers (workstations), such as Excel, Mathcad, Matlab, Maple, Mathematica, and SMath. Of




**Initial** data Pipe inner diameter: $d := 10$ mm Pipe lengt: $L := 50$ m

Relative roughness of the pipe inner surface: $\Delta := 0.0005$

Temperature: $t := 30°C$ Liquid flowrate: $Q := 15\dfrac{\text{liter}}{\text{min}}$

**Solution**
with references to "cloud" functions Reference:http://twt.mpei.ru/TTHB/D2O.xmcdz

Pipe cross section: $F := \pi\dfrac{d^2}{4} = 0.785 \cdot \text{cm}^2$ Fluid velocity in the pipe: $v := \dfrac{Q}{F} = 3.18 \cdot \dfrac{\text{m}}{\text{s}}$

Heavy water density: $\rho := \rho_{D2O}(t) = 1103.3\dfrac{\text{kg}}{3}$

Dynamic viscosity: $\mu := \mu_{D2O}(t) = 9.724 \times 10^{-4} \cdot \text{Pa} \cdot \text{s}$

Kinematic viscosity: $\nu := \dfrac{\mu}{\rho} = 8.814 \times 10^{-7}\dfrac{\text{m}^2}{\text{s}}$

Reynolds number: $\text{Re} := \dfrac{v \cdot d}{\nu} = 36114$

Flow friction coefficient as afunction of relative roughness $\Delta$ and Re number

Reference: http://twt.mpei.ru/GDHB/La-De-Re-Formulas.xmcdz $\lambda := \lambda_{\text{friction}}(\Delta, \text{Re}) = 0.0243$

Head loss: $h := \lambda \cdot \dfrac{L}{d} \cdot \dfrac{v^2}{2g} = 62.78$ m Pressure loss $\Delta p := \rho \cdot g \cdot h = 6.7$ atm

**Fig. 1.** Calculation of head loss in the pipeline carrying heavy water.

these, the Mathcad software package is best suited to the triple criterion "versatility—cheapness—accessibility," and the Mathcad Express version of this package (http://www.ptc.com/product/mathcad/free-trial) is handed over to users free of charge.

Water and steam serve as the main working fluid in nuclear power engineering [2]. We will consider the technology of using "cloud" functions and templates on the properties of working fluids and coolants applied in nuclear power engineering in the Mathcad environment for two typical problems with somewhat "nontypical" coolants: heavy water and liquid sodium.

**Problem 1.** Calculating pressure loss in a pipeline carrying heavy water (Fig. 1).

The engineer who wishes to solve the problem about pressure loss in a pipeline must recollect or find in paper or Internet handbooks (web-handbooks) the set of relevant calculation formulas and rules on applying them (formulations). In addition, the engineer must know certain properties of the liquid flowing in the pipe, i.e., heavy water. In particular, for the problem considered these properties are its density $\rho$ and kinematic viscosity $\nu$. The values of these properties of heavy water are given in handbooks in the form of tables or empirical formulas correlating the density and viscosity with the temperature and pressure. However, the specialist who takes the numbers from the table and enters them as input data for a particular calculation can make an error stemming from incorrect interpolation and even from erroneous typing of numbers on the computer keyboard and (or) from incorrect interpretation of the measurement units of density or viscosity or their multipliers. All these factors add difficulty to calculations, slow them down, and increase the probability of errors in them.

Specialists of the Moscow Engineering Institute National Research University's (www.mpei.ru) Chair for the Technology of Water and Fuel, working together with specialists from the Joint Institute of High Temperatures, Russian Academy of Sciences (www.jiht.ru) and with specialists of the Trieru company (www.trie.ru) have developed a new Internet-based technology for working with the properties of working fluids, coolants, and materials used in nuclear power engineering, in which the operation of manually transferring data from a paper or an Internet-based handbook is excluded.

If data on the thermophysical properties of heavy water are required for carrying out a calculation in the environment of the Mathcad 15 software package, it is necessary and sufficient to make reference to the D2O.xmcdz file stored on http:/twt.mpei.ru/TTHB. This reference together with the relevant comment is shown in the calculation depicted in Fig. 1. After that, the functions returning the thermophysical properties

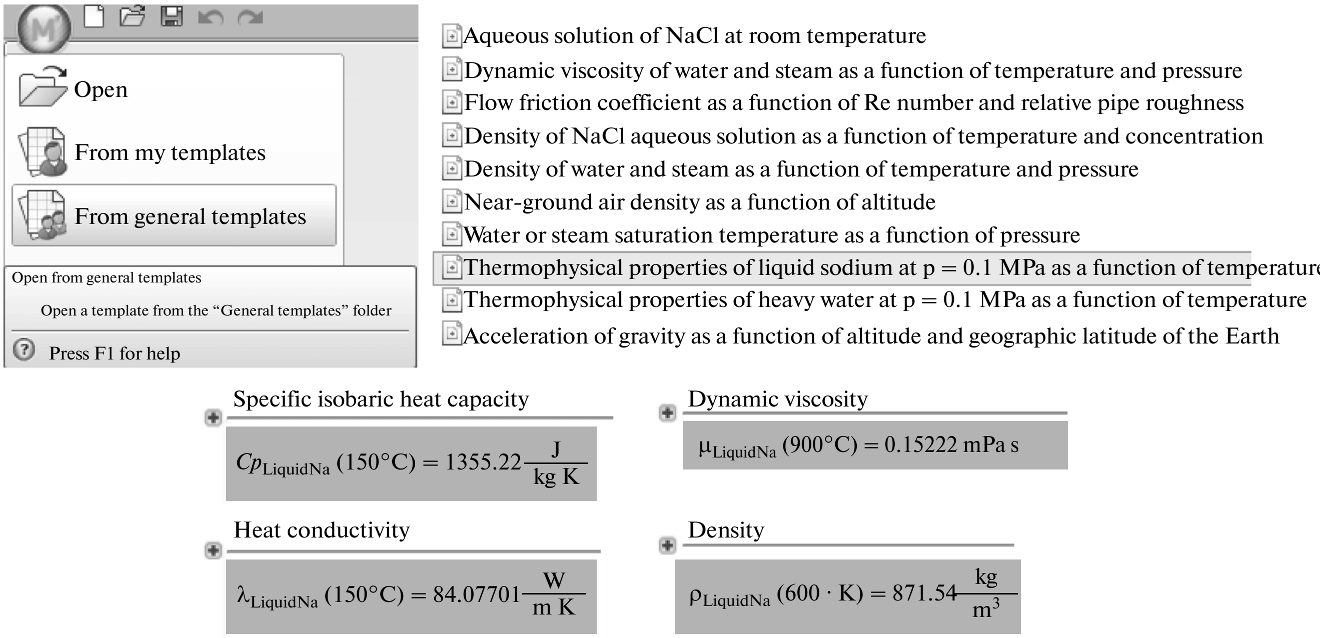



**Fig. 2.** Templates in the Mathcad Prime environment.

of heavy water vs. the temperature at atmospheric pressure (adopted as an assumption), in particular, density and dynamic viscosity, will become visible.

The calculation shown in Fig. 1 also contains a reference to the file storing the “cloud” function that returns the coefficient $\lambda$ for liquid friction in the pipe depending on the Reynolds number and relative roughness of the pipe inner surface taking into account laminar, transitive, and turbulent liquid flow modes. This coefficient appears in the formula by which the pressure loss in the pipeline is calculated.

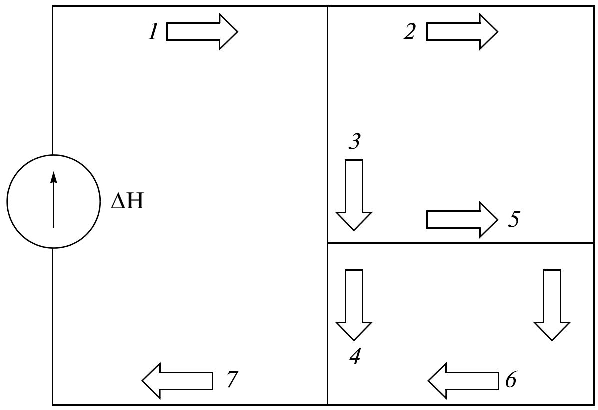
Direct application of “cloud” functions by making references to them, as is shown in Fig. 1, has one essential limitation. The point is that some “firm” institutions limit or even block direct access of their employees to the Internet from their workstations. This is done both for security purposes and in order to prevent the employees becoming distracted from their job by visiting news and entertainment sites, by communicating with their friends in the social networks, etc. The calculation shown in Fig. 1 will not work on a computer disconnected from the Internet, and the references included in the calculation (http://...) will be shown in red to indicate the alarming situation. In this case, we can recommend to do the following.

The administrator of the computer network of the institution in which access to the Internet from workstations of ordinary employees is blocked can download, on the request of a particular specialist, the required function, check it for viruses and troyan programs, and place it in the local area network and or on certain workstations. The downloaded and checked function placed at an institution can be referred to or can be simply built in the calculation, which, unlike making relative references, will not lead to malfunction in transferring the calculation from one computer to another. The downloaded file can be transformed into a template, which can be placed in the institution’s local area network.

Figure 2 shows an example of the list of templates prepared by the user himself based on the materials placed on the site http://twt.mpei.ru/TTHB. This list of templates includes blanks of Mathcad Prime documents storing the functions on the properties of working fluids, coolants and materials used in thermal,

$$\Delta h(L, d, q, \Delta) = \left\| \begin{array}{l} \left[ F \leftarrow \pi\dfrac{d^2}{4} \quad v \leftarrow \dfrac{q}{F} \quad \nu \leftarrow \dfrac{\mu_{\mathrm{LiquidNa}}(t)}{\rho_{\mathrm{LiquidNa}}(t)} \quad \mathrm{Re} \leftarrow \dfrac{vd}{\nu} \right] \\ \lambda_{\mathrm{friction}}(\Delta, \mathrm{Re})\dfrac{L}{d}\dfrac{v^2}{2g} \end{array} \right|$$

**Fig. 3.** Loss of head in pipeline segments.




Initial data

$L_1 := 50$ m $\quad d_1 := 12$ mm

$L_2 := 30$ m $\quad d_2 := 7$ mm

$L_3 := 10$ m $\quad d_3 := 10$ mm

$L_4 := 45$ m $\quad d_4 := 5$ mm

$L_5 := 5$ m $\quad d_5 := 3$ mm

$L_6 := 17$ m $\quad d_6 := 7$ mm

$L_7 := 55$ m $\quad d_7 := d_1$

Liquid sodium temperature $\quad t := 250°\mathrm{C}$

**Fig. 4.** Calculation of the hydraulic network with liquid sodium (start). (*1*)–(*7*) Pipeline segments.

Initial approximations

$\Delta H := 80$ m $\quad q_2 := 100$ L/h $\quad q_3 := q - q_2$

$q_4 := 20$ L/h $\quad q_5 := q_3 - q_4 \quad q_6 := 70$ L/h

Constraints

$q = q_2 + q_3 \quad q = q_4 - q_6 \quad q_3 = q_4 + q_5 \quad q_6 = q_2 + q_5$

$$\Delta h(L_1, d_1, q, \Delta) + \Delta h(L_3, d_3, q_3, \Delta) + \Delta h(L_4, d_4, q_4, \Delta) + \Delta h(L_7, d_7, q_7, \Delta) = \Delta H$$

$$\Delta h(L_1, d_1, q, \Delta) + \Delta h(L_2, d_2, q_2, \Delta) + \Delta h(L_6, d_6, q_6, \Delta) + \Delta h(L_7, d_7, q_7, \Delta) = \Delta H$$

$$\Delta h(L_1, d_1, q, \Delta) + \Delta h(L_3, d_3, q_3, \Delta) + \Delta h(L_5, d_5, q_5, \Delta) + \Delta h(L_6, d_6, q_6, \Delta) + \Delta h(L_7, d_7, q, \Delta) = \Delta H$$

$$\Delta h(L_1, d_1, q, \Delta) + \Delta h(L_2, d_2, q_2, \Delta) - \Delta h(L_5, d_5, q_5, \Delta) + \Delta h(L_4, d_4, q_4, \Delta) + \Delta h(L_7, d_7, q, \Delta) = \Delta H$$

$$\Delta h(L_2, d_2, q_2, \Delta) - \Delta h(L_5, d_5, q_5, \Delta) - \Delta h(L_3, d_3, q_3, \Delta) = 0 \text{ m}$$

$$\Delta h(L_6, d_6, q_6, \Delta) - \Delta h(L_4, d_4, q_4, \Delta) + \Delta h(L_5, d_5, q_5, \Delta) = 0 \text{ m}$$

$$\Delta h(L_2, d_2, q_2, \Delta) + \Delta h(L_6, d_6, q_6, \Delta) - \Delta h(L_4, d_4, q_4, \Delta) - \Delta h(L_3, d_3, q_3, \Delta) = 0 \text{ m}$$

Solver

$x(q, \Delta) := \mathrm{Find}(\Delta H, q_2, q_3, q_4, q_5, q_6)$

**Fig. 5.** Calculation of the hydraulic network with liquid sodium (continuation).

nuclear, and industrial power engineering applications.

If we open the template highlighted in gray in Fig. 2, the document containing functions on the properties of liquid sodium, which is used as coolant in some nuclear power installations, will be opened. The lower part of Fig. 2 contains four minimized regions with these functions and with the examples of calling them. The function returning the liquid friction coefficient in a pipe is also transferred in the calculation from another template, and the function correlating the pressure loss in a pipeline segment with its length, diameter, volume flow rate of liquid, and roughness of the pipe inner surface is added (Fig. 3).

The document constructed based on the template (see Fig. 2) will already contain components for determining all necessary functions on the properties of liquid sodium. With these functions at hand, the user can carry out calculation, e.g., of a certain pipe system with this liquid. Figure 4 shows the schematic diagram of the pipeline and presents the initial data for such calculation – a supplement to the document shown in Figs. 2 and 3.

**Problem 2.** It is necessary to construct the graphic dependence of liquid sodium flow rate through the pump as a function of pump head and relative roughness of the pipe inner surface. The calculation is carried out under the following assumptions (which can easily be removed): the piping system is arranged in a horizontal plane, and the local flow frictions of tee joints and angular bends are not taken into account.

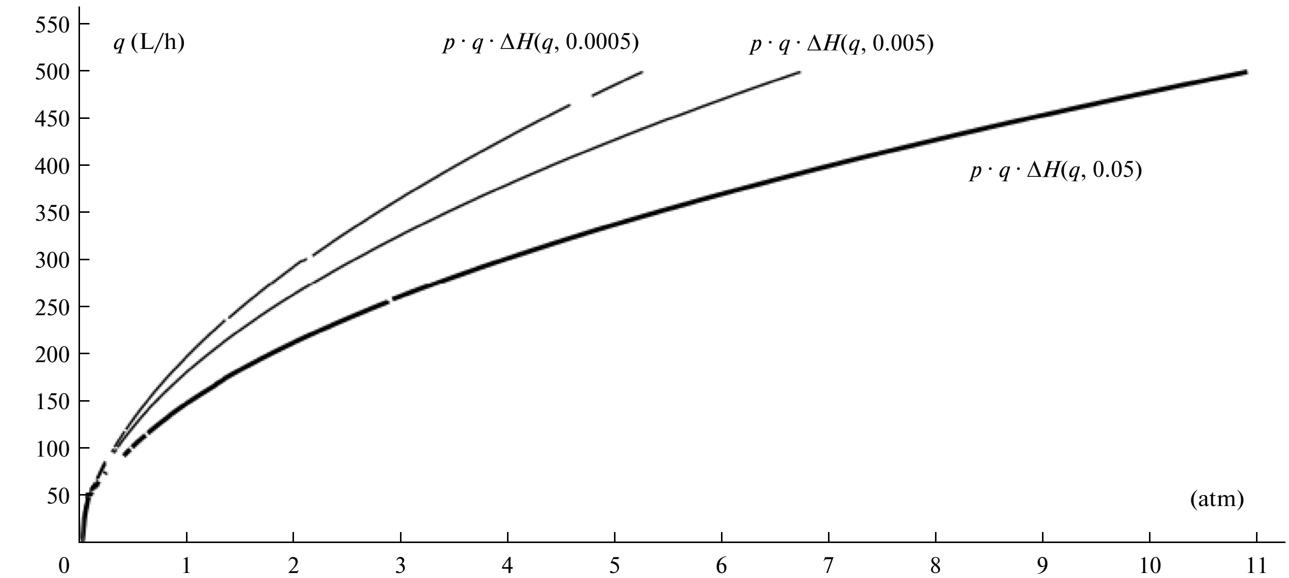



**Fig. 6.** Calculation of the hydraulic network with liquid sodium (end). $q$ is the liquid volume flow rate. The numbers 0.0005, 0.005, and 0.05 are the pipe inner surface roughness values.

The solution of the problem boils down to solving a system of nonlinear algebraic equations that take into account the balance of liquid flow rates in tee joints and loss of head in individual closed segments of the pipeline (Fig. 5). In solving the system of equations we obtain a functional dependence that can be represented in graphic form (Fig. 6).

Three curves shown in Fig. 6 depict the dependences correlating the necessary pressure difference across the pump with the flow rate of liquid through it at different values of relative roughness of the pipe inner surface. The breaks in the lines show the segments in which the Mathcad package Solver failed to find a solution of the system of nonlinear algebraic equations.

Thus, the calculation server containing a set of "cloud" functions and templates on the properties of working fluids, coolants, and materials used in thermal and nuclear power engineering that has been developed jointly by specialists of MPEI, JIHT, and Triery and fitted with the necessary service functions in its calculation software shell allows specialists to carry out calculations.

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