Steam Tables and Diagrams on Mathcad Calculation Server for Personal Computers, Pocket Computers and Smart Phones

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A set of routines is described which are devoted to the properties of water and steam. They are based on equations recommended by IAPWS, particularly from the IAPWS Industrial Formulation 1997. The site gives the possibility to determine the thermodynamic properties of water and steam in all regions of IF-97 including the region of wet steam when different pairs of input parameters are known. The program provides not only the ability to obtain numerical data, but permits building graphs of various properties in different coordinates and thermodynamic surfaces. It is important for demonstrating the changing characteristics of various properties of a water substance and sometimes, when it is needed, to emphasize their anomalous behavior. A number of diagrams which illustrate the typical character of property behavior of all substances are presented on the site such as dependencies on parameters of compressibility factor, curve of inversion, Joule and Joule-Thomson coefficients, and others. These diagrams may be useful in the process of educating students. The files of the program package may be downloaded in order to include it into the users program environment and be linked to program languages such as C, Pascal, BASIC, Fortran and others, and to mathematical programs Mathcad, Maple, etc. Taking into acoount the possibility to use these files with pocket computers (PDA) even with limited display size.

Introduction

Materials elaborated by IAPWS provide the information about the thermophysical properties of water and steam in wide regions of parameters of state. These routines were created by the Moscow Power Engineering Institute (Technical University) which is devoted to using this information in technical calculations of different types and in the education of students. These routines are oriented for use in computers of various types. The routines are presented on the Internet as part of portal http://twt.mpei.ac.ru/ochkov/WSPHB/Engindex.html which contains information about properties of working substances and heat carriers of thermal power

The demonstration site

One part of the routines is devoted to the demonstration of changing the main properties of steam in dependence on parameters. It is oriented to an application when the students are studying a chapter on thermodynamic properties of real gases in a course of thermodynamics and gives the possibility to show the general laws of changing of properties typical for all substances and anomalies of water. We think that it such a site would be desirable to have a dedicated page on IAPWS official site because users are asking about this. This page is based on equation IAPWS-95 [1]. Here, first of all, the diagram pressure- temperature is presented for low temperatures and low pressures to demonstrate triple point, anomalous part of melting line ice 1h –liquid and line of density of water maxima.
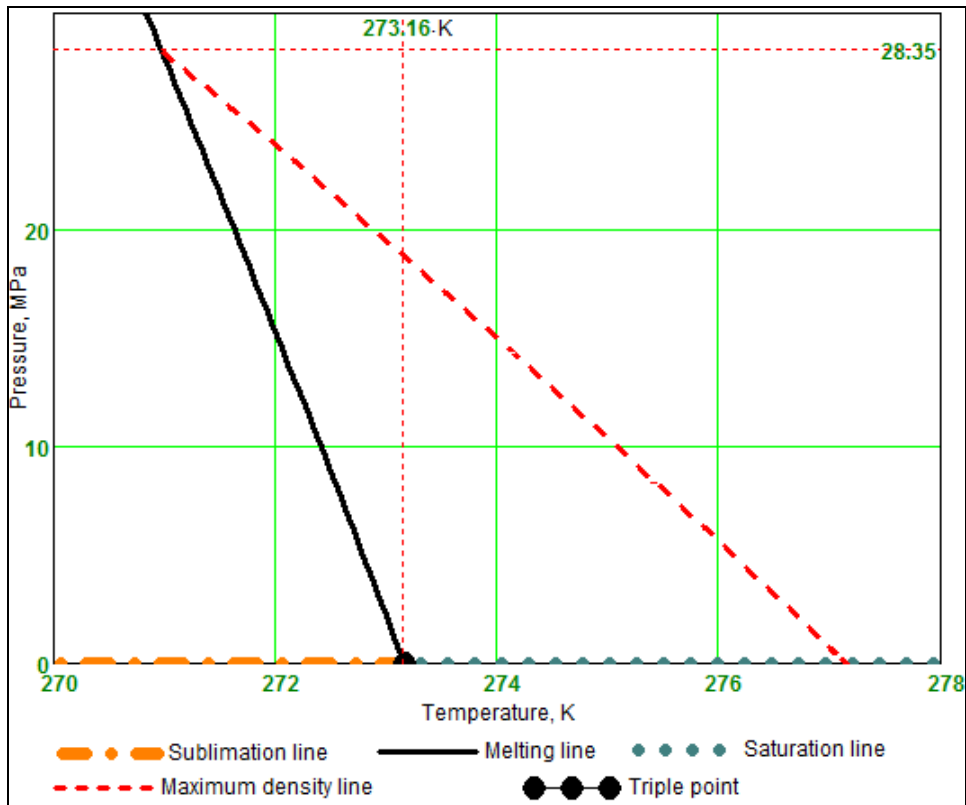
Fig. 1: The diagram p,t for region of low temperatures and low pressures

The limitation of a region of anomaly of this melting line is illustrated in the diagram for high pressures (Fig. 2) [2] and as the existence of several polymorphous transitions in solid state and existence of several triple points.
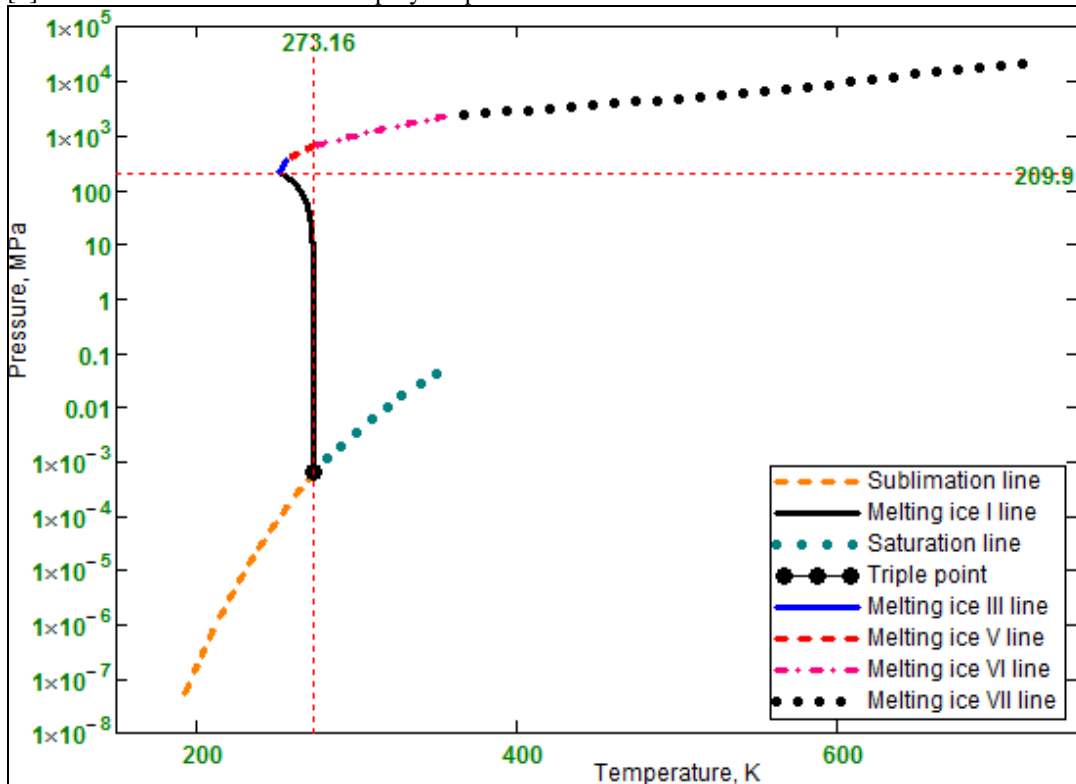

Fig. 2. The melting lines ices–liquid.

The general character of distinction of real gas density from the ideal gas one is demonstrated in Fig.3 in z,p diagram where z is compressibility factor $z = pv/RT$, $\pi = p/p_c$ This diagram is evidence of non-identical correlation
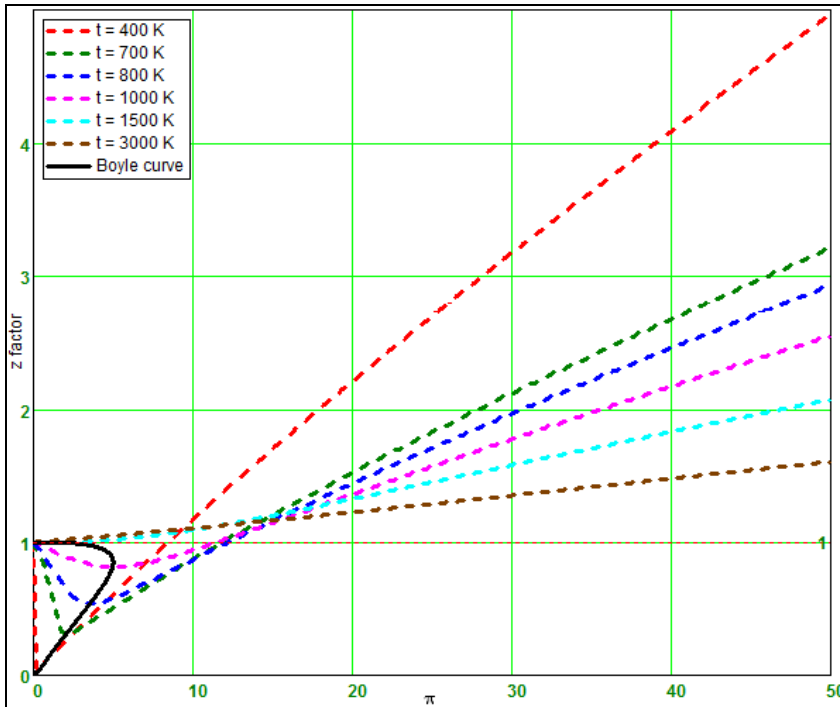
Fig. 3. The z,π diagram of water.

between specific volumes (densities) of real and ideal gases (z =1) at equal temperature and pressure in different regions. Its relation may not only decrease when pressure increases but the relation may increase also. The boundary of change for this relation trend is the Boyle curve which is determined by condition $(\partial z/\partial p)_T = 0$ and shown in Fig. 3. The specific volume of real gases is greater than an ideal one in the region of very high pressures at any temperature. Moreover specific volume of real gases is greater than ideal one at temperatures greater than the Boyle temperature T_B, which is determined by condition $(\partial z/\partial p)_{T,\,p=0} = 0$, at any pressure. The value of this temperature follows from equation IAPWS -95 equals to $T_B = 1519$ K.
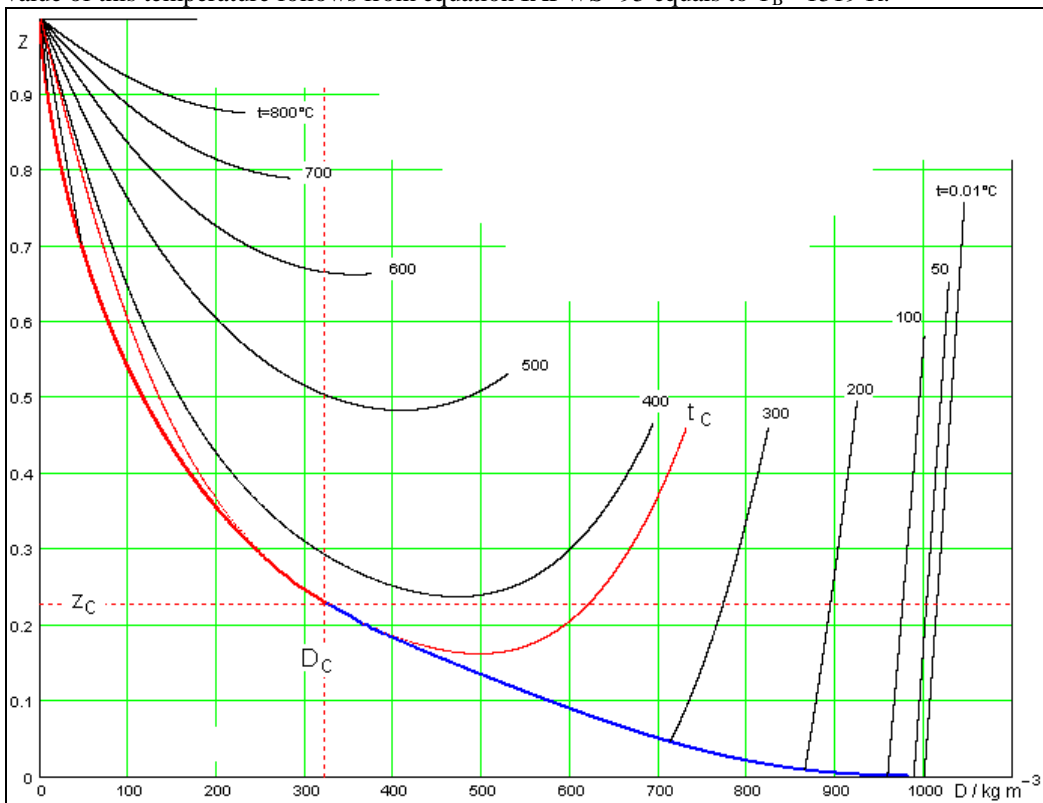

Fig. 4. The z,ρ diagram for steam

In Fig. 4 the z,ρ diagram is presented for a large interval of densities. It is of interest because the equations of state of type z =f(T,ρ) are applied to many gases now. These types of equations are obtained as pure empirical ones or with the distinction of virial coefficients in order to use them for subsequent search parameters of

intermolecular potential functions. The dependence of the second virial coefficient on temperature is shown in Fig.5 for steam according to data [3].
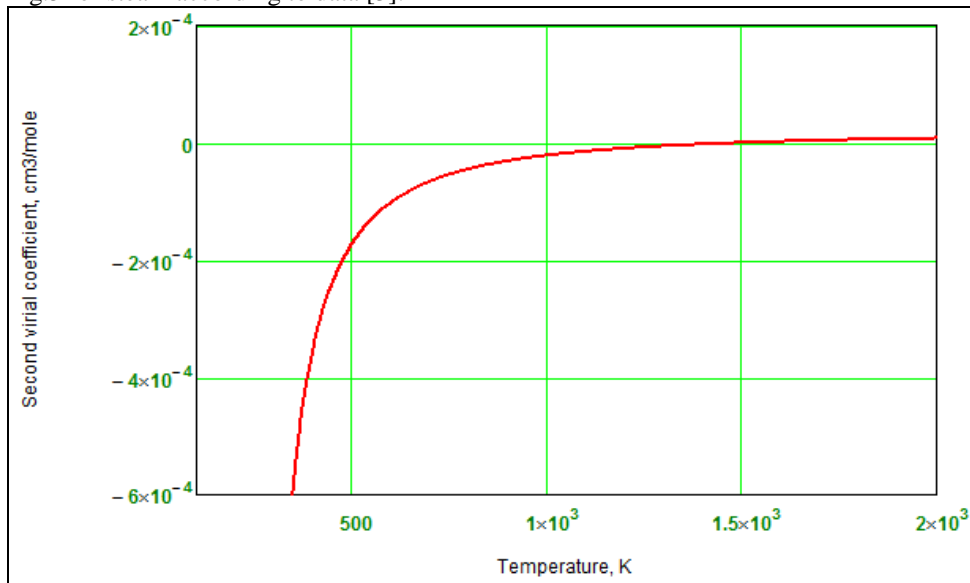

Fig. 5. Second virial coefficient of steam

The dependence of enthalpy of steam on temperature and pressure is shown in Fig. 6. It is typical for all real gases. The non monotonic trend of this dependence is well shown in this graph. The line relates minima of isotherms, i.e. states in which $(\partial h/\partial p)_T = 0$, is an inversion curve of the Joule –Thomson coefficient $\mu_{JT} = (\partial T/\partial p)_h$. This line with coordinates of reduced pressure and reduced temperature is presented in Fig. 6
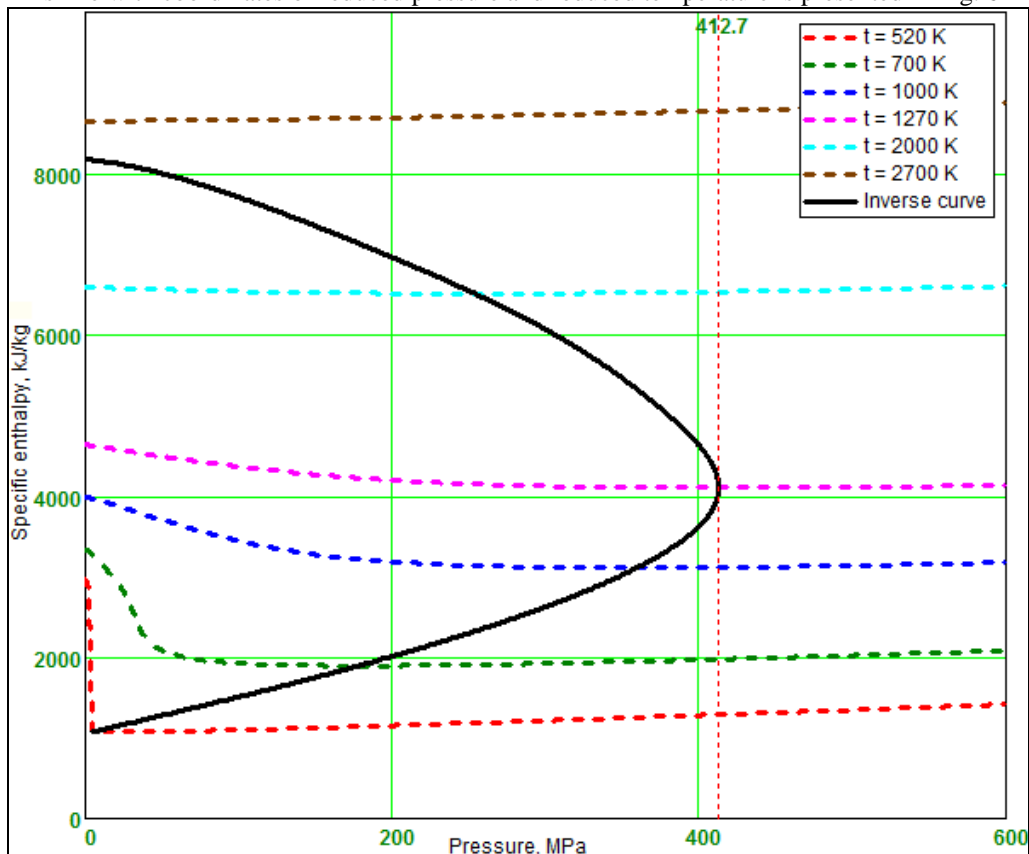

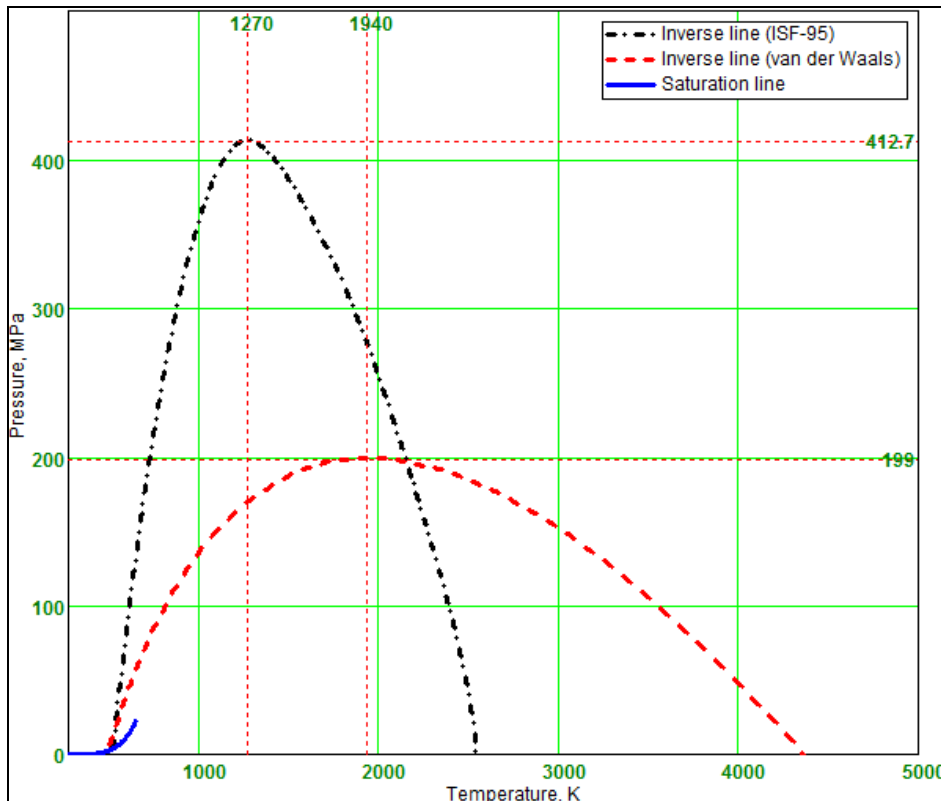**Fig. 6.** The diagram h,p of steam

Fig. 7. The inversion curve

In Fig. 8 the sound velocity in water is shown as dependent on density and pressure. The anomaly of changing the sound velocity is well seen at large densities (low temperatures). Sound velocity here is decreasing at constant pressure and increasing density (decreasing temperature) which is one of peculiarities of water
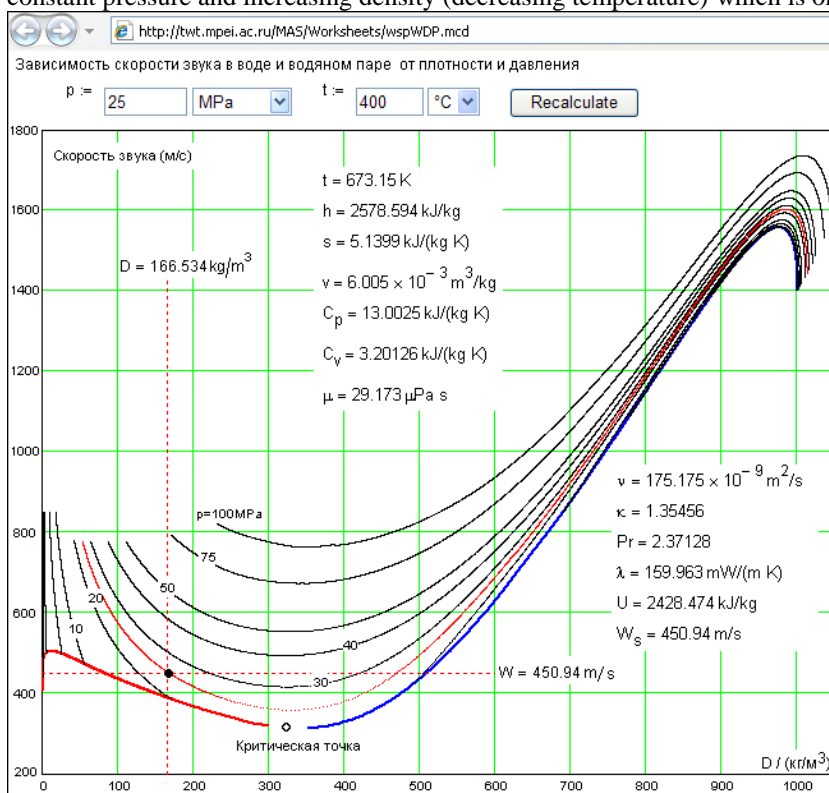

Fig. 8. The dependence of sound velocity in water on density and pressure.

The complicated characteristics of the isentropic exponent changing of steam is shown in Fig. 7a. Its dependence on parameters is valuable to demonstrate because this property is often used in technical calculations.
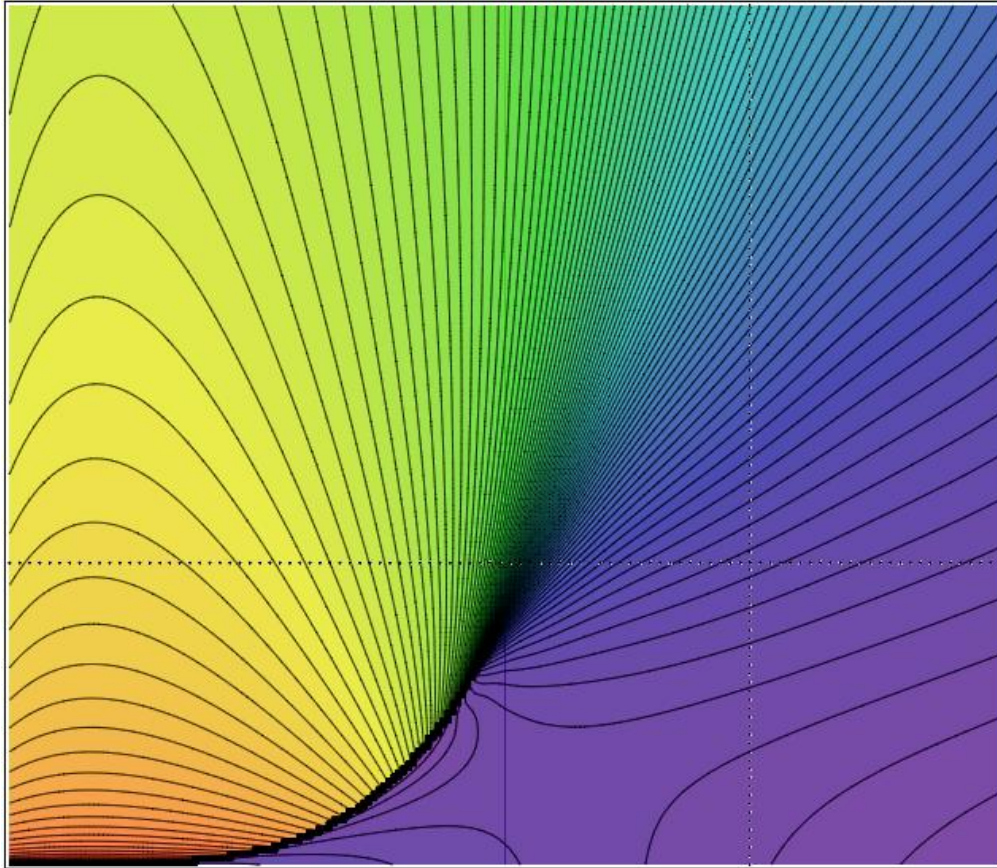
Fig. 8a. The isentropic exponent of steam.

The pack of routines for calculations

The program package WaterSteamPro was created to obtain data on the thermophysical properties of water and steam. It is based on equations presented in IAPWS documents. The calculations of thermodynamic properties is carried out on the basis of equations from Formulation IF-97 [4]. The address of this pack of routines on the Internet is www.wsp.ru. In Fig.9 the Internet page is shown where the user can download and install on their personal computer the routines or update revisions..
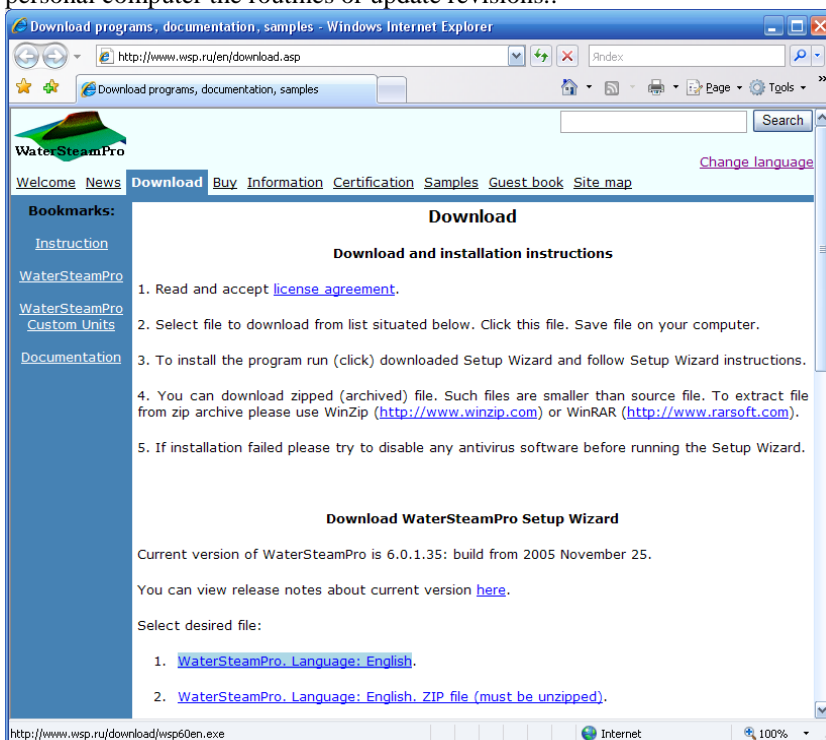

Fig. 9. The page of site WaterSteamPro for download of routines.

The routines give the possibility to calculate properties of water and steam provided different pairs of input parameters are given. Installing WaterSteamPro on a users computer provides the ability to work with a calculator for the properties of water and steam. In Fig.10 this calculator is shown calculating the situation with the properties of water in a saturated state at 120°C and the call pathI in operating system Windows: "All programs/ WaterSteamPro"/"WaterSteamPro/Calculation". The buttons of call of calculator may be placed on working table of computer in order for this special users supplement to Windows to always be easily accessible for the engineer or student.
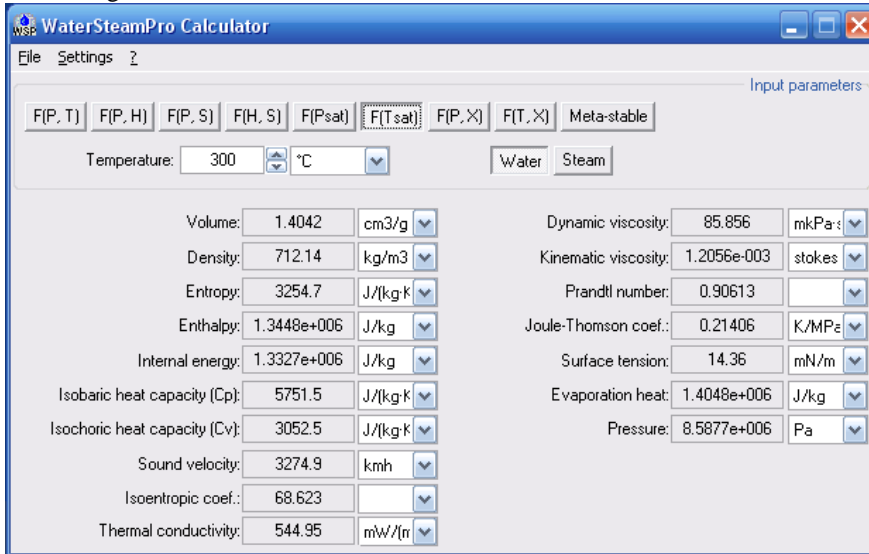

Fig. 10. The calculator of properties of water and steam on computer of user.

The installation of the package WaterSteamPro on a users computer allows for the possibility not only to fulfill one time calculations, but to also integrate functions presenting the properties of water and steam in popular calculation systems and program languages Fortran, Pascal, BASIC, C and others. In Fig. 11 it is shown that integration of package WaterSteamPro with table processor Excel and in Fig. 12 that integration is shown with mathematical program Mathcad. In these cases, conversion of units of measurements are carried out in Mathcad automatically {5}, but in environment of Excel it is necessary to manually convert auxiliary units (for example mm. Hg and Celsius grades) into basic (Pa and K).
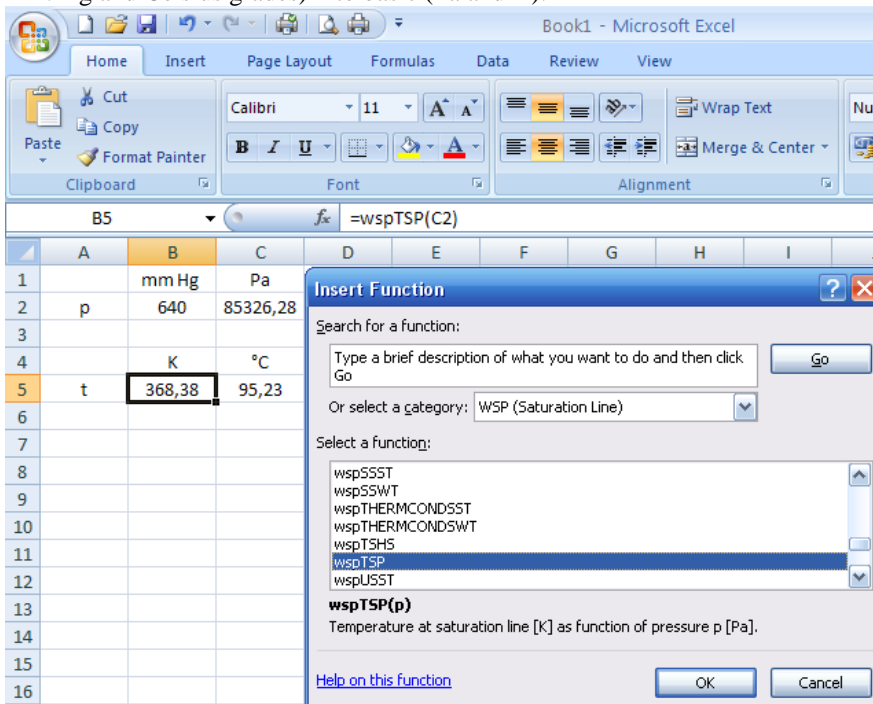

Fig. 11. The example of integration of package WaterSteamPro with table processor Excel
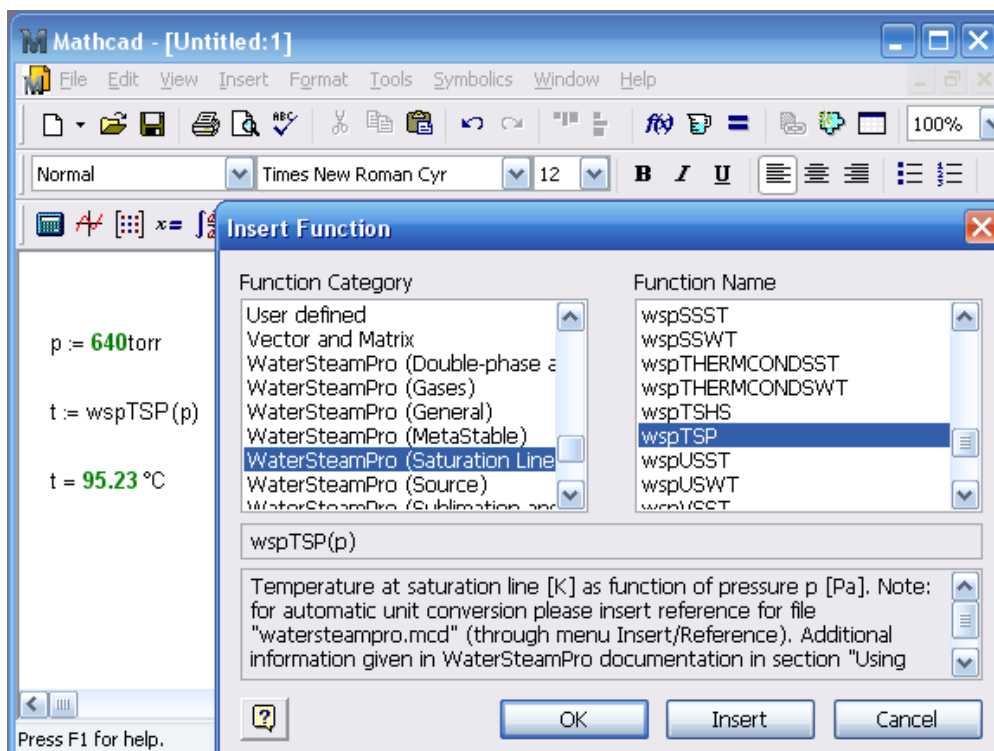
Fig. 12. The example of integration of package WaterSteamPro with mathematical program Mathcad

The calculations in MAS technology

In contemporary conditions when computers as a rule have a connection to the Internet, it is easier to obtain information about water and steam properties from special sites without loading down your own computer resources with complicated calculating programs. Therefore, a special site has been created with the technology of Mathcad Application/Calculation Server (MA/CS –http://twt.mpei.ac.ru/ochkov/Mathcad_14/Chapter7) [5]. This site can be found at Internet address http://twt.mpei.ac.ru/ochkov/WSPHB. At this site there are references to equations from Formulation IF-97 and page http://twt.mpei.ac.ru//MAS/Worksheets/wspRegionsAllAxes.mcd which makes it possible to rebuild the boundary lines of validity of these equations with various conditions. Choosing axes of graphs from its list, the user may see which equtions apply to the different regions in various thermodynamic diagrams. As a example, the next regions are shown in Fig. 13 in diagrams p,t, T,s and h,s: 1 – water; 2 –superheated steam; 3 –critical region; 4 –saturation line; 5 –steam at very high temperatures.
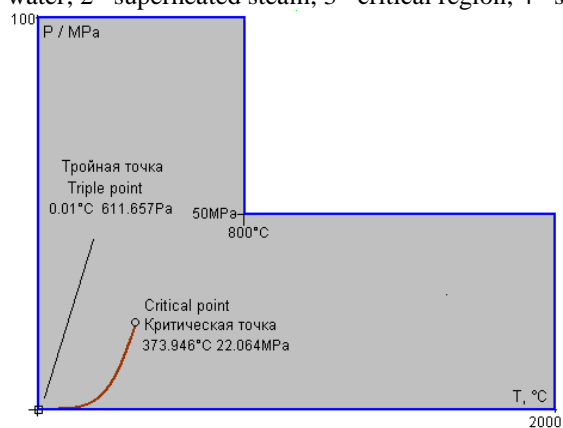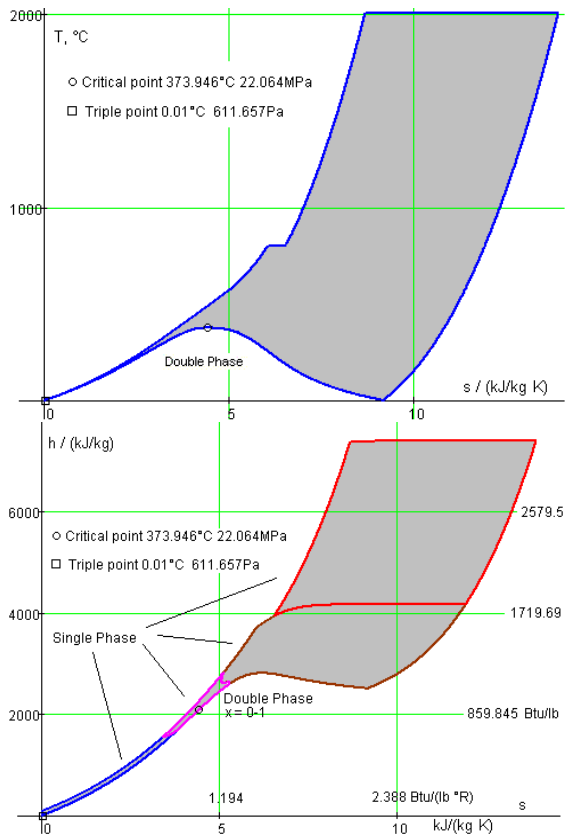
Fig.13. The regions of validity of equations of Formulation IF-97

With information about the properties of water and steam it is possible to obtain from pages on the site which list is given in Table 1. On these pages are not only the numerical values of desired properties but the equation used to determine the property and the corresponding point is shown in the graph of the region.

Table1: List of properties of water and steam

Property	Calcul without Plots SI	Calcul without Plots US	Calcul with Plots (isolines)	Calcul with Surface
Pressure, p	h, s | t, s | t, h | t, v	h, s		
Temperature, t	h, s | p, s | p, h	h, s		
Specific Enthalpy, h	p, t | p, s | t, s	p, t | p, s	p-t | t-p | d-p	p, t
Specific Entropy, s	p, t | p, h | t, h	p, t | p, h	p-t | t-p | d-p	p, t
Specific Volume, v | Density, ρ	p, t | p, s | p, h	p, t | p, s | p, h	t-p | p-t	t, p
Specific Isobaric Heat Capacity, c_p	p, t | p,s | p,h	p, t | p, s | p, h	p-t | t-p | d-p | d-t	$1/c_p(t, p)$
Specific Isochoric Heat Capacity, c_v	p, t | p,s | p, h	p, t | p, s | p, h	t-p | p-t | d-p | d-t	$1/c_v(t, p)$
Dynamic Viscosity, μ	p,t	p, t	p-t | t-p | d-p | d-t	-
Kinematic Viscosity, ν	p,t		t-p | p-t | d-p | d-t	-
Thermal Conductivity, λ	p,t	p, t	p-t | t-p | d-t	t, p
Compressibility factor, z			t-p | p-t | p-h | p-s | d-p | d-t	t, p
Prandtl Number, Pr	p,t	p, t	t-p | p-t | d-p | d-t	t, p
Speed of Sound, w	p,t	p, t	p-t | t-p | d-p | d-t	t, p
Isentropic exponent, κ	p,t		t-p | p-t | d-p | d-t	t, p
Joule-Thomson coefficient, JT			t-p | p-t	
All properties	p, t | h, s | p, h | p, s			

The example of that page is demonstrated in fig.14 where the user may obtain the numerical value of saturation pressure and its uncertainty. The value of temperature can be given in different temperature scales.
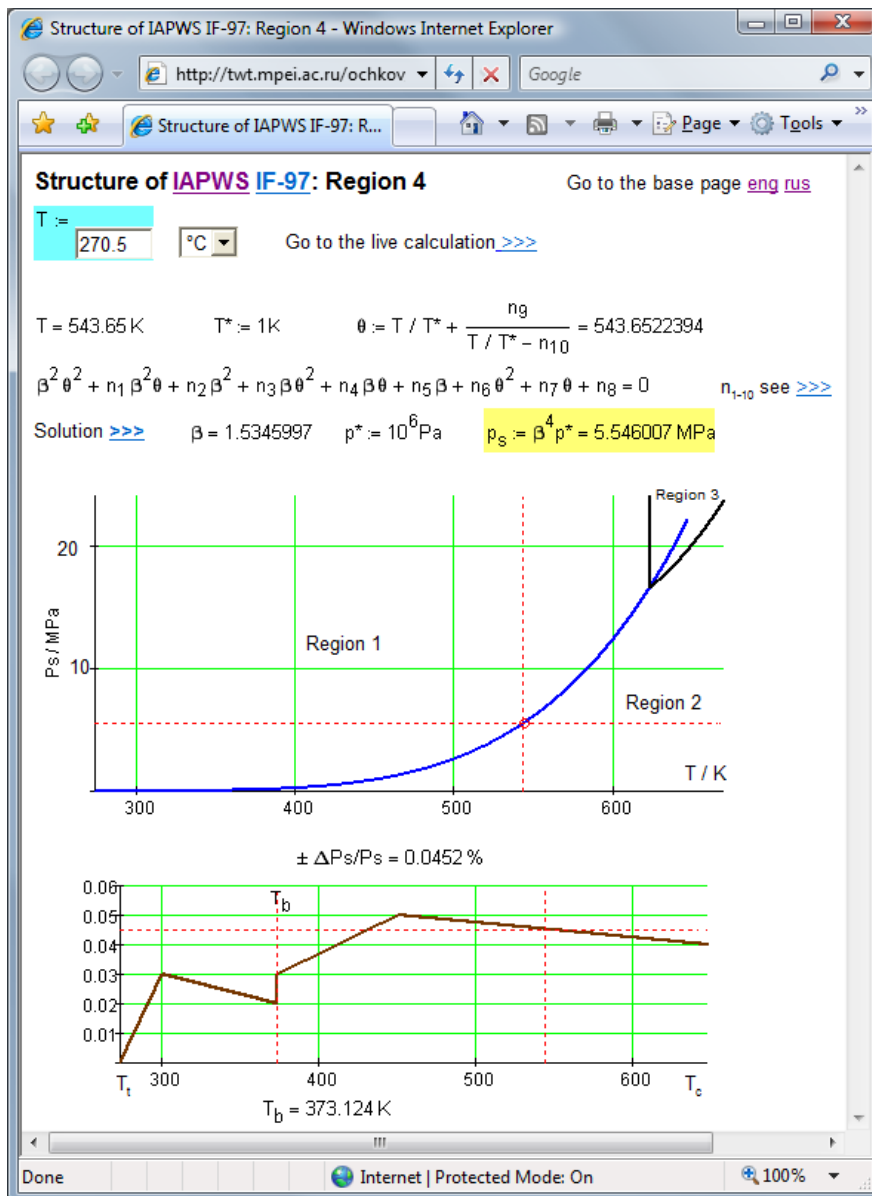
Fig. 14. The page for calculation of saturation pressure

Another page (http://twt.mpei.ac.ru/MAS/Worksheets/wsp_sat_P/.mcd) gives information about properties of water and steam at the saturation line as a function of pressure. The pressure value may be introduced in different units (MPa, bar, atm, at, ksi) within the range from triple point to critical point. After clicking the **Recalculate** button, the program produces a plot and gives numerical results for the required values –saturation temperature, specific enthalpies of water and steam, specific heat of evaporation (shown in Fig. 1), specific entropies, specific volumes, isobaric and isochoric specific heats, sound velocities, and Prandtl numbers (Fig. 15). This gives a possibility to see its changing characteristics. For example it is seen in Fig. 15 that the enthalpy of steam at saturation line has a maximum somewhat left of the chosen point –40 atm
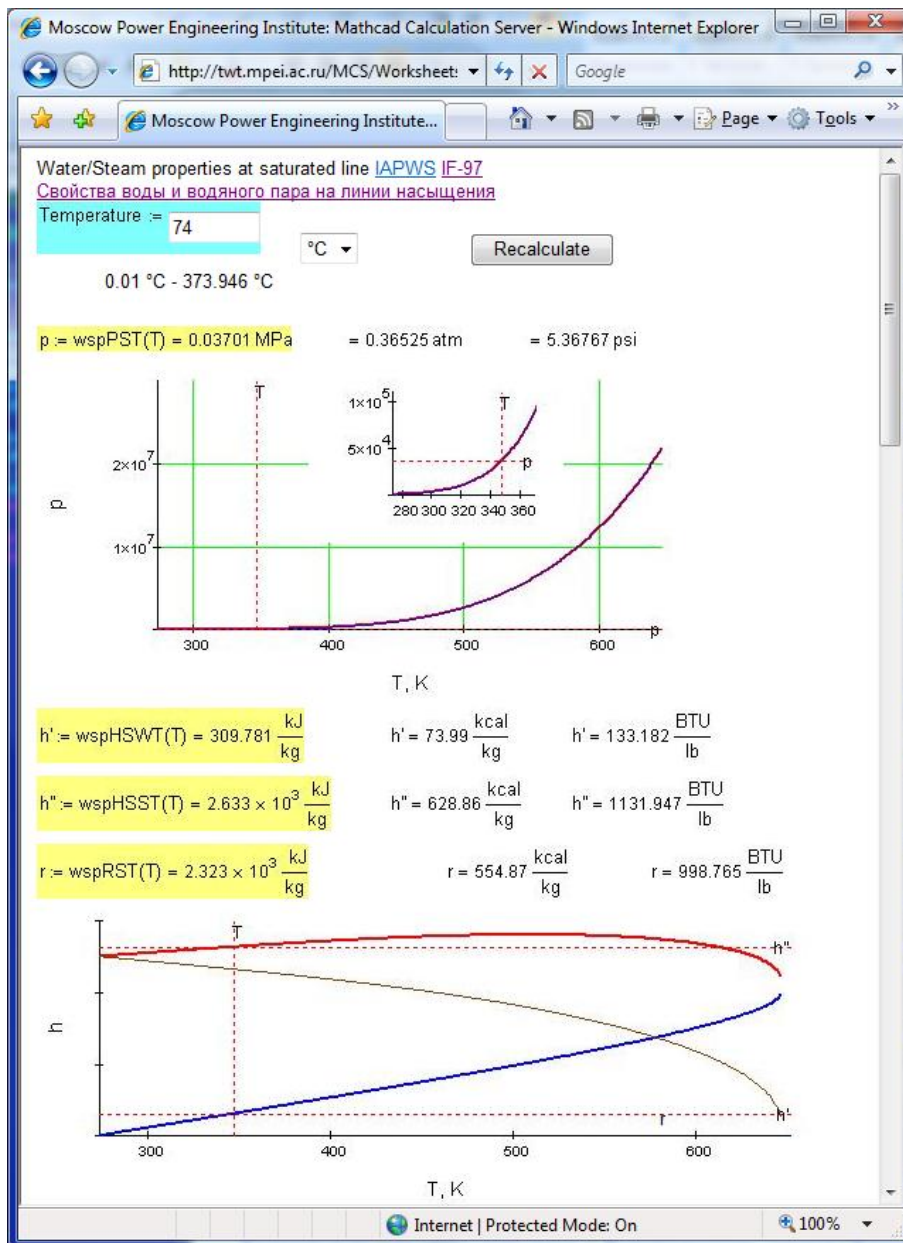
Fig. 15. The page for properties of water and steam at saturation line

On many pages of the site (see Table) there is the possibility for a property selected to build a family of curves (isobars, isotherms, isochors)or surface. In Fig. 16 the surface is demonstrated that represents dependence of specific isobaric heat capacity on temperature and pressure. Here heat capacity is presented by reversed value $1/c_p$ because near critical point isobaric heat capacity aspires to infinity
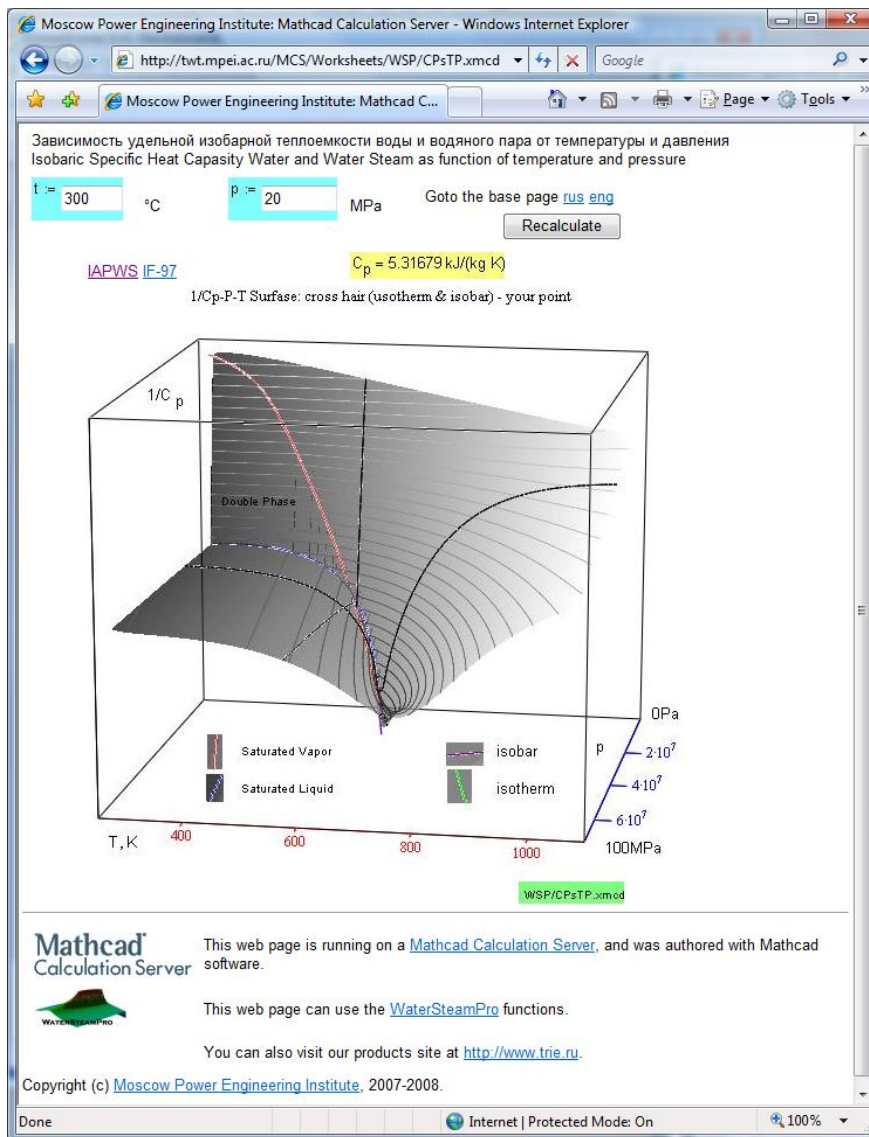
Fig. 16. The surface $1/c_p(p,T)$ of water and steam

The graphical representation of the answer provides the ability to see it dynamically i.e. at changing of input parameters. This is especially valuable in the education process. However, since calculations can be considerably slow when transferring data from the Internet, loading the server by additional work can considerably increase the Internet traffic. Taking that into consideration, the possibility to use sites with pocket computers which have limitations of display size, the special "lightened" pages were created where only numerical answers are returned. One of them is shown in Fig. 17 where access to the Internet is realized with a PDA –Personal Digital Assistant The input data are here pressure p and temperature t. The another combinations of input data are realized on similar sites pairs: pressure –enthalpy, enthalpy –entropy and others.
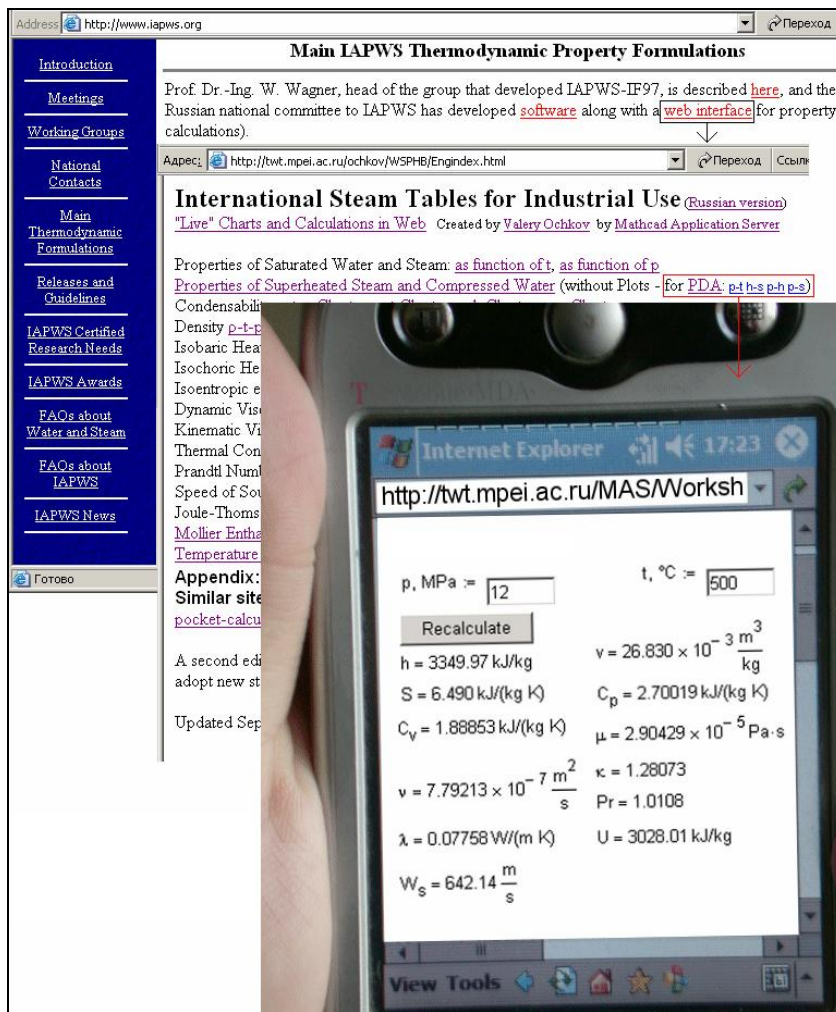
Fig. 17... The page for properties of water and steam in one phase region

But the most universal application is the page with address http://wsp_TextBox.mcd shown in Fig.18. Here the user can input the functions names from the program package **Water SteamPro,** values of one or several dimension arguments, unit for number in answer, number of digits after decimal point and clicking **Recalculate** button, obtain the result.
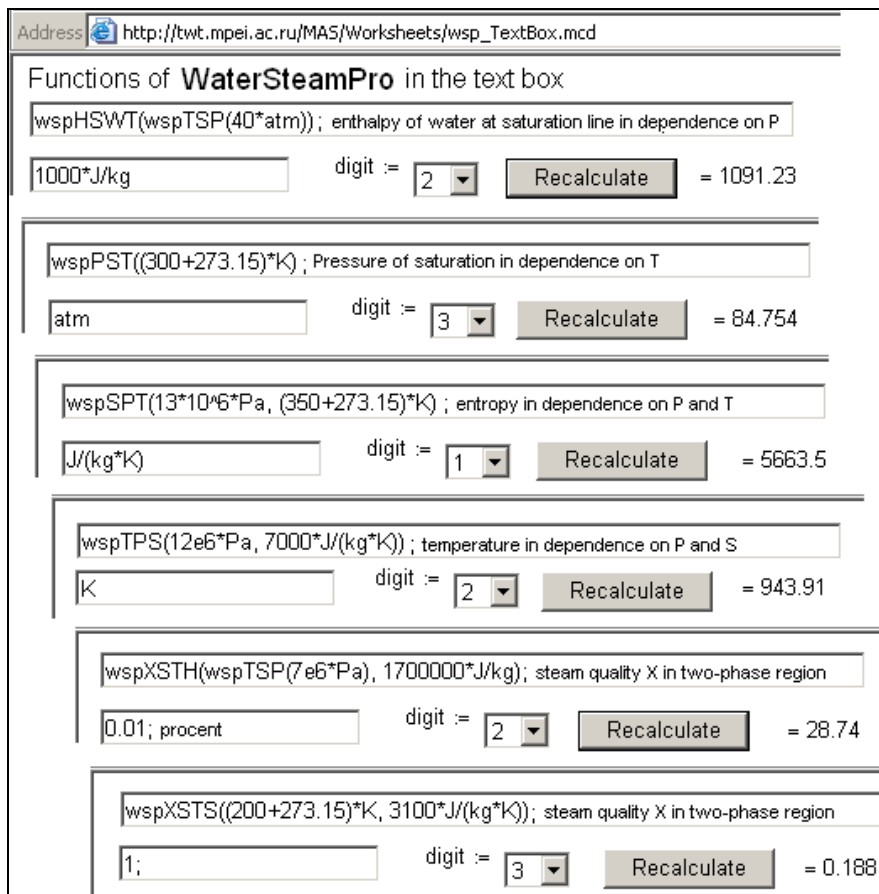
Fig. 18. The universal net document for calculations of properties of water and steam

The list of functions are kept on the site http://twt.mpei.ac.ru/ochkov/VPU_Book_New/mas/WaterSteamProFunctionsList.htm and there is a reference to it on the site shown in Fig. 18. In Fig. 18 the following calculation situations are shown:

- the determination of the enthalpy H at saturation line S of water W in dependence on temperature T – function **wspHSWT**
- the determination of the pressure P of saturation S in dependence on temperature T –function **wspPST** the determination of the entropy S in dependence on pressure P and temperature T (it is entered in Celsius scale and is recalculated to Kelvin) **-**function **wspSPT**
- the determination of the temperature T in dependence on pressure P and entropy S –function **wspTPS**
- the determination of the steam quality X in two-phase region S in dependence on temperature T (function **wpsXSTH** is enclosed into other function **wspTSP**) and enthalpy H
- the determination of the steam quality X in two-phase region S in dependence on temperature T and entropy S –f unction **wspXTS**

The names of functions show its essence –the arguments and property calculated. First part of name (prefix wsp) is abbreviation of the program package WaterSteamPro, then symbol of property calculated (T, P, S, H and other) and parameters follow. Besides, in some cases the abbreviations S (saturation), W (water), S (steam), M (metastable) are included for clarity.

Conclusion

The program package created provides information about the thermophysical properties of water and steam. It may be installed on a users computer or the calculations may be accessed directly from the Internet. In order to work with the package on the Internet it is not necessary to input the long site adrresses each time.. It is enough to tune up menu "Selected" of Internet browser (it is possible to use another browsers: Opera, Netscape, Navigator, etc.). It is necessary only to tune properly the format of the information outlet. It can be fulfilled or manual (by taking the site needed and follow command "Add to Selected") or to download from Internet (from address http://twt.mpei.ac.ru/wsp_Explorer.rar) special settings of browser, to disarchive and place it in "Selected" of own computer. After this, the position "Properties of water and steam" appears automatically in the list of operations of users computer (see Fig. 19) with tree of references to sites described here and references to sites for properties of many other substances used in thermal power.
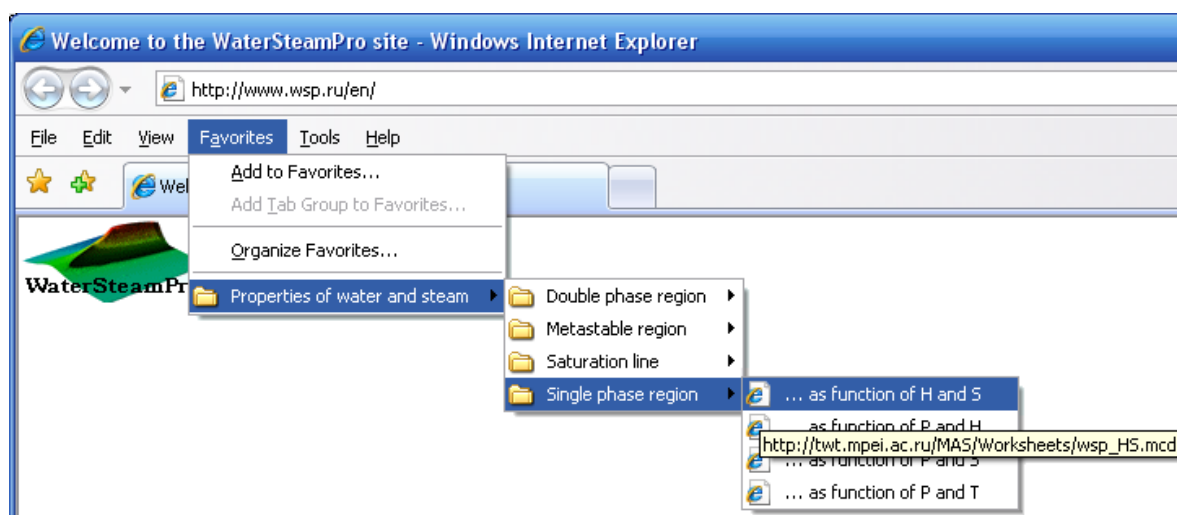
Fig. 19. The pattern of Internet browser tuning for work with sites for properties of water and steam.

Literature

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