Live calculations linked from IAPWS website

Valery Ochkov & Konstantin Orlov

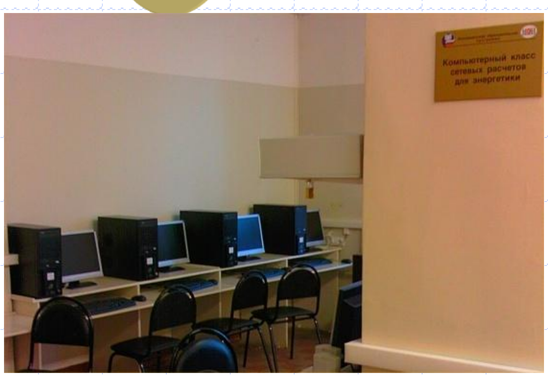
Moscow Power Engineering Institute (National Research University)

From paper book to Internet

Water and Steam Tables for Industrial Use

Calculation Server MPEI

Creators



PDA

SmartPhone

PC or NB

E-Books

Tablets

Internet & Intranet Users

http://twt.mpei.ac.ru/ochkov/VPU_Book_New/mas/eng/index.html

Calculation Server of MPEI (TU)

Contacts Russian version

Search:

Search

Contents

Interactive reference books

- Higher mathematics
- Mathematical functions
- Power & heat engineering
- Water and Steam Properties
- Properties and processes of working substances and materials of nuclear power engineering
- Thermalphysic properties of thermal power engineering working substances
- Hydraulic gas dynamics
- Physical quantities
- Pipelines of heat power plant
- Thermodynamic cycles
- Chemical kinetics

RUSSIAN VERSION

Web-version of reference book

Thermophysical properties of thermal power engineering working substances

Alexandrov A.A., Orlov K.A., Ochkov V.F.

About this reference book >>>

Last update : 16 August 2012

Some calculations are located on two or three servers: MAS11 - Mathcad Application Server 11, MCS14 - Mathcad Calculation Server 14 and sometimes WebMath. You can use anyone.

Show structure of reference book as its contents
"Live" formulations from book
Thermodynamic properties of water and steam
Thermodynamic properties of gases and seawater
Diagrams and graphical dependences

100%

Types of works with the RefBook

- 1. On-line calculations
- 2. Functions download
- 3. References on functions

Types of works with the RefBook

- 1. **On-line calculations**
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Table VI from the e-RefBook

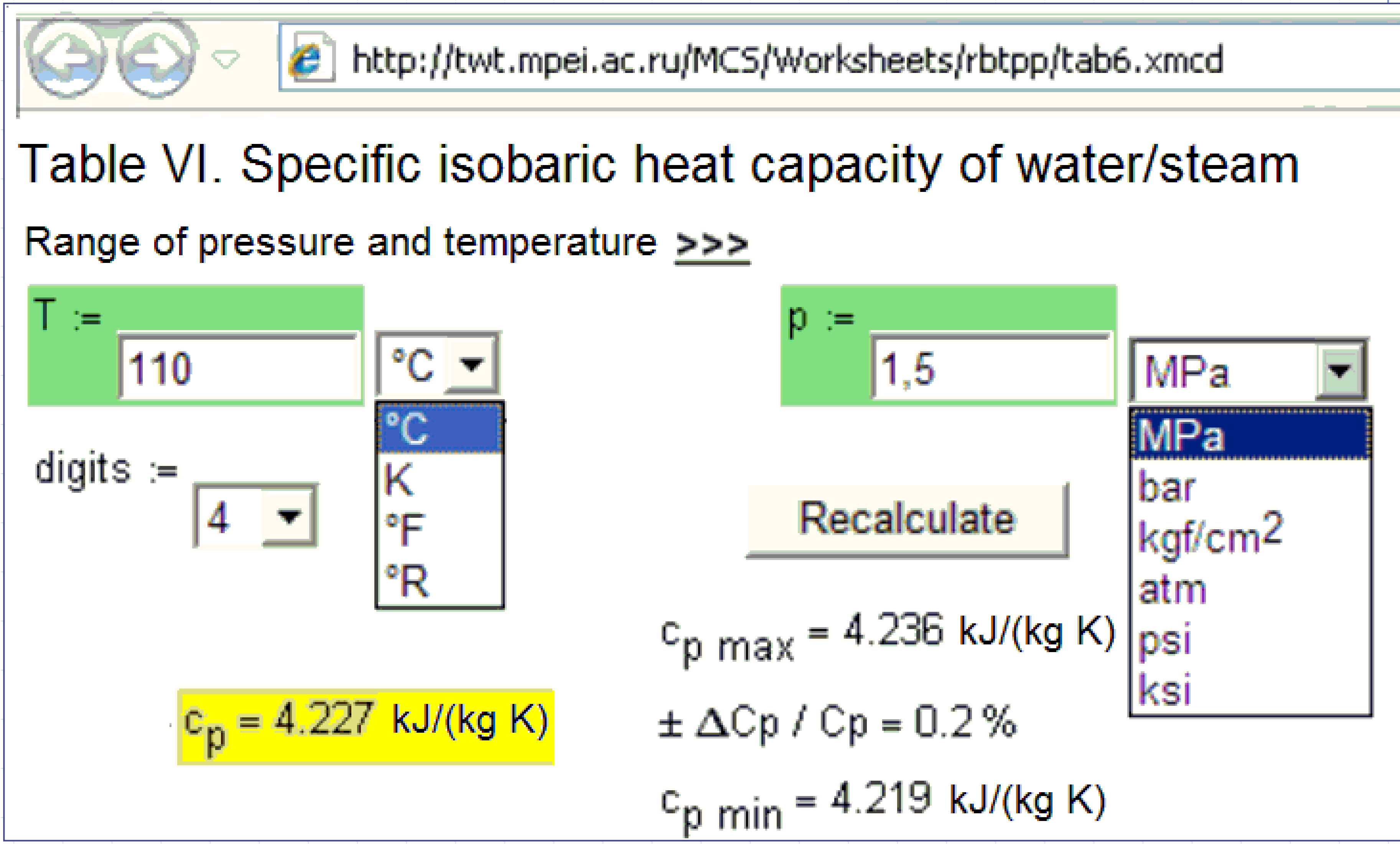
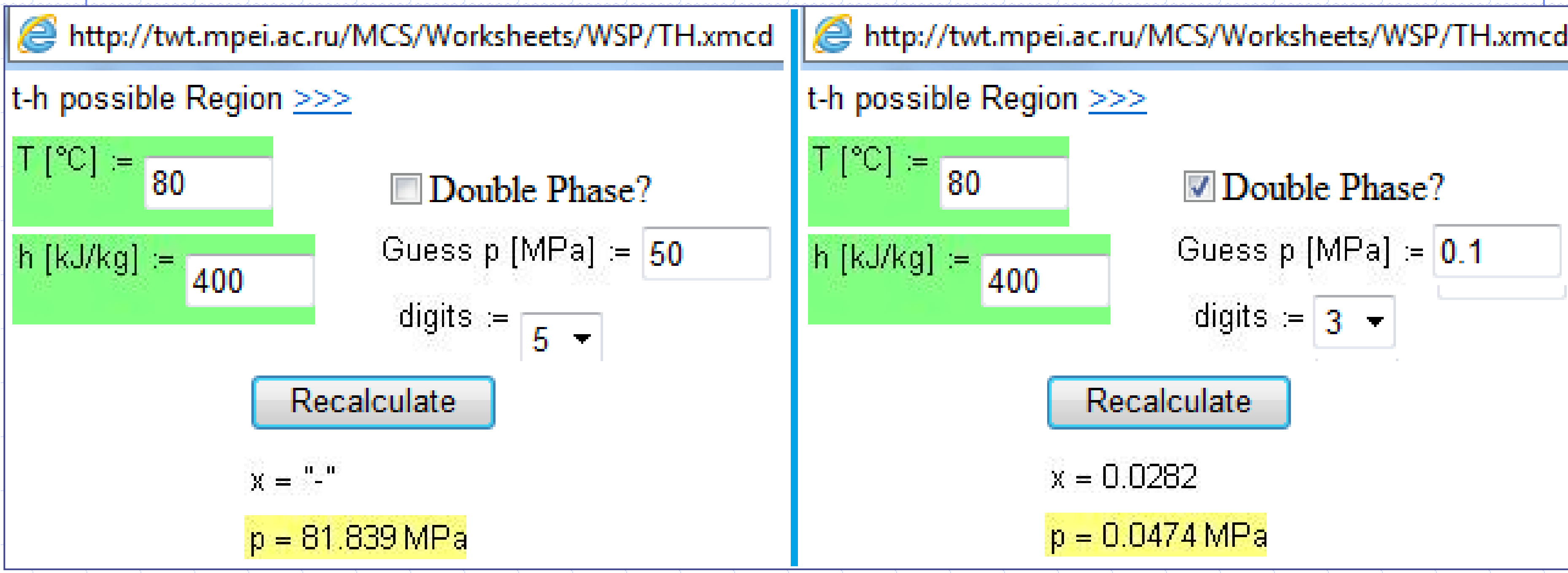
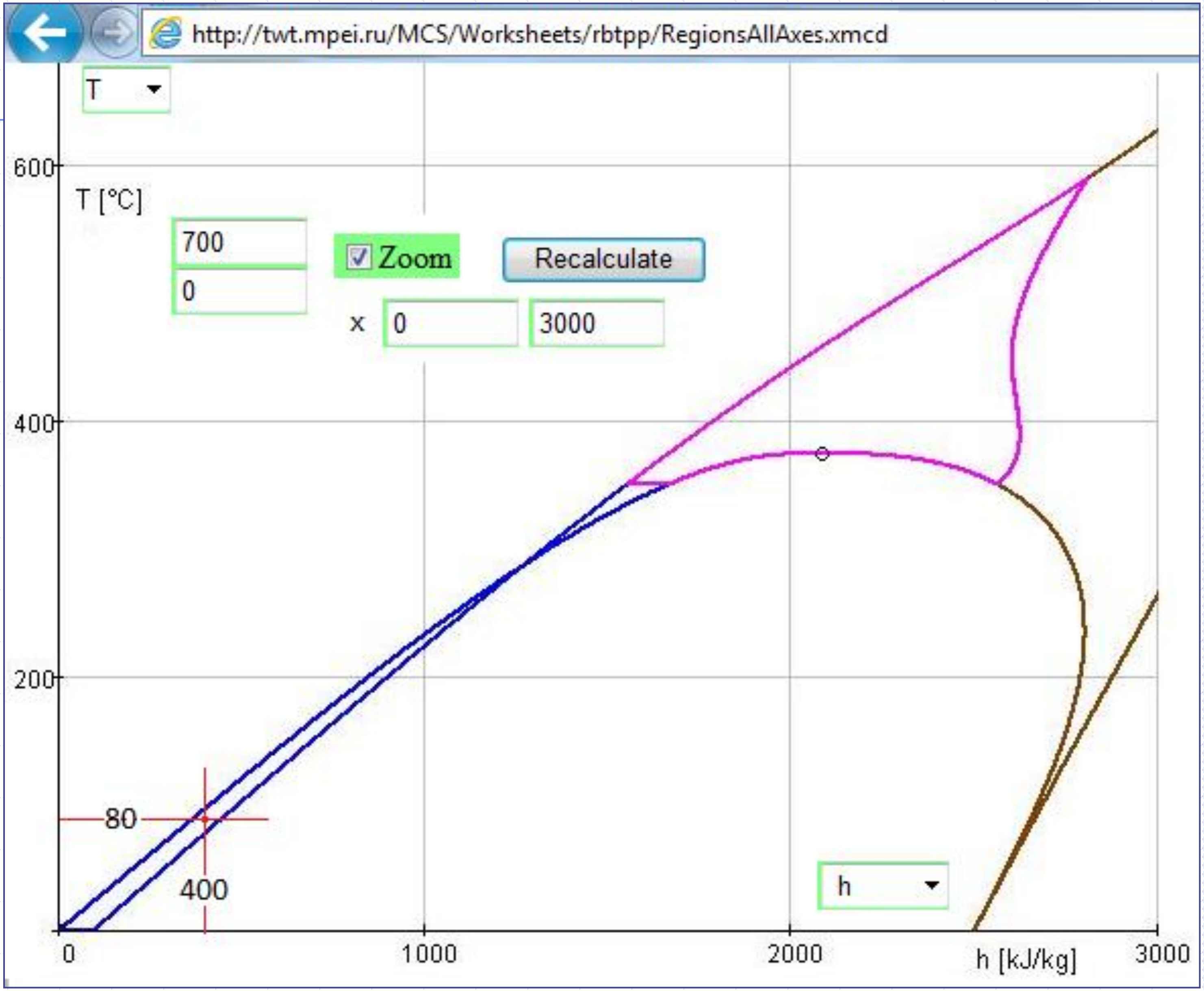


Table from the e-RefBook

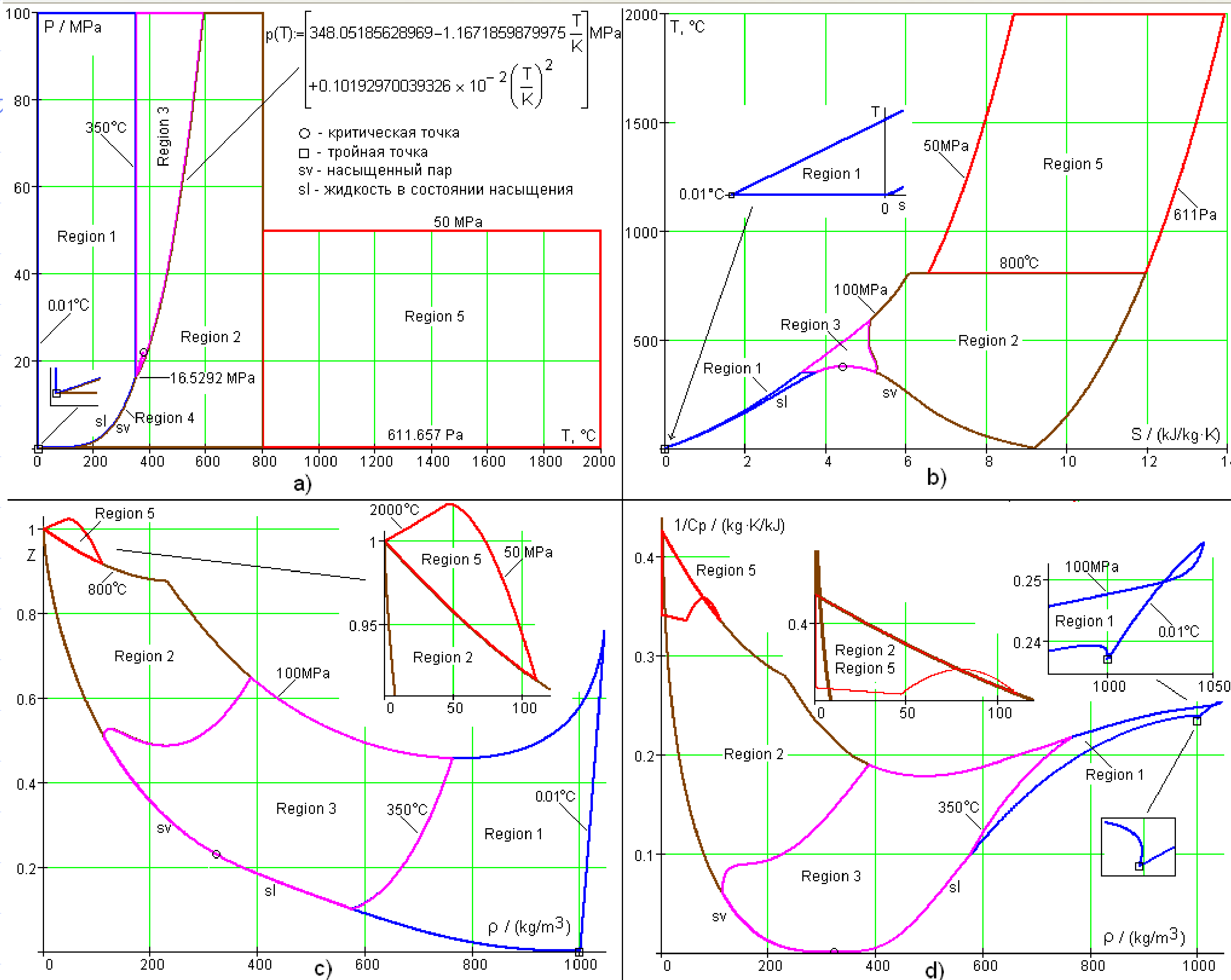


T-h diagram: not one but two points

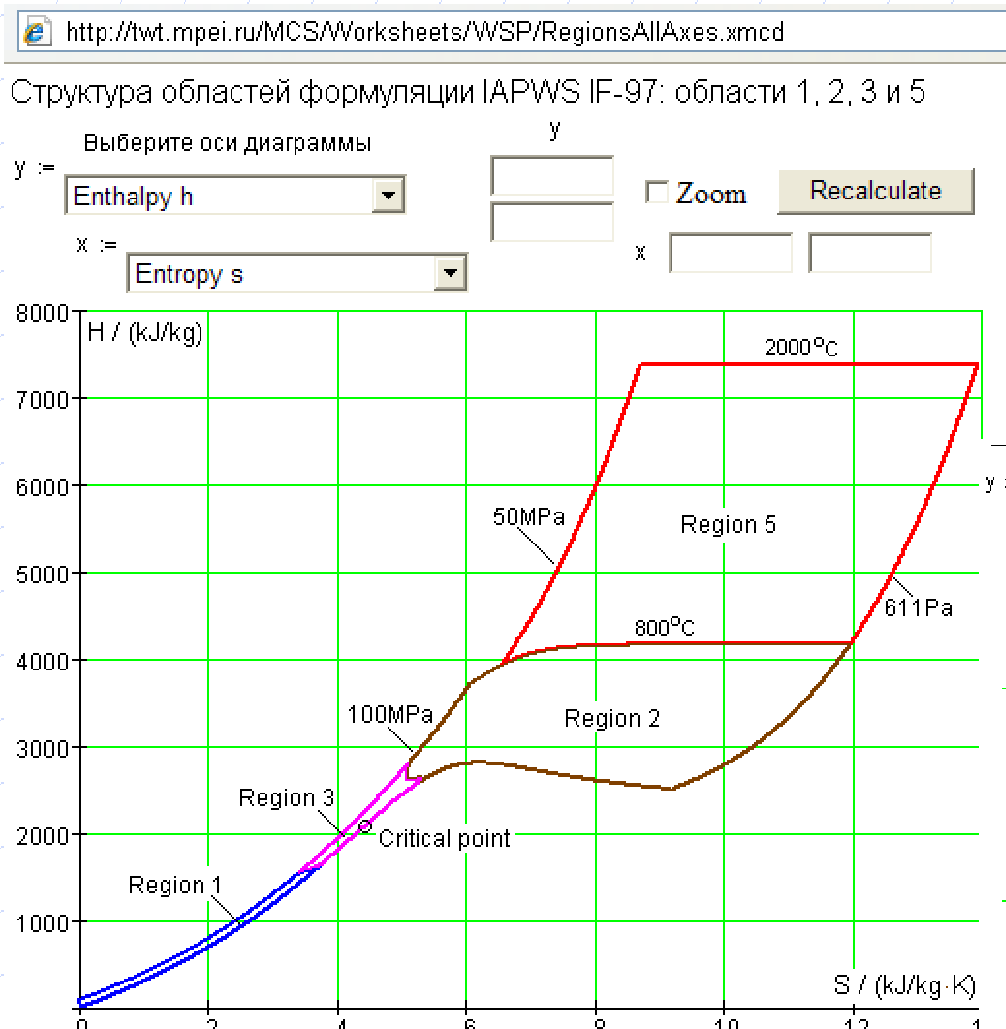


IAPWS IF-97 Regions on Internet with different axes

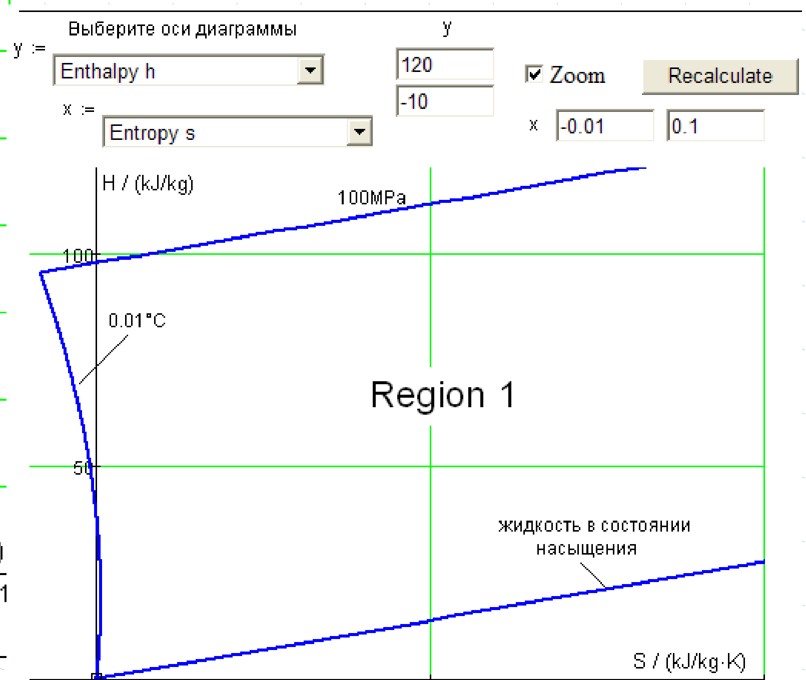
http://twt.mpei.ru/MCS/Worksheets/WSP/RegionsAllAxes.xmcd



IAPWS IF-97 Regions on Internet



a)



b)

Conductivity of water and steam

http://www.iapws.org/relguide/ThCond.htm

Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance (September 2011)

PDF of document

Description

This formulation is recommended for the calculation of the thermal conductivity of ordinary water in its fluid phases.

The formulation consists of a dilute-gas term that is only a function of temperature, a finite-density term as a function of temperature and density, and a near-critical term as a function of temperature and density.

The region of validity the entire stable fluid region from the melting curve to 1173 K at pressures to 100 MPa, with lower maximum temperatures at higher pressures up to 1000 MPa; see the release document for details. It extrapolates in a physically reasonable way outside this region.

Online calculation

The Russian National Committee of IAPWS (through Moscow Power Engineering Institute) has provided online calculation pages, which may be useful in program development and verification. **Note that IAPWS is not responsible for the content of these online calculation pages:**

- for general and scientific use
- for industrial use

Conductivity of water and steam

http://twt.mpei.ac.ru/mcs/worksheets/iapws/wspTCPT.xmcd

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For any questions or suggestions please contact RNC of IAPWS.

Thermal Conductivity of Ordinary Water Substance Calculation based on equations for industrial use

Developed by Russian National Committee (RNC) of
International Association for the Properties of Water and Steam (IAPWS).

This calculation page is based on the
"Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance" [1]
provided by IAPWS.

Detailed information about used equations, constants, range of validity etc is presented in PDF version of IAPWS Release which can be downloaded from IAPWS web site **www.iapws.org**

Authors:

- **Konstantin Orlov** (orlov@twt.mpei.ac.ru)
- **Valery Ochkov** (ochkov@twt.mpei.ac.ru)

Moscow Power Engineering Institute (MPEI). Last update: 2012/03/02
Note that displayed last digits depends on numeric implementation of underlying formulations.

Input parameters

Pressure := 27 MPa   Temperature := 300 °C   Recalculate

Conductivity of water and steam

http://twt.mpei.ac.ru/mcs/worksheets/iapws/wspTCPT.xmcd

$p = 2.7 \times 10^{7}\ \mathrm{Pa}$ $T = 573.15\ \mathrm{K}$

Density for given pressure and temperature

Density value and other thermodynamic properties and derivatives are calculated using RNC implementation of [2].

$$\rho := \mathrm{wspDPT}(p, T) = 746.138076766645\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

Formulation reference values

$$\rho_{refer} := 322.0\ \frac{\mathrm{kg}}{\mathrm{m}^3} \quad T_{refer} := 647.096\mathrm{K} \quad p_{refer} := 22.064\mathrm{MPa} \quad \lambda_{refer} := 1\ \frac{\mathrm{mW}}{\mathrm{m\,K}} \quad \mu_{refer} := 1\mathrm{mk\,Pa\,sec}$$

$$R := 0.46151805\ \frac{\mathrm{kJ}}{\mathrm{kg\,K}}$$

Dimensionless input parameters

$$T_{rel} := \frac{T}{T_{refer}} = 0.88572638372$$

$$\rho_{rel} := \frac{\rho}{\rho_{refer}} = 2.31719899617$$

Main equation

The thermal conductivity is represented by the equation

$$\lambda_{rel} = \lambda 0_{rel}\, \lambda 1_{rel} + \lambda 2_{rel}$$

Eq. (15) in [1]

Conductivity of water and steam

http://twt.mpei.ac.ru/mcs/worksheets/iapws/wspTCPT.xmcd

First factor

This factor represents the thermal conductivity in the dilute-gas limit.

Coefficients from Table 1 [1] (can be downloaded here in text format):

$$L := \begin{pmatrix} 2.443221 \times 10^{-3} \\ 1.323095 \times 10^{-2} \\ 6.770357 \times 10^{-3} \\ -3.454586 \times 10^{-3} \\ 4.096266 \times 10^{-4} \end{pmatrix}$$

$$\lambda 0_{rel} := \frac{\sqrt{T_{rel}}}{\sum_{k=0}^{4} \frac{L_k}{T_{rel}^{\,k}}} = 43.359733160195$$

Eq. (16) in [1]

Second factor

The second factor represents the contribution to thermal conductivity due to finite density.

Coefficients from Table 2 [1] (can be downloaded here in text format):

$$L := \begin{pmatrix} 1.60397357 & -0.646013523 & 0.111443906 & 0.102997357 & -0.0504123634 & 0.00609859258 \\ 2.33771842 & -2.78843778 & 1.53616167 & -0.463045512 & 0.0832827019 & -0.00719201245 \\ 2.19650529 & -4.54580785 & 3.55777244 & -1.40944978 & 0.275418278 & -0.0205938816 \\ -1.21051378 & 1.60812989 & -0.621178141 & 0.0716373224 & 0 & 0 \\ -2.7203370 & 4.57586331 & -3.18369245 & 1.1168348 & -0.19268305 & 0.012913842 \end{pmatrix}$$

$$\lambda 1_{rel} := \exp\left[\rho_{rel} \sum_{i=0}^{4} \left[\left(\frac{1}{T_{rel}} - 1\right)^i \sum_{j=0}^{5} \left[L_{i,j} \left(\rho_{rel} - 1\right)^j\right]\right]\right] = 13.287255087768$$

Eq. (17) in [1]

Conductivity of water and steam

http://twt.mpei.ac.ru/mcs/worksheets/iapws/wspTCPT.xmcd

Critical enhancement

The additive contribution represents the critical enhancement of the thermal conductivity.

Additional constants from Table 3 [1]:

$\Lambda := 177.8514 \quad q_D := \frac{1}{0.40\,\mathrm{nm}} \quad \nu := 0.630 \quad \gamma := 1.239 \quad \xi_0 := 0.13\,\mathrm{nm} \quad \Gamma_0 := 0.06 \quad T_R := 1.5$

Additional thermophysical properties for given pressure and temperature

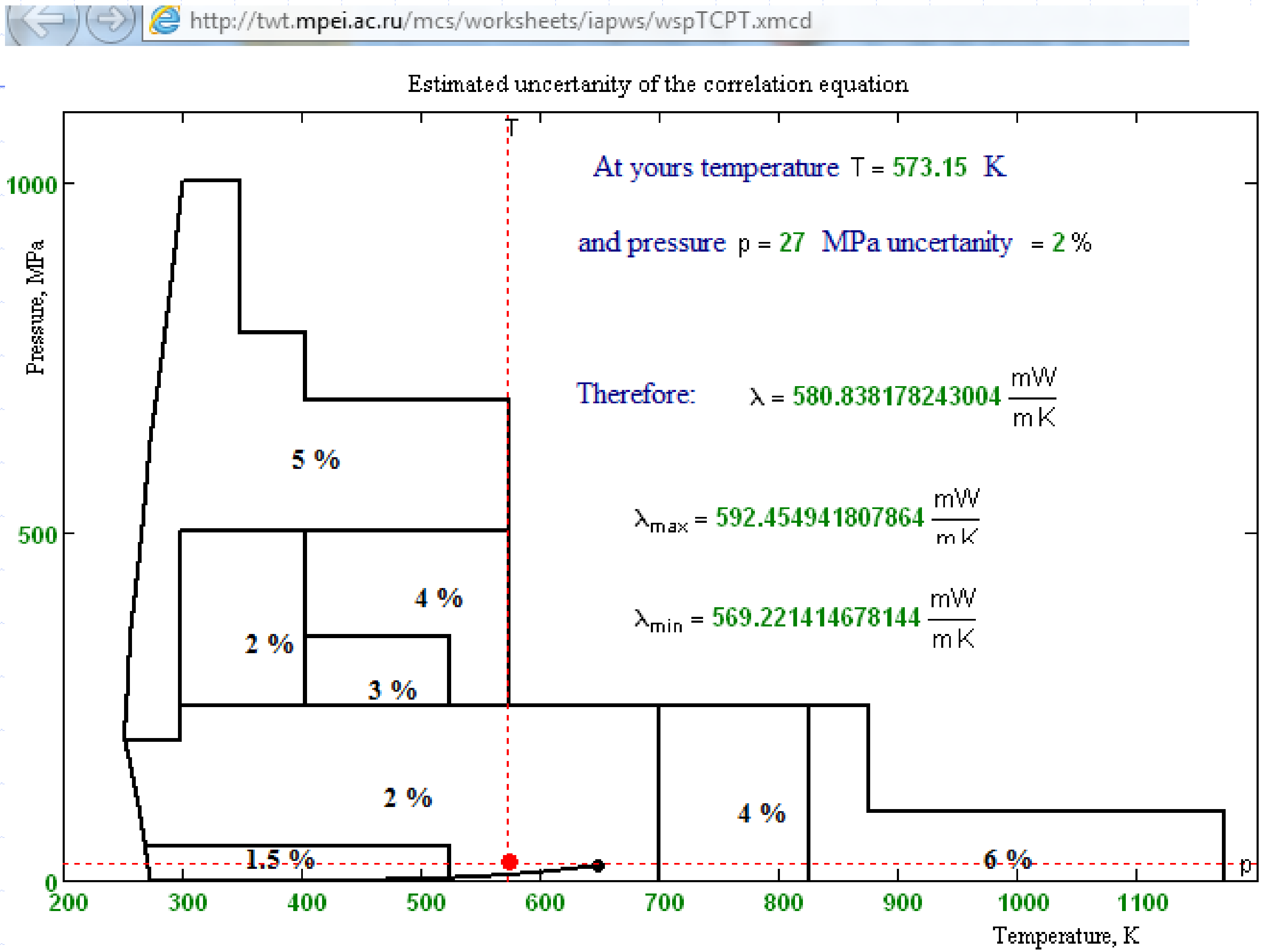
Viscosity is calculated using RNC implementation of [3] for industrial use:

$\mu := \mathrm{wspDYNVISRT}(\rho, T) = 92.346297069543\ \mathrm{mk\,Pa\,sec}$

Relative viscosity: $\mu_{rel} := \frac{\mu}{\mu_{refer}} = 92.346297069543$

Isobaric specific heat capacity: $c_p := \mathrm{wspCPPT}(p, T) = 5.143276209527\ \frac{\mathrm{kJ}}{\mathrm{kg\,K}}$

Conductivity of water and steam



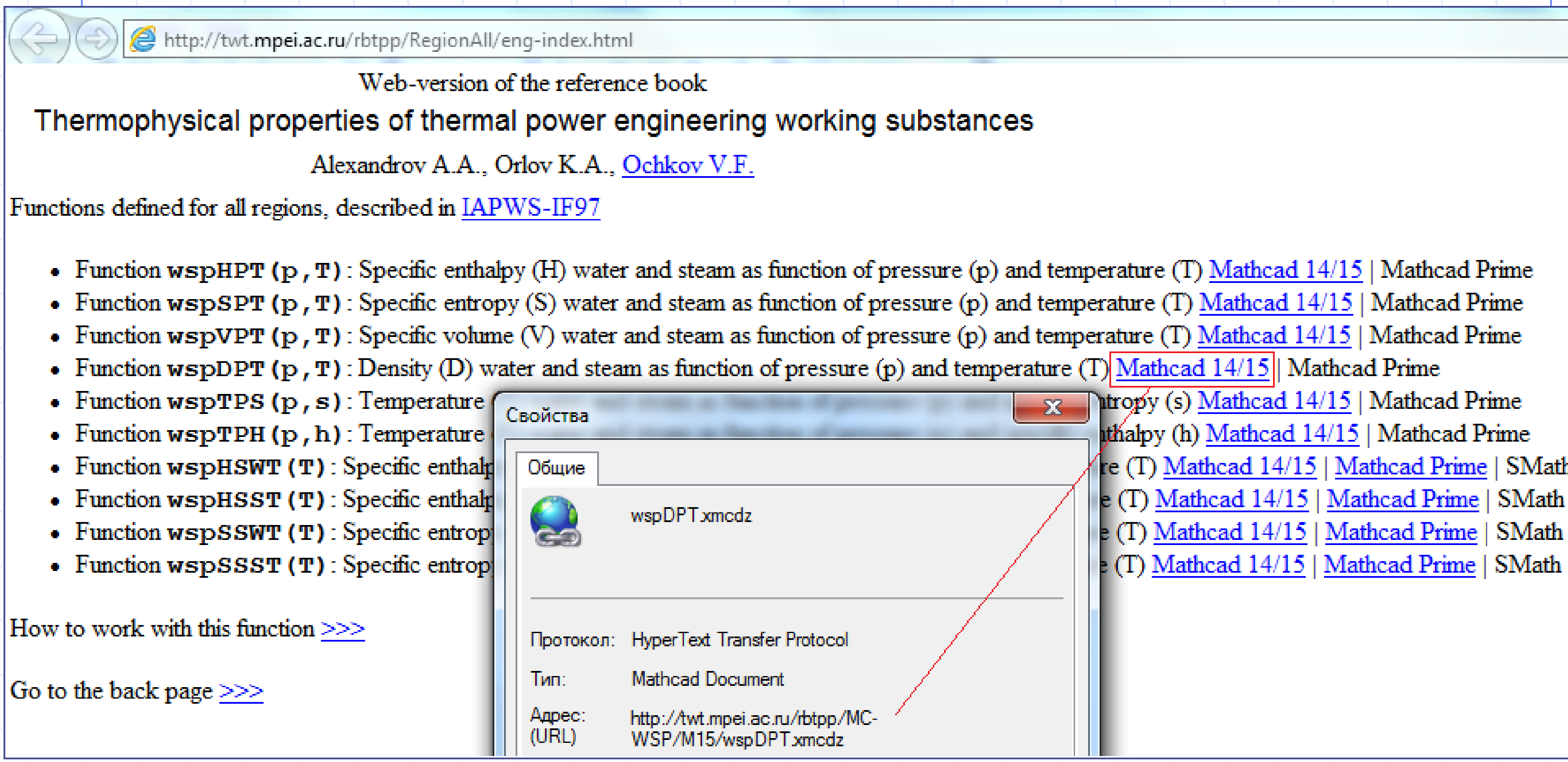
What we would like to see on the IAPWS site?

- All live formulations
- All live and cloud functions with all combinations of input data (p, s, h, T, D, x…) for all regions of water/steam
- Examples of using IAPWS-cloud-functions for industrial purposes
- 3D live plots, animations etc

Types of works with the RefBook

- 1. On-line calculations
- 2. Functions download
- 3. **References on functions**

Property of the link



http://twt.mpei.ac.ru/rbtpp/RegionAll/eng-index.html

Web-version of the reference book

Thermophysical properties of thermal power engineering working substances

Alexandrov A.A., Orlov K.A., Ochkov V.F.

Functions defined for all regions, described in IAPWS-IF97

- Function **wspHPT(p,T)**: Specific enthalpy (H) water and steam as function of pressure (p) and temperature (T) Mathcad 14/15 | Mathcad Prime
- Function **wspSPT(p,T)**: Specific entropy (S) water and steam as function of pressure (p) and temperature (T) Mathcad 14/15 | Mathcad Prime
- Function **wspVPT(p,T)**: Specific volume (V) water and steam as function of pressure (p) and temperature (T) Mathcad 14/15 | Mathcad Prime
- Function **wspDPT(p,T)**: Density (D) water and steam as function of pressure (p) and temperature (T) Mathcad 14/15 | Mathcad Prime
- Function **wspTPS(p,s)**: Temperature ... ntropy (s) Mathcad 14/15 | Mathcad Prime
- Function **wspTPH(p,h)**: Temperature ... thalpy (h) Mathcad 14/15 | Mathcad Prime
- Function **wspHSWT(T)**: Specific enthalp... re (T) Mathcad 14/15 | Mathcad Prime | SMath
- Function **wspHSST(T)**: Specific enthalp... e (T) Mathcad 14/15 | Mathcad Prime | SMath
- Function **wspSSWT(T)**: Specific entrop... e (T) Mathcad 14/15 | Mathcad Prime | SMath
- Function **wspSSST(T)**: Specific entrop... e (T) Mathcad 14/15 | Mathcad Prime | SMath

How to work with this function >>>

Go to the back page >>>

Свойства

Общие

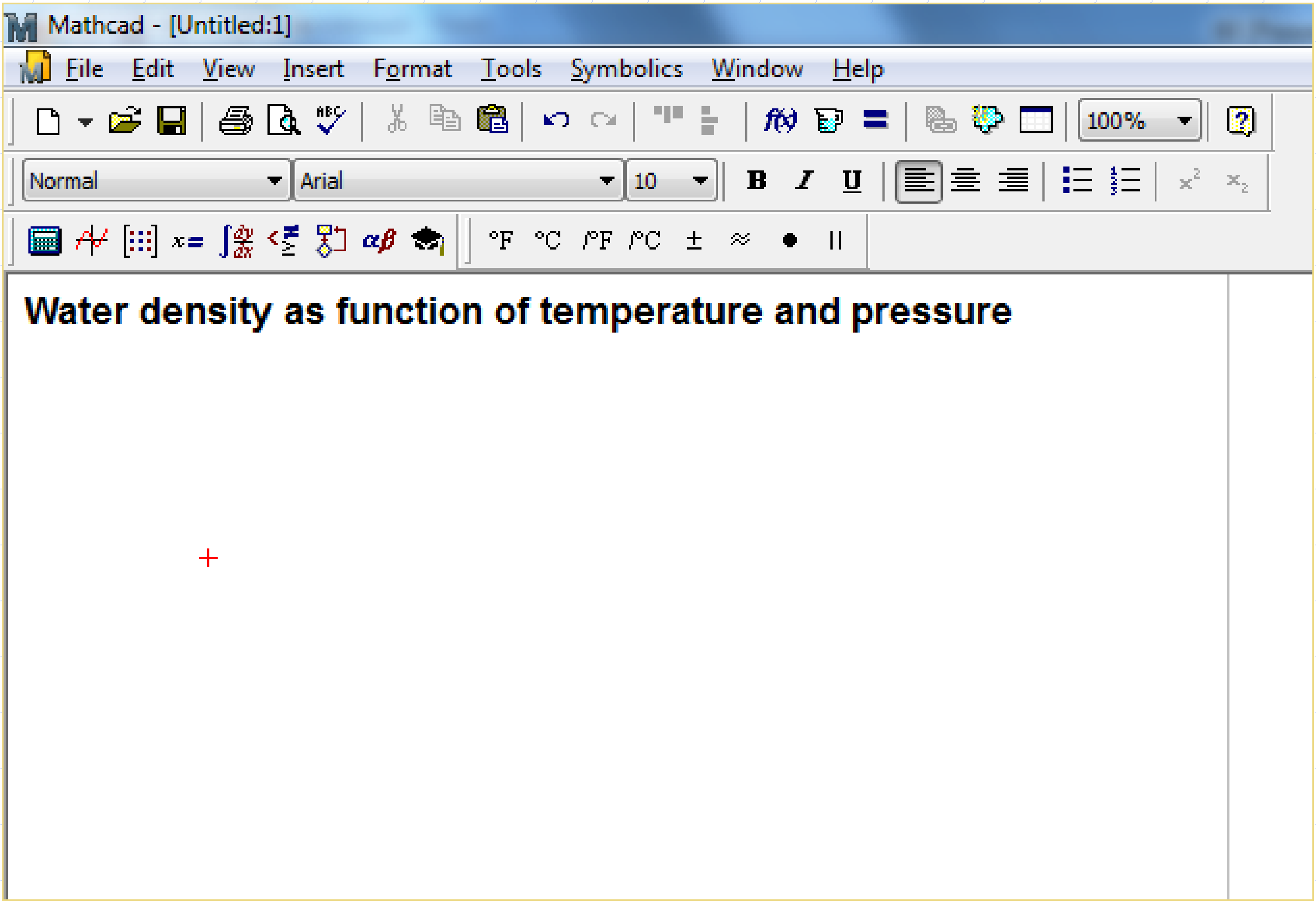
wspDPT.xmcdz

Протокол: HyperText Transfer Protocol

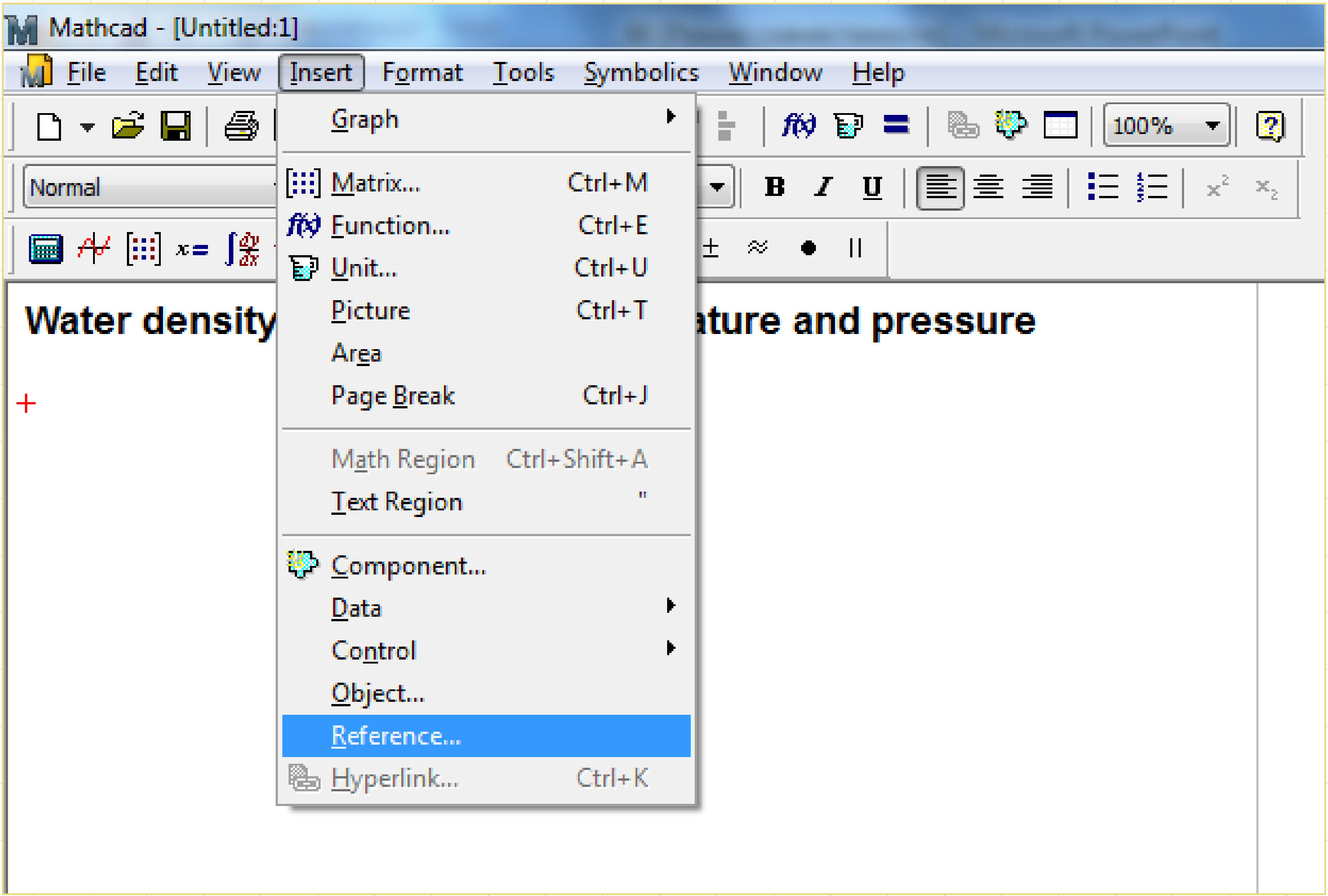
Тип: Mathcad Document

Адрес: (URL) http://twt.mpei.ac.ru/rbtpp/MC-WSP/M15/wspDPT.xmcdz

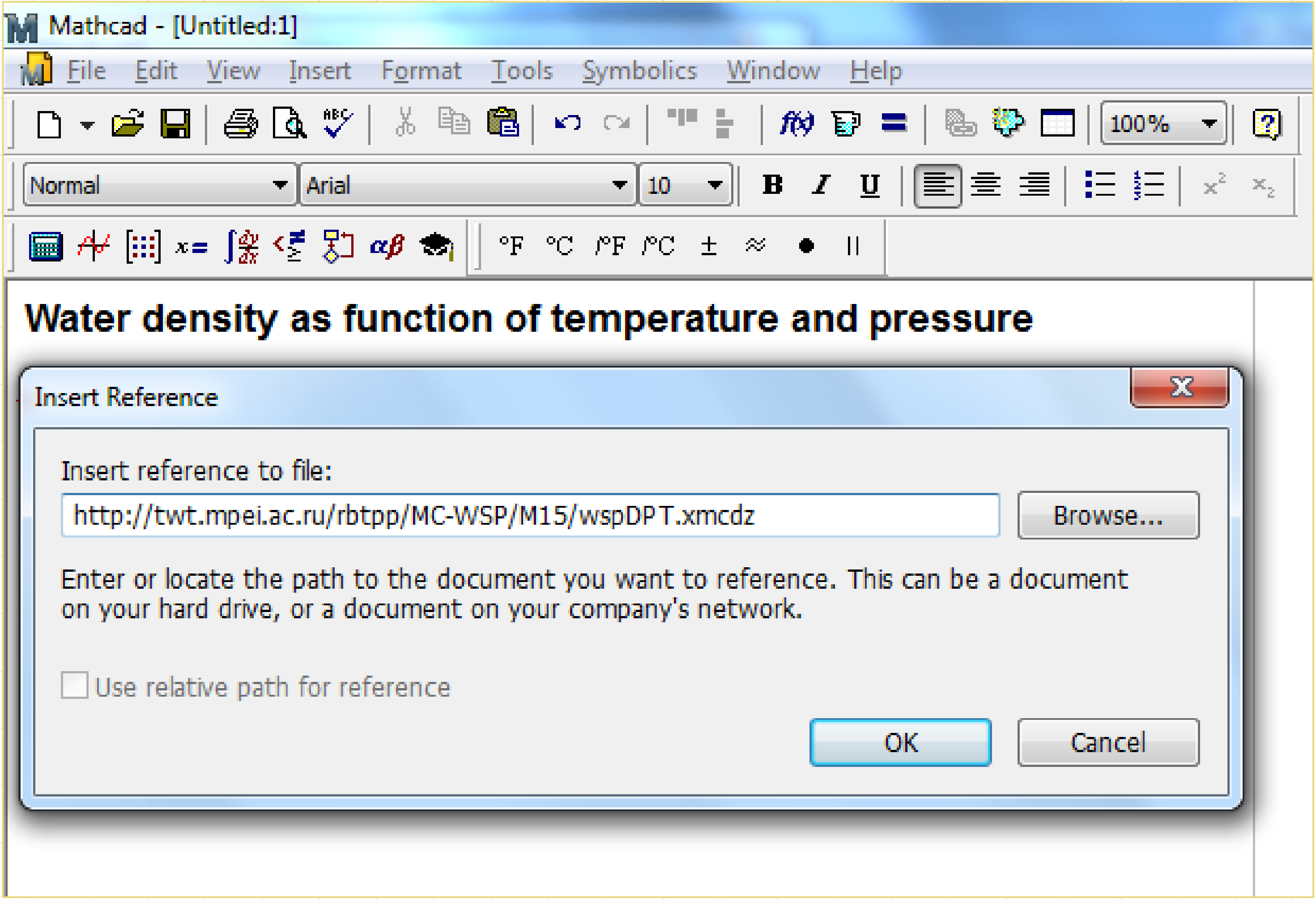
1-st work step - comments



2-d work step - Reference



3-d work step – Insert Address

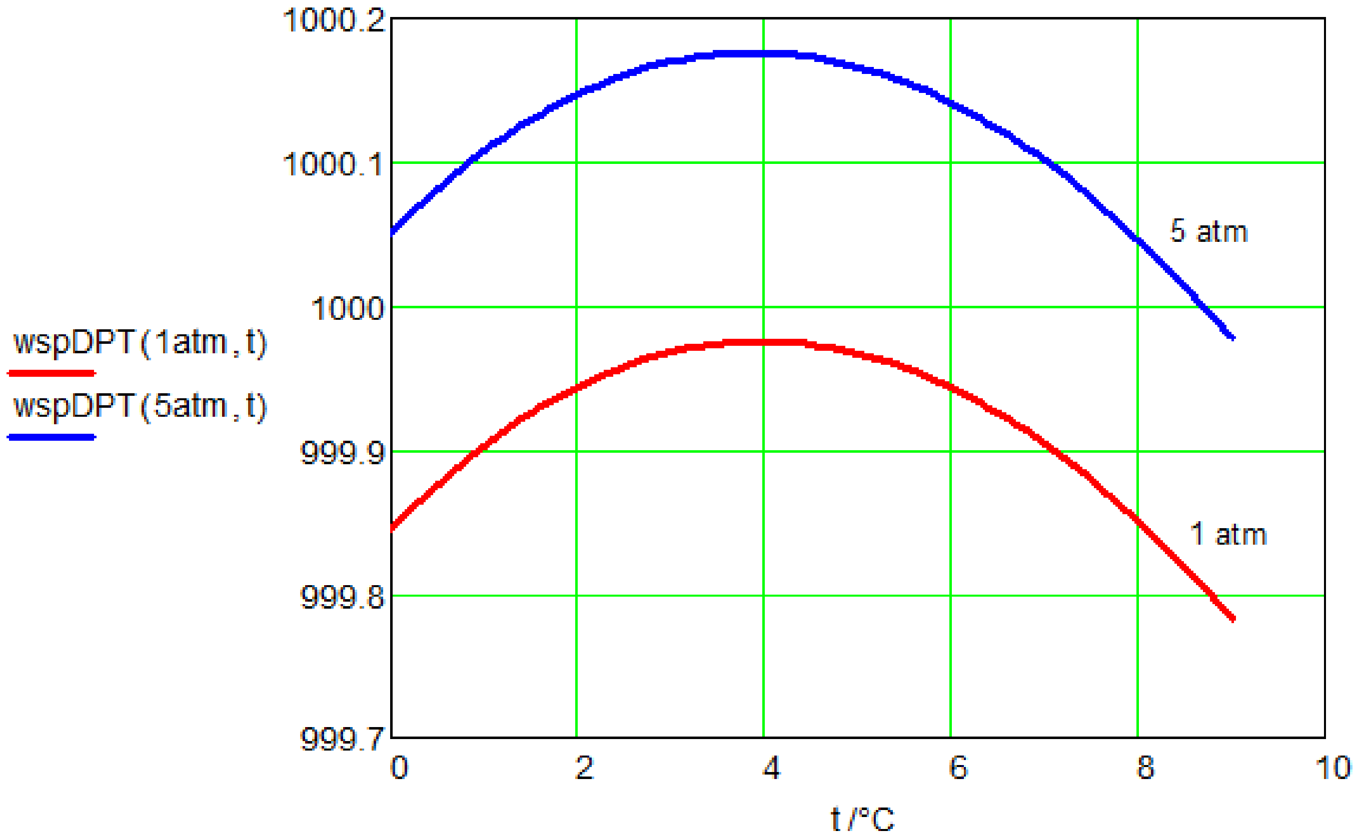


Finish - calculations

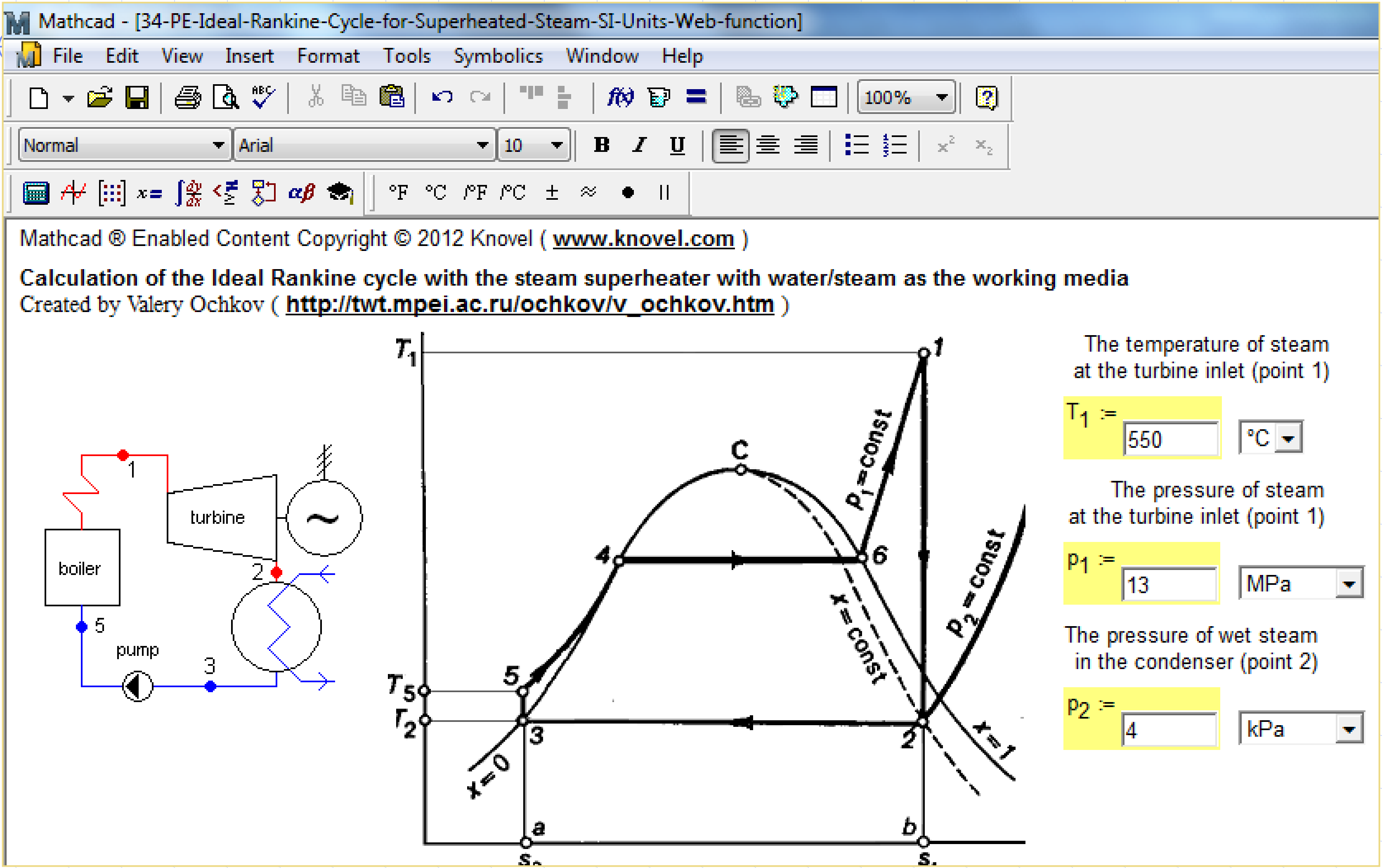
Water density as function of temperature and pressure

Reference:http://twt.mpei.ac.ru/rbtpp/MC-WSP/M15/wspDPT.xmcdz

t := 0 °C , 0.1 °C .. 9 °C



Rankine cycle with IAPWS-cloud-functions



Rankine cycle with IAPWS-cloud-functions

The specific enthalpy of steam at the turbine inlet - Link on the the Cloud-function on the site **http://www.trie.ru**:

Reference:http://twt.mpei.ac.ru/rbtpp/wspH2PT.xmcdz

$h_1 := \text{wspH2PT}(p_1, T_1) = 3471.39 \text{ kJ/kg}$

The specific entropy of steam at the turbine inlet

Reference:http://twt.mpei.ac.ru/rbtpp/wspS2PT.xmcdz

$s_1 := \text{wspS2PT}(p_1, T_1) = 6.609 \text{ kJ/(kg K)}$

The specific entropy of wet steam at the turbine outlet:

$s_2 := s_1 = 6.609 \text{ kJ/(kg K)}$

The temperature of wet steam at the turbine outlet

Reference:http://twt.mpei.ac.ru/rbtpp/wspTSP.xmcdz

$T_2 := \text{wspTSP}(p_2) = 28.96 \,°\text{C}$

The specific entropy of saturated steam at temperature T_2

Reference:http://twt.mpei.ac.ru/rbtpp/wspSSST.xmcdz

$s_{2ss} := \text{wspSSST}(T_2) = 8.473 \text{ kJ/(kg K)}$

The specific entropy of saturated water at temperature T_2

Reference:http://twt.mpei.ac.ru/rbtpp/wspSSWT.xmcdz

$s_{2sw} := \text{wspSSWT}(T_2) = 0.422 \text{ kJ/(kg K)}$

The dryness fraction of wet steam at the turbine outlet:

$$x_2 := \frac{s_2 - s_{2sw}}{s_{2ss} - s_{2sw}} = 76.84\,\%$$

Rankine cycle with IAPWS-cloud-functions

The specific enthalpy of saturated steam at temperature T_2

Reference:http://twt.mpei.ac.ru/rbtpp/wspHSST.xmcdz

$h_{2ss} := \mathrm{wspHSST}(T_2) = 2553.71\ \mathrm{kJ/kg}$

The specific enthalpy of saturated water at temperature T_2

Reference:http://twt.mpei.ac.ru/rbtpp/wspHSWT.xmcdz

$h_{2sw} := \mathrm{wspHSWT}(T_2) = 121.4\ \mathrm{kJ/kg}$

The specific enthalpy of wet steam at the turbine outlet: $h_2 := x_2(h_{2ss} - h_{2sw}) + h_{2sw} = 1990.35\ \mathrm{kJ/kg}$

The enthalpy of water at the pumpr inlet: $h_3 := h_{2sw} = 121.404\ \mathrm{kJ/kg}$

The entropy of water at the pumpr inlet: $s_3 := s_{2sw} = 0.422\ \mathrm{kJ/(kg\ K)}$

The specific entropy of water at the boiler inlet: $s_5 := s_3 = 0.422\ \mathrm{kJ/(kg\ K)}$

The temperature of water at the boiler inlet

Reference:http://twt.mpei.ac.ru/rbtpp/wspT1PS.xmcdz

$T_5 := \mathrm{wspT1PS}(p_1, s_5) = 29.24\ °\mathrm{C}$

The specific enthalpy of water at the boiler inlet

Reference:http://twt.mpei.ac.ru/rbtpp/wspH1PT.xmcdz

$h_5 := \mathrm{wspH1PT}(p_1, T_5) = 134.404\ \mathrm{kJ/kg}$

The heat added in the boiler: $q_1 := h_1 - h_5 = 3336.99\ \mathrm{kJ/kg}$

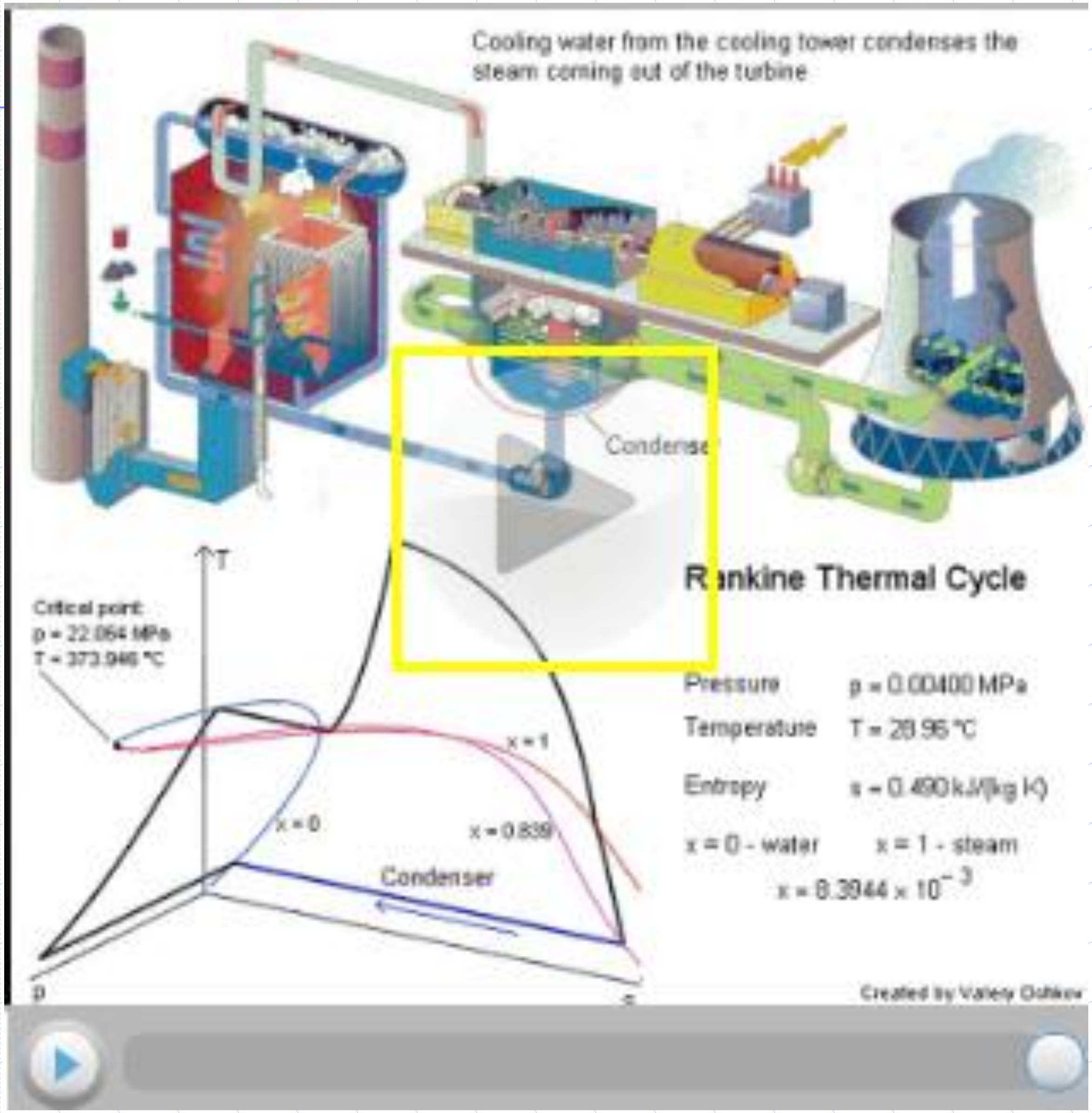
The turbine mechanical work: $l_{turb} := h_1 - h_2 = 1481.04\ \mathrm{kJ/kg}$

The heat rejected in the condenser: $q_2 := h_2 - h_3 = 1868.94\ \mathrm{kJ/kg}$

The pump mechanical work: $l_{pump} := h_5 - h_3 = 13.001\ \mathrm{kJ/kg}$

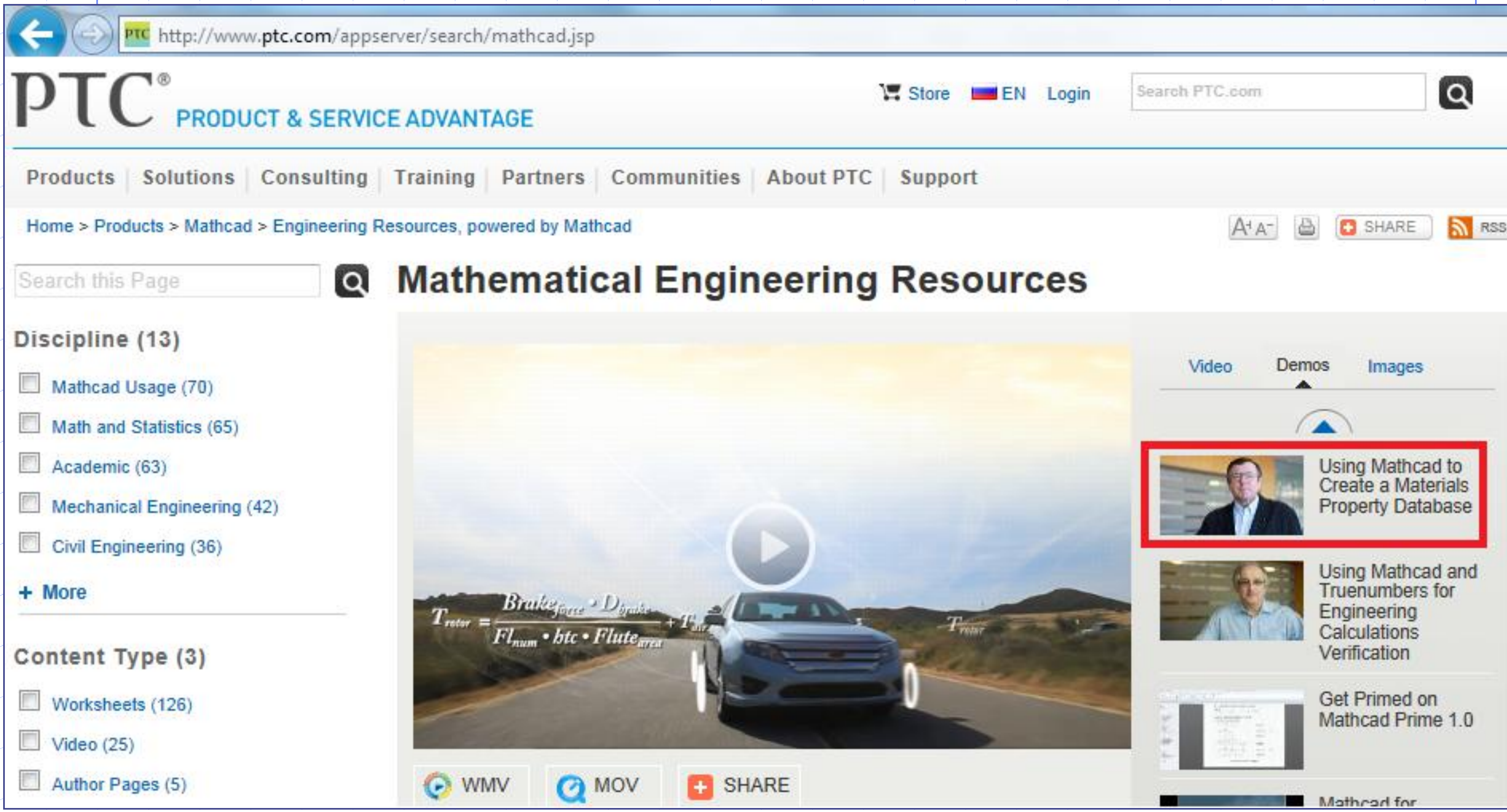
The thermal efficiency of the cycle: $\eta_t := \dfrac{q_1 - q_2}{q_1} = 43.99\ \%$

Animations

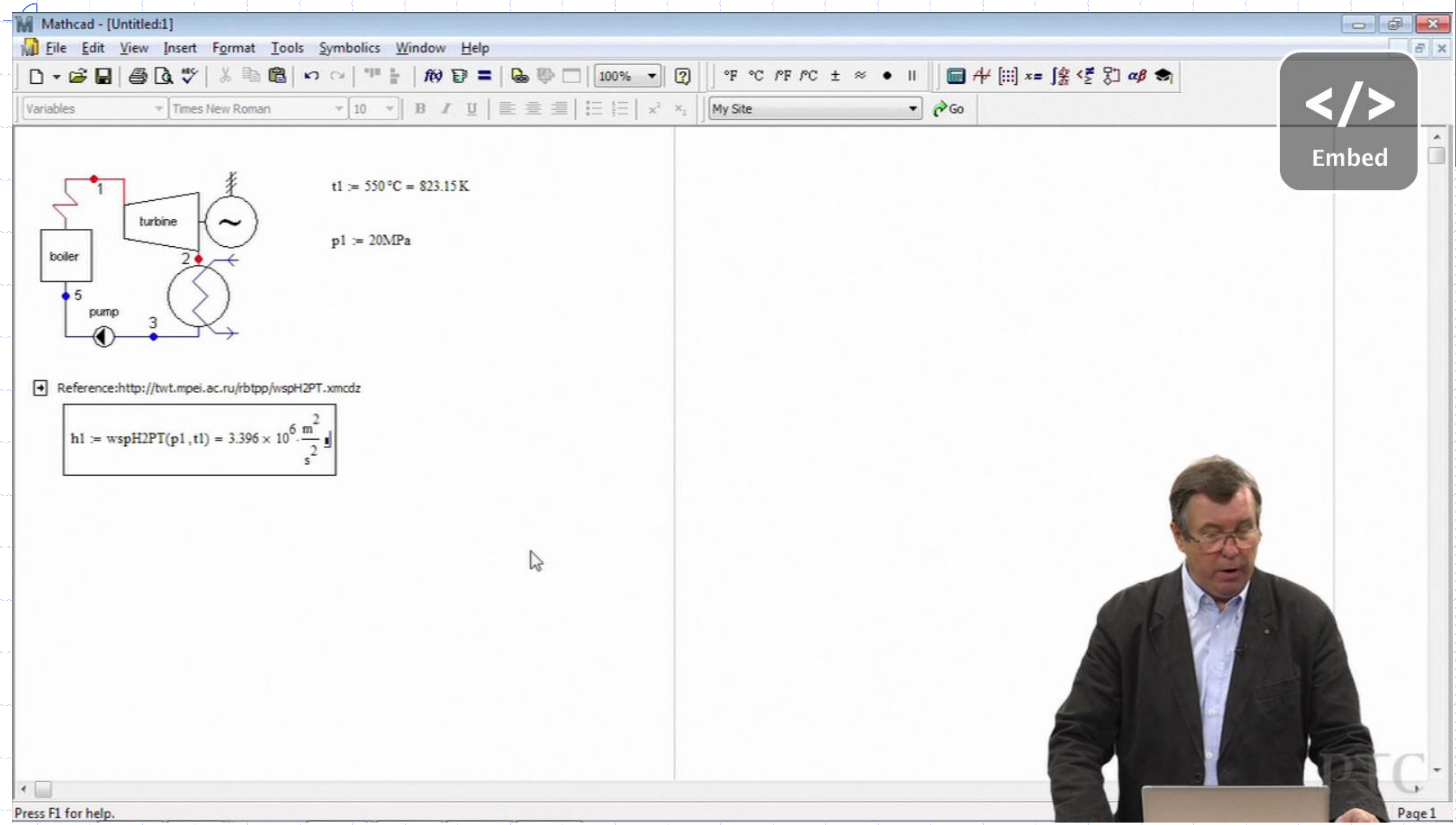


Cooling water from the cooling tower condenses the steam coming out of the turbine
Condenser
Rankine Thermal Cycle
Critical point:
p = 22.064 MPa
T = 373.946 °C
Pressure p = 0.00400 MPa
Temperature T = 28.96 °C
Entropy s = 0.490 kJ/(kg K)
x = 0 - water x = 1 - steam
x = 8.3944 x 10^-3
x = 1
x = 0
x = 0.839
Condenser
Created by Valery Ochkov

This topic on the PTC-site



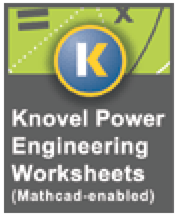
This movie on the PTC-site



This topic on the Knovel-site

http://www.knovel.com

Knovel® search knovel... Options ▾ Search ▸ Recent Searches



Title Details

Citation

Knovel Power Engineering Worksheets (Mathcad-enabled)

By: Ochkov, Valery © 2012 Knovel

Description: Knovel's Power Engineering Worksheets are a collection of over 370 worksheets specific to power generation and engineering and enabled by Mathcad. Areas of coverage include mathematics and motion; steam generation; water treatment; thermodynamics of ethanol, gases, water, and steam; and thermal conductivity and quasistatic Young's Modulus of metals and alloys. Mathcad is a computer-aided design platform with calculation and graphic capabilities which can be used to transcribe engineering content into solutions.
[Mathcad 14 or 15 is required.]

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Pressure of Water and Steam near Critical Point (Region 3 IAPWS-IF97) as a Function of Density and Temperature (SI Units)	50 %	Mathcad	Text
Pressure of Water and Steam near Critical Point (Region 3 IAPWS-IF97) as a Function of Density and Temperature (US Units)	50 %	Mathcad	Text
Pressure of Water and/or Steam as a Function of Density and Temperature (SI Units)	50 %	Mathcad	Text
Pressure of Water and/or Steam as a Function of Density and Temperature (US Units)	50 %	Mathcad	Text
Properties of Water and Steam - IAPWS-IF97 Region 1 (Water) (SI Units)	50 %	Mathcad	Text
Properties of Water and Steam - IAPWS-IF97 Region 1 (Water) (US Units)	50 %	Mathcad	Text
Properties of Water and Steam - IAPWS-IF97 Region 2 (Steam) (SI Units)	50 %		

Thank you