

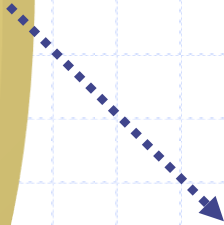
# Live calculations linked from IAPWS website

Valery Ochkov & Konstantin Orlov  
Moscow Power Engineering Institute  
(National Research University)



Creators

# Calculation Server MPEI



PDA



SmartPhone



PC or NB



E-Books



Tablets

Internet & Intranet Users



http://twf.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%

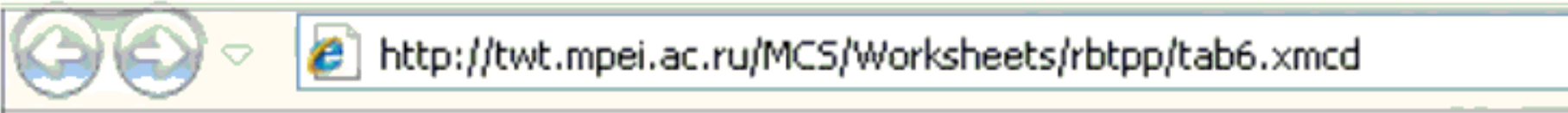
# Types of works with the RefBook

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

# Types of works with the RefBook

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

# Table VI from the e-RefBook



## Table VI. Specific isobaric heat capacity of water/steam

Range of pressure and temperature >>>

T :=  °C

digits :=

°C  
K  
°F  
°R

p :=  MPa

Recalculate

MPa  
bar  
kgf/cm<sup>2</sup>  
atm  
psi  
ksi

$c_p = 4.227 \text{ kJ/(kg K)}$

$c_{p \text{ max}} = 4.236 \text{ kJ/(kg K)}$

$\pm \Delta C_p / C_p = 0.2 \%$

$c_{p \text{ min}} = 4.219 \text{ kJ/(kg K)}$

# Table from the e-RefBook

<http://tw.t.mpei.ac.ru/MCS/Worksheets/WSP/TH.xmcd>

t-h possible Region >>>

T [°C] := 80

Double Phase?

h [kJ/kg] := 400

Guess p [MPa] := 50

digits := 5

Recalculate

x = "-"

p = 81.839 MPa

<http://tw.t.mpei.ac.ru/MCS/Worksheets/WSP/TH.xmcd>

t-h possible Region >>>

T [°C] := 80

Double Phase?

h [kJ/kg] := 400

Guess p [MPa] := 0.1

digits := 3

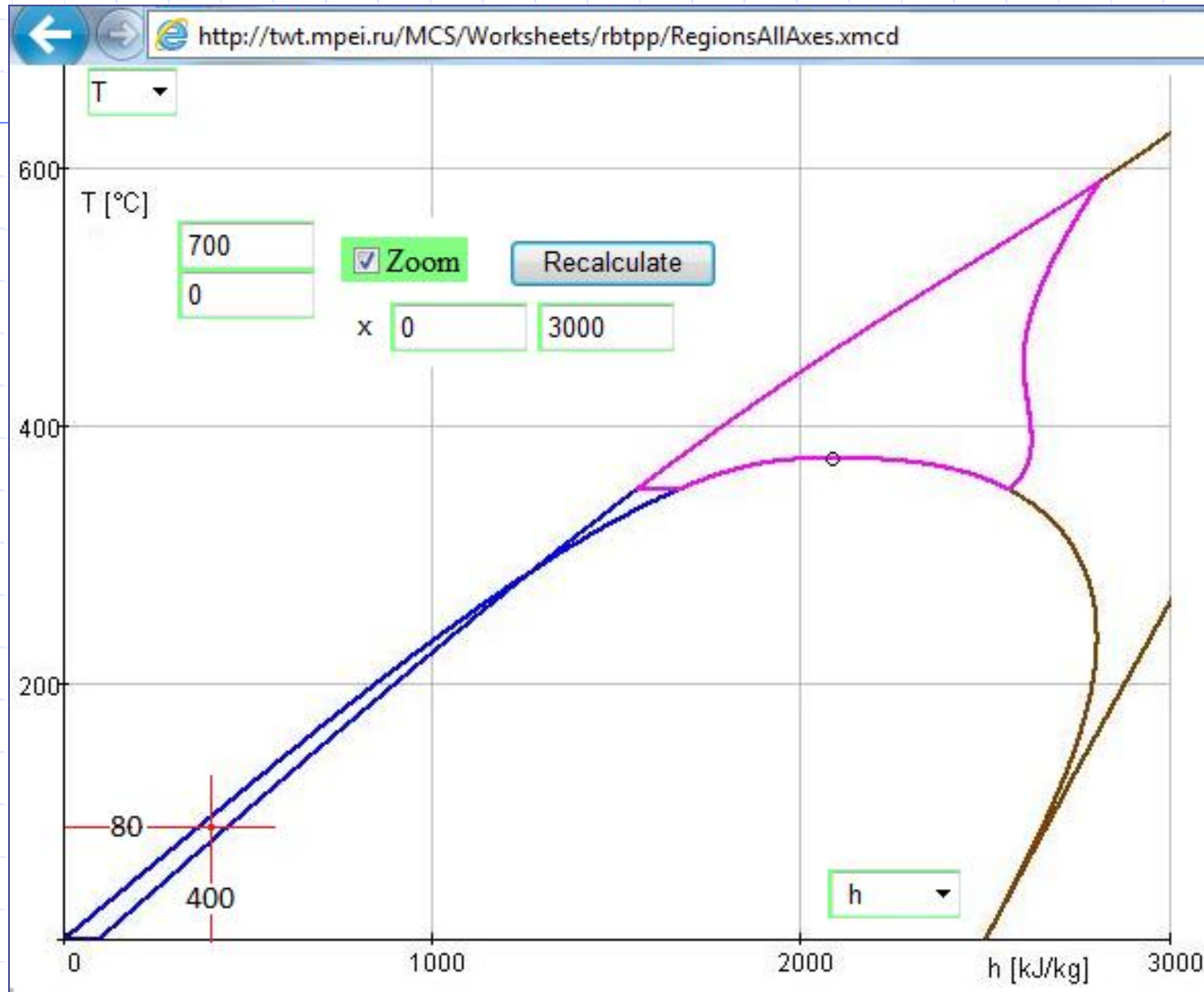
Recalculate

x = 0.0282

p = 0.0474 MPa

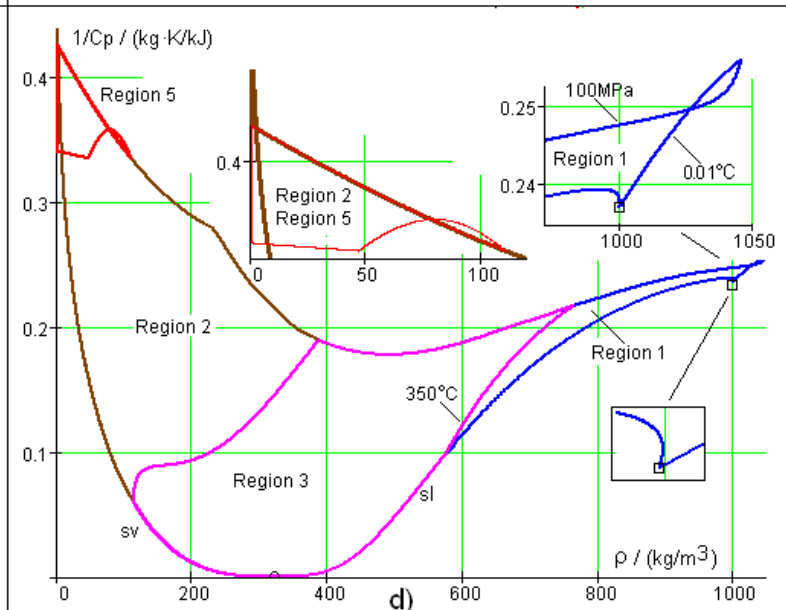
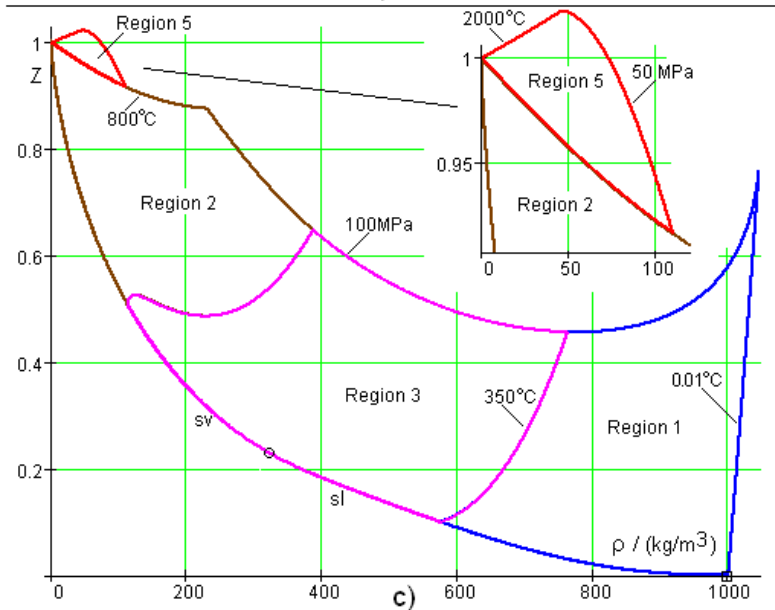
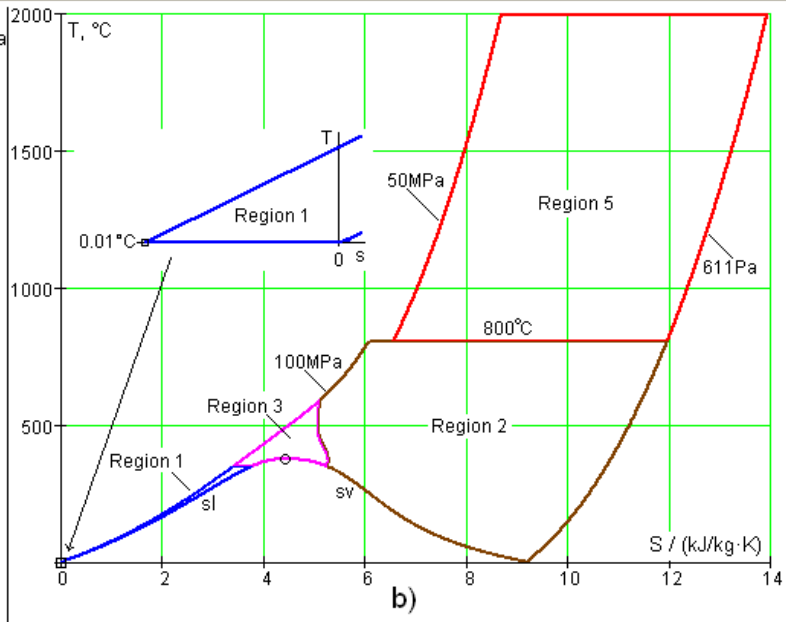
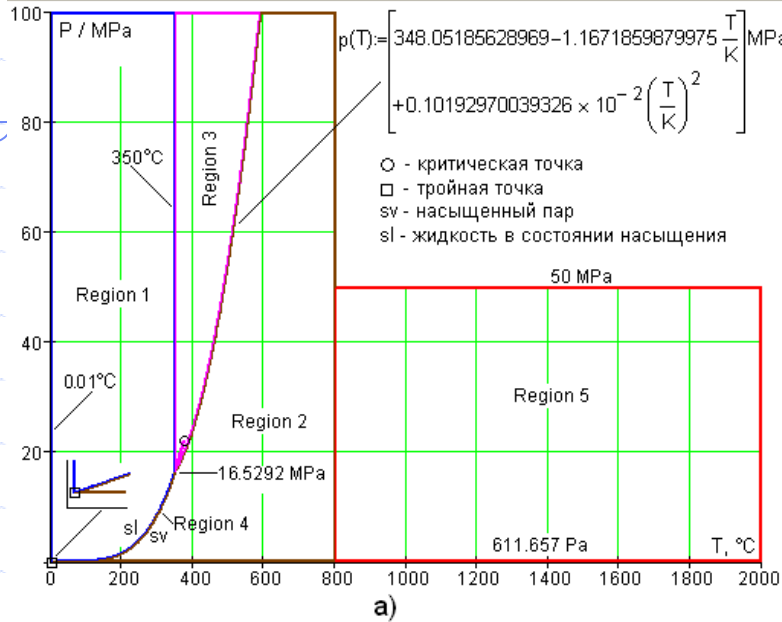


# T-h diagram: not one but two points



# IAPWS IF-97 Regions on Internet with different axes

<http://twf.mpei.ru/MCS/Worksheets/WSP/RegionsAllAxes.xmcd>



# IAPWS IF-97 Regions on Internet

<http://twf.mpei.ru/MCS/Worksheets/WSP/RegionsAllAxes.xmcd>

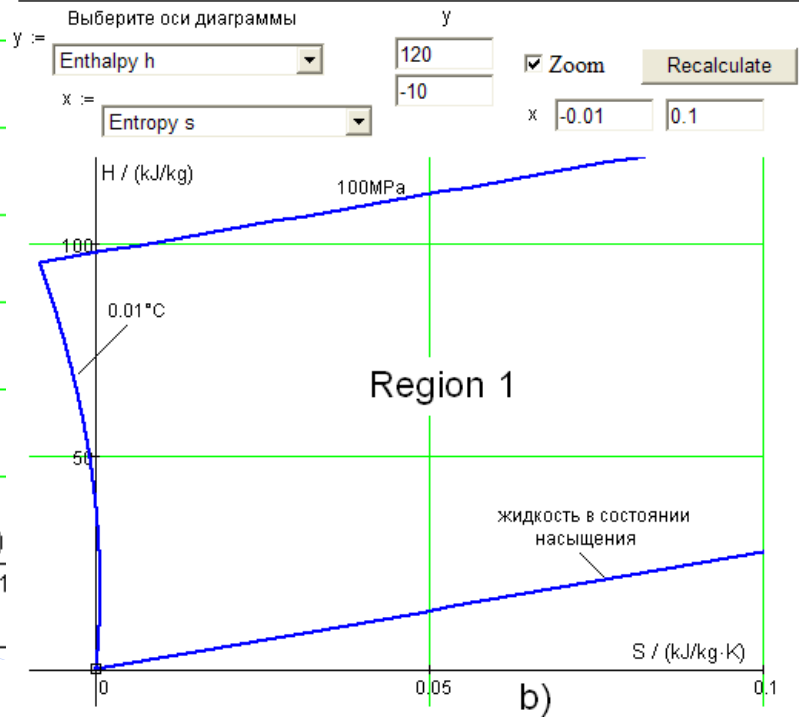
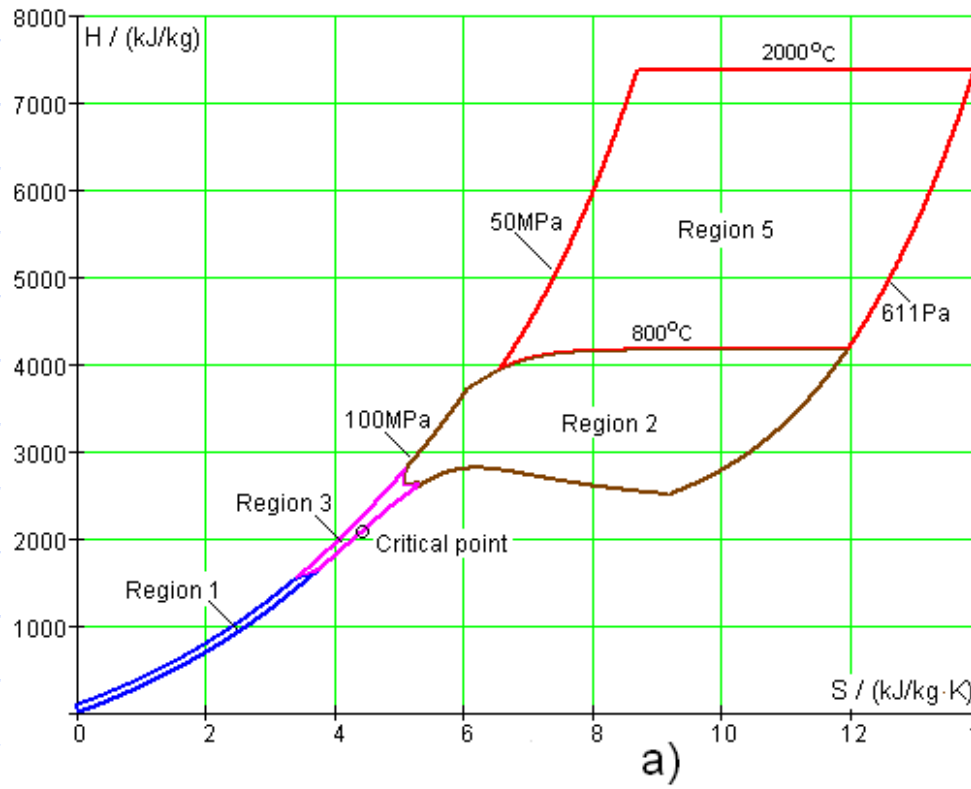
Структура областей формуляции IAPWS IF-97: области 1, 2, 3 и 5

Выберите оси диаграммы

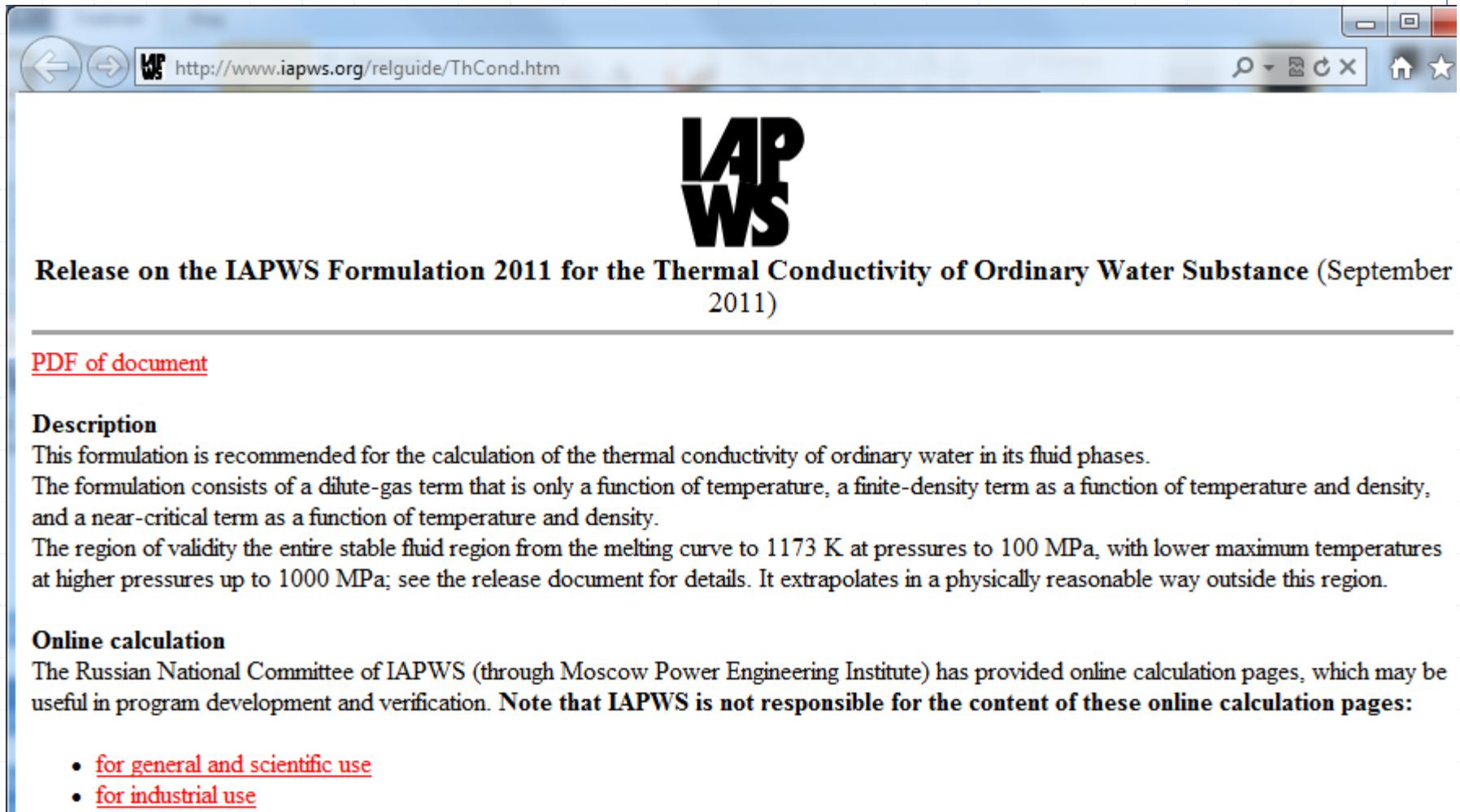
y :=

Zoom

x :=



# Conductivity of water and steam



The screenshot shows a web browser window with the address bar containing the URL <http://www.iapws.org/relguide/ThCond.htm>. The page features the IAPWS logo, which consists of the letters 'IAP' stacked above 'WS'. Below the logo is the title 'Release on the IAPWS Formulation 2011 for the Thermal Conductivity of Ordinary Water Substance (September 2011)'. A horizontal line separates the title from the main content. The content includes a red link for 'PDF of document', a 'Description' section with three paragraphs of text, an 'Online calculation' section with a paragraph of text, and a bulleted list of two red links: 'for general and scientific use' and 'for industrial use'.

**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://twf.mpei.ac.ru/mcs/worksheets/iapws/wspTCPT.xmcd

This page is provided by [Moscow Power Engineering Institute](http://www.mpei.ac.ru) and Russian National Committee (RNC) of [IAPWS](http://www.iapws.org).  
IAPWS is not responsible for this content.  
For any questions or suggestions please contact [RNC of IAPWS](mailto:rnc@iapws.org).

## 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](http://www.iapws.org)

Authors:

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- [Valery Ochkov](mailto:ochkov@twf.mpei.ac.ru) (ochkov@twf.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 :=

MPa ▼

Temperature :=

°C ▼

# Conductivity of water and steam

← → <http://tw.t.mpei.ac.ru/mcs/worksheets/iapws/wspTCPT.xmcd>

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

## Density for given pressure and temperature

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

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

## Formulation reference values

$$\rho_{\text{refer}} := 322.0 \frac{\text{kg}}{\text{m}^3} \quad T_{\text{refer}} := 647.096 \text{ K} \quad p_{\text{refer}} := 22.064 \text{ MPa} \quad \lambda_{\text{refer}} := 1 \frac{\text{mW}}{\text{mK}} \quad \mu_{\text{refer}} := 1 \text{ mk Pa sec}$$
$$R := 0.46151805 \frac{\text{kJ}}{\text{kgK}}$$

## Dimensionless input parameters

$$T_{\text{rel}} := \frac{T}{T_{\text{refer}}} = 0.88572638372$$
$$p_{\text{rel}} := \frac{p}{p_{\text{refer}}} = 2.31719899617$$

## Main equation

The thermal conductivity is represented by the equation

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

Eq. (15) in [1]

# Conductivity of water and steam

http://tw.t.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):

$$L := \begin{pmatrix} 2.443221 \times 10^{-3} \\ 1.323095 \times 10^{-2} \\ 6.770357 \times 10^{-3} \\ -3.454586 \times 10^{-3} \\ 4.096266 \times 10^{-4} \end{pmatrix} \quad \lambda_{0,rel} := \frac{\sqrt{T_{rel}}}{\sum_{k=0}^4 \frac{L_k}{T_{rel}^k}} = 43.359733160195 \quad \text{Eq. (16) in [1]}$$

## 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):

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

$$\lambda_{1,rel} := \exp \left[ p_{rel} \sum_{i=0}^4 \left[ \left( \frac{1}{T_{rel}} - 1 \right)^i \sum_{j=0}^5 [L_{i,j} (p_{rel} - 1)^j] \right] \right] = 13.287255087768 \quad \text{Eq. (17) in [1]}$$

# Conductivity of water and steam

 <http://tw.t.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]:

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

## Additional thermophysical properties for given pressure and temperature

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

$$\mu := \text{wspDYNVISRT}(p, T) = 92.346297069543 \text{ mPa sec}$$

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

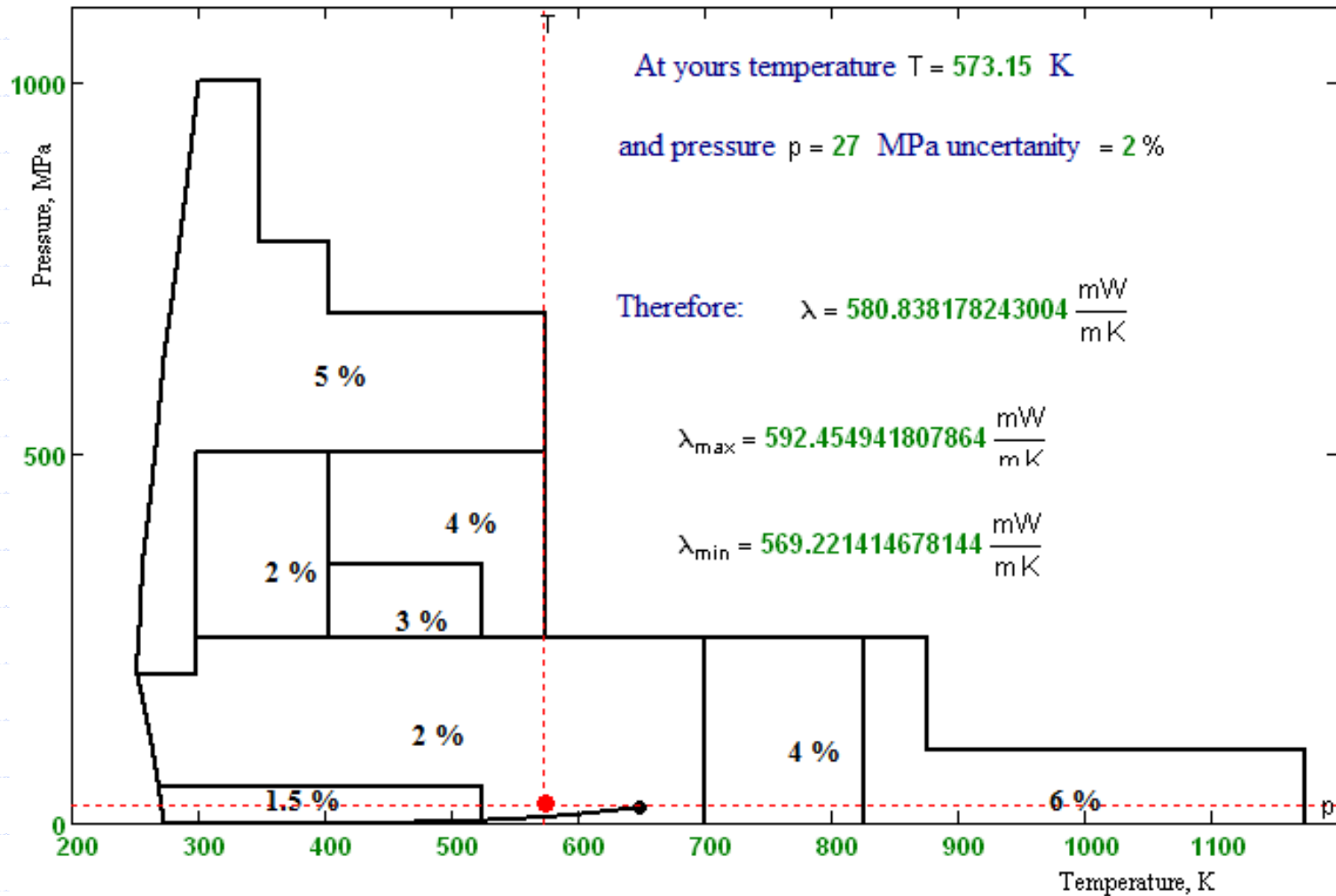
Isobaric specific heat capacity:  $c_p := \text{wspCPPT}(p, T) = 5.143276209527 \frac{\text{kJ}}{\text{kgK}}$



# Conductivity of water and steam

<http://twf.mpei.ac.ru/mcs/worksheets/iapws/wspTCPT.xmcd>

Estimated uncertainty of the correlation equation



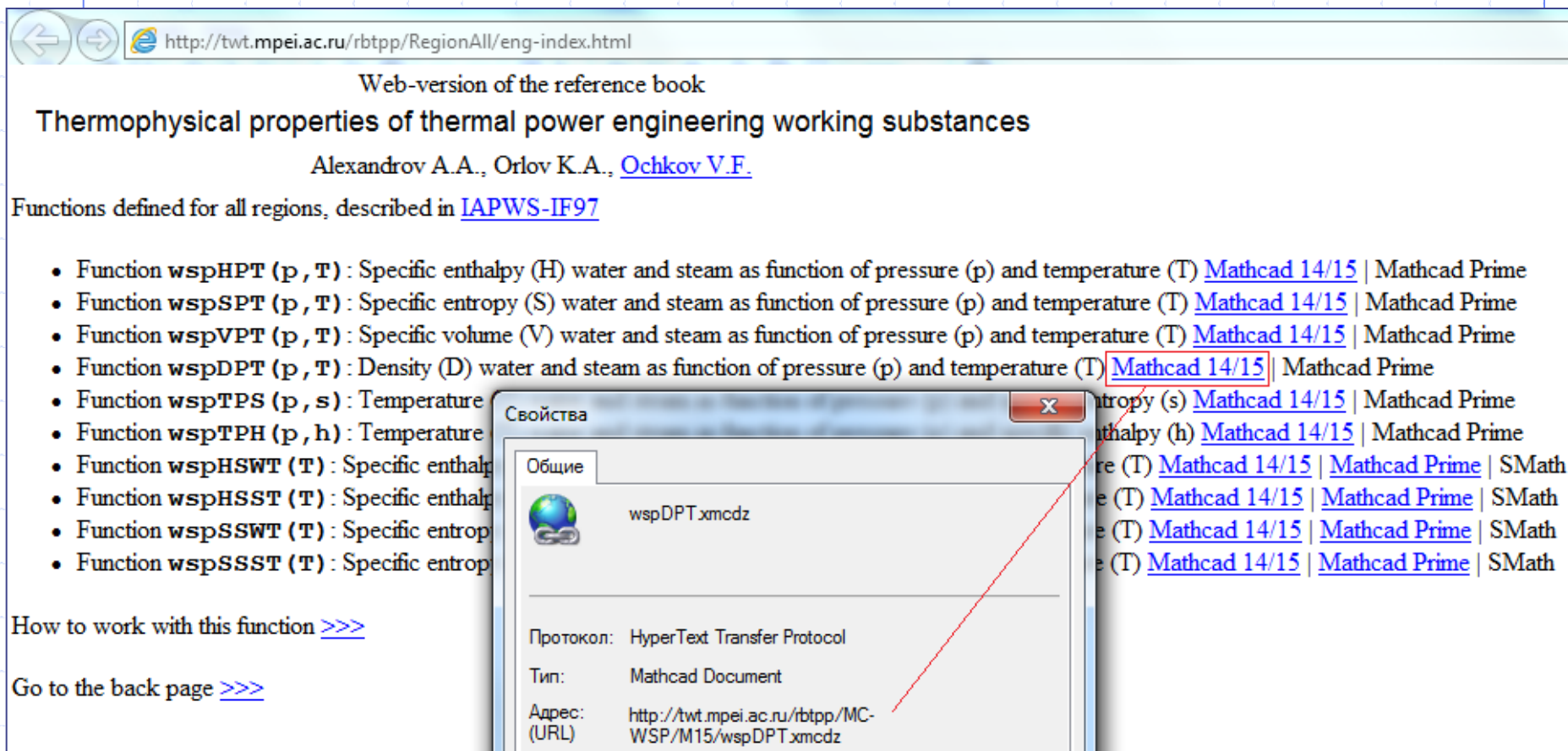
# What we would like to see on the IAPWS site?

- ◆ 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



The screenshot shows a web browser window with the address bar containing the URL <http://twt.mpei.ac.ru/rbtp/RegionAll/eng-index.html>. The page content includes the title "Web-version of the reference book" and "Thermophysical properties of thermal power engineering working substances" by Alexandrov A.A., Orlov K.A., and Ochkov V.F. A list of functions is provided, with the link for `wspDPT` highlighted in red. A "Свойства" (Properties) dialog box is open over the `wspDPT` link, showing details for the file `wspDPT.xmcdz`, including the protocol (HyperText Transfer Protocol) and the full URL.

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 `wspVPPT(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
- Function `wspTPH(p, h)`: Temperature
- Function `wspHSWT(T)`: Specific enthalpy
- Function `wspHSST(T)`: Specific enthalpy
- Function `wspSSWT(T)`: Specific entropy
- Function `wspSSST(T)`: Specific entropy

How to work with this function [>>>](#)

Go to the back page [>>>](#)

Свойства

Общие

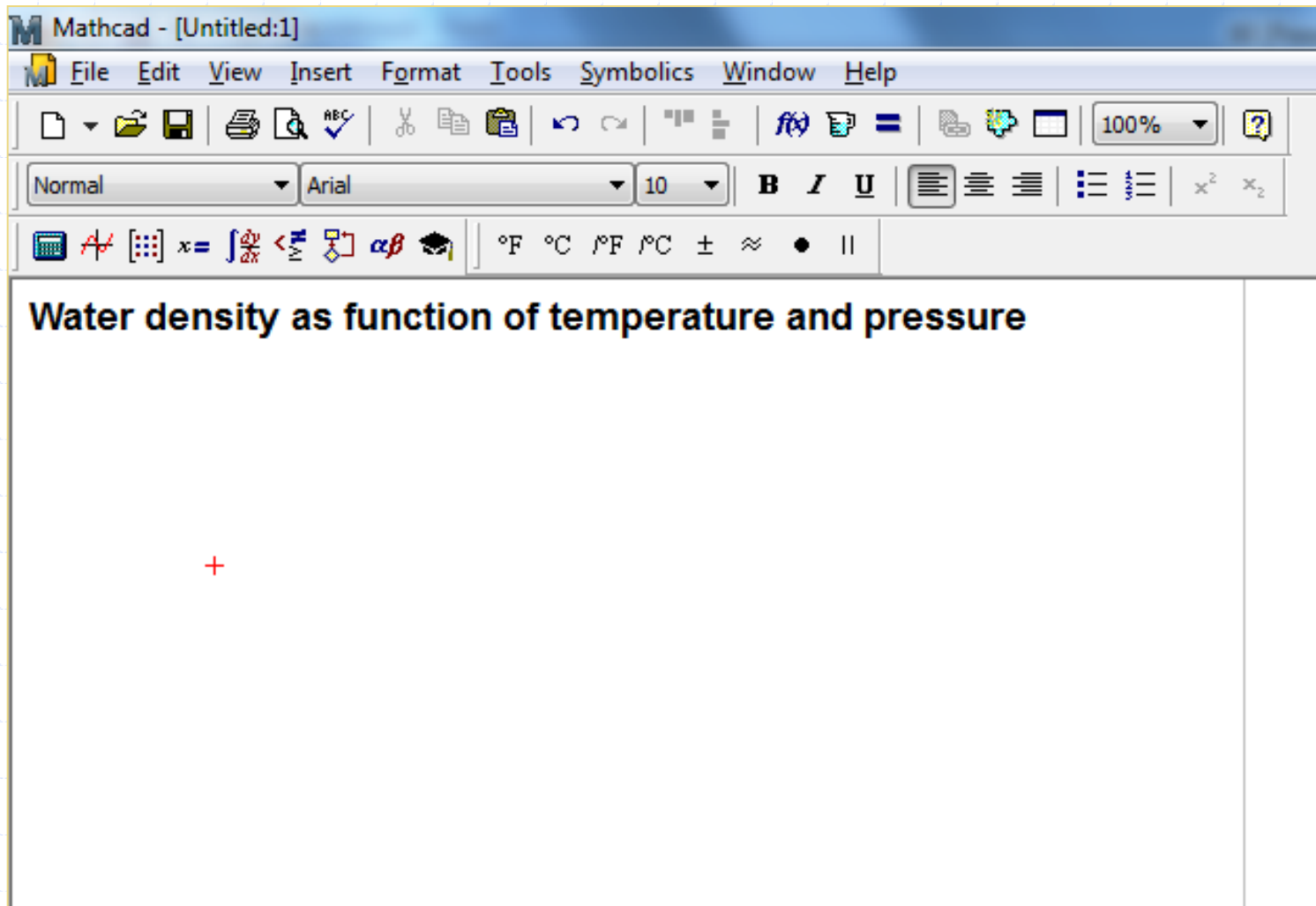
 `wspDPT.xmcdz`

Протокол: HyperText Transfer Protocol

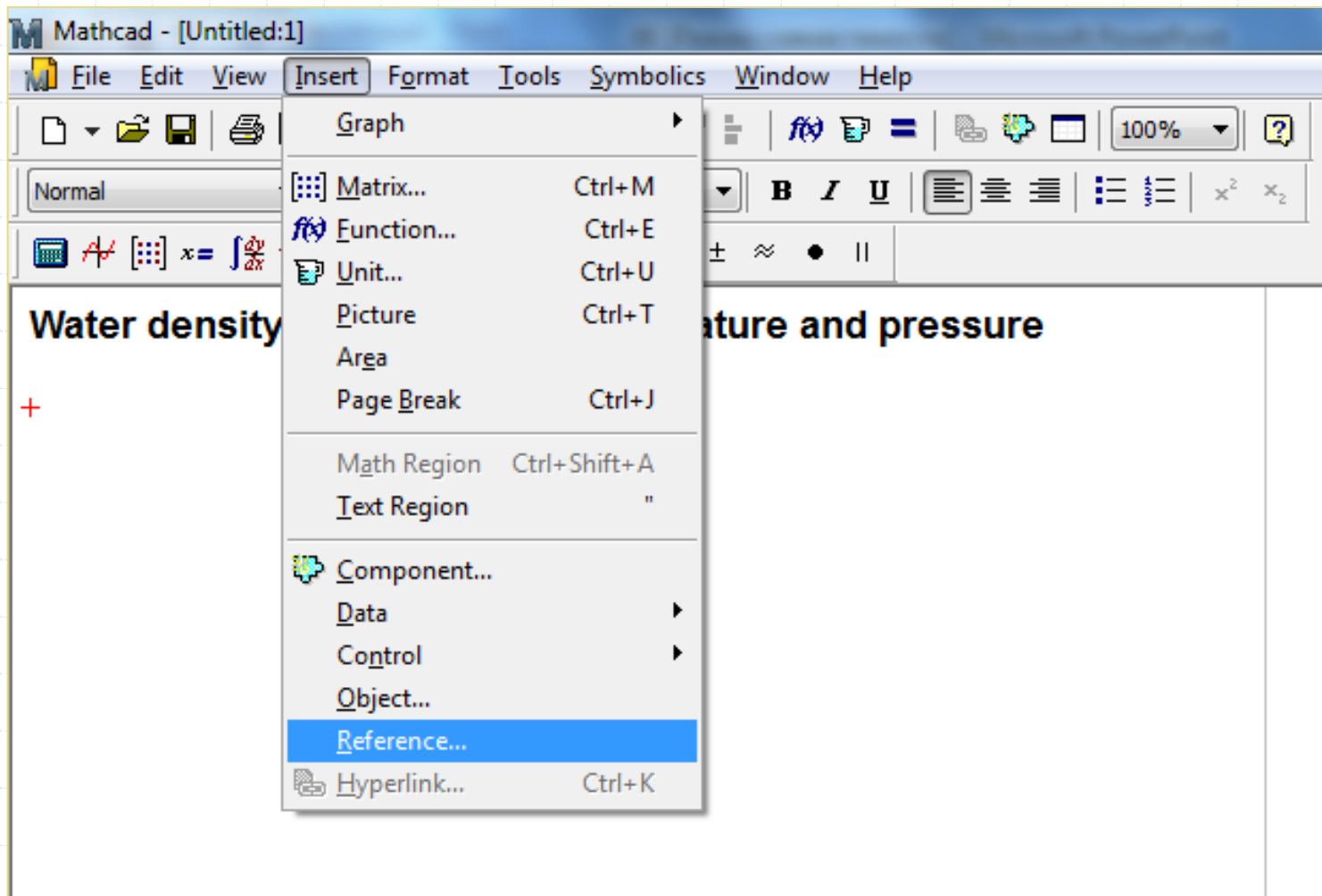
Тип: Mathcad Document

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

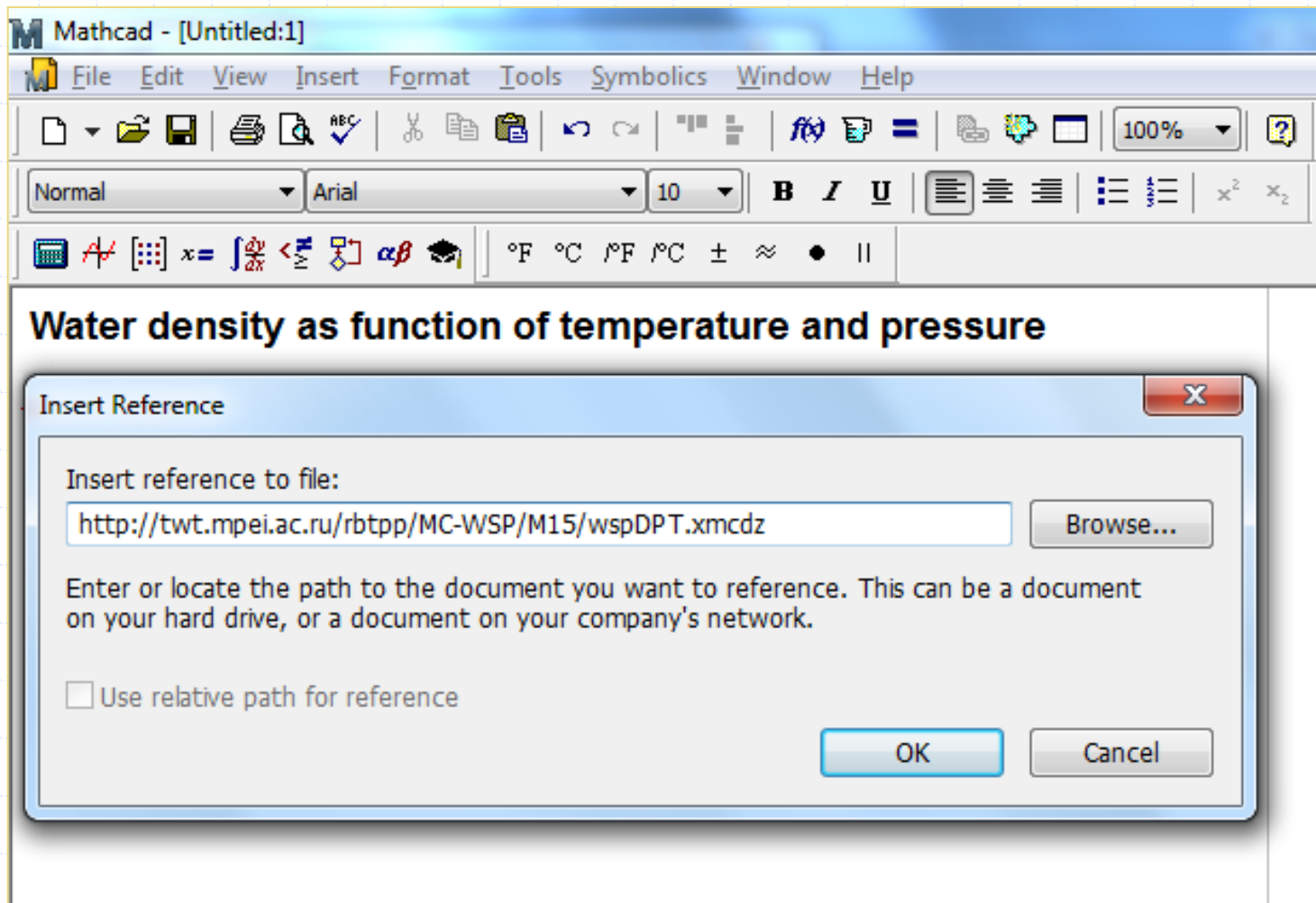
# 1-st work step - comments



# 2-d work step - Reference



# 3-d work step – Insert Address

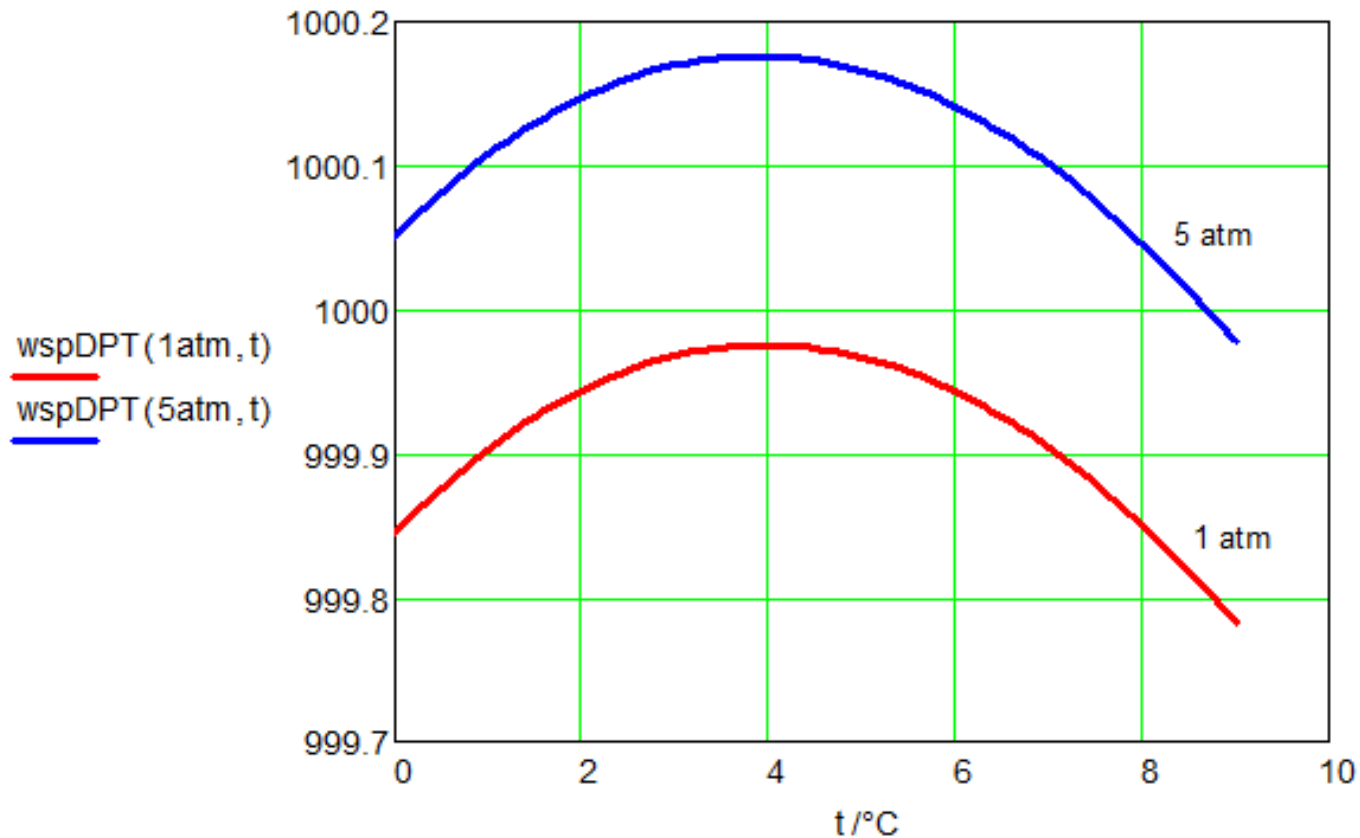


# Finish - calculations

## Water density as function of temperature and pressure

Reference: <http://twf.mpei.ac.ru/rbtp/MC-WSP/M15/wspDPT.xmcdz>

$t := 0\text{ }^{\circ}\text{C}, 0.1\text{ }^{\circ}\text{C}.. 9\text{ }^{\circ}\text{C}$







# 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/rbtp/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/rbtp/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/rbtp/wspTSP.xmcdz>

$$T_2 := \text{wspTSP}(p_2) = 28.96 \text{ }^\circ\text{C}$$

The specific entropy of saturated steam at temperature  $T_2$

➔ Reference:<http://twt.mpei.ac.ru/rbtp/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/rbtp/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://tw.t.mpei.ac.ru/rbtpp/wspHSST.xmcdz>

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

The specific enthalpy of saturated water at temperature  $T_2$

☞ Reference:<http://tw.t.mpei.ac.ru/rbtpp/wspHSWT.xmcdz>

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

The specific enthalpy of wet steam at the turbine outlet:

$$h_2 := x_2(h_{2ss} - h_{2sw}) + h_{2sw} = 1990.35 \text{ kJ/kg}$$

The enthalpy of water at the pump inlet:

$$h_3 := h_{2sw} = 121.404 \text{ kJ/kg}$$

The entropy of water at the pump inlet:

$$s_3 := s_{2sw} = 0.422 \text{ kJ/(kg K)}$$

The specific entropy of water at the boiler inlet:

$$s_5 := s_3 = 0.422 \text{ kJ/(kg K)}$$

The temperature of water at the boiler inlet

☞ Reference:<http://tw.t.mpei.ac.ru/rbtpp/wspT1PS.xmcdz>

$$T_5 := \text{wspT1PS}(p_1, s_5) = 29.24 \text{ }^\circ\text{C}$$

The specific enthalpy of water at the boiler inlet

☞ Reference:<http://tw.t.mpei.ac.ru/rbtpp/wspH1PT.xmcdz>

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

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

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

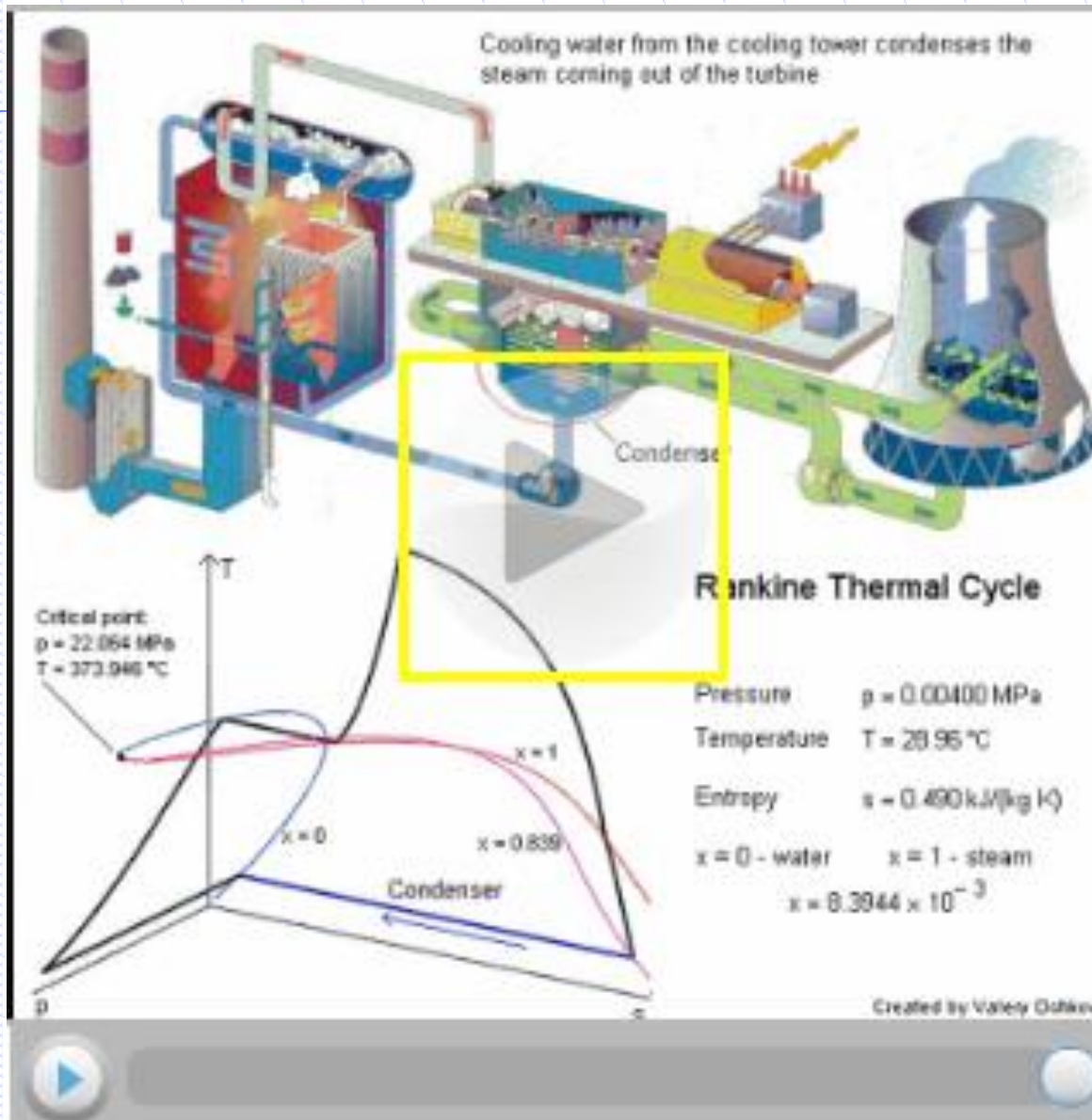
The heat rejected in the condenser:  $q_2 := h_2 - h_3 = 1868.94 \text{ kJ/kg}$

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

The thermal efficiency of the cycle:

$$\eta_t := \frac{q_1 - q_2}{q_1} = 43.99 \%$$

# Animations



# This topic on the PTC-site

The screenshot shows the PTC website interface. At the top, the browser address bar displays the URL `http://www.ptc.com/appserver/search/mathcad.jsp`. The PTC logo and tagline "PRODUCT & SERVICE ADVANTAGE" are on the left, with navigation links for "Store", "EN", and "Login" on the right. A search bar is also present. Below the navigation bar, a breadcrumb trail reads "Home > Products > Mathcad > Engineering Resources, powered by Mathcad".

The main content area features a search bar labeled "Search this Page" and a large heading "Mathematical Engineering Resources". To the left, there are filters for "Discipline (13)" and "Content Type (3)".

**Discipline (13)**

- Mathcad Usage (70)
- Math and Statistics (65)
- Academic (63)
- Mechanical Engineering (42)
- Civil Engineering (36)
- [+ More](#)

**Content Type (3)**

- Worksheets (126)
- Video (25)
- Author Pages (5)

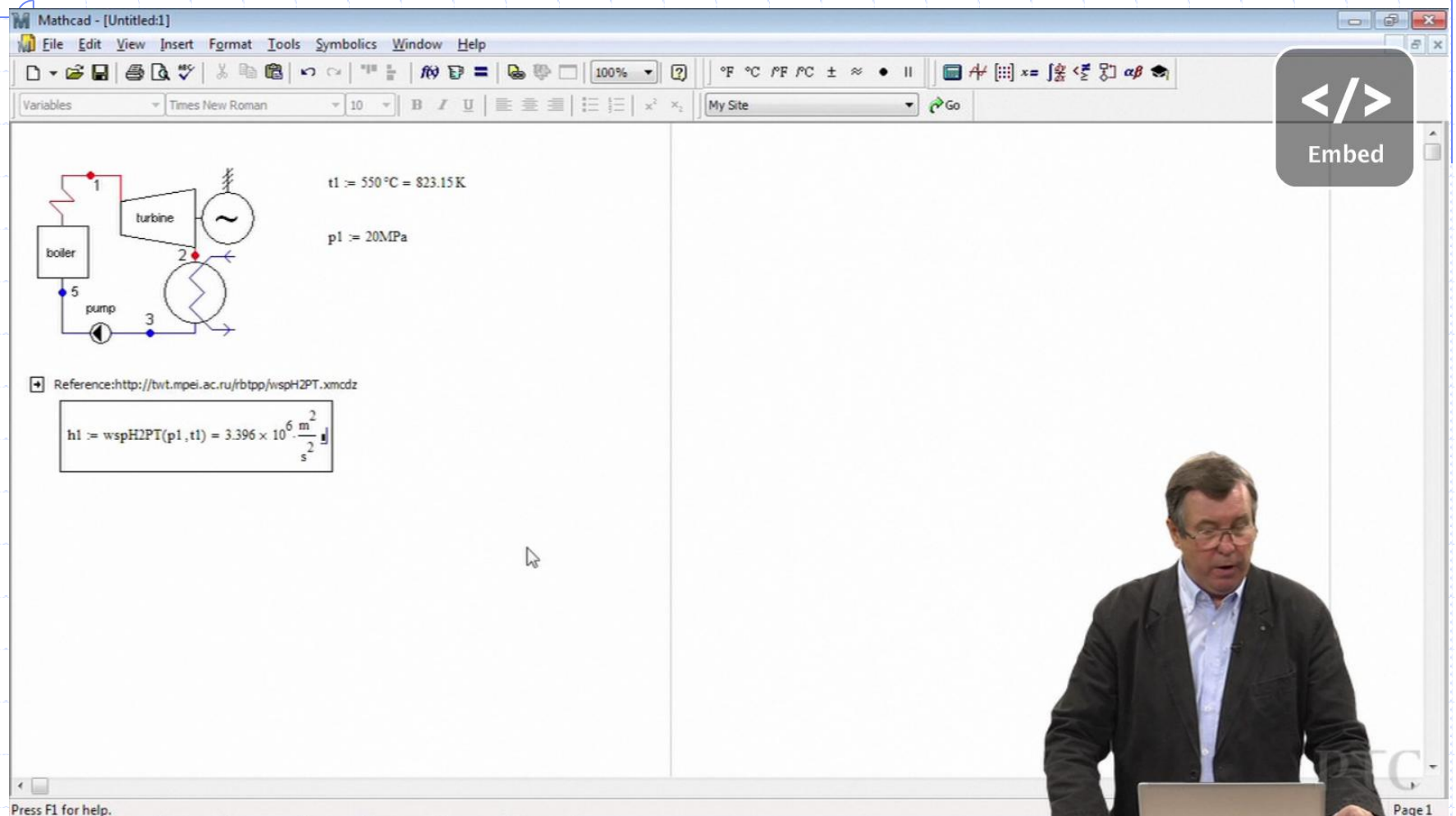
The central video player shows a blue car on a road with a play button overlay. The video title is "Using Mathcad to Create a Materials Property Database". Below the video player are options for "WMV" and "MOV" formats, and a "SHARE" button.

**Video** **Demos** **Images**

- Using Mathcad to Create a Materials Property Database**
- Using Mathcad and Truenumbers for Engineering Calculations Verification**
- Get Primed on Mathcad Prime 1.0**



# This movie on the PTC-site



The screenshot displays the Mathcad software interface. The main workspace contains a schematic of a Rankine cycle with components labeled 'boiler', 'turbine', and 'pump'. The cycle is numbered 1 through 5. To the right of the diagram, the following parameters are defined:

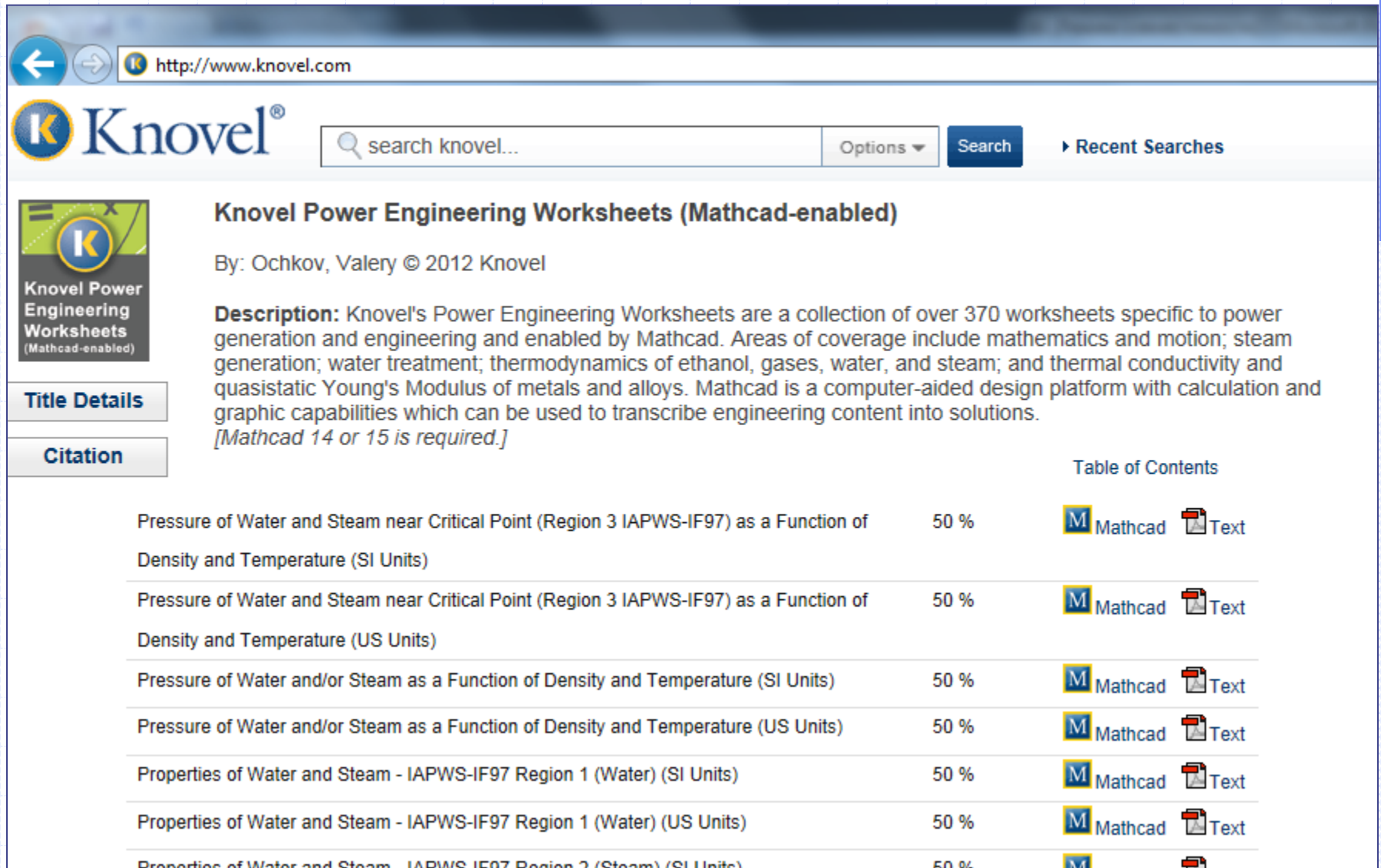
$$t1 := 550^{\circ}\text{C} = 823.15\text{ K}$$
$$p1 := 20\text{ MPa}$$


Below these definitions, a reference is provided: [Reference: http://twt.mpei.ac.ru/rbtp/wspH2PT.xmcdz](http://twt.mpei.ac.ru/rbtp/wspH2PT.xmcdz). A calculation box shows the result of the function `wspH2PT(p1, t1)`:


$$h1 := \text{wspH2PT}(p1, t1) = 3.396 \times 10^6 \frac{\text{m}^2}{\text{s}^2}$$


In the bottom right corner of the software window, a man in a dark jacket and glasses is visible, sitting at a desk with a laptop. A grey 'Embed' button with a code icon is overlaid on the top right of the software window.

# This topic on the Knovel-site



← →  http://www.knovel.com















 **Knovel**<sup>®</sup>  Options ▾ Search ▶ Recent Searches

 **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.]*

**Title Details** **Citation** [Table of Contents](#)

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 %	 Mathcad  Text



Thank you