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A Web Browser-Based Program for Determining the Thermodynamic Properties of Water

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Abstract

This work presents a web browser-based program for determining the thermodynamic properties of water. There are functions for calculating the properties in 3 regions: region 1 for the liquid state, region 2 for the vapor state, and region 3 for the saturation curve (vapor-liquid equilibrium). In each region, the property models are implemented in a suite of JavaScript subroutines/functions by searching database list files and using database functions to compute the required output data. The source of data is obtained from National Institute of Standards and Technology (NIST), USA. This program is run on a web browser via an internet that allows users to calculate instead of tables and diagrams, to rapidly determine thermodynamic properties and to better understand of thermodynamic process and phase transition. The output data are given all thermodynamic properties with unit conversion function as well as showing on the property diagrams. The main objective of the program is for learning purposes. The methods can be extended to other fluids' properties data calculations.

***Keywords**:* water properties, Thermodynamic properties calculation, web browser-based program, JavaScript

1. Introduction

One of the most common substances that used in engineering applications is water. Its thermodynamic properties are required for the design of equipment in steam power plants (boilers, turbines, condensers). All thermodynamic properties can be found in tables or diagrams. Usually, two independent properties (e.g. P, T, v, h, s) of the substance must be known in order to determine the other needed properties. The use of tables and diagrams is tedious and time consuming. Formulas for thermodynamic properties of water are available and can be programmed in a computer, which will compute the thermodynamic properties. The American Society of Mechanical Engineers (ASME) [1], and the Industrial Formulation IAPWS-IF97 [2] provided equations for computing pure water properties. Reviews of the methods are given by IAPWS [3]. Bernhard [5] developed an Add-In for MS Excel which provides a set of functions for calculating thermodynamic and transport properties of water and steam using the industrial standard IAPWS-IF97. Unfortunately, formulas for thermodynamic properties of steam are quite complicated. Many authors simplified the formulation IAPWS-IF97 with simple functions but limited in application. The method can be viewed as an empirical formula that provided reliable, very useful and easily programmable explicit equations. The principle and numerical methods are presented in Snigir [5], Jack [6], Affandi [7], and Affonso [8]. Recently, the computer development has been advanced that the thermodynamic properties can be arranged in an electronic form. The look-up methods then can be used to calculate fluid properties faster and with reasonable accuracy. In order to improve the accuracy the numerical solution and reduce the computer time, Kunick [9] used two-dimensional splines algorithms to handle interpolations of the data. Alexandrov [10] provided thermodynamic properties of water on the internet. Readers can visit at the web site
http://twt.mpei.ac.ru/ochkov/WSPHB/Engindex.html.

In this study, the author has developed computer code to aid in obtaining look-up data when required in calculations. Graphs showing various relationships of steam thermodynamics have also been developed. The tedium with handling interpolations in mid-point data are eliminated by easily programming the mathematical functions available. The advantage of such an interpretation of the water data is that it provides a simple and complete method of fixing reliable definitive values of its independent properties, and furnishes a basis for coordinating other thermodynamic data. Powerful computers are available. Therefore the data can be drawn on the graphs. The code has developed in HTML documents with JavaScript in it. The detail of programming in HTML can be seen in Johnson [11]. This means that web browser is required to perform various calculations.

2. Theoretical Basis

The thermodynamic surface is divided into 3 regions (see Fig. 1): region 1 for the liquid state, region 2 for the vapor state, and region 3 for the saturation curve (vapor-liquid equilibrium). In each region, the property models are implemented in a suite of JavaScript subroutines/functions by searching database list files and using database functions to compute the required output data. The code is available for calculating the following properties in a state for temperatures between 0.01°C and 1300 °C and pressures between 0.6117 kPa and 50 MPa. For water, its critical point is 373.95 °C and 22.064 MPa.

For pressures greater than the critical pressure, the substance is usually called a liquid when the temperature is less than the critical temperature (373.95°C) and a vapor or gas when the temperature is greater than the critical temperature. Source of the data that used as the database of the calculation are obtained from NIST Chemistry WebBook [12].

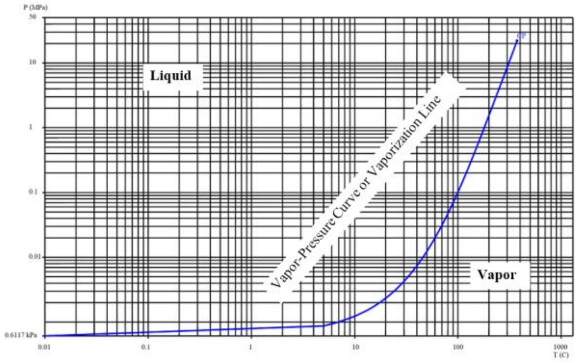

Fig. 1 Water Vapor Pressure Curve (P-T diagram for pure water)

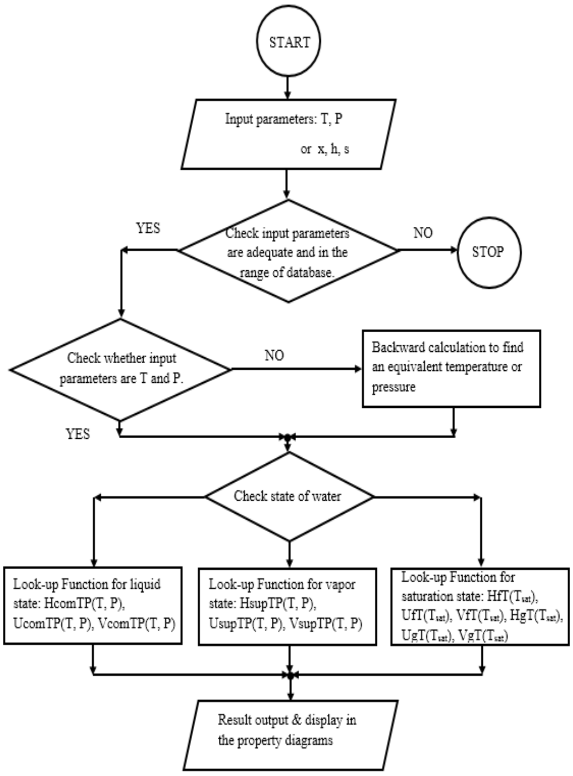

Fig. 2 Flow diagram for the program

3. Computerized Calculations of Thermodynamic Properties

Structure of this program is shown on Fig. 2. The two inlet parameters are required with at least temperature T or pressure P is selected. After checking the inlet parameters for adequacy of the information, the program determines state of water. For inlet parameters T and P, it is easily to determine since there is a definite relationship between saturation temperature and saturation pressure of a pure substance. The vapor/liquid mixture is at saturation when the conditions of pressure and temperature fall on the curve. The water property functions are then calculated according to its state. The function are available in each region as the followings.

3.1 Available functions for the saturation curve

There are functions for calculating the saturation temperature (Tsat) as a function of pressure and the saturation pressure (Psat) as a function of temperature.

Tsat = Tsat(P)
Psat = Psat(T)

where

P = inlet pressure
T = inlet temperaturehe

The other saturation properties functions are arranged in saturated liquid and saturated vapor as a function of the saturation temperature.

hf = HfT(Tsat)
hg = HgT(Tsat)
uf = UfT(Tsat)
ug = UgT(Tsat)
vf = VfT(Tsat)
vg = VgT(Tsat)

where

h = specific enthalpy
u = specific internal energy
v = specific volume

subscript

f = saturated liquid state
g = saturated vapor state

3.2 Available functions for the liquid sate

In this region, the property value is determined as a function of temperature and pressure.

h = HcomTP(T, P)
u = UcomTP(T, P)
v = VcomTP(T, P)

3.3 Available functions for the vapor sate

In this region, the property value is determined as a function of temperature and pressure.

h = HsupTP(T, P)
u = UsupTP(T, P)
v = VsupTP(T, P)

4. The Method of Database Look-up Functions

When the function is called, the property values are implemented in a suite of JavaScript subroutines/ functions by searching database list files and using database functions to compute the required output data. The database are arranged in the same formatted as that in the water tabular format. In this manner the temperature and the pressure are the primary and the secondary parameters, respectively. All parameters are listed first according temperature arrangement from smallest to largest values then follow by the pressure arrangement. This means that the bisection algorithm can be used in a database look up method. This technique makes the functions require considerably less computational effort due to simple forms of equations. The method also accelerates the finding of two nearest data that bracket the solution. The solution is obtained by linear interpolation that is a reliable process.

It should be noted that all functions are determined as the function of temperature and pressure. For the other independent variables an iterative calculation is usually required. This backward calculation is provided in the program which will find an equivalent temperature or pressure that will give the same solution of that the given inlet parameters. Once the equivalent temperature or pressure is obtained. The temperature and the pressure will be used as the inlet parameters and the calculation procedure will be performed as previous discuss.

5. Steam Properties Computation Examples

The main page is shown in Fig. 3. Select the input data files and fill in the values with appropriate units. The parameters T and P are ticked by default. To select other parameters (e.g. x, h and s), first the parameter is ticked and T or P is un-ticked. After the submit button is pressed, the result will show on the next page (Fig 4). There are two parts. The first part is the top page that displays the values of T, P, v, h, u and s. Each property has a +Unit button +Unit. Each time you press the button, the value will convert to other units. This is the conversion unit button. The note will tell about the phase of the substance. There are lists of property table (e.g. Saturation water - Temperature table / Pressure table, Superheated Water, Compressed Liquid Water). When you press it, the property table will display. Fig. 5 shows a portion of a typical saturated steam temperature table. The second part is graphic page that displays the property diagram with marking of the given point. The P-T, T-v and P-h diagrams can be changed by clicking the appropriate menu. These properties diagrams are constructed from the available functions. Fig. 1 is the P-T diagram for pure water. A T-v diagram (Fig. 6) is different from a P-T diagram in that the vaporization line consists of the saturated liquid and the saturated vapor. A P-h diagram (Fig. 7) exhibits the same features as a T-v diagram. When you finish or want to find another conditions, press Return to Main button Return to Main.

Water properties for values of T = 100 °C and P = 2 MPa is compressed liquid with v = 0.001043 m^3/kg, h = 419.17 kJ/kg, u = 419.06 kJ/kg and s = 1.3072 kJ/kg-K.

Water properties for values of T = 150 °C and x = 0.5 is saturation mixture with P = 0.476 MPa, v = 0.1967855 m^3/kg, h = 1689.04 kJ/kg, u = 1595.38 kJ/kg and s = 4.33945 kJ/kg-K.

Water properties for values of P = 1.5 MPa and h = 3000 kJ/kg is superheated vapor with T = 283.3 °C, v = 0.16456 m^3/kg, u = 2754.35 kJ/kg and s = 6.851128 kJ/kg-K.

The outputs are comparable to that available from standard steam tables and will provide a useful tool for calculations thereby eliminating time consuming mid-point interpolation routines.

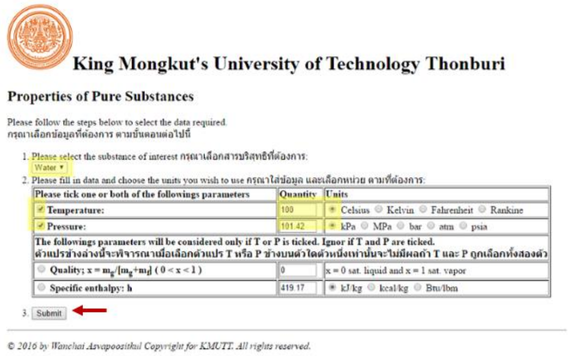

Fig. 3 The main page of the program

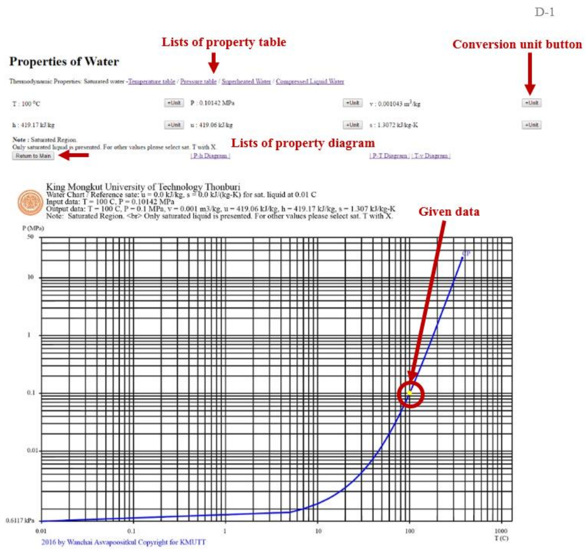

Fig. 4 The result page of the program

Table A-1 Saturated Water - Temperature Table

Temp. T [°C]	Sat. P_{sat} [kPa]	Sat. liquid v_f [m^3/kg]	Sat. vapor v_g [m^3/kg]	Sat. liquid u_f [kJ/kg]	Sat. vapor u_g [kJ/kg]	Sat. liquid h_f [kJ/kg]	Sat. vapor h_g [kJ/kg]	Sat. liquid s_f [kJ/kg-K]	Sat. vapor s_g [kJ/kg-K]
0.01	0.6117	0.001	206	0	2374.9	0.001	2500.9	0	9.1556
5	0.8725	0.001	147.03	21.019	2381.8	21.02	2510.1	0.0763	9.0249
10	1.2281	0.001	106.32	42.02	2388.7	42.022	2519.2	0.1511	8.8999
15	1.7057	0.001001	77.885	62.98	2395.5	62.982	2528.3	0.2245	8.7803
20	2.3392	0.001002	57.762	83.913	2402.3	83.915	2537.4	0.2965	8.6661
25	3.1698	0.001003	43.34	104.83	2409.1	104.83	2546.5	0.3672	8.5567
30	4.2469	0.001004	32.879	125.73	2415.9	125.74	2555.6	0.4368	8.452

Fig. 5 A portion of a typical saturated steam temperature table

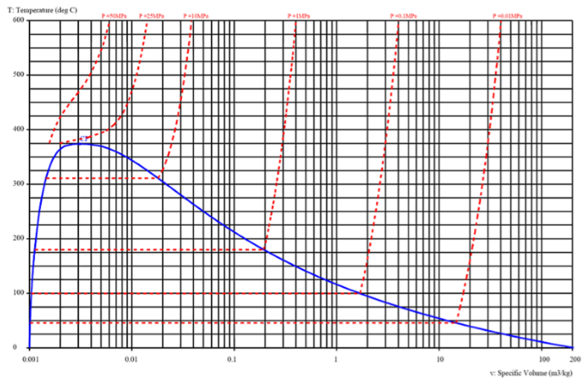

Fig. 6 T-v diagram of pure water at various pressures

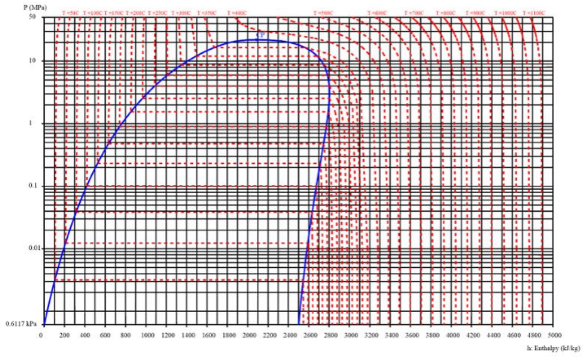

Fig. 7 Pressure-Enthalpy diagram for water/steam

5. Conclusions

The implementation and application of the program are simple and straightforward. The P-T, T-v and P-h diagrams indicate saturation line, critical point and also indicate boundaries of the various phases of water: liquid, vapor and saturation mixture. The program can be applied to calculate instead of tables and diagrams, to rapidly determine thermodynamic properties and to better understand of thermodynamic process and phase transition. Especially the visualization of the given data marked on the property diagrams. The main objective of the program is for learning purposes. The demo program can run at the web site http://webstaff.kmutt.ac.th/~meeng/PPS01.html.

This web browser-based program for determining thermodynamic properties can be applied to other pure fluids such as R-134a, R22, etc. R134a is currently being conducted.

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