

# Steam Tables DLL User's Manual

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## 1. SUMMARY

### 1.1 Range Of Tables

The ranges of the thermodynamic properties are,

- Temperature from triple point to 2273.15 °K
- Pressure from triple point to 100 MPa if temperature is less than 1073.15 °K
- Pressure from triple point to 50 Mpa if temperature is greater than 1073.15 °K.
- The functions (Tps and Tph) to compute temperature given pressure and enthalpy or given pressure and entropy are valid for temperature less than 1073.15 °K.

The range of the thermal conductivity is,

- Temperature from triple point to 1073.15 °K

- Pressure from triple point up to,
  - 100 MPa if temperature is less than 773.15 °K,
  - 70 MPa if temperature is greater than 773.15 °K but less than 923.15 °K,
  - 40 MPa if temperature is greater than 923.15 °K but less than 1073.15 °K.

The range of dynamic viscosity is,

- Temperature from triple point to 1073.15 °K,
- Pressure from triple point to 100 MPa.

## 1.2 Basis

This implementation is based on the properties of water developed by The International Association for the Properties of Water and Steam, 1997 revision for industrial use, referred as IAPWS-IF97. The same properties are also published by ASME as International Steam Tables for Industrial Use, 2<sup>nd</sup> Edition.

Specific volume, enthalpy, entropy and specific heat are calculated using the 1997 IFC formulation for industrial use given in Reference 1.

In Region 3, properties are computed from the Helmholtz function, which is expressed in terms of temperature and density. The inverse equations for density in Region 3 given pressure and temperature were calculated from Reference 4. Temperature given pressure and enthalpy or given pressure and entropy is calculated using the formulation given in Reference 5.

The viscosity was calculated from Reference 2 and the thermal conductivity was calculated from Reference 3.

## 1.3 Programming Language

This program was coded in C# and compiled in Visual Studio 2008 standard edition as a DLL. The DLL requires that .NET 3.5 or later is installed, which can be obtained from, <http://www.microsoft.com/download/en/details.aspx?displaylang=en&id=21>

## 2. REFERENCES

1. "Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam," The International Association for the Properties of Water and Steam, August 2007 (can be obtained from <http://www.iapws.org>).
2. "Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance," The International Association for the Properties of Water and Steam, September 2008 (can be obtained from <http://www.iapws.org>).

3. "Revised Release on the IAPS Formulation 1985 for the Thermal Conductivity of Ordinary Water Substance," The International Association for the Properties of Water and Steam, September 2008 (can be obtained from <http://www.iapws.org>).
4. "Supplementary Release on Backward Equations for Specific Volume as a Function of Pressure and Temperature  $v(p,T)$  for Region 3 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam," The International Association for the Properties of Water and Steam, July 2005 (can be obtained from <http://www.iapws.org>).
5. "Revised Supplementary Release on Backward Equations for the Functions  $T(p,h)$ ,  $v(p,h)$  and  $T(p,s)$ ,  $v(p,s)$  for Region 3 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam," The International Association for the Properties of Water and Steam, September 2004 (can be obtained from <http://www.iapws.org>).

### 3. ERROR CONDITIONS

The functions always return a positive value.

#### **errorMessage**

Multi-line string containing error message, each line separated by carriage return and line end characters, '\r\n'. Error message is not returned in the argument list, however, it is a public string that can be interrogated by the calling program.

#### **stat**

Integer of value either 0 or 1. stat is set to 0 for normal completion. stat is set to 1 if an error occurred. The only error detected by the code is when the inputs exceed the range of validity.

### 4. PUBLIC FUNCTIONS

#### 4.1 Saturation Pressure and Temperature

##### **Psat (double t, ref int stat, int btuFlag)**

t            Temperature (in °F in btuFlag is 1, in °K if btuFlag is 0)  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Saturation pressure. The return value is in psia if btuFlag is 1, in kPa if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **Tsat (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Saturation temperature. The return value is in °F if btuFlag is 1, in °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

## **4.2 Properties of Saturated Water as a Function of Pressure**

### **vfp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific volume of saturated liquid. The return value is in ft<sup>3</sup>/lbm if btuFlag is 1, in m<sup>3</sup>/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **vgp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).

stat           =0 if successful completion, =1 if an error occurred.  
btuFlag       =1 for BTU, =0 for SI units.

Return Value:

Specific volume of saturated steam. The return value is in ft<sup>3</sup>/lbm if btuFlag is 1, in m<sup>3</sup>/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **hfp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat         =0 if successful completion, =1 if an error occurred.  
btuFlag      =1 for BTU, =0 for SI units.

Return Value:

Specific enthalpy of saturated liquid. The return value is in Btu/lbm if btuFlag is 1, in kJ/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **hgp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat         =0 if successful completion, =1 if an error occurred.  
btuFlag      =1 for BTU, =0 for SI units.

Return Value:

Specific enthalpy of saturated steam. The return value is in Btu/lbm if btuFlag is 1, in kJ/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **sfp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat         =0 if successful completion, =1 if an error occurred.  
btuFlag      =1 for BTU, =0 for SI units.

Return Value:

Specific entropy of saturated liquid. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **sgp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific entropy of saturated steam. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **cpfp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific heat at constant pressure for saturated liquid. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **cpgp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific heat at constant pressure for saturated steam. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **kfp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Thermal conductivity of saturated liquid. The return value is in Btu/hr-ft-°F if btuFlag is 1, in W/m if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **kgp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Thermal conductivity of saturated steam. The return value is in Btu/hr-ft-°F if btuFlag is 1, in W/m if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **mufp (double p, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Dynamic viscosity of saturated liquid. The return value is in lbf-s/ft<sup>2</sup> if btuFlag is 1, in Pa-s if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **mugp (double p, ref int stat, int btuFlag)**

p              Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
stat            =0 if successful completion, =1 if an error occurred.  
btuFlag        =1 for BTU, =0 for SI units.

Return Value:

Dynamic viscosity of saturated steam. The return value is in lbf-s/ft<sup>2</sup> if btuFlag is 1, in Pa-s if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

## **4.3 Properties of Saturated Water as a Function of Temperature**

### **vft (double t, ref int stat, int btuFlag)**

t              Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat            =0 if successful completion, =1 if an error occurred.  
btuFlag        =1 for BTU, =0 for SI units.

Return Value:

Specific volume of saturated liquid. The return value is in ft<sup>3</sup>/lbm if btuFlag is 1, in m<sup>3</sup>/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **vgt (double t, ref int stat, int btuFlag)**

t              Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat            =0 if successful completion, =1 if an error occurred.  
btuFlag        =1 for BTU, =0 for SI units.

Return Value:

Specific volume of saturated steam. The return value is in ft<sup>3</sup>/lbm if btuFlag is 1, in m<sup>3</sup>/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **hft (double t, ref int stat, int btuFlag)**

t              Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat            =0 if successful completion, =1 if an error occurred.



btuFlag      =1 for BTU, =0 for SI units.

Return Value:

Specific enthalpy of saturated liquid. The return value is in Btu/lbm if btuFlag is 1, in kJ/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **hgt (double t, ref int stat, int btuFlag)**

t              Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).

stat          =0 if successful completion, =1 if an error occurred.

btuFlag      =1 for BTU, =0 for SI units.

Return Value:

Specific enthalpy of saturated steam. The return value is in Btu/lbm if btuFlag is 1, in kJ/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **sft (double t, ref int stat, int btuFlag)**

t              Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).

stat          =0 if successful completion, =1 if an error occurred.

btuFlag      =1 for BTU, =0 for SI units.

Return Value:

Specific entropy of saturated liquid. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **sgt (double t, ref int stat, int btuFlag)**

t              Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).

stat          =0 if successful completion, =1 if an error occurred.

btuFlag      =1 for BTU, =0 for SI units.

Return Value:

Specific entropy of saturated steam. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **cpft (double t, ref int stat, int btuFlag)**

t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific heat at constant pressure for saturated liquid. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **cpgt (double t, ref int stat, int btuFlag)**

t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific heat at constant pressure for saturated steam. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **kft (double p, ref int stat, int btuFlag)**

t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Thermal conductivity of saturated liquid. The return value is in Btu/hr-ft-°F if btuFlag is 1, in W/m if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **kgt (double p, ref int stat, int btuFlag)**

t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Thermal conductivity of saturated steam. The return value is in Btu/hr-ft-°F if btuFlag is 1, in W/m if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **muft (double p, ref int stat, int btuFlag)**

t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Dynamic viscosity of saturated liquid. The return value is in lbf-s/ft<sup>2</sup> if btuFlag is 1, in Pa-s if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **muft (double p, ref int stat, int btuFlag)**

t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Dynamic viscosity of saturated steam. The return value is in lbf-s/ft<sup>2</sup> if btuFlag is 1, in Pa-s if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

## 4.4 Properties of subcooled or superheated water

### **vpt (double p, double t, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific volume as a function of pressure and temperature. The return value is in ft<sup>3</sup>/lbm if btuFlag is 1, in m<sup>3</sup>/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **hpt (double p, double t, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific enthalpy as a function of pressure and temperature. The return value is in Btu/lbm if btuFlag is 1, in kJ/kg if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **spt (double p, double t, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific entropy as a function of pressure and temperature. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **cppt (double p, double t, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Specific heat at constant pressure as a function of pressure and temperature. The return value is in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **kpt (double p, double t, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Thermal conductivity. The return value is in Btu/hr-ft-°F if btuFlag is 1, in W/m if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **mupt (double p, double t, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
t            Temperature (in °F if btuFlag is 1, in °K if btuFlag is 0).  
stat        =0 if successful completion, =1 if an error occurred.  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Dynamic viscosity. The return value is in lbf-s/ft<sup>2</sup> if btuFlag is 1, in Pa-s if btuFlag is 0.

If stat = 1 on return, [errorMessage](#) has the description of the error.

## 4.5 Temperature as a function of pressure and enthalpy or entropy

### **Tph (double p, double h, ref double x, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
h            Specific enthalpy (in Btu/lbm if btuFlag is 1, in kJ/kg if btuFlag is 0).  
x            quality (output).  
stat        =0 if successful completion, =1 if an error occurred (output).  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Temperature. The return value is in °F if btuFlag is 1, in °K if btuFlag is 0.

If the pressure is less than the critical pressure, quality is also calculated which may be less than 0 (subcooled liquid) or greater than 1 (superheated steam). If pressure is greater than the critical pressure, the value of quality on return is not meaningful.

If stat = 1 on return, [errorMessage](#) has the description of the error.

### **Tps (double p, double s, ref double x, ref int stat, int btuFlag)**

p            Pressure (in psia if btuFlag is 1, in kPa if btuFlag is 0).  
s            Specific entropy (in Btu/lbm °F if btuFlag is 1, in kJ/kg °K if btuFlag is 0).  
x            quality (output).  
stat        =0 if successful completion, =1 if an error occurred (output).  
btuFlag    =1 for BTU, =0 for SI units.

Return Value:

Temperature. The return value is in °F if btuFlag is 1, in °K if btuFlag is 0.

If the pressure is less than the critical pressure, quality is also calculated which may be less than 0 (subcooled liquid) or greater than 1 (superheated steam). If pressure is greater than the critical pressure, the value of quality on return is not meaningful.

If stat = 1 on return, [errorMessage](#) has the description of the error.

## 5. CALLING BY C# PROGRAMS

The DLL must be included in the references of the project. In Visual Studio project explorer, right click on the “references” and select “Browse” in the pop-up window. Find the DLL and add to the references.

The following example illustrates the use vpt of function in the calling program.

```
private void Example()
{
    int stat = 0;
    int btuFlag = 0;

    SteamProperties.StmProp libStm = new SteamProperties.StmProp();

    double p = 10000.0;
    double t = 500.0;

    double v = libStm.vpt(p, t, ref stat, btuFlag)
    if (stat != 0)
        MessageBox.Show( libStm.errorMessage );
    else
        MessageBox.Show ("Specific Volume is " + v.ToString());
}
```