IAPWS-IF97

Water and Steam Properties

Dynamic-Link Library (DLL)

USER GUIDE

Windows® Operating System
SI and I-P Units
Version 2.0

1.1 Introduction

STEAM IF97 DLL is a C++ Dynamic-Link Library used in the development of Windows applications that incorporate the calculation of thermodynamic and transport properties of Water and Steam based on the latest IAPWS-IF97 Formulation and IAPWS releases.

Any Windows client application that supports C++ function imports can make use of this library by including it in its deployment.

The numerical results obtained are suitable for academic, engineering, scientific or industrial use.

1.2 Description

• Full support of .NET, C++, C# framework development environments.

• Performs all the calculations implementing the latest mathematical formulations from the IAPWS (International Association for the Properties of Water and Steam), IAPWS-IF97 Industrial formulation (Revision 2007).

• Calculates the following Thermodynamic and Transport properties of water and steam all over the valid range of the IAPWS-IF97:
  • Pressure
  • Temperature
  • Specific Enthalpy
  • Specific Entropy
  • Specific Internal Energy
  • Specific Volume
  • Density
  • Speed of Sound
  • Dynamic Viscosity
  • Kinematic Viscosity
  • Thermal Conductivity
  • Thermal Diffusivity
  • Specific Isobaric Heat Capacity
  • Specific Isochoric Heat Capacity
  • Isentropic Exponent
  • Isobaric Cubic Expansion Coefficient

- Isothermal Compressibility
- Prandtl Number
- Vapor Fraction
- IAPWS-IF97 Region
- Specific Helmholtz Energy
- Specific Gibbs Energy
- Compression factor
- Relative pressure coefficient
- Isothermal stress coefficient
- Joule-Thomson coefficient
- Dielectric constat
- Surface Tension
- Refractive index

- Calculates the differential quotients:

$\left(\dfrac{\partial v}{\partial p}\right)_T$ Partial derivate of specific volume on pressure with constant temperature

$\left(\dfrac{\partial u}{\partial p}\right)_T$ Partial derivate of specific internal energy on pressure with constant temperature

$\left(\dfrac{\partial s}{\partial p}\right)_T$ Partial derivate of specific entropy on pressure with constant temperature

$\left(\dfrac{\partial h}{\partial p}\right)_T$ Partial derivate of specific enthalpy on pressure with constant temperature

$\left(\dfrac{\partial v}{\partial T}\right)_P$ Partial derivate of specific volume on temperature with constant temperature

$\left(\dfrac{\partial u}{\partial T}\right)_P$ Partial derivate of specific internal energy on temperature with constant pressure

$\left(\dfrac{\partial s}{\partial T}\right)_P$ Partial derivate of specific entropy on temperature with constant pressure

$\left(\dfrac{\partial h}{\partial T}\right)_P$ Partial derivate of specific enthalpy on temperature with constant pressure

$\left(\dfrac{\partial P}{\partial T}\right)_v$ Partial derivate of pressure on temperature with constant specific volume

$\left(\dfrac{\partial P}{\partial v}\right)_T$ Partial derivate of pressure on specific volume with constant temperature

- Allows for 14 different combinations of thermodynamic properties to be entered as input parameters in both the SI (metric) and the I-P (english) system of units.
  - Temperature / Pressure
  - Temperature / Enthalpy
  - Temperature / Internal Energy
  - Temperature / Entropy
  - Temperature / Specific Volume
  - Pressure / Enthalpy
  - Pressure / Internal Energy
  - Pressure / Entropy
  - Pressure / Specific Volume
  - Enthalpy / Entropy
  - Enthalpy / Specific Volume
  - Internal Energy / Specific Volume
  - Temperature / Vapor Fraction
  - Pressure / Vapor Fraction

1.3 Deployment Requirements

The following are the requirements in order to deploy STEAM IF97 DLL as part of a Windows application. Please note that if the operating system in which the client application will be deployed doesn't have the corresponding C++ Runtime Library or the necessary files from this library to operate, STEAM IF97 DLL will not work as expected.

The C++ Runtime Library should be distributed and installed as part of the client application, or the necessary core files from this library should be accessible to the dll file.

Operating System (64 and 32-bit)	Windows 7 Windows 8 Windows 8.1 Windows 10
C++ Runtime Library (64-bit)	Microsoft Visual C++ 2015-2019 Redistributable (x64)
C++ Runtime Library (32-bit)	Microsoft Visual C++ 2015-2019 Redistributable(x86)

Table 1. Requirements to deploy STEAM IF97 DLL in a client Windows application.

FLUIDIKA

1.4 Installation

Double-click on the installation file and follow the on-screen instructions. When prompted, introduce the **License Key** that was delivered to you. Contact **support@fluidika.com** if you require assistance.
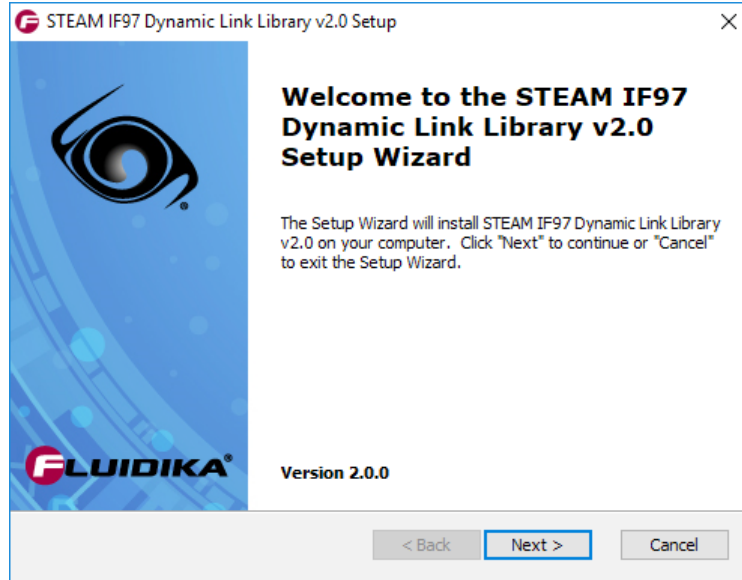
Figure 1. Installation screen of STEAM IF97 DLL.

1.5 Contents of installation

```
+---DOCS
|       EULA.rtf
|       STEAMIF97_DLL_KEY_DEFINITIONS.pdf
|       STEAMIF97_DLL_USER_GUIDE.pdf
|
+---EXAMPLES
|   \---VS2019
|       +---32BIT
|       |   +---TEST_LIB_CPP32
|       |   |
|       |   \---TEST_LIB_NET32
|       |
|       \---64BIT
|           +---TEST_LIB_CPP64
|           |
|           \---TEST_LIB_NET64
|
+---VC
|       vc_redist.x64.exe
|       vc_redist.x86.exe
|
\--LIBS
    +---32BIT
    |       STEAMIF97FLK32.dll
    |
    \---64BIT
            STEAMIF97FLK64.dll
```

Figure 2. Tree view of directories and main files after installation of STEAM IF97 DLL.

Figure 2 shows the contents of the installation as a tree view of the directories and main files included in STEAM IF97 DLL. Figures 3 and 4 show a detailed description of the main files and directories installed.

```
+---DOCS
|       EULA.rtf
|                       End-User License Agreement for the Dynamic Link Libraries and related
|                       material included in this installation.
|
|       STEAMIF97_DLL_KEY_DEFINITIONS.pdf
|                       Document that comprises all the key constants needed to call, in the client
|                       application, the export calculation functions defined in STEAM IF97 DLL.
|
|       STEAMIF97_DLL_USER_GUIDE.pdf
|                       This document.
|
+---EXAMPLES
|    \---VS2019
|        +---32BIT
|        |    +---TEST_LIB_CPP32
|        |    |    |       Application example of the STEAMIF97 dll used in a Visual Studio 2019
|        |    |    |       console app developed in C++ (32-bit).
|        |    |    |
|        |    \---TEST_LIB_NET32
|        |    |           Application example of the STEAMIF97 dll used in a Visual Studio 2019
|        |    |           console app developed in .NET C#  (32-bit).
|        |    |
|        \---64BIT
|            +---TEST_LIB_CPP64
|            |    |       Application example of the STEAMIF97 dll used in a Visual Studio 2019
|            |    |       console app developed in C++ (64-bit).
|            |    |
|            \---TEST_LIB_NET64
|                        Application example of the STEAMIF97 dll used in a Visual Studio 2019
|                        console app developed in .NET C#  (64-bit).
|
+---VC
        vc_redist.x64.exe
                        Microsoft Visual C++ 2015-2019 Redistributable (x64) 14.21.27702
        vc_redist.x86.exe
                        Microsoft Visual C++ 2015-2019 Redistributable (x86) 14.21.27702
```

Figure 3. Detailed description of directories and main files after installation of STEAM IF97 DLL.

FLUIDIKA

```
\---LIBS
    +---32BIT
    |       STEAMIF97FLK32.dll
    |
```
Dynamic -Link Library file of STEAM IF97 in 32-bit for release. This is the file to be included when releasing 32-bit client applications.
```
    |
    \---64BIT
            STEAMIF97FLK64.dll
```
Dynamic -Link Library file of STEAM IF97 in 64-bit for release. This is the file to be included when releasing 64-bit client applications.

Figure 4. Detailed description of directories and main files after installation of STEAM IF97 DLL (continuation).

1.6 Upgrades

Information about upgrades will be send to the email address that was registered at the time of acquiring the **License Key**. Contact **support**@**fluidika.com** if you require assistance.

2.1 Range of validity

The range of validity comprises all the valid range of the IAPWS-IF97 Formulation as stated by the IAPWS, see *References*. This is shown in Figures 5 and 6, together with the region assignment.

In the case of any other combination of input thermodynamic properties other than the combination <p, T>, **STEAM IF97 DLL** will determine the corresponding region and properties.

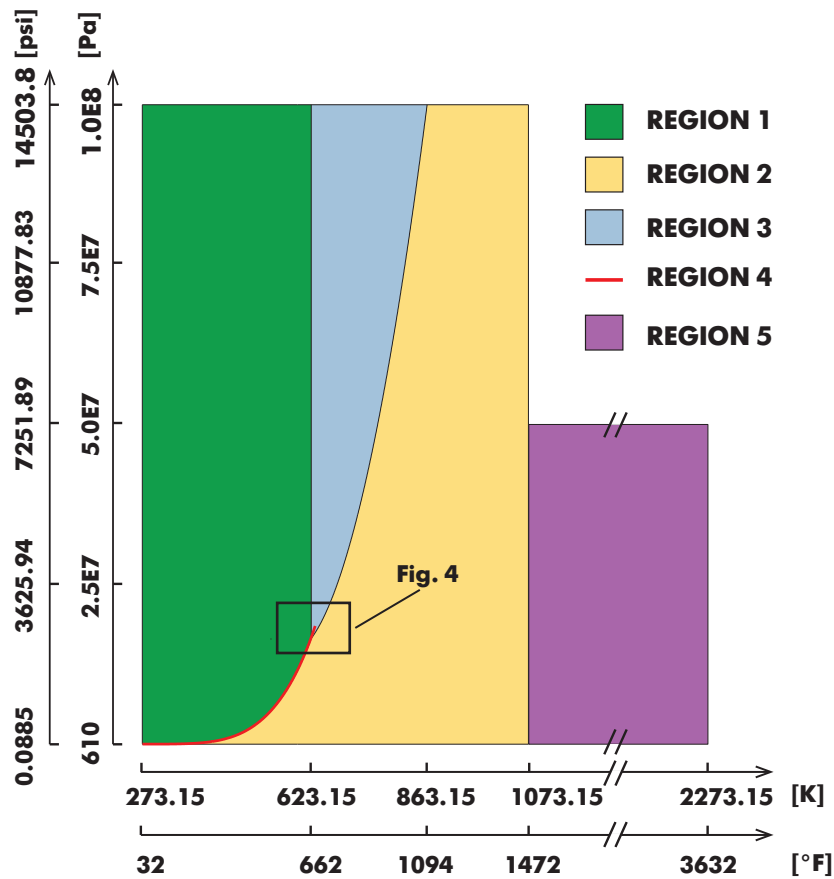As an example, Figure 7 shows the combination of variables <h, s> (enthalpy-entropy).

Figure 5. Range validity of the IAPWS-IF97 formulation (p-T)
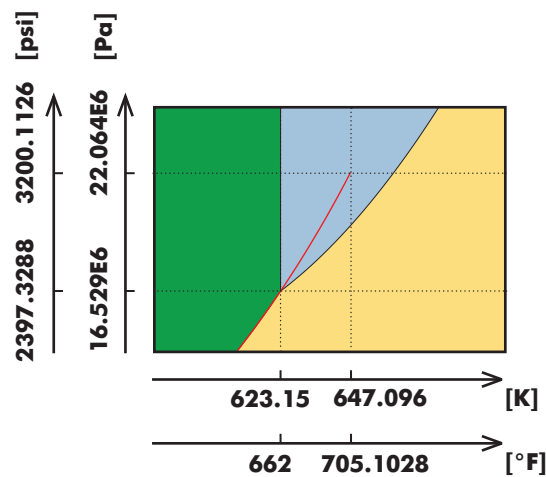
Figure 6. Zoom view of the critical point on the p-T Diagram
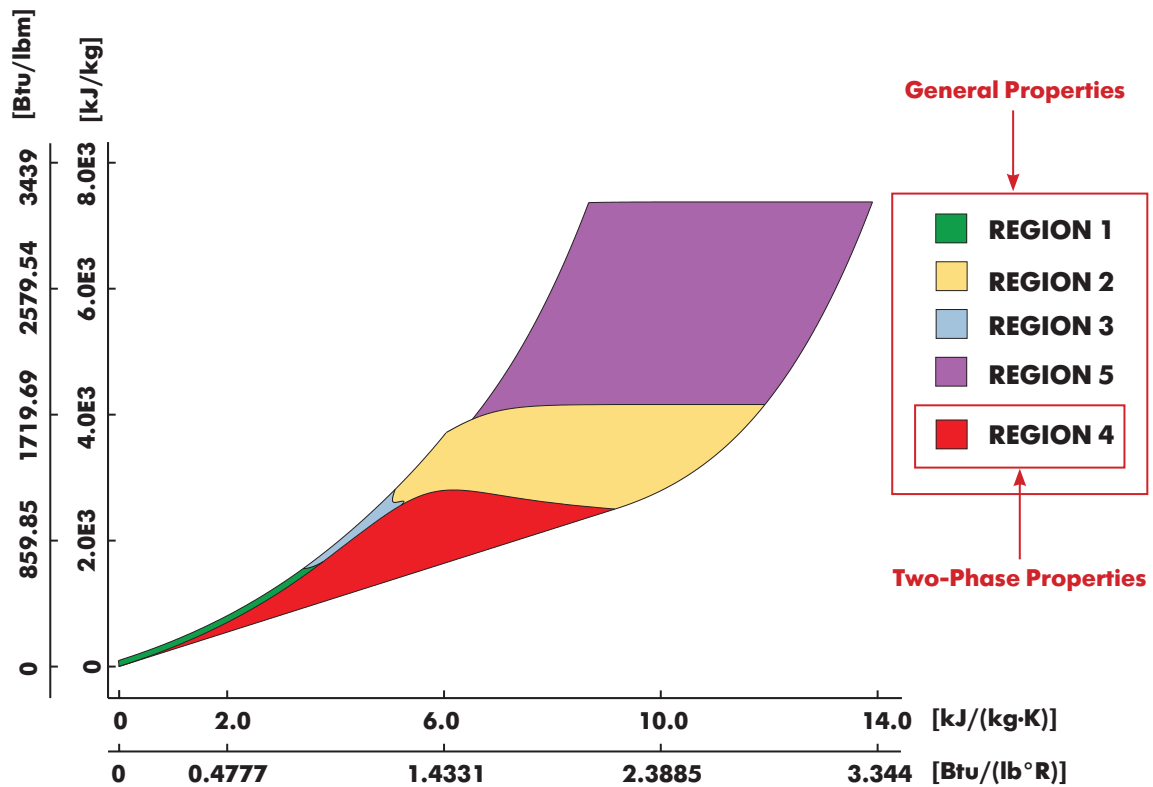
Figure 7. Enthalpy-Entropy Diagram

The IAPWS Formulations divides the calculations into five regions, shown as examples in the previous figures. The input variables used in this library have the following absolute ranges:

Property	Range in SI Units	SI Units
Pressure	610 ≤ p ≤ 100.0E6	Pa
Temperature	273.15 ≤ T ≤ 2273.15	K
Specific Enthalpy	-41.5878 ≤ h ≤ 2810.0E3	J/kg
Specific Internal Energy	-282.7252 ≤ u ≤ 6327.862E3	J/kg
Specific Entropy	-8.5823 ≤ s ≤ 13905.8727	J/(kg·K)
Specific Volume	1.00007E-4 ≤ v ≤ 1719.8658	m³/kg
Vapor Fraction	0 ≤ x ≤ 1.0	kg/kg
Wavelength	0.2 ≤ n ≤ 1.1	μm

Property	Range in I-P Units	I-P Units
Pressure	0.088473 ≤ p ≤ 1450.4	psi
Temperature	32.0 ≤ T ≤ 3632.0	°F
Specific Enthalpy	-0.017879 ≤ h ≤ 3171.5306	Btu/lbm
Specific Internal Energy	-0.12155 ≤ u ≤ 2720.491	Btu/lbm
Specific Entropy	-0.0020498 ≤ h ≤ 3.32136	Btu/(lbm·°R)
Specific Volume	1.601958E-2 ≤ v ≤ 27549.6	ft³/lbm
Vapor Fraction	0 ≤ x ≤ 1.0	lb/lb
Wavelength	7.8740157 ≤ n ≤ 43.3070866	μin

Table 2. Absolute ranges for input variables used in STEAM IF97 DLL

The upper temperature range for Kinematic Viscosity, Dynamic Viscosity, Thermal Conductivity, Thermal Diffusivity and Prandtl Number is 1173.15 K / 1652 °F.

2.2 Export Functions

STEAM IF97 DLL Dynamic-Link Library is composed of Export Functions that take parameters (char * and double) and returns a double (result number).

If incorrect or out of bounds input parameters are entered, the function will return the value of **-999**.

Table 3 shows the functions exported by the dll, both in the SI or I-P system of units. These are the functions that are to be imported by the client application. The combinations of input variables considered in these functions is listed in Table 4.

Table 6 lists the properties together with their output units that are calculated for each combination of input thermodynamic variables, where the char * defined in column **prop** corresponds to the string variable used as input parameter in functions of the form

$$STEAMFLK\_SI\_XX\_prop$$
or
$$STEAMFLK\_IP\_XX\_prop$$

where **XX** is one of the combinations in Table 4.

SI UNITS	I-P UNITS	OUTPUT RESULT
STEAMFLK_SI_pT_prop	STEAMFLK_IP_pT_prop	Depending on value of "prop", see Table 6
STEAMFLK_SI_Th_prop	STEAMFLK_IP_Th_prop	
STEAMFLK_SI_Tu_prop	STEAMFLK_IP_Tu_prop	
STEAMFLK_SI_Ts_prop	STEAMFLK_IP_Ts_prop	
STEAMFLK_SI_Tv_prop	STEAMFLK_IP_Tv_prop	
STEAMFLK_SI_ph_prop	STEAMFLK_IP_ph_prop	
STEAMFLK_SI_pu_prop	STEAMFLK_IP_pu_prop	
STEAMFLK_SI_ps_prop	STEAMFLK_IP_ps_prop	
STEAMFLK_SI_pv_prop	STEAMFLK_IP_pv_prop	
STEAMFLK_SI_hs_prop	STEAMFLK_IP_hs_prop	
STEAMFLK_SI_hv_prop	STEAMFLK_IP_hv_prop	
STEAMFLK_SI_uv_prop	STEAMFLK_IP_uv_prop	
STEAMFLK_SI_Tx_prop	STEAMFLK_IP_Tx_prop	
STEAMFLK_SI_px_prop	STEAMFLK_IP_px_prop	
STEAMFLK_SI_REFRACTIVE	STEAMFLK_IP_REFRACTIVE	**Refractive index**
STEAMFLK_SI_T_sigma	STEAMFLK_IP_T_sigma	**Surface Tension**
STEAMFLK_SI_p_sigma	STEAMFLK_IP_p_sigma	**Surface Tension**
STEAMFLK_SI_T_psat	STEAMFLK_IP_T_psat	**Saturation Pressure**
STEAMFLK_SI_p_Tsat	STEAMFLK_IP_p_Tsat	**Saturation Temperature**

Table 3. Export Functions defined in STEAM IF97 DLL

FLUIDIKA

Input variable		Input variable		Combination
Pressure	(p)	Temperature	(T)	**pT**
Temperature	(T)	Specific Enthalpy	(h)	**Th**
Temperature	(T)	Specific Internal Energy	(u)	**Tu**
Temperature	(T)	Specific Entropy	(s)	**Ts**
Temperature	(T)	Specific Volume	(v)	**Tv**
Pressure	(p)	Specific Enthalpy	(h)	**ph**
Pressure	(p)	Specific Internal Energy	(u)	**pu**
Pressure	(p)	Specifc Entropy	(s)	**ps**
Pressure	(p)	Specific Volume	(v)	**pv**
Specific Enthalpy	(h)	Specific Entropy	(s)	**hs**
Specific Enthalpy	(h)	Specific Volume	(v)	**hv**
Specific Internal Energy	(u)	Specific Volume	(v)	**uv**
Temperature	(T)	Vapor Fraction	(x)	**Tx**
Pressure	(p)	Vapor Fraction	(x)	**px**

Table 4. **Combination of input thermodynamic variables**

Property	SI Units (output)	I-P Units (output)
Refractive index	[-]	[-]
Surface tension	mPa·m	lbf/ft
Saturation Pressure	Pa	psi
Saturation Temperature	K	°F

Table 5. Additional properties calculated

Property	SI Units (output)	I-P Units (output)	(prop)
Pressure	Pa	psi	**p**
Temperature	K	°F	**T**
Specific Enthalpy	J/kg	Btu/lbm	**h**
Specific Entropy	J/(kg·K)	Btu/(lbm·°R)	**s**
Specific Internal Energy	J/kg	Btu/lbm	**u**
Specific Volume	m³/kg	ft³/lbm	**v**
Density	kg/m³	lbm/ft³	**rho**
Speed of Sound	m/s	ft/s	**w**
Dynamic Viscosity	Pa·s	lbf·s/ft²	**eta**
Kinematic Viscosity	m²/s	ft²/s	**ny**
Thermal Conductivity	W/(m·K)	Btu/(ft·h·°R)	**lambda**
Thermal Diffusivity	m²/s	ft²/s	**a**
Specific Isobaric Heat Capacity	J/(kg·K)	Btu/(lbm·°R)	**cp**
Specific Isochoric Heat Capacity	J/(kg·K)	Btu/(lbm·°R)	**cv**
Isentropic Exponent	[-]	[-]	**kappa**
Isobaric Cubic Expansion Coefficient	1/K	1/°R	**alphav**
Isothermal Compressibility	1/kPa	1/psi	**kappaT**
Prandtl Number	[-]	[-]	**prandtl**
Vapor Fraction	kg/kg	lb/lb	**x**
IAPWS-IF97 Region	-	-	**region**
Specific Helmholtz Energy	J/kg	Btu/lbm	**f**
Specific Gibbs Energy	J/kg	Btu/lbm	**g**
Compression factor	[-]	[-]	**z**
Relative pressure coefficient	1/K	1/°R	**alphap**
Isothermal stress coefficient	kg/m³	lbm/ft³	**betap**
Joule-Thomson coefficient	K/MPa	°F/psi	**my**
Dielectric constant	[-]	[-]	**epsilon**
Differential quotient (dvdP)T	m³/(kg·MPa)	ft³/(lb·psi)	**dvdpT**
Differential quotient (dudP)T	J/(kg·Pa)	Btu/(lb·psi)	**dudpT**
Differential quotient (dsdP)T	J/(kg·K·Pa)	Btu/(lb·°F·psi)	**dsdpT**
Differential quotient (dhdP)T	J/(kg·Pa)	Btu/(lb·psi)	**dhdpT**
Differential quotient (dvdT)P	m³/(kg·K)	ft³/(lb·°F)	**dvdTp**
Differential quotient (dudT)P	J/(kg·K)	Btu/(lb·°F)	**dudTp**
Differential quotient (dsdT)P	J/(kg·K·K)	Btu/(lb·°F·°F)	**dsdTp**
Differential quotient (dhdT)P	J/(kg·K)	Btu/(lb·°F)	**dhdTp**
Differential quotient (dPdT)v	MPa/K	psi/°F	**dpdTv**
Differential quotient (dPdv)T	MPa·kg/m³	psi·lb/ft³	**dpdvT**

Table 6. **Properties calculated for each combination of input thermodynamic variables**

FUNCTION NAME:	STEAMFLK_SI_pT_prop

Function call : STEAMFLK_SI_pT_prop(p, T, prop, key)

Input values : **p [double]:** Pressure in Pa.
Range: $610 \leqslant p \leqslant 1.0E8$ [Pa]

T [double]: Temperature in K.
Range: $273.15 \leqslant T \leqslant 2273.15$ [K]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_PT (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

Notes : It is not possible to calculate points over the two-phase region. When prop = "x". i.e., vapor fraction, the result will be -999.

FUNCTION NAME:	STEAMFLK_SI_hs_prop

Function call : STEAMFLK_SI_hs_prop(h, s, prop, key)

Input values : **h [double]:** Specific enthalpy in J/kg.
Range: $-41.5878 \leqslant h \leqslant 2810.0E3$ [J/kg]

s [double]: Specific entropy in J/(kg·K).
Range: $-8.5823 \leqslant s \leqslant 13905.8727$ [J/(kg·K)]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_HS (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_SI_hv_prop

Function call : STEAMFLK_SI_hv_prop(h, v, prop, key)

Input values : **h [double]:** Specific enthalpy in J/kg.
Range: $-41.5878 \leq h \leq 2810.0E3$ [J/kg]

v [double]: Specific volume in m³/kg.
Range: $1.00007E-4 \leq v \leq 1719.8658$ [m³/kg]

prop[const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_HV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_SI_ph_prop

Function call : STEAMFLK_SI_ph_prop(p, h, prop, key)

Input values : **p [double]:** Pressure in Pa.
Range: $610 \leq p \leq 1.0E8$ [Pa]

h [double]: Specific enthalpy in J/kg.
Range: $-41.5878 \leq h \leq 2810.0E3$ [J/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_PH (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	**STEAMFLK_SI_ps_prop**

Function call : STEAMFLK_SI_ps_prop(p, s, prop, key)

Input values : **p [double]:** Pressure in Pa.
Range: 610 ⩽ p ⩽ 1.0E8 [Pa]

s [double]: Specific entropy J/(kg·K).
Range: -8.5823 ⩽ s ⩽ 13905.8727 [J/(kg·K)]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_PS (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	**STEAMFLK_SI_pu_prop**

Function call : STEAMFLK_SI_pu_prop(p, u, prop, key)

Input values : **p [double]:** Pressure in Pa.
Range: 610 ⩽ p ⩽ 1.0E8 [Pa]

u [double]: Specific internal energy J/Kg.
Range: -282.7252 ⩽ u ⩽ 6327.862E3 [J/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_PU (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_SI_pv_prop

Function call : STEAMFLK_SI_pv_prop(p, v, prop, key)

Input values : **p [double]:** Pressure in Pa.
Range: 610 ≤ p ≤ 1.0E8 [Pa]

v [double]: Specific volume in m³/kg.
Range: 1.00007E-4 ≤ v ≤ 1719.8658 [m³/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_PV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_SI_px_prop

Function call : STEAMFLK_SI_px_prop(p, x, prop, key)

Input values : **p [double]:** Pressure in Pa.
Range: 610.0 ≤ p ≤ 22064000.0 [Pa]

x [double]: Vapor fraction in
kg(saturated steam)/kg(wet steam).
Range: 0 ≤ x ≤ 1 [kg/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_PX (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

Notes: Setting x = 1 or x = 0, returns the corresponding value of **prop** at saturation.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_SI_Th_prop

Function call : STEAMFLK_SI_Th_prop(T, h, prop, key)

Input values : **T [double]:** Temperature in K.
Range: $273.15 \leq T \leq 2273.15$ [K]

h [double]: Specific enthalpy in J/kg.
Range: $-41.5878 \leq h \leq 2810.0E3$ [J/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_TH (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_SI_Tu_prop

Function call : STEAMFLK_SI_Tu_prop(T, u, prop, key)

Input values : **T [double]:** Temperature in K.
Range: $273.15 \leq T \leq 2273.15$ [K]

u [double]: Specific internal energy in J/Kg.
Range: $-282.7252 \leq u \leq 6327.862E3$ [J/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_TU (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_SI_Tv_prop

Function call : STEAMFLK_SI_Tv_prop(T, v, prop, key)

Input values : **T [double]:** Temperature in K.
Range: 273.15 ≤ T ≤ 2273.15 [K]

v [double]: Specific volume in m³/kg.
Range: 1.00007E-4 ≤ v ≤ 1719.8658 [m³/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_TV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_SI_Ts_prop

Function call : STEAMFLK_SI_Ts_prop(T, s, prop, key)

Input values : **T [double]:** Temperature in K.
Range: 273.15 ≤ T ≤ 2273.15 [K]

s [double]: Specific entropy in J/(kg·K).
Range: -8.5823 ≤ s ≤ 13905.8727 [J/(kg·K)]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_TS (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_SI_Tx_prop

Function call : STEAMFLK_SI_Tx_prop(T, x, prop, key)

Input values : **T [double]:** Temperature in K.
Range: $273.15 \leqslant T \leqslant 2273.15$ [K]

x [double]: Vapor fraction in
kg(saturated steam)/kg(wet steam).
Range: $0 \leqslant x \leqslant 1$ [kg/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_TX (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

Notes : Setting x = 1 or x = 0, returns the corresponding value of **prop** at saturation.

FUNCTION NAME:	STEAMFLK_SI_uv_prop

Function call : STEAMFLK_SI_uv_prop(u, v, prop, key)

Input values : **u [double]:** Specific internal energy in J/Kg.
Range: $-282.7252 \leqslant u \leqslant 6327.862E3$ [J/kg]

v [double]: Specific volume in m³/kg.
Range: $1.00007E-4 \leqslant v \leqslant 1719.8658$ [m³/kg]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_SI_UV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_SI_T_sigma
	Surface Tension

Function call :   STEAMFLK_SI_T_sigma(T, key)

Input values :   **T [double]:** Temperature in K.
Range: 273.15 ≤ T ≤ 647.096 [K]

key [const char *]: KEY_SI_T_SIGMA

Output Result :   **[double]** Surface Tension [mPa·m]

Invalid Output Result :   **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_SI_p_sigma
	Surface Tension

Function call :   STEAMFLK_SI_p_sigma(p, key)

Input values :   **p [double]:** Pressure in Pa.
Range: 611.0 ≤ p ≤ 22064000.0 [Pa]

key [const char *]: KEY_SI_P_SIGMA

Output Result :   **[double]** Surface Tension [mPa·m]

Invalid Output Result :   **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	**STEAMFLK_SI_T_psat**
	Vapor pressure

Function call : STEAMFLK_SI_T_psat(T, key)

Input values : **T [double]:** Input temperature in K.
Range: $273.15 \leqslant T \leqslant 647.096$ [K]

key [const char *]: KEY_SI_T_PSAT

Output Result : **[double]** Vapor Pressure [Pa]

Invalid Output Result : **-999** For input values/results outside the valid range for **T.**

FUNCTION NAME:	**STEAMFLK_SI_p_Tsat**
	Saturation Temperature

Function call : STEAMFLK_SI_p_Tsat(p, key)

Input values : **p [double]:** Pressure in Pa.
Range: $611.0 \leqslant p \leqslant 22064000.0$ [Pa]

key [const char *]: KEY_SI_P_TSAT

Output Result : **[double]** Saturation Temperature [K]

Invalid Output Result : **-999** For input values/results outside the valid range for **p.**

STEAMFLK_SI_REFRACTIVE

Refractive Index

Input var_1		Input var_2		combination
Pressure	(p)	Temperature	(T)	**pT**
Temperature	(T)	Specific Enthalpy	(h)	**Th**
Temperature	(T)	Specific Internal Energy	(u)	**Tu**
Temperature	(T)	Specific Entropy	(s)	**Ts**
Temperature	(T)	Specific Volume	(v)	**Tv**
Pressure	(p)	Specific Enthalpy	(h)	**ph**
Pressure	(p)	Specific Internal Energy	(u)	**pu**
Pressure	(p)	Specifc Entropy	(s)	**ps**
Pressure	(p)	Specific Volume	(v)	**pv**
Specific Enthalpy	(h)	Specific Entropy	(s)	**hs**
Specific Enthalpy	(h)	Specific Volume	(v)	**hv**
Specific Internal Energy	(u)	Specific Volume	(v)	**uv**
Temperature	(T)	Vapor Fraction	(x)	**Tx**
Pressure	(p)	Vapor Fraction	(x)	**px**

Function call :   STEAMFLK_SI_REFRACTIVE(var_1, var_2, var_wl, combination, key)

Input values :   **var_1 [double]:** Depending on value from above table.

   var_2 [double]: Depending on value from above table.

   var_wl [double]: Wavelength in µm.
   Range: $0.2 \leqslant n \leqslant 1.1$ [µm]

   combination [const char *]: See above table.

   key [const char *]: KEY_SI_REFRACTIVE (see attached document)

Output Result :   **[double]** Refractive index [-]

Invalid Output Result :   **-999** For input values outside the IAPWS-IF97 valid regions, or values outside the range for **n.**

Notes: When using STEAMFLK_SI_REFRACTIVE with combinations **Tx** or **px,** the refractive index is calculated only for saturation states, i.e., only when x = 0, or x = 1.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_pT_prop

Function call : STEAMFLK_IP_pT_prop(p, T, prop, key)

Input values : **p [double]:** Pressure in psi.
Range: $0.088473 \leqslant p \leqslant 1450.4$ [psi]

T [double]: Temperature in °F.
Range: $32.0 \leqslant T \leqslant 3632.0$ [°F]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_PT (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

Notes : It is not possible to calculate points over the two-phase region. When prop = "x". i.e., vapor fraction, result will always be -999.

FUNCTION NAME:	STEAMFLK_IP_hs_prop

Function call : STEAMFLK_IP_hs_prop(h, s, prop, key)

Input values : **h [double]:** Specific enthalpy in Btu/lbm.
Range: $-0.017879 \leqslant h \leqslant 3171.5306$ [Btu/lbm]

s [double]: Specific entropy Btu/(lbm·°R).
Range: $-0.0020498 \leqslant s \leqslant 3.32136$ [Btu/(lbm·°R)]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_HS (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_hv_prop

Function call : STEAMFLK_IP_hv_prop(h, v, prop, key)

Input values : **h [double]:** Specific enthalpy in Btu/lbm.
Range: $-0.017879 \leqslant h \leqslant 3171.5306$ [Btu/lbm]

v [double]: Specific volume in ft³/lbm.
Range: $1.601958E\text{-}2 \leqslant v \leqslant 27549.6$ [ft³/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_HV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_IP_ph_prop

Function call : STEAMFLK_IP_ph_prop(p, h, prop, key)

Input values : **p [double]:** Pressure in psi.
Range: $0.088473 \leqslant p \leqslant 1450.4$ [psi]

h [double]: Specific enthalpy in Btu/lbm.
Range: $-0.017879 \leqslant h \leqslant 3171.5306$ [Btu/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_PH (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_ps_prop

Function call : STEAMFLK_IP_ps_prop(p, s, prop, key)

Input values : **p [double]:** Pressure in psi.
Range: $0.088473 \leqslant p \leqslant 1450.4$ [psi]

s [double]: Specific entropy Btu/(lbm·°R).
Range: $-0.0020498 \leqslant s \leqslant 3.32136$ [Btu/(lbm·°R)]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_PS (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_IP_pu_prop

Function call : STEAMFLK_IP_pu_prop(p, u, prop, key)

Input values : **p [double]:** Pressure in psi.
Range: $0.088473 \leqslant p \leqslant 1450.4$ [psi]

u [double]: Specific internal energy Btu/lbm.
Range: $-0.12155 \leqslant u \leqslant 2720.491$ [Btu/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_PU (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_pv_prop

Function call : STEAMFLK_IP_pv_prop(p, v, prop, key)

Input values : **p [double]:** Pressure in psi.
Range: $0.088473 \leqslant p \leqslant 1450.4$ [psi]

v [double]: Specific volume in ft³/lbm.
Range: $1.601958E\text{-}2 \leqslant v \leqslant 27549.6$ [ft³/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_PV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_IP_px_prop

Function call : STEAMFLK_IP_px_prop(p, x, prop, key)

Input values : **p [double]:** Pressure in psi.
Range: $0.088473 \leqslant p \leqslant 3200$ [psi]

x [double]: Vapor fraction in
lb(saturated steam)/lb(wet steam).
Range: $0 \leqslant x \leqslant 1$ [lb/lb]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_PX (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

Notes: Setting x = 1 or x = 0, returns the corresponding value of **prop** at saturation.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_Th_prop

Function call : STEAMFLK_IP_Th_prop(T, h, prop, key)

Input values : **T [double]:** Temperature in °F.
Range: $32.0 \leq T \leq 3632.0$ [°F]

h [double]: Specific enthalpy in Btu/lbm.
Range: $-0.017879 \leq h \leq 3171.5306$ [Btu/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_TH (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_IP_Tu_prop

Function call : STEAMFLK_IP_Tu_prop(T, υ, prop, key)

Input values : **T [double]:** Temperature in °F.
Range: $32.0 \leq T \leq 3632.0$ [°F]

υ [double]: Specific internal energy Btu/lbm.
Range: $-0.12155 \leq υ \leq 2720.491$ [Btu/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_TU (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_Tv_prop

Function call : STEAMFLK_IP_Tv_prop(T, v, prop, key)

Input values : **T [double]:** Temperature in °F.
Range: $32.0 \leqslant T \leqslant 3632.0$ [°F]

v [double]: Specific volume in ft³/lbm.
Range: $1.601958E\text{-}2 \leqslant v \leqslant 27549.6$ [ft³/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_TV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_IP_Ts_prop

Function call : STEAMFLK_IP_Ts_prop(T, s, prop, key)

Input values : **T [double]:** Temperature in °F.
Range: $32.0 \leqslant T \leqslant 3632.0$ [°F]

s [double]: Specific entropy Btu/(lbm·°R).
Range: $-0.0020498 \leqslant s \leqslant 3.32136$ [Btu/(lbm·°R)]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_TS (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_Tx_prop

Function call : STEAMFLK_IP_Tx_prop(T, x, prop, key)

Input values : **T [double]:** Temperature in °F.
Range: $32.0 \leq T \leq 705.1028$ [°F]

x [double]: Vapor fraction in
lb(saturated steam)/lb(wet steam).
Range: $0 \leq x \leq 1$ [lb/lb)]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_TX (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

Notes : Setting x = 1 or x = 0, returns the corresponding value of **prop** at saturation.

FUNCTION NAME:	STEAMFLK_IP_uv_prop

Function call : STEAMFLK_IP_uv_prop(u, v, prop, key)

Input values : **u [double]:** Specific internal energy Btu/lbm.
Range: $-0.12155 \leq u \leq 2720.491$ [Btu/lbm]

v [double]: Specific volume in ft³/lbm.
Range: $1.601958\text{E-}2 \leq v \leq 27549.6$ [ft³/lbm]

prop [const char *]: Output Property (see Table 6)

key [const char *]: KEY_IP_UV (see attached document)

Output Result : **[double]** (see Table 6)

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_T_sigma
	Surface Tension

Function call : STEAMFLK_IP_T_sigma(T, key)

Input values : **T [double]:** Temperature in °F.
Range: $32.0 \leqslant T \leqslant 705.1028$ [°F]

key [const char *]: KEY_IP_T_SIGMA

Output Result : **[double]** Surface Tension [lbf/ft]

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FUNCTION NAME:	STEAMFLK_IP_p_sigma
	Surface Tension

Function call : STEAMFLK_IP_p_sigma(p, key)

Input values : **p [double]:** Pressure in psi.
Range: $0.088473 \leqslant p \leqslant 3200.1126$ [psi]

key [const char *]: KEY_IP_P_SIGMA

Output Result : **[double]** Surface Tension [lbf/ft]

Invalid Output Result : **-999** For input values/results outside the valid range of the IAPWS-IF97 Formulation, or incorrect string **prop**.

FLUIDIKA

FUNCTION NAME:	STEAMFLK_IP_T_psat
	Vapor saturation pressure

Function call : STEAMFLK_IP_T_psat(T, key)

Input values : **T [double]:** Temperature in °F.
Range: $32.0 \leqslant T \leqslant 705.1028$ [°F]

key [const char *]: KEY_IP_T_PSAT

Output Result : **[double]** Vapor Saturation Pressure [psi]

Invalid Output Result : **-999** For input values/results outside the valid range for **T.**

FUNCTION NAME:	STEAMFLK_IP_p_Tsat
	Saturation Temperature

Function call : STEAMFLK_IP_p_Tsat(p, key)

Input values : **p [double]:** Pressure in psi.
Range: $610.0 \leqslant p \leqslant 3200.1126$ [psi]

key [const char *]: KEY_IP_P_TSAT

Output Result : **[double]** Saturation Temperature [°F]

Invalid Output Result : **-999** For input values/results outside the valid range for **p.**

FLUIDIKA

FUNCTION NAME: STEAMFLK_IP_REFRACTIVE

Refractive Index

Input var_1		Input var_2		combination
Pressure	(p)	Temperature	(T)	**pT**
Temperature	(T)	Specific Enthalpy	(h)	**Th**
Temperature	(T)	Specific Internal Energy	(u)	**Tu**
Temperature	(T)	Specific Entropy	(s)	**Ts**
Temperature	(T)	Specific Volume	(v)	**Tv**
Pressure	(p)	Specific Enthalpy	(h)	**ph**
Pressure	(p)	Specific Internal Energy	(u)	**pu**
Pressure	(p)	Specifc Entropy	(s)	**ps**
Pressure	(p)	Specific Volume	(v)	**pv**
Specific Enthalpy	(h)	Specific Entropy	(s)	**hs**
Specific Enthalpy	(h)	Specific Volume	(v)	**hv**
Specific Internal Energy	(u)	Specific Volume	(v)	**uv**
Temperature	(T)	Vapor Fraction	(x)	**Tx**
Pressure	(p)	Vapor Fraction	(x)	**px**

Function call : STEAMFLK_IP_REFRACTIVE(var_1, var_2, var_wl, combination, key)

Input values : **var_1 [double]:** Depending on value from above table.

var_2 [double]: Depending on value from above table.

var_wl [double]: Wavelength in µin.
Range: $7.874015748032 \leq n \leq 43.30708661417$ [µin]

combination [const char *]: See above table.

key [const char *]: KEY_IP_REFRACTIVE (see attached document)

Output Result : **[double]** Refractive index [-]

Invalid Output Result : **–999** For input values outside the IAPWS-IF97 valid regions, or values outside the range for **n.**

Notes: When using STEAMFLK_IP_REFRACTIVE with combinations **Tx** or **px,** the refractive index is calculated only for saturation states, i.e., only when x = 0, or x = 1.

References

- Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, IAPWS (2007).

- Release on the IAPWS Formulation 2008 for the Viscosity of Ordinary Water Substance, IAPWS (2008).

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

- Supplementary Release on Backward Equations for Pressure as a Function of Enthalpy and Entropy p(h,s) to the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, IAPWS (2001).

- Wagner, W.; Pruß, A.: The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use. J. Phys. Chem. Ref. Data 31, 387-535 (2002).

- Wagner, W.; Kretzschmar, H.-J.: International Steam Tables. Springer, Berlin (2008).