IAPWS-IF97

Water and Steam Properties

MATLAB® Functions Library

USER GUIDE

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

Table of Contents

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OVERVIEW

WaterSteamIF97 is a MATLAB Functions Library that allows the calculation of thermodynamic and transport properties of Water and Steam based on the latest IAPWS-IF97 Formulation and IAPWS releases.

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

1.1 Description

• 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:

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

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

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

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

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

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

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

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

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

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

- 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

1.2 System Requirements

The following are the requirements in order to install and utilize WaterSteamIF97. Please note that if your operating system does not include the corresponding C++ Runtime Library it will be installed by the installation file.

	OPERATING SYSTEM
Windows OS	Windows 7 Windows 8 Windows 8.1 Windows 10

	MINIMUM VERSION	REQUIREMENT
MATLAB	R2009a (7.8)	32-bit or 64-bit

	BITNESS	REQUIREMENT
C++ Runtime Library	32-bit	Microsoft Visual C++ 2012 Redistributable (32-bit) - 11.0.6.61030
	64-bit	Microsoft Visual C++ 2012 Redistributable (64-bit) - 11.0.6.61030

- Please note that the minimum supported Windows OS is Windows 7, and the minimum supported MATLAB version is R2009a (7.8).

WaterSteamIF97 is available as a 32-bit or 64-bit Functions Library in accordance with the MATLAB version. Please select the right installation file that matches your MATLAB installation.

Installation File	MATLAB Version
WaterSteamIF97_Matlab_x86_Setup	32-bit
WaterSteamIF97_Matlab_x64_Setup	64-bit

1.3 Installation

Once you have downloaded the suitable version of WaterSteamIF97 Functions Library for your MATLAB installation, double click the corresponding file:

WaterSteamIF97_Matlab_x86_Setup.exe (for 32-bit MATLAB Installation)
WaterSteamIF97_Matlab_x64_Setup.exe (for 64-bit MATLAB installation)

You need to agree to the *License terms and conditions* before installing the software.

You need to have **Administrator** privileges on your computer in order to install the software

1.4 License

Introduce the SERIAL KEY that you received in order to install the Library.

If your system does not include the Microsoft VC++ 2012 Redistributable runtime library, it will be installed by the application. Once you agreed to the license terms and conditions, click on the install button to proceed with the installation.

1.5 Upgrades

Information about upgrades will be send to the email address that was registered.

1.6 Uninstalling the software

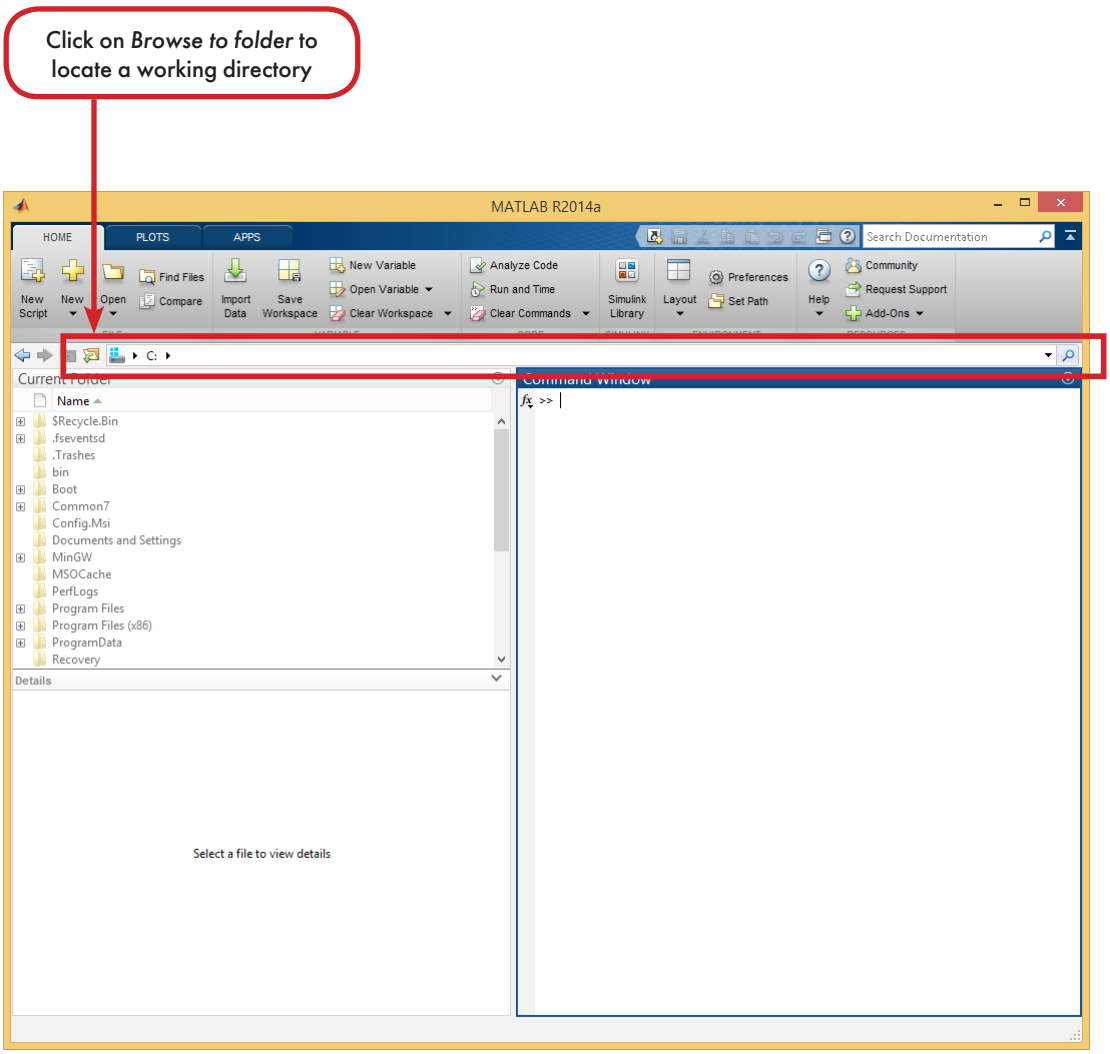
To uninstall the Library, double click the installation file and follow the on-screen instructions, or use the standard windows uninstaller, usually located at

Control Panel → *Programs* → *Programs and Features*

1.7 Use of Library Functions in MATLAB

In order to utilize the installed library functions, it is necessary to add the directory where the function files (files with extension ***.mexw32*** for a 32-bit installation or ***.mexw64*** for a 64-bit) together with all the files with extension ***.dll*** to the *Matlab Path*. Several approaches exist to accomplish this. One possibility is to click on the ***Browse for folder*** button on the MATLAB toolbar to navigate to this folder. This action will set the *Current Folder Window* to the selected directory.

In order to maintain a clean installation of the library, the recommended usage is to copy the set of function files that are required **together with all the files with extension** *.dll* to a new directory, and then add this directory to the *Matlab Path*.



IMPORTANT: **Do not rename or move any of the files with extension** *.dll* **that are located in the current working directory of the function files.**

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 1 and 2, together with the region assignment.

In the case of any other combination of input thermodynamic properties other than the combination <p, T>, **WaterSteamIF97** will determine the corresponding region and properties.

As an example, Figure 3 shows the combination of variables <h, s> (enthalpy-entropy).

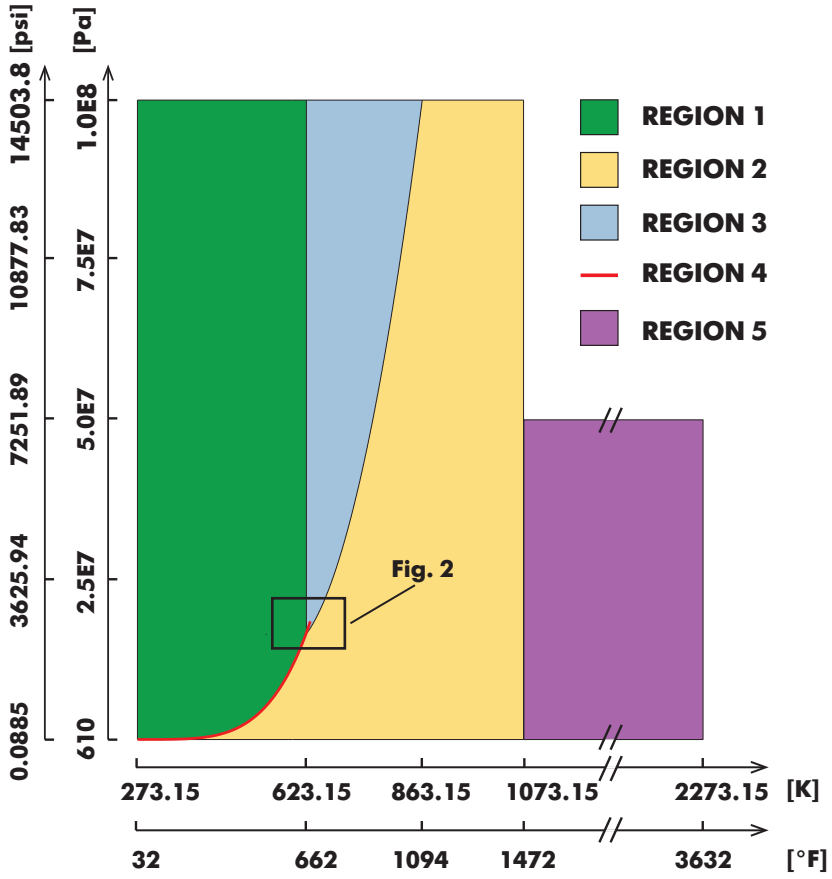


Figure 1. **Range validity of the IAPWS-IF97 formulation (p-T)**

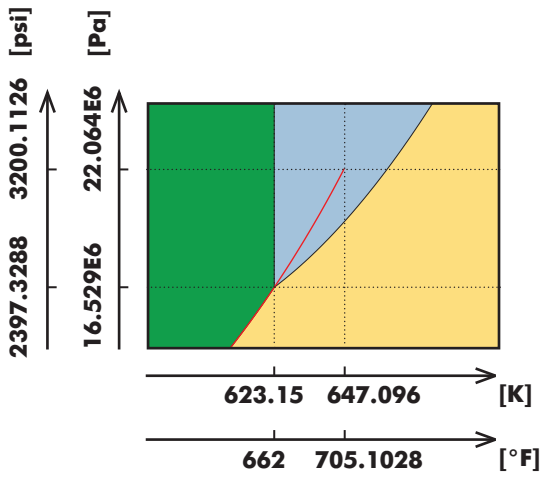


Figure 2. **Zoom view of the critical point on the p-T Diagram**

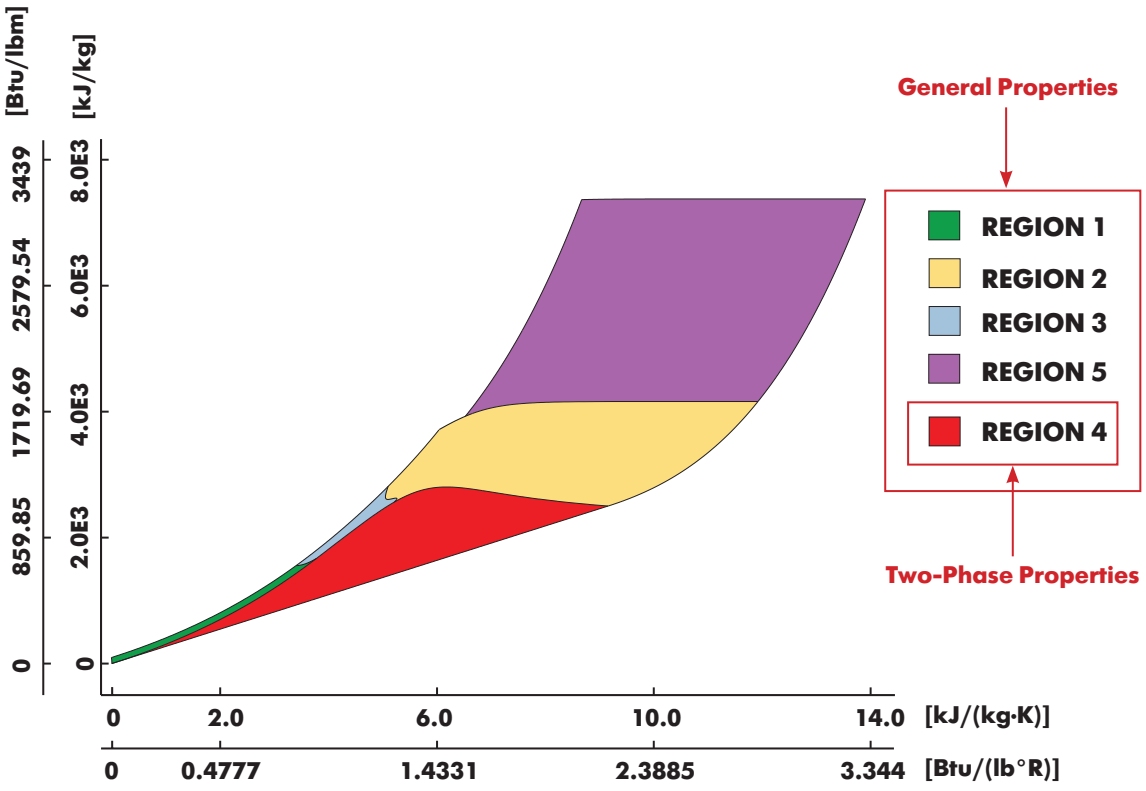


Figure 3. **Enthalpy-Entropy Diagram**

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	m^3/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	ft^3/lbm
Vapor Fraction	0 ≤ x ≤ 1.0	lb/lb
Wavelength	7.8740157 ≤ n ≤ 43.3070866	µin

Table 1. **Absolute ranges for input variables used in WaterSteamIF97**

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

2.2 Library Functions

WaterSteamIF97 for MATLAB is a library composed of User Defined Functions (UDF) that take parameters (string and/or double) and returns a double (number). If incorrect or out of bounds input parameters are entered, the function will return the value of **-999**.

Table 2 shows the functions to be used in a MATLAB environment, both in the SI or I-P system of units. The combinations of input variables considered in these functions is listed in Table 3.

Table 5 lists the properties together with their output units that are calculated for each combination of input thermodynamic variables, where the strings defined in column ***prop*** correspond to the string variables used as input parameter in functions of the form

S97FLK_SI_XX_prop

or

S97FLK_IP_XX_prop

where ***XX*** is one of the combinations in Table 3.

SI UNITS	IP UNITS	OUTPUT RESULT
S97FLK_SI_pT_prop	S97FLK_IP_pT_prop	**Depending on value of "prop", see Table 5**
S97FLK_SI_Th_prop	S97FLK_IP_Th_prop	
S97FLK_SI_Tu_prop	S97FLK_IP_Tu_prop	
S97FLK_SI_Ts_prop	S97FLK_IP_Ts_prop	
S97FLK_SI_Tv_prop	S97FLK_IP_Tv_prop	
S97FLK_SI_ph_prop	S97FLK_IP_ph_prop	
S97FLK_SI_pu_prop	S97FLK_IP_pu_prop	
S97FLK_SI_ps_prop	S97FLK_IP_ps_prop	
S97FLK_SI_pv_prop	S97FLK_IP_pv_prop	
S97FLK_SI_hs_prop	S97FLK_IP_hs_prop	
S97FLK_SI_hv_prop	S97FLK_IP_hv_prop	
S97FLK_SI_uv_prop	S97FLK_IP_uv_prop	
S97FLK_SI_Tx_prop	S97FLK_IP_Tx_prop	
S97FLK_SI_px_prop	S97FLK_IP_px_prop	
S97FLK_SI_VARwl_n	S97FLK_IP_VARwl_n	**Refractive index**
S97FLK_SI_T_sigma	S97FLK_IP_T_sigma	**Surface Tension**
S97FLK_SI_p_sigma	S97FLK_IP_p_sigma	**Surface Tension**
S97FLK_SI_T_psat	S97FLK_IP_T_psat	**Vapor Pressure**
S97FLK_SI_p_Tsat	S97FLK_IP_p_Tsat	**Saturation Temperature**

Table 2. Functions defined in WaterSteamIF97

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 3. **Combination of input thermodynamic variables**

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

Table 4. **Additional properties calculated**

Property	SI Units (output)	I-P Units (output)	String (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	m^3/kg	ft^3/lbm	**v**
Density	kg/m^3	lbm/ft^3	**rho**
Speed of Sound	m/s	ft/s	**w**
Dynamic Viscosity	Pa·s	$lbf·s/ft^2$	**eta**
Kinematic Viscosity	m^2/s	ft^2/s	**ny**
Thermal Conductivity	W/(m·K)	Btu/(ft·h·°R)	**lambda**
Thermal Diffusivity	m^2/s	ft^2/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/m^3	lbm/ft^3	**betap**
Joule-Thomson coefficient	K/MPa	°F/psi	**my**
Dielectric constant	[-]	[-]	**epsilon**
Differential quotient (dvdP)T	$m^3/(kg·MPa)$	$ft^3/(lb·psi)$	**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	$m^3/(kg·K)$	$ft^3/(lb·°F)$	**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	$MPa·kg/m^3$	$psi·lb/ft^3$	**dpdvT**

Table 5. **Properties calculated for each combination of input thermodynamic variables**

2.3 Property Functions Reference (SI Units)

FUNCTION NAME: S97FLK_SI_pT_prop

MATLAB function usage : S97FLK_SI_pT_prop(p, T, prop)

Input values :

p : Pressure in Pa.
Range: 610 ⩽ p ⩽ 1.0E8 [Pa]

T : Temperature in K.
Range: 273.15 ⩽ T ⩽ 2273.15 [K]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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.

Example : Calculation returns the value of specific enthalpy("h") as function of pressure and temperature.

```
>> h = S97FLK_SI_pT_prop(5000000, 300, 'h')
h =
      1.17167374255E+05
```

FUNCTION NAME: S97FLK_SI_hs_prop

MATLAB function usage : S97FLK_SI_hs_prop(h, s, prop)

Input values :

h : Specific enthalpy in J/kg.
Range: -41.5878 ⩽ h ⩽ 2810.0E3 [J/kg]

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

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as function of specific enthalpy and specific entropy.

```
>> v = S97FLK_SI_hs_prop(117167.3473, 391.7371, 'v')
v =
      0.001001259564
```

FUNCTION NAME: S97FLK_SI_hv_prop

MATLAB function usage : S97FLK_SI_hv_prop(h, v, prop)

Input values : **h :** Specific enthalpy in J/kg.
Range: -41.5878 ⩽ h ⩽ 2810.0E3 [J/kg]

v: Specific volume in m^3/kg.
Range: 1.00007E-4 ⩽ v ⩽ 1719.8658 [m^3/kg]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of pressure ("p") as function of specific enthalpy and specific volume.

```
>> p = S97FLK_SI_hv_prop(117167.3473, 0.00100126, 'p')
p =
      5000000
```

FUNCTION NAME: S97FLK_SI_ph_prop

MATLAB function usage : S97FLK_SI_ph_prop(p, h, prop)

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

h : Specific enthalpy in J/kg.
Range: -41.5878 ⩽ h ⩽ 2810.0E3 [J/kg]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of pressure and specific enthalpy.

```
>> v = S97FLK_SI_ph_prop(5000000, 117167.3473, 'v')
v =
      0.00100126
```

FUNCTION NAME: S97FLK_SI_ps_prop

MATLAB function usage : S97FLK_SI_ps_prop(p, s, prop)

Input values :

p : Pressure in Pa.
Range: 610 ⩽ p ⩽ 1.0E8 [Pa]

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

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of pressure and specific entropy.

```
>> v = S97FLK_SI_ps_prop(5000000, 391.7371, 'v')
v =
      0.00100126
```

FUNCTION NAME: S97FLK_SI_pu_prop

MATLAB function usage : S97FLK_SI_pu_prop(p, u, prop)

Input values :

p : Pressure in Pa.
Range: 610 ⩽ p ⩽ 1.0E8 [Pa]

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

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of pressure and specific internal energy.

```
>> v = S97FLK_SI_pu_prop(5000000, 112161.0764, 'v')
v =
      0.00100126
```

FUNCTION NAME: S97FLK_SI_pv_prop

MATLAB function usage : S97FLK_SI_pv_prop(p, v, prop)

Input values :

p : Pressure in Pa.
Range: 610 ⩽ p ⩽ 1.0E8 [Pa]

v: Specific volume in m^3/kg.
Range: 1.00007E-4 ⩽ v ⩽ 1719.8658 [m^3/kg]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific enthalpy ("h") as a function of pressure and specific volume.

```
>> h = S97FLK_SI_pv_prop(5000000, 0.00100126, 'h')
h =
      1.17167374255E+05
```

FUNCTION NAME: S97FLK_SI_px_prop

MATLAB function usage : S97FLK_SI_px_prop(p, x, prop)

Input values :

p : Pressure in Pa.
Range: 610.0 ⩽ p ⩽ 22064000.0 [Pa]

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

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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.

Example : Calculation returns the value of specific enthalpy ("h") as a function of pressure and vapor fraction.

```
>> h = S97FLK_SI_px_prop(5000000, 0.5, 'h')
h =
      1.9743645541E+06
```

FUNCTION NAME: S97FLK_SI_Th_prop

MATLAB function usage : S97FLK_SI_Th_prop(T, h, prop)

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

h : Specific enthalpy in J/kg.
Range: -41.5878 ⩽ h ⩽ 2810.0E3 [J/kg]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of temperature and specific enthalpy.

```
>> v = S97FLK_SI_Th_prop(300, 117167.3473, 'v')
v =
      0.00100126
```

FUNCTION NAME: S97FLK_SI_Tu_prop

MATLAB function usage : S97FLK_SI_Tu_prop(T, u, prop)

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

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

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of temperature and specific internal energy.

```
>> v = S97FLK_SI_Tu_prop(300, 112161.0764, 'v')
v =
      0.00100126
```

FUNCTION NAME: S97FLK_SI_Tv_prop

MATLAB function usage : S97FLK_SI_Tv_prop(T, v, prop)

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

v: Specific volume in m^3/kg.
Range: 1.00007E-4 ⩽ v ⩽ 1719.8658 [m^3/kg]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific enthalpy ("h") as a function of temperature and specific volume.

```
>> h = S97FLK_SI_Tv_prop(300,  0.00100126,  'h')
h  =
      1.17167374255E+05
```

FUNCTION NAME: S97FLK_SI_Ts_prop

MATLAB function usage : S97FLK_SI_Ts_prop(T, s, prop)

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

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

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of temperature and specific entropy.

```
>> v = S97FLK_SI_Ts_prop(300,  391.7371,  'v')
v  =
      0.00100126
```

FUNCTION NAME: S97FLK_SI_Tx_prop

MATLAB function usage : S97FLK_SI_Tx_prop(T, x, prop)

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

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

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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.

Example : Calculation returns the value of specific enthalpy ("h") as a function of temperature and vapor fraction.

```
>> h = S97FLK_SI_Tx_prop(300,  0.5,  'h')
h  =
      1.3312339995E+06
```

FUNCTION NAME: S97FLK_SI_uv_prop

MATLAB function usage : S97FLK_SI_uv_prop(u, v, prop)

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

v: Specific volume in m^3/kg.
Range: 1.00007E-4 ⩽ v ⩽ 1719.8658 [m^3/kg]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific enthalpy ("h") as a function of specific internal energy and specific volume.

```
>> h = S97FLK_SI_uv_prop(112161.0764,  0.00100126,  'h')
h  =
      1.17167374255E+05
```

FUNCTION NAME:	**S97FLK_SI_T_sigma** **Surface Tension**

MATLAB function usage : S97FLK_SI_T_sigma(T)

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

Output Result : **Surface Tension in mPa·m.**

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

Example : Calculation returns the value of surface tension as a function of temperature.

```
>> sigma = S97FLK_SI_T_sigma(300)
sigma  =
       71.685962
```

FUNCTION NAME:	**S97FLK_SI_p_sigma** **Surface Tension**

MATLAB function usage : S97FLK_SI_p_sigma(p)

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

Output Result : **Surface Tension in mPa·m.**

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

Example : Calculation returns the value of surface tension as a function of pressure.

```
>> sigma = S97FLK_SI_p_sigma(5000000)
sigma  =
       22.760897058
```

FUNCTION NAME:	**S97FLK_SI_T_psat** **Vapor pressure**

MATLAB function usage : S97FLK_SI_T_psat(T)

Input values : **T :** Input temperature in K.
Range: 273.15 ⩽ T ⩽ 647.096 [K]

Output Result : **Vapor Pressure in Pa.**

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

Example : Calculation returns the value of vapor pressure as a function of temperature.

```
>> psat = S97FLK_SI_T_psat(300)
psat  =
       3.53658941E+03
```

FUNCTION NAME:	**S97FLK_SI_p_Tsat** **Saturation Temperature**

MATLAB function usage : S97FLK_SI_p_Tsat(p)

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

Output Result : **Saturation Temperature in K.**

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

Example : Calculation returns the value of saturation temperature as a function of pressure.

```
>> psat = S97FLK_SI_p_Tsat(5000000)
psat  =
       5.3709287118E+02
```

FUNCTION NAME: **S97FLK_SI_VARwl_n**

Refractive Index

Where ***variables*** is defined as :

Input variable		Input variable		**Variables**
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**

MATLAB function usage : S97FLK_SI_VARwl_n(variables, variable1, variable2, n)

Input values : **variables :** See above table.

variable1 : Depending on value from above table.

variable2 : Depending on value from above table.

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

Output Result : **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 S97FLK_SI_VARwl_n, with variables Tx or px the refractive index is calculated only for saturation states, i.e., when x = 0, or x = 1.

Example : Calculation returns the value of the refractive index as a function of pressure, temperature, and wavelength = 0.2 μm.

```
>> n = S97FLK_SI_VARwl_n('pT', 5000000, 300, 0.2)
n =
    1.42427194148
```

2.4 Property Functions Reference (I-P Units)

FUNCTION NAME: S97FLK_IP_pT_prop

MATLAB function usage : S97FLK_IP_pT_prop(p, T, prop)

Input values :

p : Pressure in psi.
Range: 0.088473 ⩽ p ⩽ 1450.4 [psi]

T : Temperature in °F.
Range: 32.0 ⩽ T ⩽3632.0 [°F]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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.

Example : Calculation returns the value of specific enthalpy("h") as function of pressure and temperature.

```
>> h = S97FLK_IP_pT_prop(725.887, 80.33, 'h')
h =
      50.37480092
```

FUNCTION NAME: S97FLK_IP_hs_prop

MATLAB function usage : S97FLK_IP_hs_prop(h, s, prop)

Input values :

h : Specific enthalpy in Btu/lbm.
Range: -0.017879 ⩽ h ⩽ 3171.5306 [Btu/lbm]

s : Specific entropy Btu/(lbm·°R).
Range: -0.0020498 ⩽ s ⩽ 3.32136 [Btu/(lbm·°R)]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as function of specific enthalpy and specific entropy.

```
>> v = S97FLK_IP_hs_prop(50.3748, 0.093564, 'v')
v =
      0.016038595
```

FUNCTION NAME: S97FLK_IP_hv_prop

MATLAB function usage : S97FLK_IP_hv_prop(h, v, prop)

Input values : **h :** Specific enthalpy in Btu/lbm.
Range: -0.017879 ⩽ h ⩽ 3171.5306 [Btu/lbm]

v: Specific volume in ft^3/lbm.
Range: 1.601958E-2 ⩽ v ⩽ 27549.6 [ft^3/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of pressure ("p") as function of specific enthalpy and specific volume.

```
>> p = S97FLK_IP_hv_prop(50.3748, 0.01603859, 'p')
p =
      725.887
```

FUNCTION NAME: S97FLK_IP_ph_prop

MATLAB function usage : S97FLK_IP_ph_prop(p, h, prop)

Input values : **p :** Pressure in psi.
Range: 0.088473 ⩽ p ⩽ 1450.4 [psi]

h : Specific enthalpy in Btu/lbm.
Range: -0.017879 ⩽ h ⩽ 3171.5306 [Btu/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of pressure and specific enthalpy.

```
>> v = S97FLK_IP_ph_prop(725.887, 50.3748, 'v')
v =
      0.01603859
```

FUNCTION NAME: S97FLK_IP_ps_prop

MATLAB function usage : S97FLK_IP_ps_prop(p, s, prop)

Input values :

p : Pressure in psi.
Range: 0.088473 ⩽ p ⩽ 1450.4 [psi]

s : Specific entropy Btu/(lbm·°R).
Range: -0.0020498 ⩽ s ⩽ 3.32136 [Btu/(lbm·°R)]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of pressure and specific entropy.

```
>> v = S97FLK_IP_ps_prop(725.887,  0.09356447,  'v')
v  =
      0.01603859
```

FUNCTION NAME: S97FLK_IP_pu_prop

MATLAB function usage : S97FLK_IP_pu_prop(p, u, prop)

Input values :

p : Pressure in psi.
Range: 0.088473 ⩽ p ⩽ 1450.4 [psi]

u : Specific internal energy Btu/lbm.
Range: -0.12155 ⩽ u ⩽ 2720.491 [Btu/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of pressure and specific internal energy.

```
>> v = S97FLK_IP_pu_prop(725.887,  48.2204141,  'v')
v  =
      0.01603859
```

FUNCTION NAME: S97FLK_IP_pv_prop

MATLAB function usage : S97FLK_IP_pv_prop(p, v, prop)

Input values : **p :** Pressure in psi.
Range: 0.088473 ⩽ p ⩽ 1450.4 [psi]

v: Specific volume in ft^3/lbm.
Range: 1.601958E-2 ⩽ v ⩽ 27549.6 [ft^3/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific enthalpy ("h") as a function of pressure and specific volume.

```
>> h = S97FLK_SI_pv_prop(725.887,  0.01603859,  'h')
h  =
      50.3748
```

FUNCTION NAME: S97FLK_IP_px_prop

MATLAB function usage : S97FLK_IP_px_prop(p, x, prop)

Input values : **p :** Pressure in psi.
Range: 0.088473 ⩽ p ⩽ 3200 [psi]

x : Vapor fraction in lb(saturated steam)/lb(wet steam).
Range: 0 ⩽ x ⩽ 1 [lb/lb]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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.

Example : Calculation returns the value of specific enthalpy ("h") as a function of pressure and vapor fraction.

```
>> h = S97FLK_IP_px_prop(725.887,  0.5,  'h')
h  =
      817.6799902
```

FUNCTION NAME: S97FLK_IP_Th_prop

MATLAB function usage : S97FLK_IP_Th_prop(T, h, prop)

Input values : **T :** Temperature in °F.
Range: 32.0 ⩽ T ⩽ 3632.0 [°F]

h : Specific enthalpy in Btu/lbm.
Range: -0.017879 ⩽ h ⩽ 3171.5306 [Btu/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of temperature and specific enthalpy.

```
>> v = S97FLK_IP_Th_prop(80.33, 50.3748, 'v')
v =
      0.01603859
```

FUNCTION NAME: S97FLK_IP_Tu_prop

MATLAB function usage : S97FLK_IP_Tu_prop(T, u, prop)

Input values : **T :** Temperature in °F.
Range: 32.0 ⩽ T ⩽ 3632.0 [°F]

u : Specific internal energy Btu/lbm.
Range: -0.12155 ⩽ u ⩽ 2720.491 [Btu/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of temperature and specific internal energy.

```
>> v = S97FLK_SI_Tu_prop(80.33, 48.2204141, 'v')
v =
      0.01603859
```

FUNCTION NAME: S97FLK_IP_Tv_prop

MATLAB function usage : S97FLK_IP_Tv_prop(T, v, prop)

Input values : **T :** Temperature in °F.
Range: 32.0 ⩽ T ⩽3632.0 [°F]

v: Specific volume in ft^3/lbm.
Range: 1.601958E-2 ⩽ v ⩽ 27549.6 [ft^3/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific enthalpy ("h") as a function of temperature and specific volume.

```
>> h = S97FLK_IP_Tv_prop(80.33, 0.01603859, 'h')
h =
      817.6799902
```

FUNCTION NAME: S97FLK_IP_Ts_prop

MATLAB function usage : S97FLK_IP_Ts_prop(T, s, prop)

Input values : **T :** Temperature in °F.
Range: 32.0 ⩽ T ⩽ 3632.0 [°F]

s : Specific entropy Btu/(lbm·°R).
Range: -0.0020498 ⩽ s ⩽ 3.32136 [Btu/(lbm·°R)]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific volume ("v") as a function of temperature and specific entropy.

```
>> v = S97FLK_IP_Ts_prop(80.33, 0.09356447, 'v')
v =
      0.01603859
```

FUNCTION NAME: S97FLK_IP_Tx_prop

MATLAB function usage : S97FLK_IP_Tx_prop(T, x, prop)

Input values : **T :** Temperature in °F.
Range: 32.0 ⩽ T ⩽ 705.1028 [°F]

x : Vapor fraction in lb(saturated steam)/lb(wet steam).
Range: 0 ⩽ x ⩽ 1 [lb/lb)]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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.

Example : Calculation returns the value of specific enthalpy ("h") as a function of temperature and vapor fraction.

```
>> h = S97FLK_IP_Tx_prop(80.33, 0.5, 'h')
h =
      572.3276
```

FUNCTION NAME: S97FLK_IP_uv_prop

MATLAB function usage : S97FLK_IP_uv_prop(u, v, prop)

Input values : **u :** Specific internal energy Btu/lbm.
Range: -0.12155 ⩽ u ⩽ 2720.491 [Btu/lbm]

v: Specific volume in ft^3/lbm.
Range: 1.601958E-2 ⩽ v ⩽ 27549.6 [ft^3/lbm]

prop: Output Property. String (see Table 5)

Output Result : See Table 5.

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

Example : Calculation returns the value of specific enthalpy ("h") as a function of specific internal energy and specific volume.

```
>> h = S97FLK_IP_uv_prop(48.2204141,  0.01603859, 'h')
h =
      50.37574881
```

FUNCTION NAME:	**S97FLK_IP_T_sigma** **Surface Tension**

MATLAB function usage : S97FLK_IP_T_sigma(T)

Input values : **T :** Temperature in °F.
Range: 32.0 ⩽ T ⩽ 705.1028 [°F]

Output Result : Surface Tension in lbf/ft.

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

Example : Calculation returns the value of surface tension as a function of temperature.

```
>> sigma = S97FLK_IP_T_sigma(80.33)
sigma  =
      0.004911922152361
```

FUNCTION NAME:	**S97FLK_IP_p_sigma** **Surface Tension**

MATLAB function usage : S97FLK_IP_p_sigma(p)

Input values : **p :** Pressure in psi.
Range: 0.088473 ⩽ p ⩽ 3200.1126 [psi]

Output Result : Surface Tension in lbf/ft.

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

Example : Calculation returns the value of surface tension as a function of pressure.

```
>> sigma = S97FLK_IP_p_sigma(725.887)
sigma  =
      0.001558606866542
```

FUNCTION NAME:	**S97FLK_IP_T_psat** **Vapor pressure**

MATLAB function usage : S97FLK_IP_T_psat(T)

Input values : **T :** Temperature in °F.
Range: 32.0 ⩽ T ⩽ 705.1028 [°F]

Output Result : Vapor Pressure in psi.

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

Example : Calculation returns the value of vapor pressure as a function of temperature.

```
>> psat = S97FLK_IP_T_psat(80.33)
psat =
       0.512938928698155
```

FUNCTION NAME:	**S97FLK_IP_p_Tsat** **Saturation Temperature**

MATLAB function usage : S97FLK_IP_p_Tsat(p)

Input values : **p :** Pressure in psi.
Range: 610.0 ⩽ p ⩽ 3200.1126 [psi]

Output Result : Saturation Temperature in °F.

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

Example : Cell B2 returns the value of saturation temperature as a function of pressure.

```
>> Tsat = S97FLK_IP_p_Tsat(725.887)
Tsat =
       5.072054480779245e+02
```

FUNCTION NAME: **S97FLK_IP_VARwl_n**

Refractive Index

Where ***variables*** is defined as :

Input variable		Input variable		**Variables**
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**

MATLAB function usage : S97FLK_IP_VARwl_n(variables, variable1, variable2, n)

Input values : **variables :** See above table.

variable1 : Depending on value from above table.

variable2 : Depending on value from above table.

n : Wavelength in µin.
Range: 7.874015748032 ⩽ n ⩽ 43.30708661417 [µin]

Output Result : 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 S97FLK_IP_VARwl_n, with variables Tx or px the refractive index is calculated only for saturation states, i.e., when x = 0, or x = 1.

Example : Calculation returns the value of the refractive index as a function of pressure, temperature, and wavelength = 10 µin.

```
>> n = S97FLK_IP_VARwl_n('pT', 725.887, 80.33, 10)
n =
      1.375717602565139
```

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).
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- 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).