IAPWS-IF97

# Water and Steam Properties

## MATLAB® Functions Library

# DEMO VERSION

## USER GUIDE

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



www.fluidika.com
support@fluidika.com

## 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 for evaluation purposes.

This Demo Version includes limitations in the range of the input variables that are included.

## REQUIREMENTS

The following are the requirements in order to install and utilize WaterSteamIF97 (Demo Version) . 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<br>Windows 8<br>Windows 8.1<br>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 (Demo Version) **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_MatlabDemo_x86_Setup | 32-bit |
| WaterSteamIF97_MatlabDemo_x64_Setup | 64-bit |

## INSTALLATION

Unzip the file that corresponds to your MATLAB version. Double-click on the *_Setup.exe* file that is located on the unzipped directory and follow the screen instructions.

Once the function libraries are installed (all files with extension *.mexw32* for a 32-bit installation or *.mexw264* for a 64-bit installation and all files with extendion *.dll*), you need to add this directory to your working PATH environment in MATLAB.

Note : When including another working directory different from the original installation, be sure to include all files with extension *.dll*. These files are necessary for the numerical evaluation of the library functions.

Please check *www.fluidika.com* for information on how to add a working directory to your PATH environment in MATLAB.

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

## USER DEFINED FUNCTIONS (UDF)

**WaterSteamIF97 (Demo Version)** Functions Library for MATLAB is 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.**

The functions to be used in MATLAB are shown in Table 1, both in the SI and I-P system of units. Only the first 3 combinations of input variables are available in this demo version (from all the 14 possible combinations, see Table 2).

Table 4 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 2.

Properties not available in this Demo Version return a value of **-1**.

| SI UNITS | I-P UNITS | OUTPUT RESULT |
|---|---|---|
| **S97FLK_SI_pT_prop** | **S97FLK_IP_pT_prop** | **DEMO - PRESSURE FIXED AT 700000 Pa/101.5264 psi TEMPERATURE RANGE : 273.15 - 350 K/ 32 - 170.3 °F** |
| **S97FLK_SI_Th_prop** | **S97FLK_IP_Th_prop** | **TEMPERATURE RANGE : 273.15 - 350 K/ 32 - 170.3 °F** |
| **S97FLK_SI_Ts_prop** | **S97FLK_IP_Ts_prop** | **TEMPERATURE RANGE : 273.15 - 350 K/ 32 - 170.3 °F** |
| **S97FLK_SI_Tx_prop** | **S97FLK_IP_Tx_prop** | **TEMPERATURE RANGE : 273.15 - 350 K/ 32 - 170.3 °F** |
| *S97FLK_SI_Tu_prop* | *S97FLK_IP_Tu_prop* | **Depending on value of "prop", see Table 4 NOT AVAILABLE IN DEMO VERSION(VALUE = -1)** |
| *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_px_prop* | *S97FLK_IP_px_prop* | |
| *S97FLK_SI_VARwl_n* | *S97FLK_IP_VARwl_n* | **Refractive index N/A IN DEMO VERSION** |
| *S97FLK_SI_T_sigma* | *S97FLK_IP_T_sigma* | **Surface Tension N/A IN DEMO VERSION** |
| *S97FLK_SI_p_sigma* | *S97FLK_IP_p_sigma* | **Surface Tension N/A IN DEMO VERSION** |
| *S97FLK_SI_T_psat* | *S97FLK_IP_T_psat* | **Vapor Pressure N/A IN DEMO VERSION** |
| *S97FLK_SI_p_Tsat* | *S97FLK_IP_p_Tsat* | **Saturation Temperature N/A IN DEMO VERSION** |

**Table 1. Functions defined in WaterSteamIF97FLK (Demo Version)**

| 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 2.** **Combination of input 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 3.** **Properties NOT included in WaterSteamIF97FLK (Demo Version)**

| 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* | *$m^3/(kg·K)$* | *$ft^3/(lb·°F)$* | **dvdpT** |
| *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 4. Properties calculated for each combination of input thermodynamic variables.**
**PROPERTIES IN ITALIC ARE NOT INCLUDED IN THE DEMO VERSION AND RETURN A VALUE = -1**

## FUNCTION NAME: S97FLK_SI_pT_prop

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

**Input values :**

**p :** Pressure in Pa.
FIXED PRESSURE AT : 10000 Pa

**T :** Temperature in K.
Range: 273.15 ⩽ T ⩽ 350.0 [K]

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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(10000, 300, 'h')
h =
        112580.9431
```

## 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 ⩽ 350.0 [K]

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

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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, 112580.9431, 'v')
v =
        0.001003495
```

## 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 ⩽ 350.0 [K]

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

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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,  393.1218225,  'v')
v  =
       0.001003495
```

## 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 ⩽ 350.0 [K]

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

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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,  'h')
h  =
       112574.9908
```

## FUNCTION NAME: S97FLK_IP_pT_prop

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

**Input values :**

**p :** Pressure in psi.
FIXED PRESSURE AT : 1.4504 psi

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

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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(1.4504, 80.33, 'h')
h =
      48.40109178
```

## 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 ⩽ 170.3 [°F]

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

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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, 48.40109178, 'v')
v =
      0.016074438
```

## 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 ⩽ 170.3 [°F]

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

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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, 0.093895532, 'v')
v =
      0.016074438
```

## 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 ⩽ 170.3 [°F]

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

**prop:** Output Property. String (see Table 4)

**Output Result :** See Table 4. VALUE = -1 : RESULT NOT AVAILABLE IN DEMO

**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, 'h')
h =
      48.39853275
```

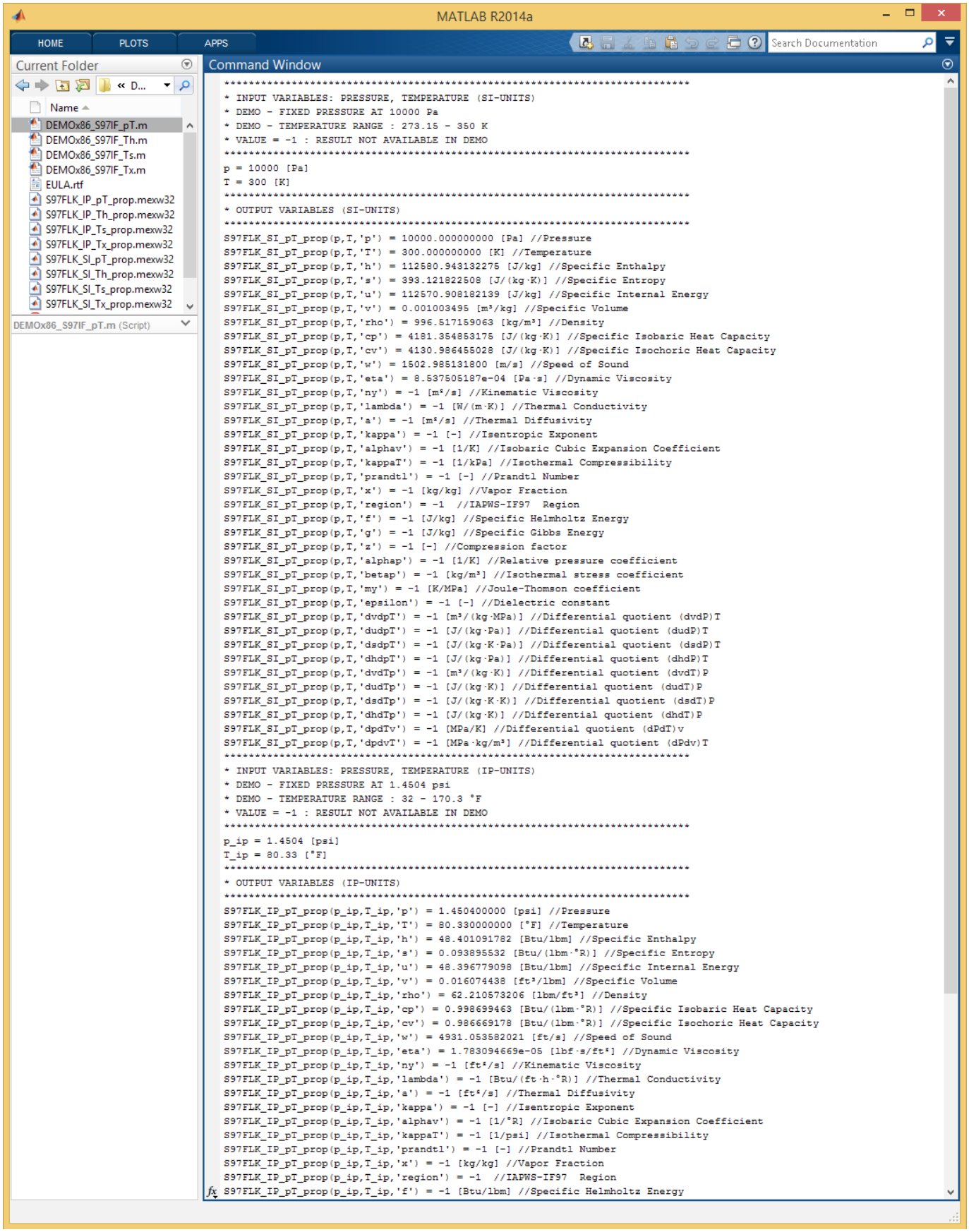


**Figure 1. Screenshot of MATLAB Command Window with results from the pressure-temperature combination of variables.**

# 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).