

EESy Solutions

Engineering Equation Solver Newsletter

Inside this issue:

Welcome	1
Support for High Resolution Monitors	1
Improvements in Convergence	1
Improved Convergence Example	3
The Combustor3_CL Model	4
Flow Maps	6
Saving and Retrieving Plot Files	7
Recent Changes to EES	8
Instant Update & Technical Service	8

Welcome

This is the 42nd issue of EESy Solutions, a newsletter that provides news, tips, and other updates for users of the Engineering Equation Solver software. This issue discusses recent changes to the methods used by EES to solve equations that improve convergence and make the problems less dependent on guess values. Recent additions of a combustor component to the Component Library and Flow Maps to the Heat Transfer Library are also presented. Finally, new capability for EES to store and retrieve plots is discussed.

Previous issues of EESy Solutions, they can be downloaded from <https://fchartsoftware.com>.

Support for High Resolution Monitors

EES now provides high-DPI support. Users who have high resolution (4k+) monitors or newer portable computers will immediately notice an improved display with sharper text and cleaner lines.

Improvements in Convergence

EES uses a version of Newton's method to solve systems of simultaneous, nonlinear equations. The equations are organized (or "blocked") into the smallest number of equations that must be simultaneously solved and then Newton's method is applied to each block of equations sequentially. Newton's method depends on starting from a set of "guess" values (i.e., initial values that define the starting point for the iteration) and proceeding towards the solution based on the partial derivatives that are computed numerically in order to build the Jacobian matrix. Newton's method does not always work; this is particularly true if the guess values are far from the solution. When Newton's method does work, the values of the "residual" for each equation (or the error in the solution) will become smaller after each iteration. When EES is unable to reduce the residuals using Newton's method, it will resort to several alternative backup methods. These backup methods have recently been improved and now include strategically changing the guess values used for the solution process before trying again. This process has significantly improved EES' ability to converge to a solution for previously difficult problems.

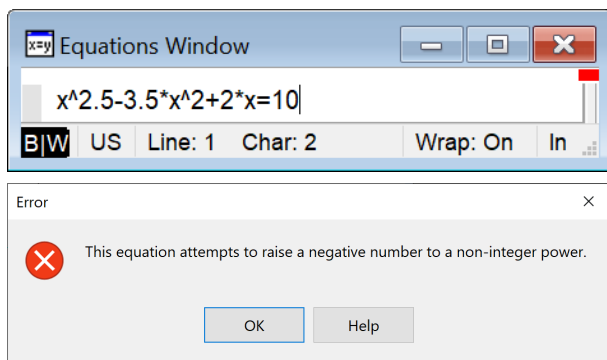
Consider the single equation, single unknown problem shown below:

Internally, EES subtracts the right $x^{2.5} - 3.5x^2 + 2x = 10$ side from the left side of the equation in order to define a residual that must be equal to zero when x is a solution:

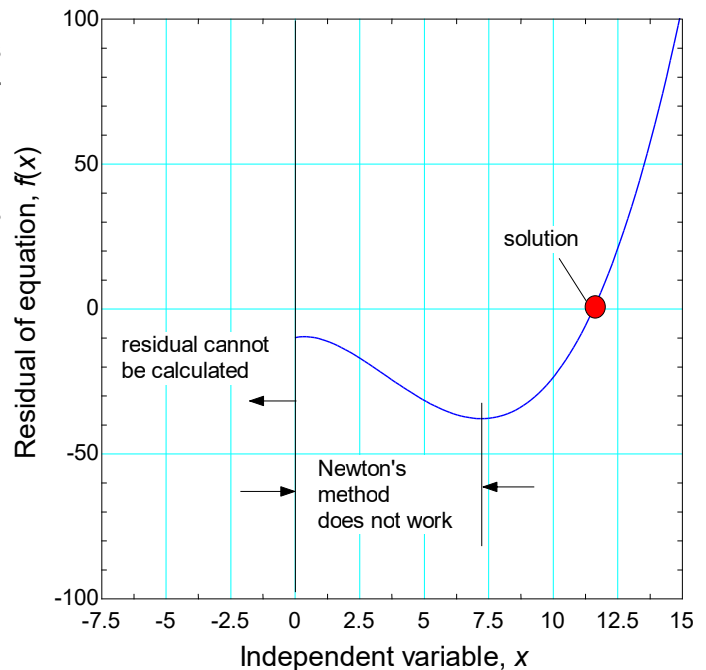
$$f(x) = x^{2.5} - 3.5x^2 + 2x - 10$$

Improvements in Convergence (continued)

The residual as a function of x is shown in the figure. The residual cannot be evaluated for $x < 0$ as this would attempt to raise a negative number to a non-integer value. Further, for guess values in the range $0 < x < 7.4$, Newton's method will not work because the derivative of the residual will drive successive iterations towards smaller values of x . Newton's method will work for guess values of $x > 7.4$, and EES will provide a solution.

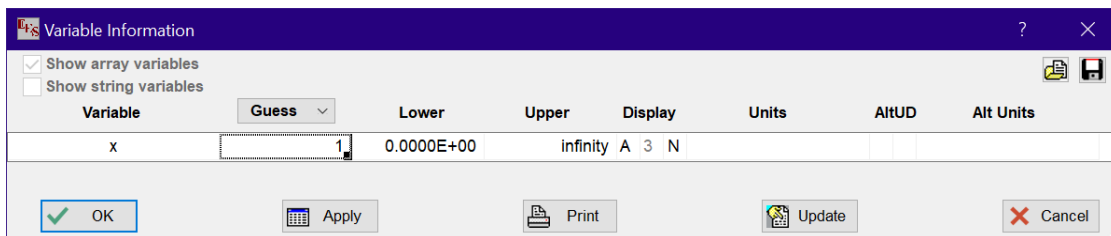


Result of solving without setting the limits

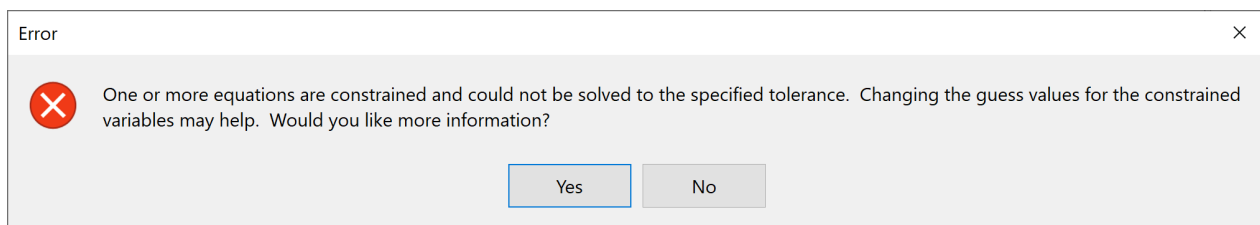


The equation is entered into EES and Solve (F2) is selected from the Calculate menu. An error message results because no limits are provided for the variable x and therefore the iteration moves into the range $x < 0$ where the residual cannot be evaluated.

We can control the limits and guess values by selecting Variable Info from the Options menu. Placing a lower limit of 0 on x will restrict the solution process to regions where the equation can be evaluated. However, notice that the default guess value for x is equal to 1 and therefore, for EES versions before 11.324, the problem will fail to solve unless a different guess value is supplied.



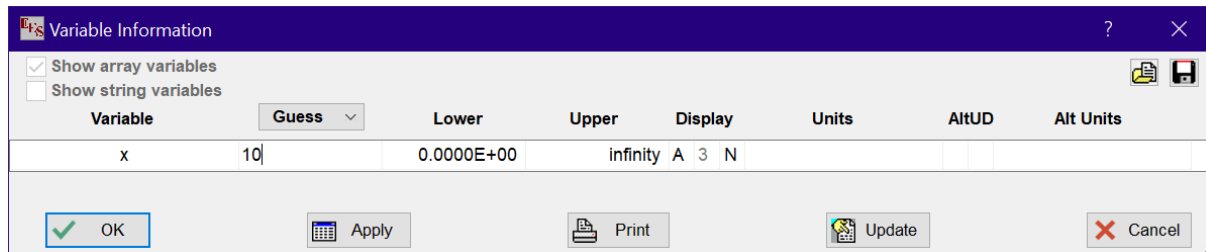
Variable Information Window with lower limit set to 0



Error message obtained with EES versions before 11.324.

Improvements in Convergence (continued)

In order for EES to converge to solution for versions before 11.324, it would be necessary to specify a guess value that is greater than 7.4; this will allow Newton's Method to find a solution starting from the prescribed guess value.



It is necessary to set a guess value > 7.4 for EES versions before 11.324 to converge to a solution.

Due to the improvements made in version 11.324, EES will converge to a solution even starting with the default guess value of 1. If Newton's Method fails, EES will adjust the guess value within the prescribed range to look for a better starting place for the solution process. The result is that EES is more likely to solve the equations and less attention is needed to setting guess values.

Main

Unit Settings: SI C kPa kJ mass deg

x = 11.57

No unit problems were detected.

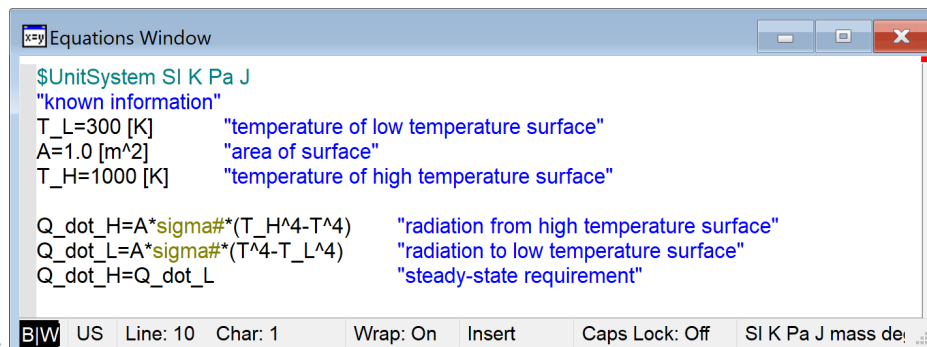
Compilation time = 47 ms Calculation time = 0 ms

Solution obtained with a guess value of 1 for EES version after 11.324.

Improved Convergence Example

heat transfer problem in which a black object at steady state is transferring energy by radiation with reservoirs that are at two temperatures, $T_H = 1000$ K and $T_L = 300$ K.

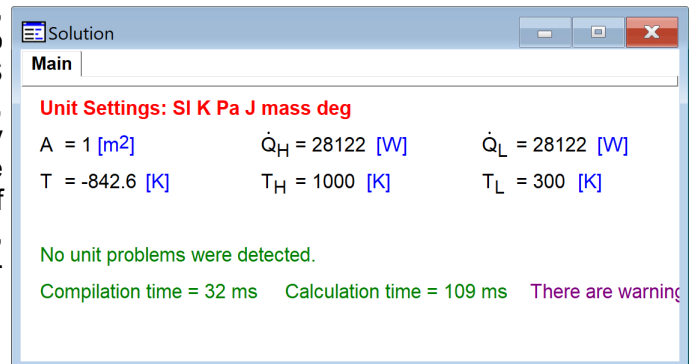
The equations below result from a radiation



The default guess value for the object temperature, T , is 1 K. In EES versions before 11.324, it would not be possible to solve these equations without specifying a guess value for the object temperature (T) that was more reasonable (e.g., 450 K or at least something that is between T_L and T_H).

Improved Convergence Example (continued)

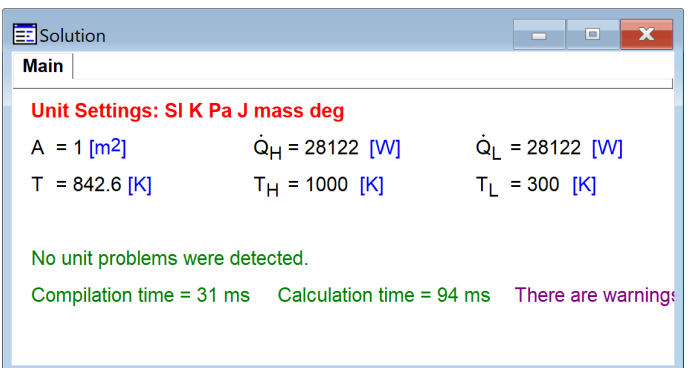
Due to the improvements in the solution methods, these equations can be solved without having to resort to manipulation of the guess values in EES versions 11.324 and later. With no intervention at all, EES will solve the equations. However, it will identify a negative temperature (a solution that satisfies the equation set, but is non-physical). If a lower bound of 0 is placed on T in order to constrain it to be positive, then EES will converge to the correct positive solution.



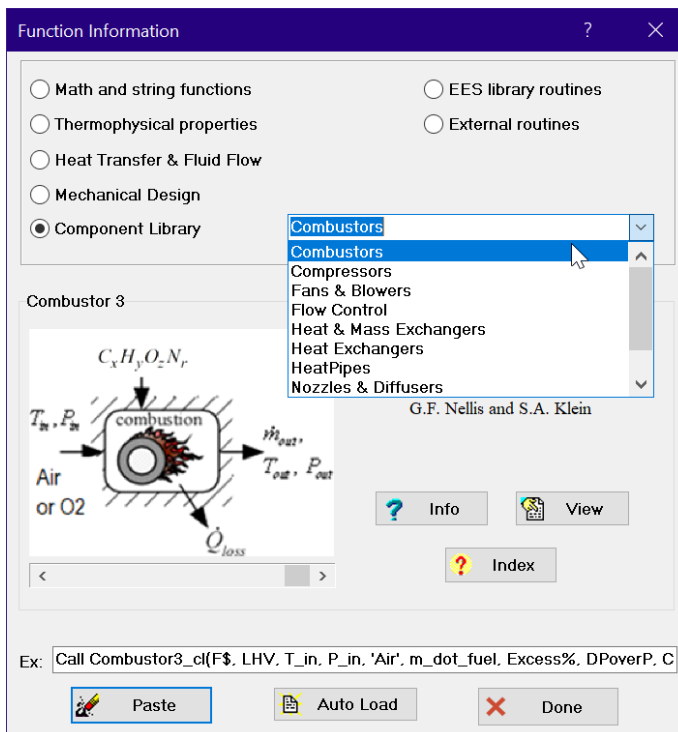
Negative solution identified by EES version 11.324 or later without any limits

Combustor3_CL Model

The Component Library in the Professional version of EES provides models for many of the devices that are required to simulate or design thermal fluid systems. The Component Library can be accessed by selecting Function Info from the Options menu and then selecting the Component Library radio button. The resulting dialog will allow you to navigate through the various component models that are available.



Positive solution identified by EES version 11.324 or later when the lower limit of T is set to 0.



Function Information dialog showing the Component Library

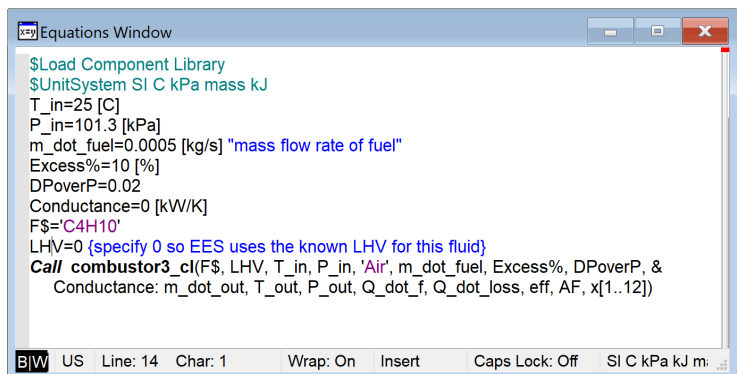
New component models have been added, e.g., the Combustor3_CL model. This model takes as inputs the fuel and oxidizer and does both combustion and chemical equilibrium calculations in order to determine the temperature and composition of the products. The presence of dissociation products can have a substantial effect on the temperature of the products, as compared to that determined assuming complete combustion. Heat loss can be included by specifying the overall conductance (UA value) of the combustor. The efficiency of the combustion process is calculated based on the lower heating value of the fuel. The model will work with any fuel that consists of elements C, H, O, N and with either air or pure oxygen.

Combustor3_CL Model (continued)

The calling protocol for the procedure Combustor3_CL is:

Call Combustor3_CL(F\$, LHV, T_in, P_in, 'Air', m_dot_fuel, Excess%, DPOverP, Conductance: m_dot_out, & T_out, P_out, Q_dot_f, Q_dot_loss, eff, AF, x[1..12])

The input F\$ is a string identifying the fuel which can consist of C, H, O, and N. The input LHV is the lower heating value of the fuel; if the fuel (F\$) is one of EES' built-in substances, then set LHV to 0 and EES will internally determine the lower heating value. The inputs T_in and P_in are the temperature of the oxidizer and fuel and the pressure of the oxidizer, respectively. The input O\$ specifies the oxidizer (either 'Air' or 'O2'). The input m_dot_fuel is the mass flow rate of fuel and Excess% is the % of excess air (note that 0 is stoichiometric and this parameter must be >0). The parameters DPOverP and Conductance are the fractional pressure drop in the combustor and the conductance of the combustor jacket, respectively. The heat loss from the combustor is calculated based on the product of conductance and the outlet to inlet temperature difference.



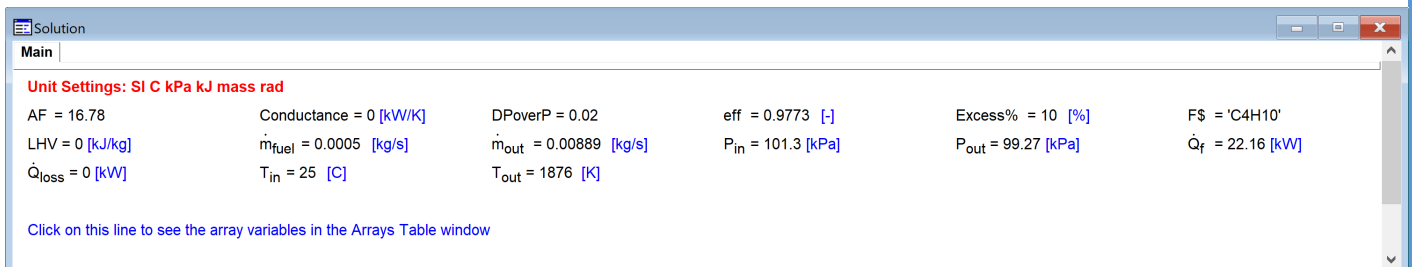
```

$Load Component Library
$UnitSystem SI C kPa mass kJ
T_in=25 [C]
P_in=101.3 [kPa]
m_dot_fuel=0.0005 [kg/s] "mass flow rate of fuel"
Excess%=10 [%]
DPOverP=0.02
Conductance=0 [kW/K]
F$='C4H10'
LHV=0 {specify 0 so EES uses the known LHV for this fluid}
Call combustor3_cl(F$, LHV, T_in, P_in, 'Air', m_dot_fuel, Excess%, DPOverP, &
Conductance: m_dot_out, T_out, P_out, Q_dot_f, Q_dot_loss, eff, AF, x[1..12])
  
```

The EES code calls the procedure in order to determine the temperature resulting from the adiabatic combustion of butane with 10% excess air using the Combustor3_CL procedure.

EES code that calls Combustor3_CL procedure to determine the adiabatic combustion temperature of butane when combusted with 10% excess air

The Solution Window shows not only the adiabatic flame temperature ($T_{out} = 1876$ K) but also several other parameters of interest.



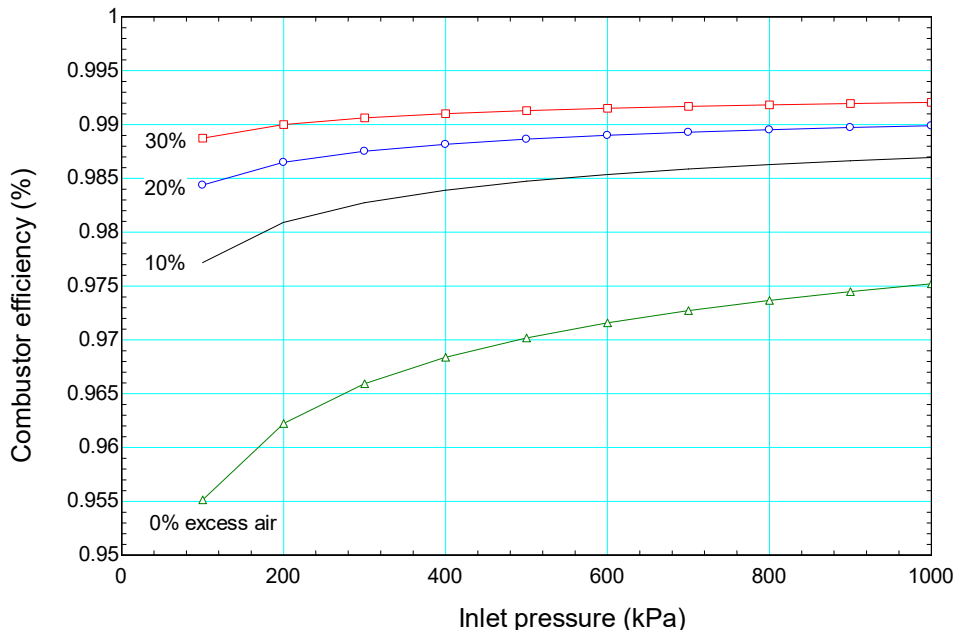
Unit Settings: SI C kPa kJ mass rad					
AF = 16.78	Conductance = 0 [kW/K]	DPOverP = 0.02	eff = 0.9773 [-]	Excess% = 10 [%]	F\$ = 'C4H10'
LHV = 0 [kJ/kg]	m_fuel = 0.0005 [kg/s]	m_out = 0.00889 [kg/s]	P_in = 101.3 [kPa]	P_out = 99.27 [kPa]	Q_f = 22.16 [kW]
Q_loss = 0 [kW]	T_in = 25 [C]	T_out = 1876 [K]			

[Click on this line to see the array variables in the Arrays Table window](#)

The output parameter Q_dot_f (22.16 kW) is the rate of heat transfer that would result if the products were cooled to the inlet temperature. The efficiency (97.73%) is the ratio of Q_dot_f to the rate of heat transfer associated with the fuel mass flow rate and the lower heating value of the fuel. Notice that the value of the efficiency is not 100% for this problem even though the reaction occurred adiabatically (i.e., the conductance of the combustor was set to zero) because the dissociation reactions prevented complete combustion of the fuel. Examination of the Arrays window shows that the products consist of molecules such as CO, HO, and NO_x in addition to CO₂, N₂, O₂, and H₂O.

Combustor3_CL Model (continued)

The arrays table shows the composition (by mole) of CO₂, CO, H₂O, H, H₂, OH, O, O₂, NO, NO₂, N₂ and N. Thus, the products contain 0.14% CO, 0.44% OH, and 0.30% NO, which have energy implications on the combustion reaction.



Sort	x_i	$N\$_i$
[1]	0.1085	CO ₂
[2]	0.001446	CO
[3]	0.1348	H ₂ O
[4]	0.00008009	H
[5]	0.0003517	H ₂
[6]	0.004427	OH
[7]	0.0006223	O
[8]	0.01588	O ₂
[9]	0.002971	NO
[10]	0.000002823	NO ₂
[11]	0.7309	N ₂
[12]	2.311E-09	N

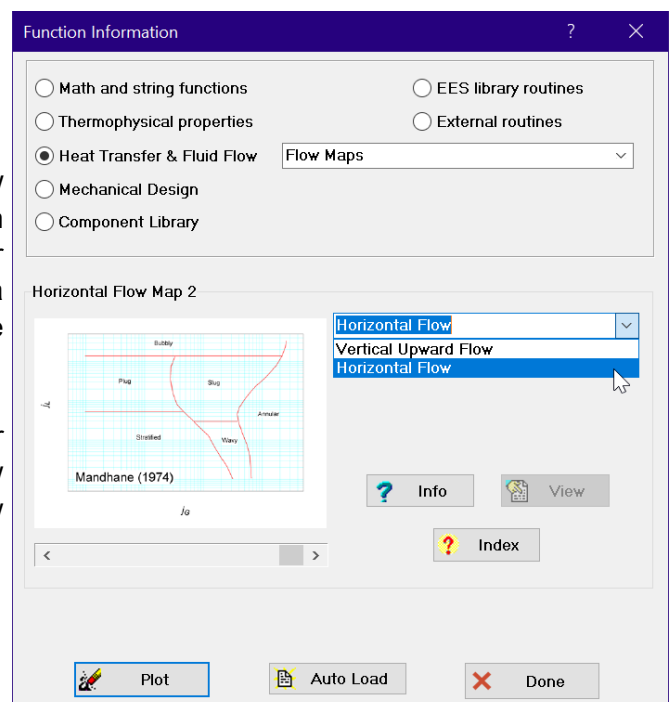
Arrays Table showing product composition

Combustor efficiency as a function of inlet pressure for various values of %excess air. Notice that the efficiency is <100% due to the dissociation reactions and that lower pressure and higher temperature (caused by reduced excess air) tend to promote these reactions and reduce the efficiency.

Flow Maps

Flow maps provide a graphical way to represent flow regimes in two-phase flow situations. Several common flow maps have been implemented in the Heat Transfer Library in EES so that users can overlay their own data or calculations onto these maps and thereby anticipate what flow regime might result.

For example, select Flow Maps from the Heat Transfer Library and then Horizontal Flow and Horizontal Flow Map 2 (Mandhane, 1974) to retrieve the Mandhane flow map.



Function Information dialog showing Flow Maps in the Heat Transfer Library.

Flow Maps (continued)

Consider an application in which the refrigerant R455a is evaporated as it passes through a horizontal, 1 cm diameter pipe with mass flow rate 0.1 kg/s at pressure 200 kPa. We can track the trajectory of this evaporation process on the Mandhane flow map by calculating the superficial gas velocity (j_G) and superficial liquid velocity (j_L) as a function of quality and then overlaying these results onto the flow map.

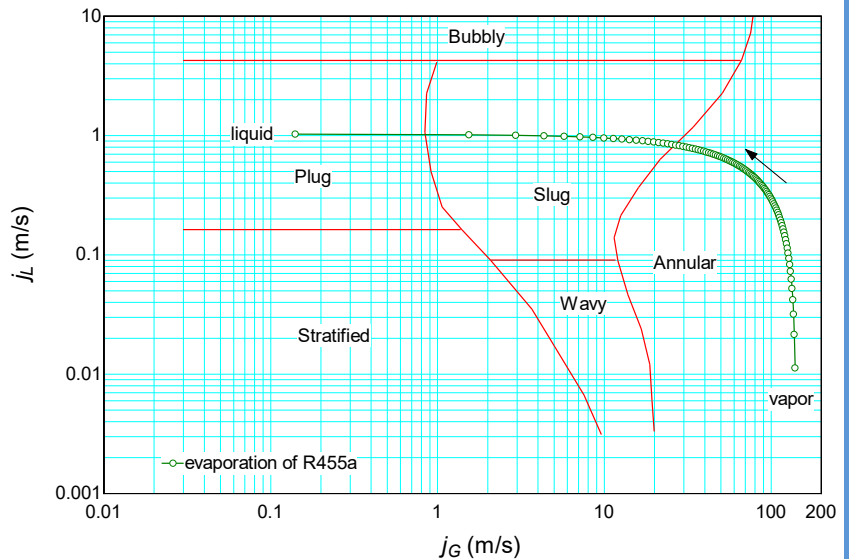
```

Equations Window
$UnitSystem SI Mass J K Pa
F$="R455a"
D = 0.01 [m]
m_dot = 0.1 [kg/s]
P = 2e5 [Pa]
/x = 0.5 [-]

A=pi*D^2/4
G = m_dot/A
rho_L = density(F$,P=P,x=0)
rho_G = density(F$,P=P,x=1)
j_L = G*(1-x)/rho_L
j_G = G*x/rho_G

"refrigerant"
"inner diameter"
"mass flow rate"
"pressure"
"quality"
"area"
"mass flux"
"liquid density"
"gas density"
"superficial liquid velocity"
"superficial gas velocity"
  
```

Equations Window calculating the superficial gas and liquid velocities associated with the evaporation of R455a

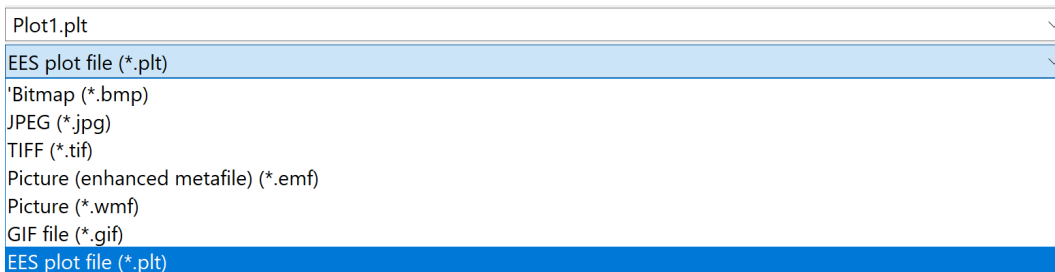


Evaporation of R455a shown on the Mandhane (1974) flow map. Note that the process will initially be annular flow then transitioning to slug flow and finally to plug flow.

Saving and Retrieving Plot Files

Be-

ginning with EES version 11.308 it is possible to save EES plots as .plt files that can be opened in another EES program. In the plots menu, select Store EES plot to save a .plt file and Retrieve Plot to open an existing .plt file. It is also possible to save a .plt file by right-clicking on the tab of a plot and selecting the Save button. In the resulting Save Plot As dialog, several graphical formats are available as well as .plt files. The .plt selection will save the plot in a format that will allow it to be opened and edited from any EES program.



Formats available to save a plot from the Save Plot as dialog

Recent Changes to EES

- HeatExchanger4_CL, HeatExchanger5_CL and HeatExchanger6_CL simulate counterflow recuperators using the sub heat exchanger model and allow UA, eff, or a pinch point to be specified.
- Yield and ultimate stress for 37 types of steels have been added to the Incompressible library.
- The component library includes heat pipe modeling tools.
- Property data for Haynes 282 and Haynes Stellite 3, 6, and 21 have been added.
- EES can read .xlsx Excel files into Lookup Tables.
- Multi-monitor support with correct scaling for each monitor's resolution is now available.
- Thermodynamic data are provided for potassium in the liquid metal library.
- Thermodynamic and transport data for R407A are available.
- New properties GibbsFreeEnergy and HelmholtzFreeEnergy are available.
- The display style and number of digits for answers in both primary and alternate units can be specified in the Variable Information Window.
- Viscosity and thermal conductivity functions have been added for Lithium Chloride-Water.
- Properties for several mineral oils and Fluorinert_FC770 have been added
- Thermodynamic and transport properties for sodium are available in the liquid metal library.
- The Combustor3_CL model provides a combustor model that accounts for the impact of dissociation reactions on the products of the combustion reaction using chemical equilibrium concepts.
- The computational methods used by EES to solve systems of equations have been improved so that they converge more readily and are less dependent on guess values.
- Flow maps have been added to the heat transfer library.
- It is possible to store and retrieve plots using .plt files that allow plots made in EES to be stored independently from the EES file used to make them. The \$ExportPlot directive can be used to save a plot (.plt) file.



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Instant Update & Technical Service

EES uses a different model for updating than most other programs. Each time that there is a change in the EES program, either to correct a problem or to add a new feature, the version number is incremented by 0.001 and the latest version of EES is placed on our website. There have been many new versions of EES released since the last EESy Solutions was distributed.

Any user who has a current subscription to our [Instant Update Service](#) (IUTS) can download the latest version. All new non-academic licenses of EES are provided with one year of Instant Update Service. The fee to continue service after the first year is 20% of the current cost of the program per year if renewed within 12 months after expiration.

A subscription to [Academic Update Service](#) (AUS) is required in order to access the current academic EES version.

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