EES Demo

Equations

Thermodynamic properties from tables

Solve

- EES is a calculator with properties.

- Objectives

- Ideal gas properties
- Real fluid properties ⇨ Example 1
- Isentropic process ⇨ Example 2
- Psychometric properties

- Example 1:

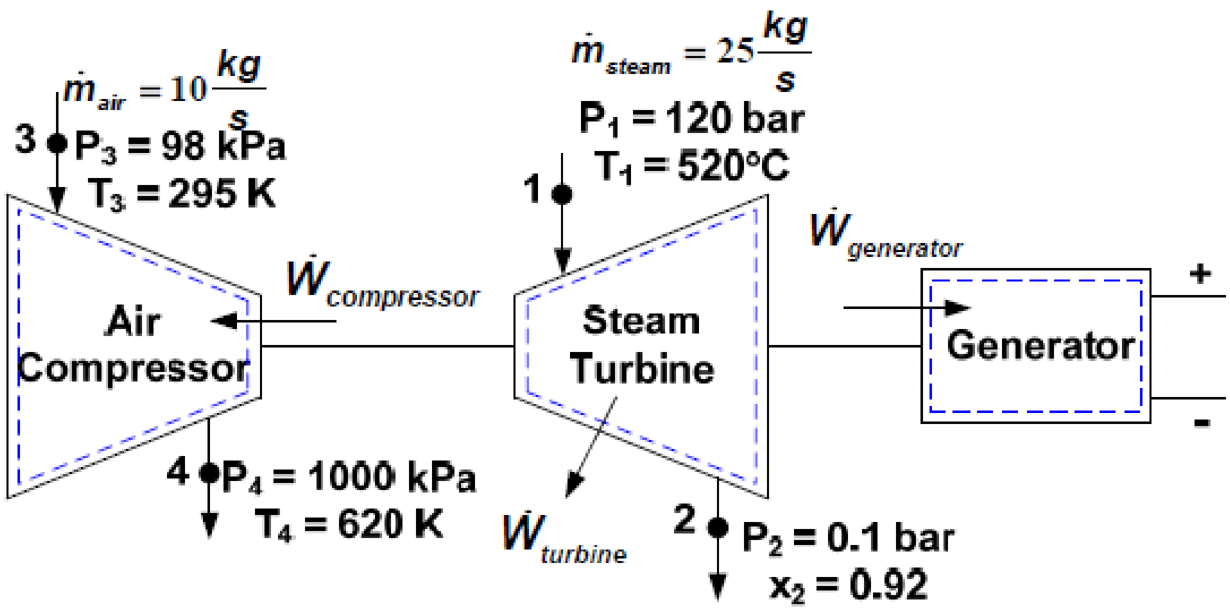
Given

An adiabatic steam turbine coupled to an adiabatic air compressor and a generator

Find

Net power (MW) delivered to the generator

System



- Example 1:

Assumptions

- Steady state
- One-dimensional flow
- Ignore KE and PE changes
- No heat transfer for turbine and compressor
- Air behaves as an ideal gas

Basic Equations

$$\frac{dm_{cv}}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e$$

$$\frac{dE_{cv}}{dt} = \dot{Q} - \dot{W} + \sum_i \dot{m}_i \left(h_i + \frac{\forall_i^2}{2} + gz_i \right) - \sum_e \dot{m}_e \left(h_e + \frac{\forall_e^2}{2} + gz_e \right)$$

$$\Downarrow$$

$$\dot{W}_{turbine} = \dot{m}_{steam} \left(h_1 - h_2 \right)$$

$$\dot{W}_{compressor} = \dot{m}_{air} \left(h_3 - h_4 \right)$$

EES can NOT do this part for you!

- Example 1:

Thermodynamic data

(a) State 1: $P_1 = 12$ MPa, $T_1 = 520°C$
Table A-3 for water: $T_1 > T_{sat}(120 \text{ bar}) = 324.8°C \Rightarrow$ SHV
Table A-4 for superheated water vapor: $h_1 = 3401.8$ kJ/kg

State 2: $P_2 = 10$ kPa = 0.1 bar, $x_2 = 0.92 \Rightarrow$ SLVM
Table A-3 for water:

$$h_2 = h_f + x_2\left(h_g - h_f\right) = h_f + x_2 h_{fg} = 191.83\frac{\text{kJ}}{\text{kg}} + 0.92 \times 2392.8\frac{\text{kJ}}{\text{kg}} = 2393.2\frac{\text{kJ}}{\text{kg}}$$

Since air behaves as an ideal gas, enthalpy depends only on temperature.
Table A-22 for air: $h_3 = 295.17$ kJ/kg at $T_3 = 295$ K; $h_4 = 628.07$ kJ/kg at $T_3 = 620$ K

<u>EES can do this part for you!</u>

- Example 1:

Solution

Considering mass balance for steam turbine: $\dot{m}_1 = \dot{m}_2 = \dot{m}_{steam}$

Considering energy balance for the turbine, power developed by expansion of steam:

$$\dot{W}_{turbine} = \dot{m}_{steam}\left(h_1 - h_2\right) = 25\frac{\text{kg}}{\text{s}} \times \left(3401.8 - 2393.2\right)\frac{\text{kJ}}{\text{kg}} = 25,215\ \text{kW} = 25.2\ \text{MW}$$

Considering mass balance for air compressor: $\dot{m}_3 = \dot{m}_4 = \dot{m}_{air}$

Considering energy balance for the compressor, power required for compression of air:

$$\dot{W}_{compressor} = \dot{m}_{air}\left(h_3 - h_4\right) = 10\frac{\text{kg}}{\text{s}} \times \left(295.17 - 628.07\right)\frac{\text{kJ}}{\text{kg}} = -3,329\ \text{kW} = -3.3\ \text{MW}$$

Since the steam turbine is directly coupled to the air compressor and the generator:

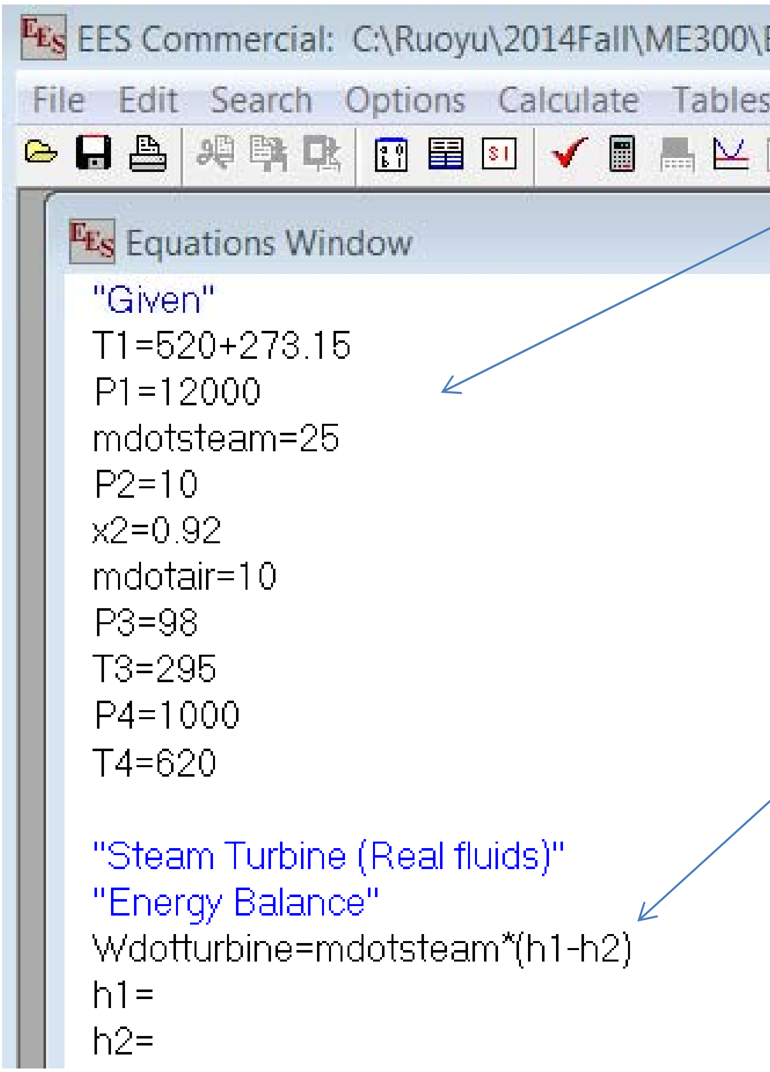
$$\dot{W}_{turbine} = \dot{W}_{compressor} + \dot{W}_{generator}$$

Net power delivered to the generator by the steam turbine:

$$\dot{W}_{generator} = \dot{W}_{turbine} - \left|\dot{W}_{compressor}\right| \Rightarrow \underline{\boldsymbol{\dot{W}_{generator} = +21.9\ \text{MW}}}$$

EES can do this part for you!

- Example 1:
- 1. type in Given data & basic equation



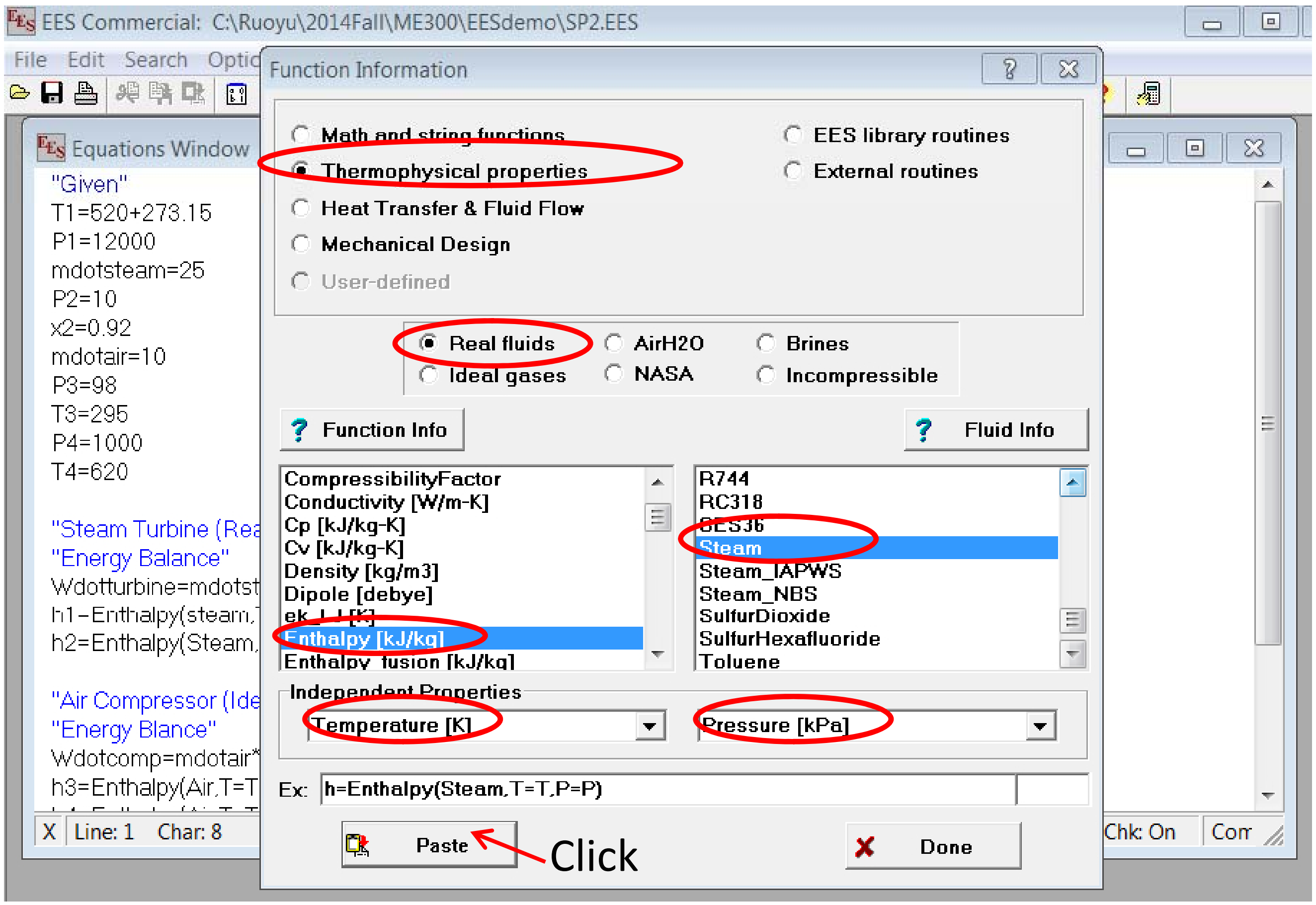
Given data

Basic equation (steam)

$$\dot{W}_{turbine} = \dot{m}_{steam} \left(h_1 - h_2 \right)$$

The next step is to pull h1 value and h2 value

- Example 1:
- 2. Thermodynamic properties for real fluids
- Options→ Function Info



- Example 1:
- 2. Thermodynamic properties for <u>real fluids</u>
- Change independent variables to given values

Equations Window

```
"Given"
T1=520+273.15
P1=12000
mdotsteam=25
P2=10
x2=0.92
mdotair=10
P3=98
T3=295
P4=1000
T4=620

"Steam Turbine (Real fluids)"
"Energy Balance"
Wdotturbine=mdotsteam*(h1-h2)
h1=Enthalpy(steam,T=T1,P=P1)
```

- Example 1
- 1. type in basic equation

Equations Window

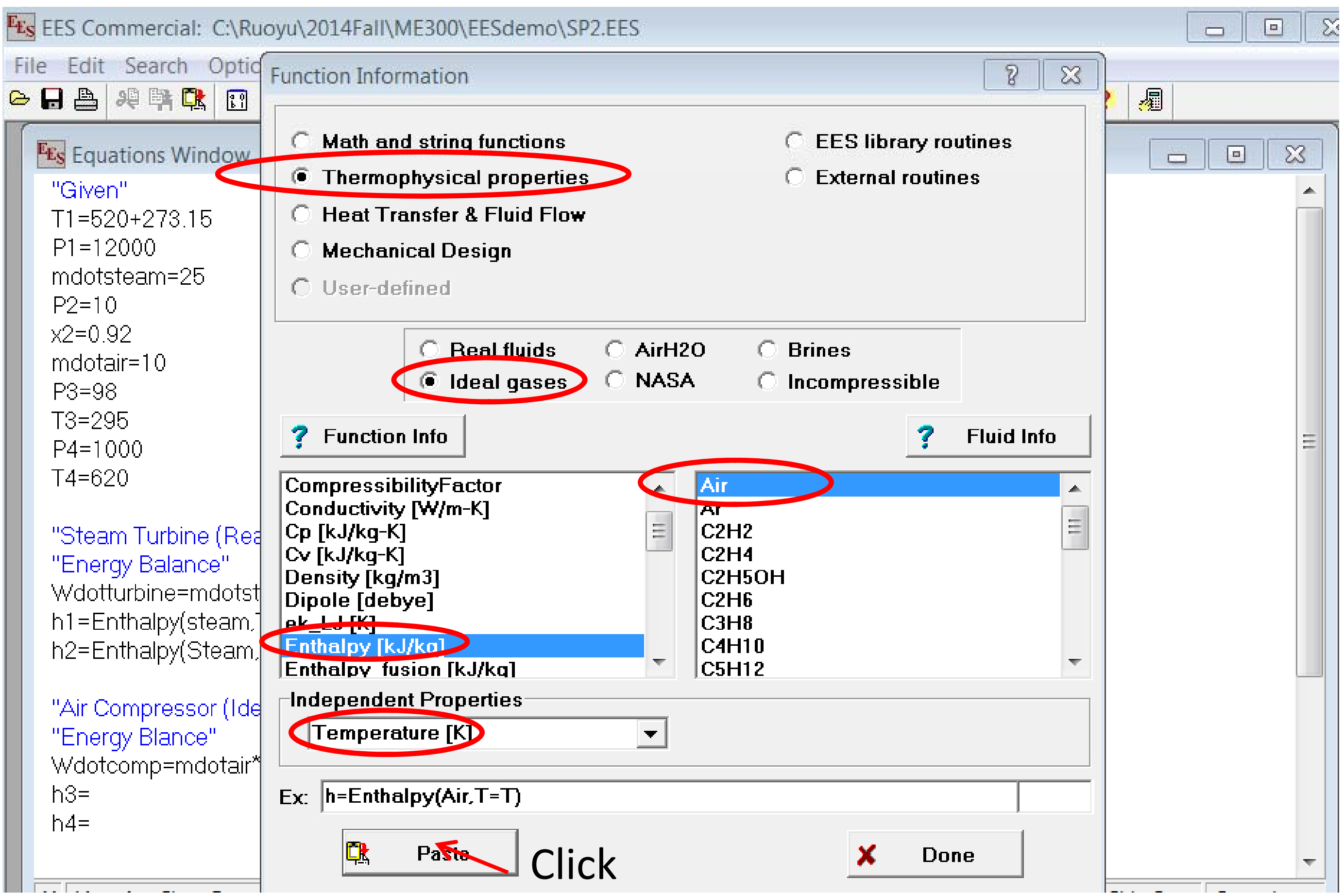
```
"Given"
T1=520+273.15
P1=12000
mdotsteam=25
P2=10
x2=0.92
mdotair=10
P3=98
T3=295
P4=1000
T4=620

"Steam Turbine (Real fluids)"
"Energy Balance"
Wdotturbine=mdotsteam*(h1-h2)
h1=Enthalpy(steam,T=T1,P=P1)
h2=Enthalpy(Steam,P=P2,x=x2)

"Air Compressor (Ideal Gas)"
"Energy Blance"
Wdotcomp=mdotair*(h3-h4)
h3=
h4=
```

Basic equation (air)

$$\dot{W}_{compressor} = \dot{m}_{air}\left(h_3 - h_4\right)$$

The next step is to pull h3 value and h4 value

- Example 1
- 2. Thermodynamic properties for ideal gas
- Options→ Function Info



- Example 1
- 2. Thermodynamic properties for ideal gas
- Change independent variables to given values

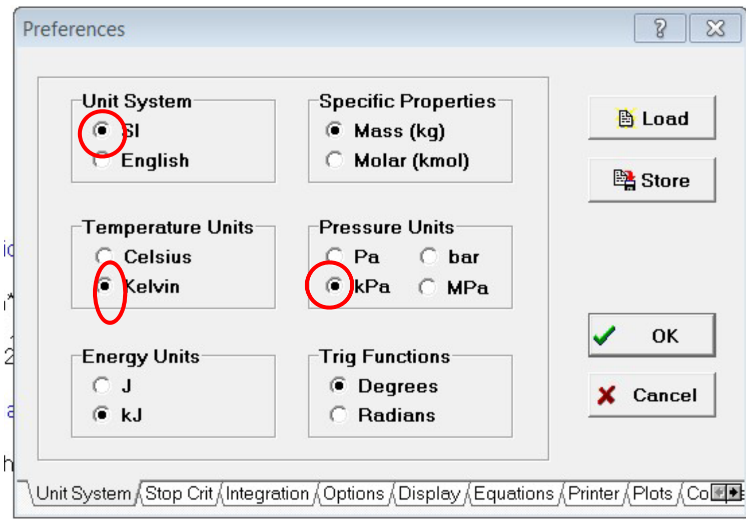
Equations Window

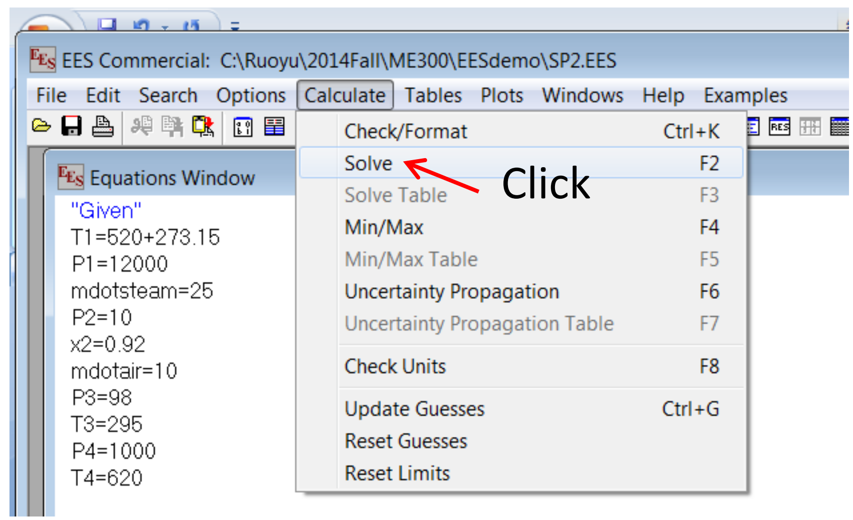
```
"Given"
T1=520+273.15
P1=12000
mdotsteam=25
P2=10
x2=0.92
mdotair=10
P3=98
T3=295
P4=1000
T4=620

"Steam Turbine (Real fluids)"
"Energy Balance"
Wdotturbine=mdotsteam*(h1-h2)
h1=Enthalpy(steam,T=T1,P=P1)
h2=Enthalpy(Steam,P=P2,x=x2)

"Air Compressor (Ideal Gas)"
"Energy Blance"
Wdotcomp=mdotair*(h3-h4)
h3=Enthalpy(Air,T=T3)
h4=Enthalpy(Air,T=T4)

"Energy Balance"
Wdotturbine=-Wdotcomp+Wdotg
```

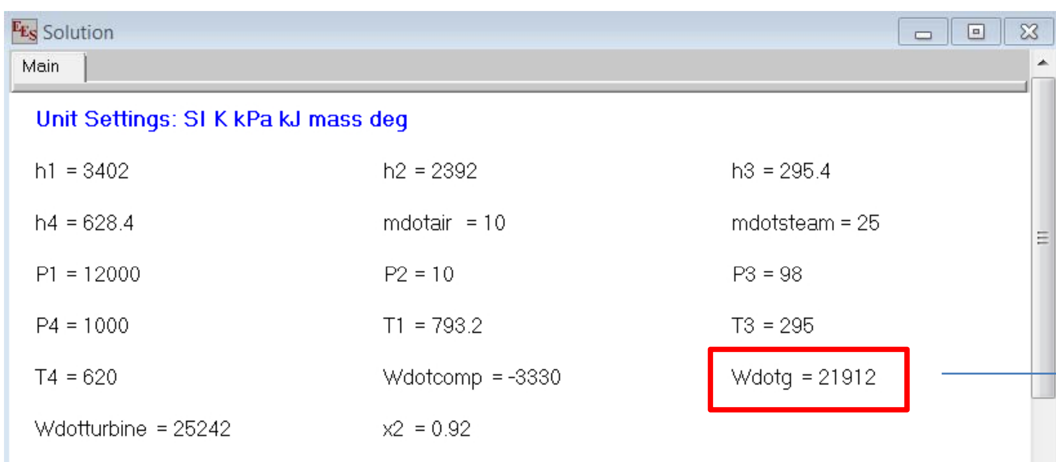
X | Line: 1 Char: 1 | Wrap: On | Insert

The next step is check the unit system and run

- Example 1
- 3. check unit system and run
- Options→ Unit system







$$\dot{W}_{generator} = +21.9\ \text{MW}$$

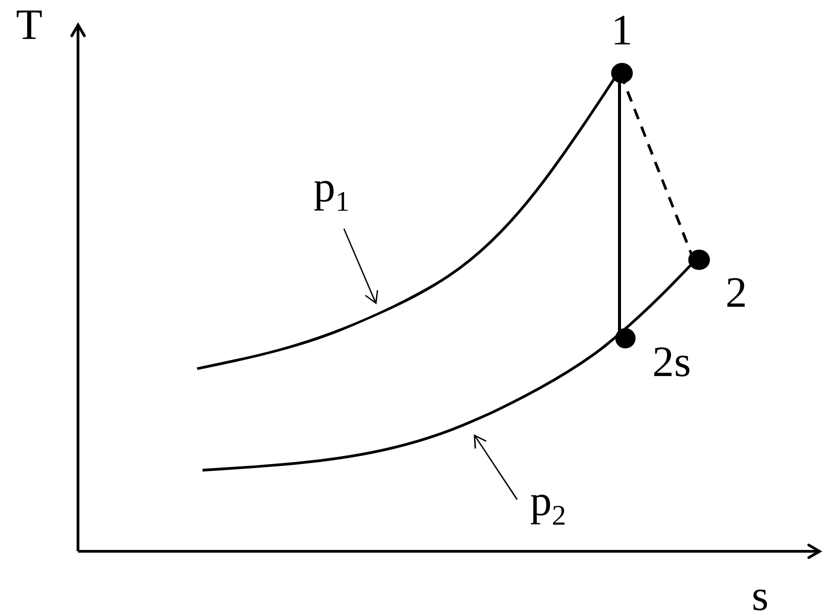
• Example 2

- Air enters the high-pressure turbine in a power plant at 25 bar and 1227 °C (State 1) and expands to 6 bar and 927 °C (State 2), calculate the isentropic efficiency (%) of the turbine.

Basic equation:

$$\eta_{isentropic} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

$$s_1 = s_{2s} \qquad p_2 = p_{2s}$$



Thermodynamic data (air):

From Table A-22:

$T_1, p_1 \rightarrow h_1, s_1;$

$T_2 \rightarrow h_2;$

$p_{2s}, s_{2s} \rightarrow h_{2s};$

⇨ $$\eta_{isentropic} = \frac{h_1 - h_2}{h_1 - h_{2s}} = 68.9\%$$

- Example 2
- Isentropic process
- Pull entropy values, and make them equal

```
Equations Window
"SP6 High T turbine isentropic efficiency"

"Given"
P1=25[bar]
T1=1500[K]
P2=6[bar]
T2=1200[K]

"P1/P2=Pr1(T1)/Pr2(T2s)"

"isentropic Process"
P2s=P2
s1=Entropy(Air,T=T1,P=P1)
s2s=s1
h2s=Enthalpy(Air,P=P2s,s=s2s)
"turbine efficiency"
h1=Enthalpy(Air,T=T1)
h2=Enthalpy(Air,T=T2)
eta=(h1-h2)/(h1-h2s)
```

Given data

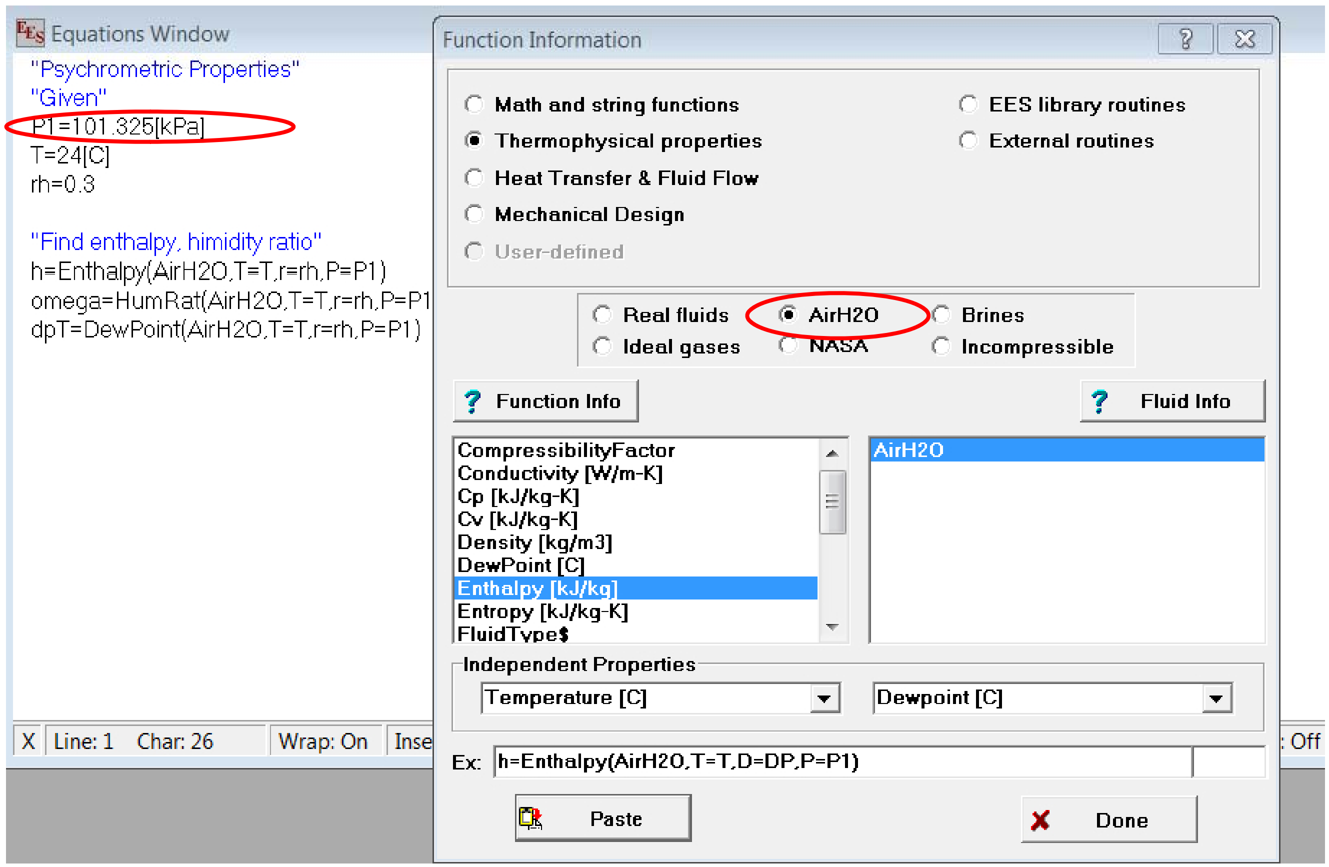
Basic equations

$$p_2 = p_{2s}$$

$$s_1 = s_{2s}$$

$$\eta_{isentropic} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

- Example 3
- Psychometric properties
- Let p=patm
- Choose AirH_2O.



- Procedure

- Equations
- Thermodynamic properties
- Unit system
- Run

Note: For thermo combustion problems and chemical equilibrium problems, set bounds for variables.

For example, set lower bounds for temperature to be 273K.

Options-> Variable Information->Upper and Lower limits