

EES Demo

Equations

Thermodynamic properties from tables

Solve

- EES is a calculator with properties.

- Objectives

- Ideal gas properties

- Real fluid properties

- Isentropic process

- Psychrometric properties



Example 1



Example 2

- Example 1:

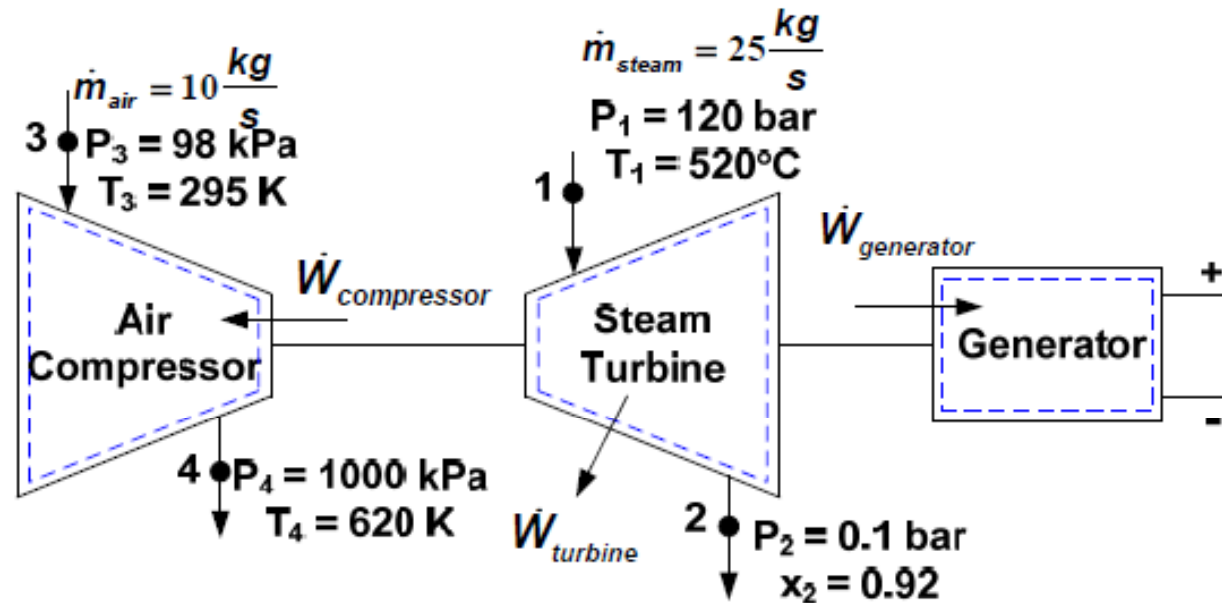
Given

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

Find

Net power (MW) delivered to the generator

System



- Example 1:

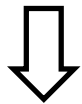
Assumptions

- 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

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

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



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

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

EES can **NOT** do this part for you!

- Example 1:

Thermodynamic data

(a) State 1: $P_1 = 12 \text{ MPa}$, $T_1 = 520^\circ\text{C}$

Table A-3 for water: $T_1 > T_{\text{sat}}(120 \text{ bar}) = 324.8^\circ\text{C} \Rightarrow \text{SHV}$

Table A-4 for superheated water vapor: $h_1 = 3401.8 \text{ kJ/kg}$

State 2: $P_2 = 10 \text{ kPa} = 0.1 \text{ bar}$, $x_2 = 0.92 \Rightarrow \text{SLVM}$

Table A-3 for water:

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

Since air behaves as an ideal gas, enthalpy depends only on temperature.

Table A-22 for air: $h_3 = 295.17 \text{ kJ/kg}$ at $T_3 = 295 \text{ K}$; $h_4 = 628.07 \text{ kJ/kg}$ at $T_3 = 620 \text{ K}$

EES can do this part for you!

- 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:

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

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:

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

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:

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

EES can do this part for you!

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

EES Commercial: C:\Ruoyu\2014Fall\ME300\...

File Edit Search Options Calculate Tables

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=
h2=

```

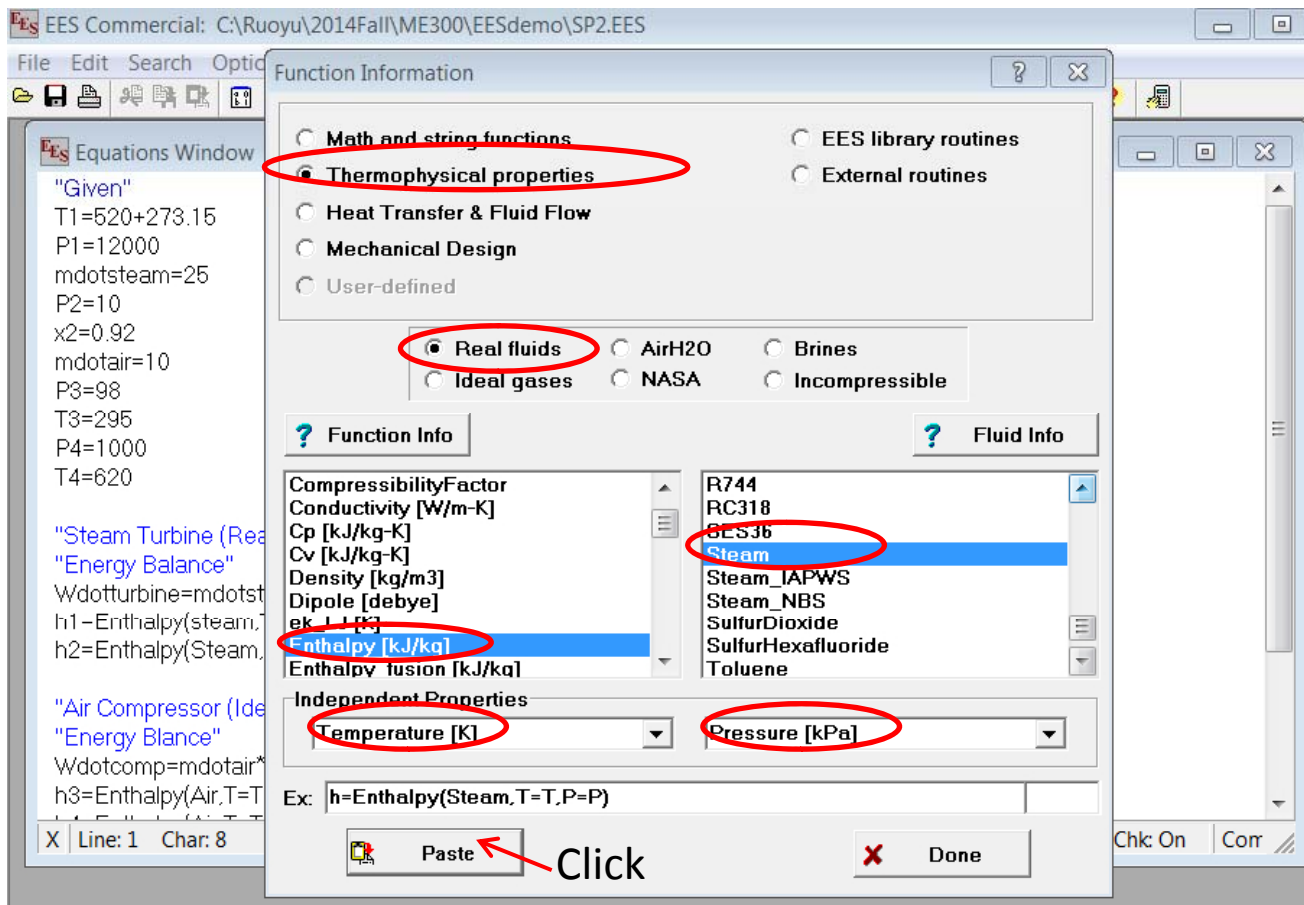
Given data

Basic equation (steam)

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

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 real fluids
- 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

```

EES 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=

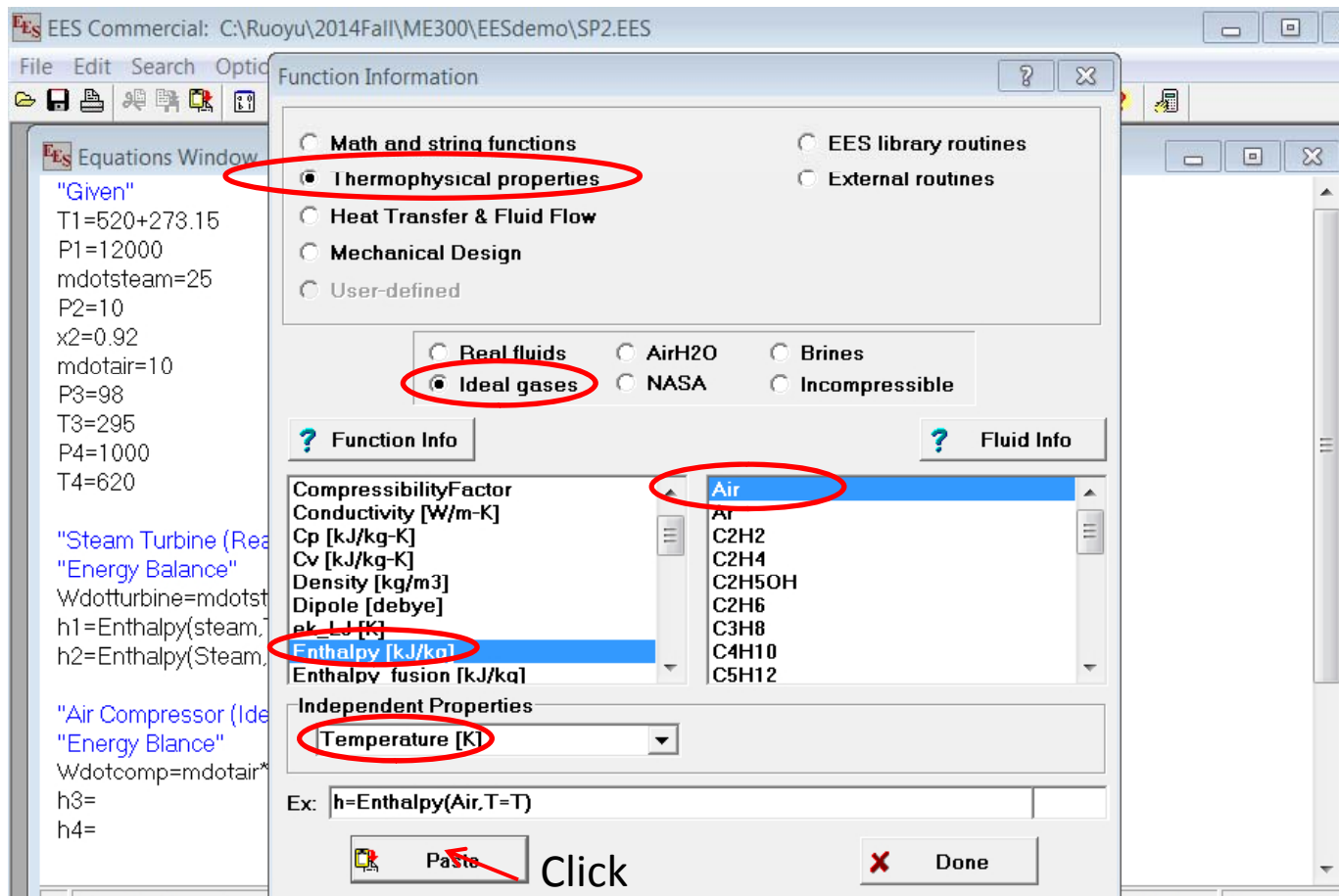
```

Basic equation (air)

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

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

```

Es 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 Balance"
Wdotcomp=mdotair*(h3-h4)
h3=Enthalpy(Air,T=T3)
h4=Enthalpy(Air,T=T4)

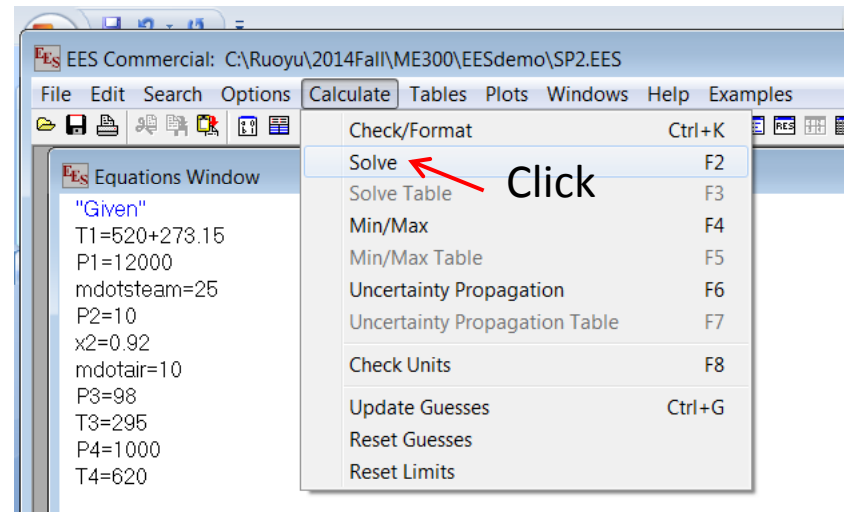
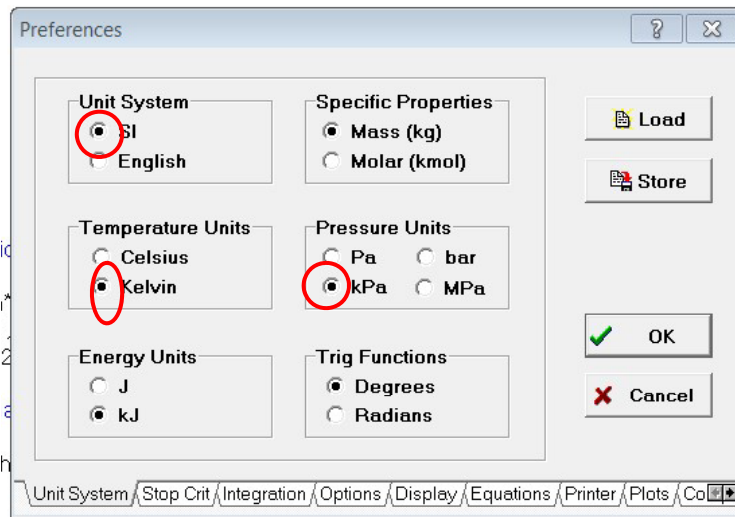
"Energy Balance"
Wdotturbine=-Wdotcomp+Wdotg

```

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:

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

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

Thermodynamic data (air):

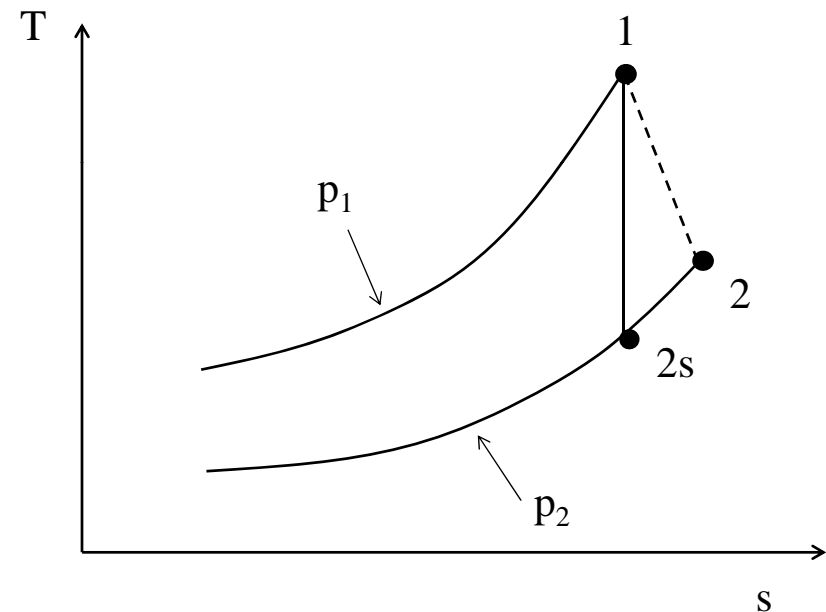
From Table A-22:

$$T_1, p_1 \rightarrow h_1, s_1;$$

$$T_2 \rightarrow h_2;$$

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

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



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

Equations Window

"SP6 High T turbine isentropic efficiency"

"Given"

P1=25[bar] ← Given data

T1=1500[K]

P2=6[bar]

T2=1200[K]

"Basic equations"

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

"isentropic Process"

P2s=P2 ← $p_2 = p_{2s}$

s1=Entropy(Air,T=T1,P=P1)

s2s=s1 ← $s_1 = s_{2s}$

h2s=Enthalpy(Air,P=P2s,s=s2s)

"turbine efficiency"

h1=Enthalpy(Air,T=T1)

h2=Enthalpy(Air,T=T2)

eta=(h1-h2)/(h1-h2s) ← $\eta_{isentropic} = \frac{h_1 - h_2}{h_1 - h_{2s}}$

- Example 3
- Psychrometric properties
- Let $p = p_{atm}$
- Choose AirH₂O.

The screenshot shows the EES software interface with the following components:

- Equations Window:**
 - "Psychrometric Properties"
 - "Given"
 - $P1 = 101.325 \text{ [kPa]}$ (circled in red)
 - $T = 24 \text{ [C]}$
 - $rh = 0.3$
 - "Find enthalpy, humidity ratio"
 - $h = \text{Enthalpy}(\text{AirH2O}, T=T, r=rh, P=P1)$
 - $\omega = \text{HumRat}(\text{AirH2O}, T=T, r=rh, P=P1)$
 - $dpT = \text{DewPoint}(\text{AirH2O}, T=T, r=rh, P=P1)$
- Function Information:**
 - Selected: **Thermophysical properties**
 - Fluid selection: **AirH2O** (circled in red)
 - Other options: Real fluids, Ideal gases, EES library routines, External routines, Brines, Incompressible, NASA, User-defined.
- Property Lists:**
 - Function Info:** CompressibilityFactor, Conductivity [W/m-K], Cp [kJ/kg-K], Cv [kJ/kg-K], Density [kg/m3], DewPoint [C], **Enthalpy [kJ/kg]**, Entropy [kJ/kg-K], FluidType\$. "Enthalpy [kJ/kg]" is highlighted.
 - Fluid Info:** AirH2O
- Independent Properties:**
 - Temperature [C] (dropdown)
 - Dewpoint [C] (dropdown)
- Example:** $h = \text{Enthalpy}(\text{AirH2O}, T=T, D=DP, P=P1)$
- Buttons:** Paste, Done

- 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