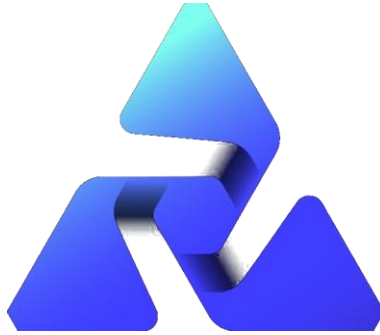




AutoTherm

Thermodynamics Validation Cases & Tutorial

AutoTherm Thermodynamics Tools – Validation and Tutorials

- 01: Evaluating Properties – Saturation and Superheated Tables
- 02: Evaluating Properties – Ideal Gases and Ideal Gas Processes
- 03: Steady-Flow Engineering Devices
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- 05: Gas Power Cycles: Reciprocating Engines
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- 08: Vapor Cycles: Rankine Cycle
- 09: Refrigeration Cycles: Vapor-Compression Cycle
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Saturated Properties Calculator:

AutoTherm's built-in material functions extract material properties for both saturated and superheated states. These features are integrated into different thermodynamic toolsets. However, the tools in this section allow users to perform these functions manually.

Saturated Properties Calculator

Water

Set all units to SI

Set all units to English

Step1: Enter temperature or Pressure

T

118.00

C

P

186.87

kPa

Update

vf

0.0010584

m3/kg

uf

495.13

kJ/kg

hf

495.32

kJ/kg

sf

1.5062

kJ/kg.K

vg

0.949

m3/kg

ug

2526.66

kJ/kg

hg

2703.04

kJ/kg

sg

7.1507

kJ/kg.K

Step2: Evaluate Properties

Option 1. Enter Quality (must be between zero and one)

Option 2. Enter Known Property (value must be between saturated liquid and saturated vapor values)

x

0.700000

v

0.6647561

m3/kg

u

1917.20

kJ/kg

h

2040.72

kJ/kg

s

5.46

kJ/kg.K

Update

1. Select the material from the combo box options:
2. To work with Imperial Units, click “Set all units to English”.
3. The upper panel works like the saturation property table. Enter a temperature or pressure, then click **Update** to display saturated fluid and saturated vapor property values. These values are automatically interpolated for any temperature/pressure.
4. To obtain mixture average properties:
 - a. Enter the quality (x) in the lower panel and click on the Update button in the panel.
 - b. If an average property is given, to get other properties and the quality, check the radio button indicating the property, enter the value, and click **Update**.

Average property values are interpolated from values already extracted and shown in the upper panel.

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Superheated Properties Calculator:

The superheated property tool enables users to look up superheated property tables effortlessly, eliminating the need for complex double interpolation.

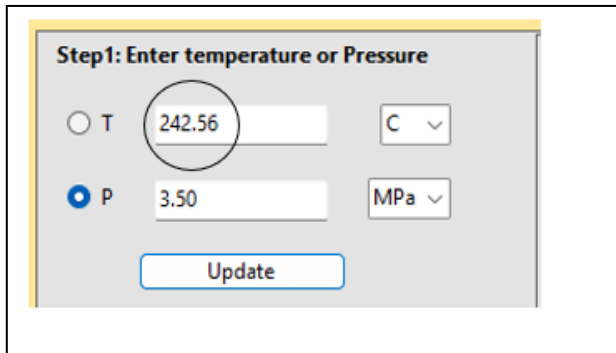
The screenshot shows a software window titled "Superheated Properties". At the top, there is a dropdown menu with "Water" selected. Below this is a "Pressure" section with a label "P", a text input field containing "3.25", and a unit dropdown menu showing "MPa". Underneath is a larger section for selecting a property. It features a vertical list of radio buttons next to labels: "T" (selected), "v", "u", "h", and "s". To the right of each label is a text input field and a unit dropdown menu. The values in the input fields are: "280.00" for T, "0.0708" for v, "2700.62" for u, "2929.05" for h, and "6.3900" for s. The units are: "C" for T, "m3/kg" for v, "kJ/kg" for u, "kJ/kg" for h, and "kJ/kg.K" for s. At the bottom of the window is a blue "Update" button.

Property	Value	Unit
Pressure (P)	3.25	MPa
Temperature (T)	280.00	C
Specific Volume (v)	0.0708	m3/kg
Internal Energy (u)	2700.62	kJ/kg
Enthalpy (h)	2929.05	kJ/kg
Entropy (s)	6.3900	kJ/kg.K

1. Select the material and choose the system of measurement.
2. Enter the fluid pressure. *Note that in the SI system, MPa is the unit for pressure, which differs from kPa used in the Saturated Properties tool.*
3. Select the other known property and enter its value.
4. Click **Update** to extract values for other properties.

Example: A piston-cylinder device contains steam initially at 3.5 MPa and superheated by 5 °C (State-1). The steam then loses heat to the surroundings, and the piston moves down until it hits a set of stops. At this point, the cylinder contains saturated liquid water (State-2). The cooling continues until the water reaches 200 °C. a) Determine the initial temperature and enthalpy; b) Determine the enthalpy change per unit mass of steam by the time the piston first hits the stops; d) Determine the final pressure, quality, and enthalpy.

- a) To find the temperature at State-1, we must first find the saturation temperature at $P_1=3.5$ MPa and add 5 °C to it.
- Change the unit of pressure from kPa to MPa
 - Enter 3.5 MPa for pressure and click Update.
 - The Saturation temperature is calculated to be 242.56 °C

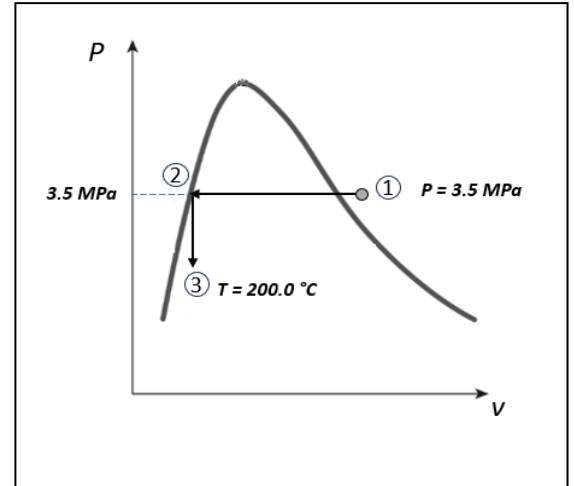


Step1: Enter temperature or Pressure

☐ T 242.56 C

☒ P 3.50 MPa

Update



- Add 5 degrees to get the **temperature at State-1=247.53 °C**

To get the enthalpy for State-1, open the superheated tool and enter a pressure of 3.5 MPa and a temperature of 247.53 °C. Click Update to see the property values.

- b) The process 1-2 is at a constant pressure of 3.5 MPa, and state 2 is saturated liquid. Therefore, we can use the Saturated Property tool to obtain h_2 :

$$h_2 = 1049.7 \text{ kJ/kg}; \quad v_2 = 0.001235 \text{ m}^3/\text{kg};$$

The enthalpy change of the system will be:

$$\Delta h = h_2 - h_1 = 2820.85 - 1049.7 = -1771.15 \text{ kJ/kg}$$

- c) The process 1-3 is constant volume at $0.001235 \text{ m}^3/\text{kg}$. So, State-3 is at 200°C , $0.001235 \text{ m}^3/\text{kg}$ in a mixed state. We will use the Saturated Properties tool:
1. Top panel: $T = 200^\circ\text{C}$ to get saturated liquid and vapor values.
 2. Bottom panel: set $v = 0.001235 \text{ m}^3/\text{kg}$ to get all other average properties.

Saturated Properties Calculator

Water

Set all units to SI

Set all units to English

Step1: Enter temperature or Pressure

T

200.00

C

P

1.55

MPa

Update

vf	0.0011570	m3/kg	vg	0.127	m3/kg
uf	850.46	kJ/kg	ug	2594.20	kJ/kg
hf	852.26	kJ/kg	hg	2792.00	kJ/kg
sf	2.3305	kJ/kg.K	sg	6.4302	kJ/kg.K

Step2: Evaluate Properties

Option 1. Enter Quality (must be between zero and one)

Option 2. Enter Known Property (value must be between saturated liquid and saturated vapor values)

x

0.000619

v

0.0012350

m3/kg

u

851.54

kJ/kg

h

853.46

kJ/kg

s

2.33

kJ/kg.K

Update

$$p_3 = 1.55 \text{ MPa}; h_3 = 853.46 \frac{\text{kJ}}{\text{kg}}; x_3 = 0.00062$$

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Select Fluid

Air

Molar Mass, M

28.97

kg/kmol

Gas Constant, R

0.287

kJ/kg.K

Critical Point Properties

Tc

132.50

K

Pc

3.770

MPa

vc

0.0883

m3/kmol

Initial State

Enter Two Properties

T1

C

P1

kPa

☒

ρ 1

kg/m3

☐

v1

m3/kg

Update

Cp1

kJ/kg.K

Cv1

kJ/kg.K

k1

Final State

Fix State

Enter Two Properties

T2

C

P2

kPa

☒

ρ 2

kg/m3

☐

v2

m3/kg

Update

Cp2

kJ/kg.K

Cv2

kJ/kg.K

k2

u2-u1

kJ/kg

h2-h1

kJ/kg

s2-s1

kJ/kg.K

This automated tool provides several functionalities for Ideal Gas calculations:

Top Panel: This panel allows the user to select an ideal gas from the library and provides the molecular weight, gas constant (in any unit), and critical point data for the selected gas. This selection is also used for all other calculations on this form.

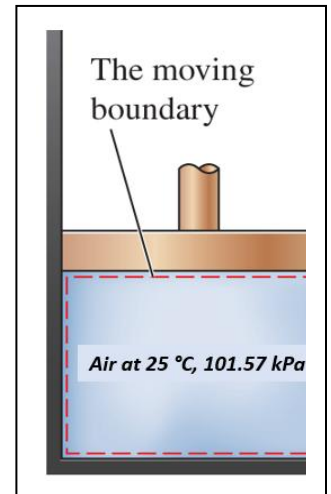
Middle-Left Panel: This panel's upper section lets the user determine ideal gas properties by inputting values for two other properties, using the ideal gas law. ($Pv = RT$).

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Example: A frictionless piston-cylinder is initially filled with air at 25 °C and 101.57 kPa (State 1). Heat is then added to the device until its volume doubles (State 2). Determine the amount of heat transfer per unit mass of air for this process.

1. We use the Ideal Gas Properties tool, enter the given pressure and temperature, and click **Update** on the left panel to obtain other thermodynamic properties for State-1.
2. Since the process 1-2 is constant pressure (*note: frictionless piston-cylinder*), select the **isobaric** process on the right panel process selector.
3. Since the problem states that the volume is doubled from State-1 to State-2, enter $v_2 = 2 \times v_1 = 2 \times 0.842 = 1.684 \text{ m}^3/\text{kg}$.
4. Click **Update** in the right panel to get the properties for the final state and property changes for the process 1-2. The completed form is shown below:



Ideal Gas Properties and Processes

Select Fluid: **Air**

Molar Mass, M: 28.97 kg/kmol

Gas Constant, R: 0.287 kJ/kg.K

Critical Point Properties:

Tc: 132.50 K

Pc: 3.770 MPa

vc: 0.0883 m³/kmol

Initial State

Enter Two Properties

T1: 25 C

P1: 101.57 kPa

☒ ρ_1 : 1.1870 kg/m³

☐ v_1 : 0.842 m³/kg

Update

Cp1: 1.005 kJ/kg.K

Cv1: 0.718 kJ/kg.K

k1: 1.400

Final State

Isobaric Process

Enter one Property

T2: 322.82 C

P2: 101.570 kPa

☐ ρ_2 : 0.5938 kg/m³

☒ v_2 : 1.684 m³/kg

Update

Cp2: 1.050 kJ/kg.K

Cv2: 0.763 kJ/kg.K

k2: 1.376

u2-u1: 220.54 kJ/kg

h2-h1: 306.02 kJ/kg

s2-s1: 0.71 kJ/kg.K

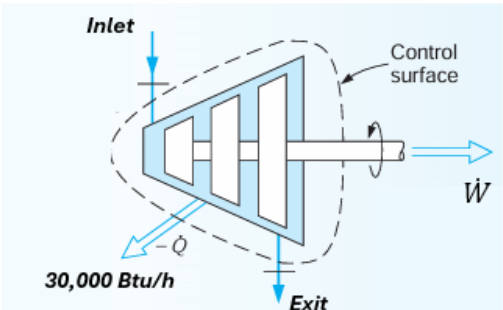
The amount of heat transfer per unit mass of air for this process can now be found for this constant-pressure process:

$$q = h_2 - h_1 = 306.2 \text{ kJ/kg}$$

03: Steady-Flow Engineering Devices

Example – Turbine [3]: The mass flow rate into a steam turbine is 10,000 lbm/h, and the heat transfer from the turbine is 30,000 Btu/h. The following data are known for the steam entering and leaving the turbine. Determine the turbine's power output in horsepower.

	Inlet	Exit
Pressure	300 psia	15 psia
Temperature	700 F	
Quality		100%
Velocity	200 ft/s	600 ft/s
Elevation above reference	16 ft	10 ft



- Open the “1st Law – Steady Devices” tool from the *Thermodynamics/Control Volume Analysis* menu.
- Change units to the English System and enter inlet and exit properties as provided.
- Enter the mass flow rate in **lbm/h**, heat loss in **Btu/h**, and change the unit for Wout to **Hp**.
- Click Update to solve the problem.

1st Law - Steady Devices

Select Device: a) Turbine

Select Fluid: H2O

Units: ☐ SI System ☒ English System

Inlet Properties

☒ P1 300.00 psi ☐ v1 2.24 ft³/lbm

☒ T1 700.00 F ☐ x1

☐ h1 1368.55 Btu/lbm ☐ A1 ft²

☒ V1 200.00 ft/s

☒ Z1 16.00 ft

Outlet Properties

☒ P2 15.00 psi ☐ v2 26.38 ft³/lbm

☐ T2 212.90 F ☒ x2 1.0

☐ h2 1150.70 Btu/lbm ☐ A2 ft²

☒ V2 600.00 ft/s

☒ Z2 10.00 ft

Flow Info

☒ mdot 10000.00 lbm/h

☐ Vdot1 6.22 ft³/s

☐ Vdot2 73.28 ft³/s

Device

☐ Wout 819.26 Hp

☒ Qout 30000 Btu/h

Delta_H -605.11 **Delta_KE** 17.75 **Delta_PE** -0.02143 **Btu/s**

Update

a) Turbine

b) Compressor

c) Nozzle

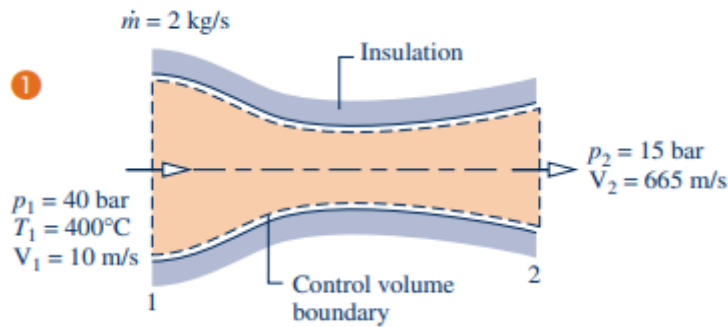
d) Diffuser

e) Throttling Valve

f) Duct

Note: The work output (power) is 819.26 HP. The change in potential energy is negligible, and the change in kinetic energy is “small” compared to the change in enthalpy.

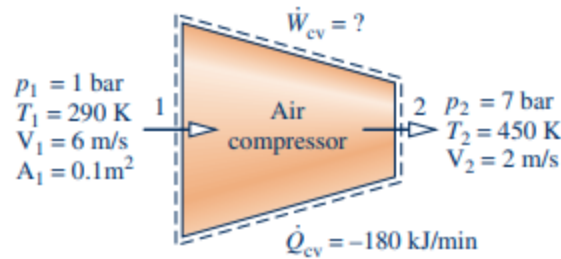
Example – Exit Area of a Steam Nozzle [2]: Steam enters a converging–diverging nozzle operating at steady state with $p_1 = 40$ bar, $T_1 = 400$ °C, and a velocity of 10 m/s. The steam flows through the nozzle with negligible heat transfer and no significant change in potential energy. At the exit, $p_2 = 15$ bar, and the velocity is 665 m/s. The mass flow rate is 2 kg/s. Determine the nozzle exit area in in².



- Open the “1st Law – Steady Devices” tool from the *Thermodynamics/Control Volume Analysis* menu.
- Change *Device* to *Nozzle*.
- Enter the inlet and exit pressures in bars, inlet and exit temperatures, velocities, and mass flow rate.
- Change the requested unit for the exit area to in² and click **Update** to solve the problem.

All properties for the inlet and exit are calculated. The exit area is calculated to be 0.762 in².

Example – Calculating Compressor Power [2]: Air enters a compressor operating at steady state at a pressure of 1 bar, a temperature of 290 K, and a velocity of 6 m/s through an inlet with an area of 0.1 m². At the exit, the pressure is 7 bars, the temperature is 450 K, and the velocity is 2 m/s. Heat transfer from the compressor to its surroundings occurs at a rate of 180 kJ/min. Employing the ideal gas model, calculate the power input to the compressor, in kW.



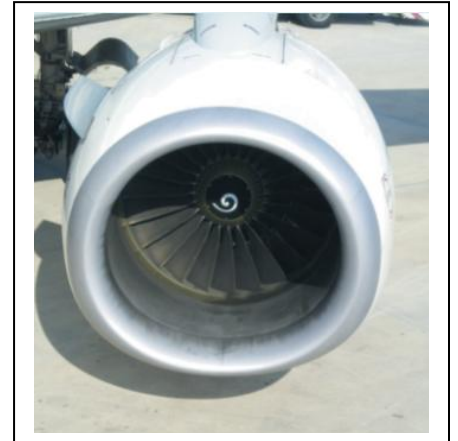
- Open the “1st Law – Steady Devices” tool from the *Thermodynamics/Control Volume Analysis* menu.
- Change *Device* to *Compressor* and choose *Air* as fluid.
- Enter the inlet and exit pressures in bars, inlet and exit temperatures, velocities, inlet area, and enter 180 kJ/min for the heat loss. Uncheck the mass flow rate checkbox to calculate it from the inlet information.
- Click **Update** to solve the problem.

The screenshot shows the '1st Law - Steady Devices' software interface. The 'Compressor' device is selected for 'Air'. The inlet properties are: $P_1 = 1.00000 \text{ bar}$, $T_1 = 290.00 \text{ K}$, $V_1 = 6.00 \text{ m/s}$, and $A_1 = 0.1 \text{ m}^2$. The outlet properties are: $P_2 = 7.00 \text{ bar}$, $T_2 = 450.00 \text{ K}$, and $V_2 = 2.00 \text{ m/s}$. The heat transfer rate Q_{out} is set to 180 kJ/min. The calculated work rate W_{in} is 123.86 kW. The 'Update' button is visible at the bottom right.

The compressor work is estimated at about 124 kW.

Example – Air Flow in a Diffuser [1]: Air at 10 °C and 80 kPa enters the diffuser of a jet engine with a velocity of 200 m/s. The inlet area of the diffuser is 0.4 m², and the air exit velocity is very small compared to the inlet velocity. Determine a) the mass flow rate of the air, and b) the temperature of the air leaving the diffuser in K.

Open the “1st Law – Steady Devices” tool from the *Thermodynamics/Control Volume Analysis* menu.



- Change *Device* to *Diffuser* and choose *Air* as fluid.
- Enter 10 ° and 80 kPa for the inlet temperature, 200 m/s for the inlet velocity, and 0.1 m² for the inlet area.
- Change the requested unit for the exit temperature to degrees K.
- Uncheck the mass flow rate checkbox to indicate that it needs to be solved for.
- Click **Update** to solve the problem.

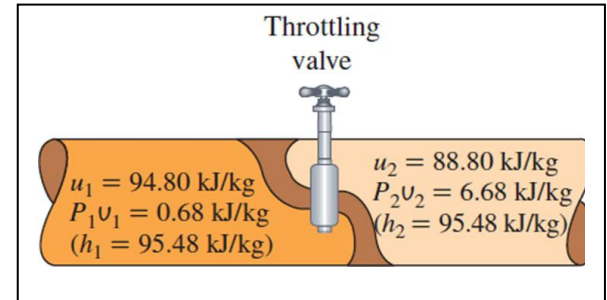
The software interface shows the following settings and results:

- Select Device:** d) Diffuser
- Select Fluid:** Air
- Inlet Properties:**
 - P1: 80.00 kPa
 - T1: 10.00 C
 - V1: 200.00 m/s
 - A1: 0.4 m²
- Outlet Properties:**
 - T2: 302.81 K
- Flow Info:**
 - mdot: 78.76 kg/s
- Device:**
 - Qout: 0.000 kW
- Bottom Section:**
 - Delta_H: 1575.11
 - Delta_KE: -1575.11
 - Delta_PE: 0.000E00

- Mass flow rate is 78.8 kg/s. It is calculated by applying the mass conservation at the inlet.
- The exit temperature is approximately 303 K.

Example – Expansion of Refrigerant-134a [1]: Saturated liquid refrigerant-134a enters the capillary tube of a refrigerator at 0.8 MPa and is throttled to 0.12 MPa. Determine the quality of the refrigerant at the exit and the temperature drop for this process.

- Open the “1st Law – Steady Devices” tool from the *Thermodynamics/Control Volume Analysis* menu.
- Change *Device* to *Throttling Valve* and choose *R134A* as fluid.
- Enter the “0” for the inlet quality, 0.8 MPa for the inlet pressure, and 0.12 MPa for the exit pressure.
- Keep the mass flow rate unchanged at “1” to solve the problem on a per mass basis.
- Click **Update** to solve the problem.



1st Law - Steady Devices

Select Device: e) Throttling Valve

Select Fluid: R134a

Inlet Properties:

- ☒ P1: 0.80000 MPa
- ☐ T1: 31.31 C
- ☐ h1: 95.48 kJ/kg
- ☐ v1: 8.457E-04 m³/kg
- ☒ x1: 0.000E00
- ☐ A1: 0.000E00 m²

Outlet Properties:

- ☒ P2: 0.12000 MPa
- ☐ T2: -22.32 C
- ☐ h2: 95.48 kJ/kg
- ☐ v2: 0.05567 m³/kg
- ☐ x2: 0.34034
- ☐ A2: 0.000E00 m²

Flow Info:

- ☒ mdot: 1.00000 kg/s
- ☐ Vdot1: 8.457E-04 m³/s
- ☐ Vdot2: m³/s

Device: e) Throttling Valve

Delta_H: 0.000E00, Delta_KE: 0.000E00, Delta_PE: 0.000E00, kW

Update

Diagram illustrating various steady-state devices and their associated flow and energy interactions:

- a) Turbine: Inlet P_1, T_1, V_1, Z_1 , mass flow $\dot{m}$, heat transfer $\dot{Q}_{out}$, work output $\dot{W}_{out}$, outlet P_2, T_2, V_2, Z_2 .
- b) Compressor: Inlet P_1, T_1, V_1, Z_1 , mass flow $\dot{m}$, work input $\dot{W}_{in}$, heat transfer $\dot{Q}_{out}$, outlet P_2, T_2, V_2, Z_2 .
- c) Nozzle: Inlet P_1, T_1, V_1, Z_1 , mass flow $\dot{m}$, heat transfer $\dot{Q}_{out}$, outlet P_2, T_2, V_2, Z_2 .
- d) Diffuser: Inlet P_1, T_1, V_1, Z_1 , mass flow $\dot{m}$, heat transfer $\dot{Q}_{out}$, outlet P_2, T_2, V_2, Z_2 .
- e) Throttling Valve: Inlet P_1, T_1, x_1 , mass flow $\dot{m}$, outlet P_2, T_2, x_2 .
- f) Duct: Inlet P_1, T_1, x_1 , mass flow $\dot{m}$, heat transfer $\dot{Q}_{out}$, work input $\dot{W}_{in}$, outlet P_2, T_2, x_2 .

The exit quality is 34%, and the exit temperature is -22.32 °C. This represents $-22.34 - 31.31 = -53.63$ °C temperature drop during this throttling process.

04: Heat Engines and Refrigerators

2nd Law Devices

Device Type

a) Heat Engine

Please Enter two Values

Q_H

kJ/h

Q_L

kJ/h

W_{net}

kW

Efficiency

Update

High-temperature reservoir at T_H

Q_H

HE

$W_{net,out}$

Q_L

Low-temperature reservoir at T_L

a) Heat Engine

Warm environment at $T_H > T_L$

Q_H

R

$W_{net,in}$

Q_L

Cold refrigerated space at T_L

b) Refrigerator

Warm heated space at $T_H > T_L$

Q_H

HP

$W_{net,in}$

Q_L

Cold environment at T_L

c) Heat Pump

This tool provides an environment for 2nd-law calculations of heat engines and refrigerators.

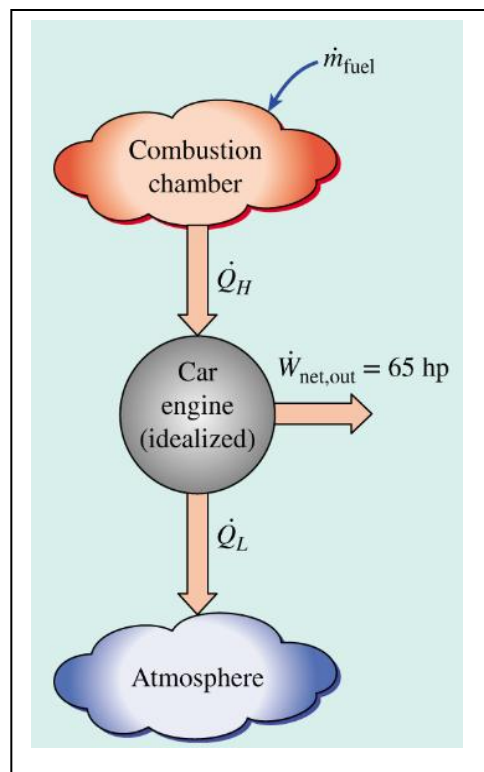
- Select the device type (heat engine/refrigerator/heat pump). The form's appearance changes based on the selection (e.g., "Efficiency" changes to "C.O.P." for the refrigerator).
- Enter values for two fields and press Update to calculate the other two fields.

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Example – Fuel Consumption Rate of a Car [1]: A car engine with a power output of 65 hp has a thermal efficiency of 24 percent. Determine the fuel consumption rate of this car. Assume the fuel has a heating value of 19,000 Btu/lbm (19000 Btu is released per pound of fuel).

- Open the “2nd Law Devices” tool from the 2nd Law Concepts and Entropy Analysis menu.
- Keep Device as Heat Engine.
- Enter the “65” for W_{net} and change its unit to HP.
- Enter 0.24 for its Thermal Efficiency.
- Change the requested unit for the heat rate field to Btu/h.
- Click **Update** to solve the problem.



2nd Law Devices

Device Type: a) Heat Engine

Please Enter two Values

QH: 689117.43 Btu/h

QL: 523729.24 Btu/h

Wnet: 65 Hp

Efficiency: .24

Update

a) Heat Engine

High-temperature reservoir at T_H

Low-temperature reservoir at T_L

Heat Engine (HE)

Heat input: Q_H

Heat output: Q_L

Net work output: $W_{net,out}$

b) Refrigerator

Warm environment at $T_H > T_L$

Cold refrigerated space at T_L

Refrigerator (R)

Heat input: Q_H (Required input)

Heat output: Q_L (Desired output)

Net work input: $W_{net,in}$

c) Heat Pump

Warm heated space at $T_H > T_L$

Cold environment at T_L

Heat Pump (HP)

Heat input: Q_H (Desired output)

Heat output: Q_L (Required input)

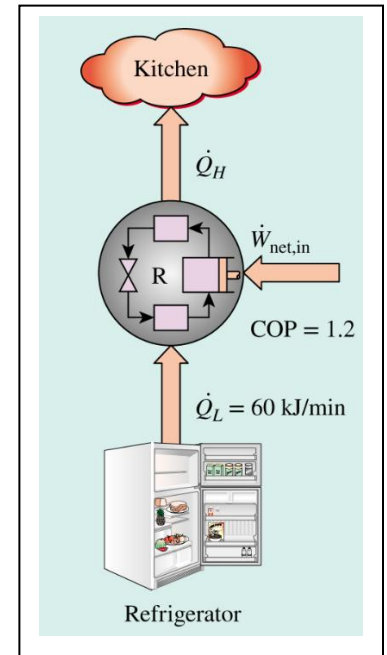
Net work input: $W_{net,in}$

The rate of heat addition (Q_H) is 689,117 Btu/h. This energy must be supplied by the fuel. Therefore, the fuel consumption rate is:

$$\dot{m}_{Fuel} = \frac{689,117 \text{ Btu/h}}{19,000 \text{ Btu/lbm}} = 36.3 \text{ lbm/h}$$

Example – Household Refrigerator [1]: A household refrigerator with a COP of 1.2 removes heat from the refrigerated space at a rate of 60 kJ/min. Determine a) the electrical power consumption of this refrigerator in kW, b) the rate of heat transfer to the kitchen air.

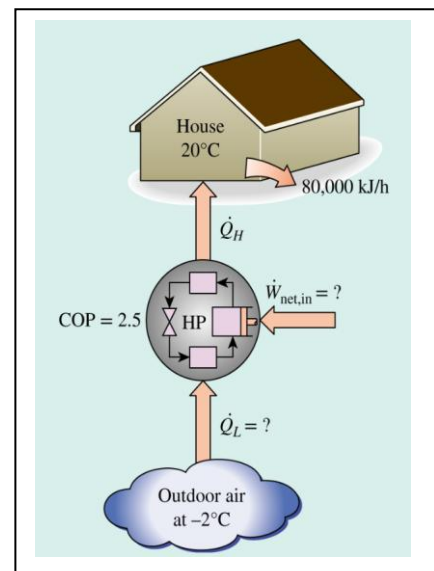
- Open the “2nd Law Devices” tool from the 2nd Law Concepts and Entropy Analysis menu.
- Change *Device* to a *Refrigerator*.
- Enter the “60” for *kJ/min* for heat rate from cold space ($\dot{Q}_L$).
- Enter 1.2 for its *COP*.
- Change the requested unit for the heat rate field to Btu/h.
- Click **Update** to solve the problem.



- The electrical power (W_{net}) needed is 0.833 kW.
- The rate of heat transfer to the kitchen ($\dot{Q}_H$) is 110 kJ/min.

Example – Heating of a House using a Heat Pump [1]: A heat pump is used to maintain a house at 20 °C. On a day when the outdoor air temperature drops to -2 °C, the house is estimated to lose heat at a rate of 80,000 kJ/h. If the heat pump under these conditions has a COP of 2.5, determine a) the power consumed by the heat pump, and b) the rate at which heat is absorbed from the cold outside air.

- Open the “2nd Law Devices” tool from the 2nd Law Concepts and Entropy Analysis menu.
- Change Device to a Heat Pump.
- Enter the “80,000” for kJ/h for heat rate to warm space (QH).
- Enter 2.5 for its COP.
- Click **Update** to solve the problem.



- The power consumed by the heat pump is 8.9 kW.
- The rate of heat absorption from the cold outside air is 48,000 kJ/min

Note that 48,000 kJ/min of the 80,000 kJ/min delivered to the house is extracted from the cold outside air, which is a freely available energy source. We are, in fact, paying for the remaining 32,000 kJ/min. If an electric resistance heater is used, the unit must supply the full 80,000 kJ/min.

05: Gas Power Cycles: Reciprocating Engines

Otto/Diesel Cycle
— □ ×

Input

☒ Otto Cycle
 ☐ Diesel Cycle

P1 kPa

T1 C

Compression Ration

☒ qin kJ/kg

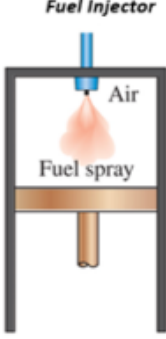
☐ T3 C

Units

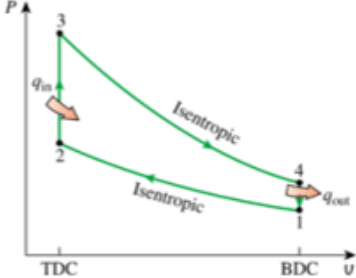
☒ SI System
 ☐ English System



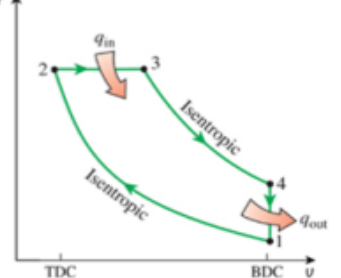
a) SI Engine



b) CI Engine



Otto Cycle



Diesel Cycle

Results

qout kJ/kg

Net Work kJ/kg

MEP kPa

Thermal Efficiency %

Properties

	No	P	T	u
▶	1			
	2			
	3			
	4			
*				

Total Quantities

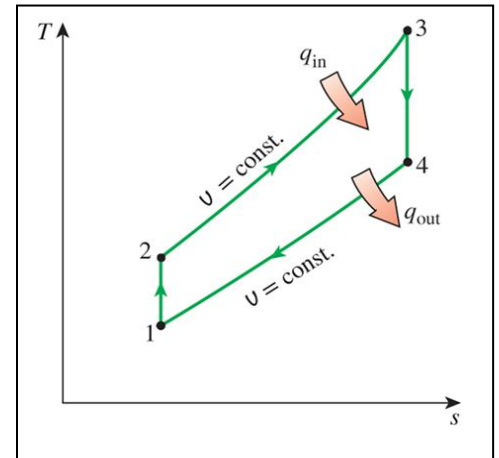
☐ V1 m³
m kg
Wtot kJ
Update

Example – Otto Cycle Calculations – using variable specific heat [1]: For an ideal Otto cycle with a compression ratio of 8 and at the beginning of the compression process, air is at 100 kPa and 17 °C, and heat input is 800 kJ/kg, determine a) temperature and pressure for every point, b) net work output per unit mass, and thermal efficiency.

Note: This AutoTherm tool uses the Variable Specific method, which utilizes air tables.

Open the “Otto/Diesel Cycle” tool from the *Thermodynamic/Gas Cycles* menu.

1. Keep default selections for *SI units* and *Otto Cycle options*.
2. Enter “100” kPa and “17” °C for State-1 pressure and temperature.
3. Enter “8” for the compression ratio.
4. Enter “800” kJ/kg for q_{in} .
5. Change all output units of temperature to degrees K, to be consistent with the textbook.
6. Click **Update** to solve the problem.



Otto/Diesel Cycle

Input

☒ Otto Cycle ☐ Diesel Cycle

Units

☒ SI System ☐ English System

P1 100 kPa

T1 17 C

Compression Ratio 8

☒ q_{in} 800.00 kJ/kg

☐ T3 1575.37 K

Results

q_{out} 381.76 kJ/kg

Net Work 418.24 kJ/kg

MEP 574.00 kPa

Thermal Efficiency 52.3 %

Properties

No	P	T	u
1	100.00	290.15	207.02
2	1799.58	652.69	475.33
3	4343.61	1575.37	1275.33
4	274.22	795.65	588.78
*			

a) SI Engine

b) CI Engine

Otto Cycle

Diesel Cycle

Total Quantities

☐ V1 m³

m kg

Wtot kJ

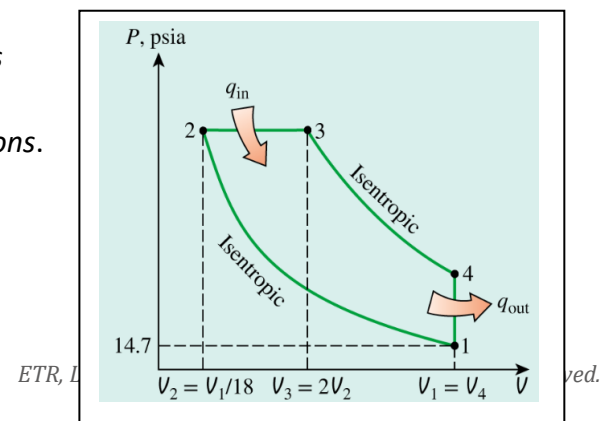
Update

- Temperature and pressure at every point are shown in the grid box.
- All other result quantities are shown in the encircled text boxes.

Example – Diesel Cycle Calculations – using variable specific heat [1]: An ideal Diesel cycle with a compression ratio of 18 and cutoff ratio of 2 at the beginning of the compression process, air is at 14.7 psia and 80 °F, and 117 in³. Utilizing cold-air-standard, determine a) the temperature and pressure at the end of each process, b) the net work output and efficiency, c) the mean effective pressure.

Open the “Otto/Diesel Cycle” tool from the *Thermodynamic/Gas Cycles* menu.

1. Change Units to the *English System* and select *Diesel Cycle options*.
2. Enter “14.7” psia and “80” °F for State-1 pressure and temperature.
3. Enter “18” for the compression ratio.



- Enter "2" for the cutoff ratio.
- Enable the *Total Quantities* calculations by clicking "ON" V1 and entering 117 in3 for the initial volume.
- Click **Update** to solve the problem.

Otto/Diesel Cycle

Input ☐ Otto Cycle ☒ Diesel Cycle

Units ☐ SI System ☒ English System

P1 14.7 psi

T1 80 F

Compression Ratio 18

☒ Cutoff Rat. 2

☐ qin 458.87 Btu/lbm

☐ T3 2772.09 F

Results

qout 193.40 Btu/lbm

Net Work 265.47 Btu/lbm

MEP 111.69 psi

Thermal Efficiency 57.9 %

Properties psi F Btu/lbm

No	P	T	u
1	14.70	80.00	91.98
2	792.27	1156.21	289.21
3	792.27	2772.09	637.54
4	43.49	1136.92	285.38
*			

a) SI Engine

b) CI Engine

Otto Cycle

Diesel Cycle

Total Quantities

☒ V1 117 in³

m 0.00498 lbm

Wtot 1.32 Btu

Update

- The total work output is 1.3 Btu's.

06: Gas Power Cycles: Brayton Cycle

This tool provides an environment to analyze the Brayton cycle – the ideal cycle for gas-turbine engines.

1

Units

SI System

English System

3

Comp. Inlet Temp.C

4

Comp. Inlet PressurekPa

5

Turbine Inlet PressureMPa

T3

Qin

CkW

Compressor Efficiency

100

%

Turbine Efficiency

100

%

6

Results

Comp. PowerkW

Turbine PowerkW

Net PowerkW

QoutkW

Thermal Efficiency%

Back Work Ratio%

Properties

kPa

C

kJ/kg

	No	P	T	h
▶	1			
	2			
	3			
	4			
*				

2

mdot

1.0

kg/s

Vdot1

m3/s

Update

2

3

1

4

Compressor

Turbine

Q_{in}

Q_{out}

W_{net}

T

s

1

2

3

4

q_{in}

q_{out}

$P = \text{const.}$

$P = \text{const.}$

This automated tool can be accessed from the “Brayton Cycle” tool from the *Thermodynamic/Gas Cycles* menu.

- 1. Choose the unit system.
- 2. By default, calculations are performed assuming 1 unit of mass (per mass basis), but here the mass flow rate or the volumetric flow rate at state-1 may be entered.
- 3. Enter the compressor inlet (state-1) conditions (pressure and temperature).
- 4. Enter the turbine inlet pressure. If the pressure ratio is given, this is p1 times the pressure ratio.
Caution: the default unit here is MPa; make sure to select the correct unit.
- 5. Enter either T3 (the turbine inlet temperature) or Qin (heat added in process 2-3).

 AutoTherm

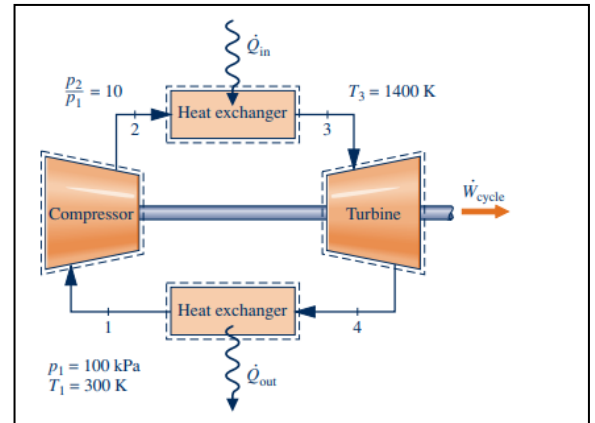
ETR, LLC. Proprietary and Confidential. All rights reserved.

6. If analyzing a non-ideal Brayton cycle, enter the isentropic efficiencies.

Example – Brayton Cycle Gas Turbine [2]: Air enters the compressor of an ideal air-standard Brayton cycle at 100 kPa, 300 K, with a volumetric flow rate of 5 m³/s. The compressor pressure ratio is 10. The turbine inlet temperature is 1400 K. Determine (a) the thermal efficiency of the cycle, (b) the back work ratio, (c) the net power developed, in kW.

Open the “Brayton Cycle” tool from the *Thermodynamic/Gas Cycles* menu.

1. Change flow selection to *Vdot1* and enter “5” m³/s.
2. Enter “100” kPa and “300” K for State-1 pressure and temperature.
3. Enter 1000 (10x100) for p_2 , change unit to kPa.
4. Enter 1400 K for T_3 .
5. Leave the other field set to its default value and click **Update**.



Brayton Cycle

Units: ☒ SI System ☐ English System

Input

2 → Comp. Inlet Temp. 300 K

Comp. Inlet Pressure 100 kPa

3 → Turbine Inlet Pressure 1000 kPa

4 → ☒ T3 1400 K

☐ Qin 5432.53 kW

Compressor Efficiency 100 %

Turbine Efficiency 100 %

Results

Comp. Power 1624.56 kW

Turbine Power 4103.81 kW

Net Power 2479.25 kW

Qout 2953.28 kJ/s

Thermal Efficiency 45.64 %

Back Work Ratio 39.59 %

Properties kPa C kJ/kg

No	P	T	h
1	100.00	26.85	300.19
2	1000.00	301.01	579.94
3	1000.00	1126.85	1515.42
4	100.00	514.80	808.74
*			

1 → ☐ mdot 5.81 kg/s

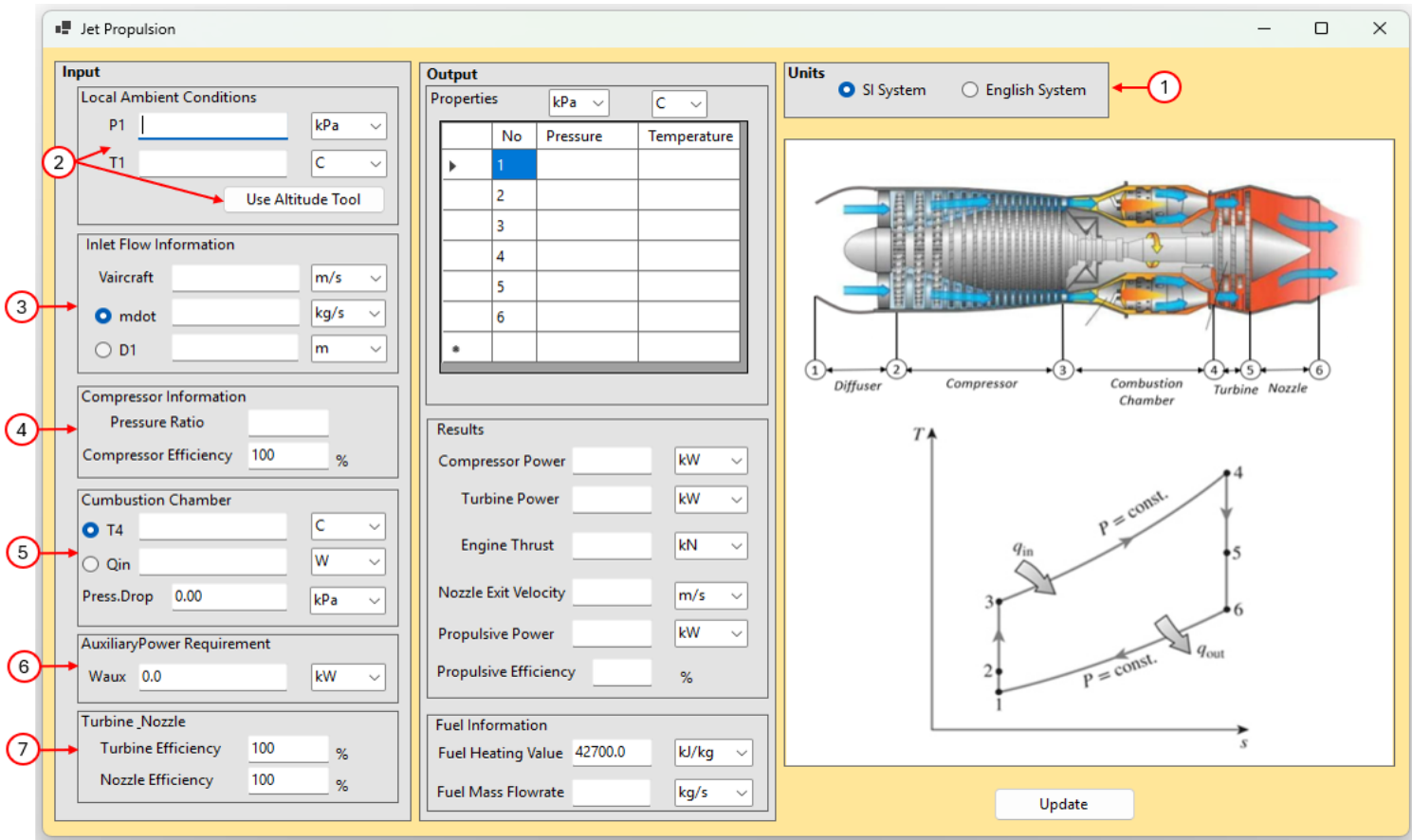
☒ Vdot1 5 m³/s

Update

The thermal efficiency is 45.6%, the back work ratio is 39.6%, and the net power is roughly 2480 kW.

07: Gas Power Cycles: Turbojet Engine

This tool is used to perform thermodynamic analysis of turbojet engines. The tool is accessed from the top menu: *Thermodynamic/Gas Cycles/Tool: Turbojet Engine*.



The user must follow the following steps:

1. Choose the unit system.
2. Provide the local pressure and temperature (state-1). Alternatively, the "Use Altitude Tool" button can be clicked to open the tool, where the pressure can be specified, and temperature and pressure are automatically applied.
3. Enter the aircraft velocity and provide the flow rate by either specifying the mass flow rate or the engine inlet diameter.
4. Enter the compressor pressure ratio and its isentropic efficiency (if non-ideal).
5. Enter either T4 (the turbine inlet temperature) or Qin (heat added in the combustion chamber).
6. Enter the value for the auxiliary power needed to be provided by the turbine.
7. For non-ideal cases, enter the isentropic efficiencies for the turbine and nozzle.
8. Click **Update**.

The pressure and temperature values at all state points are presented in the grid box, along with all relevant results.

Example – Jet Propulsion Cycle [1]: A turbojet is flying with a velocity of 595 miles per hour, at an altitude of 20,000 ft. The pressure ratio across the compressor is 13, and the temperature at the turbine inlet is 2400 R. Assuming ideal operation for all components, and an airflow through the compressor at a rate of 110 lbm/s, and the fuel jet heating value of 42,700 kJ/kg, determine a) the velocity of exhaust gases, b) the propulsive power and the propulsive efficiency, and c) the rate of fuel consumption.

Open the “Turbojet Engine” tool from the *Thermodynamic/Gas Cycles* menu.

1. Change the unit system to *English*.
2. Click the “Use Altitude Tool” button and enter 20,000 ft for the altitude in the “Atmospheric Conditions at Altitude” tool. Then, click the “Update” button. The tool will automatically close, and the atmospheric pressure and temperature in your selected units will be displayed.
3. Enter “595” mile/h for the aircraft speed and “110” lbm/s for the mass flow rate of air.
4. Enter “13” for the pressure ratio.
5. Enter “2400” for T4 (turbine inlet temperature) and change its unit to “R”.
6. Change the temperature unit to “R” for the state points spreadsheet, and the power unit to kW for the propulsive power unit.
7. Leave the other field set to its default value and click **Update**.

The screenshot shows the 'Jet Propulsion' software interface. It is divided into several sections: Input, Output, Units, Results, and Fuel Information. Red circles with numbers 1 through 6 point to specific elements in the interface as per the instructions.

Input Section:

- Local Ambient Conditions:** P1 = 6.75 psi, T1 = -12.32 F. A red circle 2 points to the 'Use Altitude Tool' button.
- Inlet Flow Information:** Vaircraft = 595 mile/h, mdot = 110 lbm/s. A red circle 3 points to the mdot input field.
- Compressor Information:** Pressure Ratio = 13. A red circle 4 points to this field.
- Combustion Chamber:** T4 = 2400 R. A red circle 5 points to the T4 input field.
- Auxiliary Power Requirement:** Waux = 0.0 Btu/s.
- Turbine/Nozzle:** Turbine Efficiency = 100%, Nozzle Efficiency = 100%.

Output Section:

- Properties:** A table showing state points 1 through 6. A red circle 6 points to the 'Temperature' column header.

Units: English System is selected. A red circle 1 points to the 'English System' radio button.

Results:

- Compressor Power: 14534.90 Btu/s
- Turbine Power: 14534.90 Btu/s
- Engine Thrust: 8299.91 lbf
- Nozzle Exit Velocity: 3300.32 ft/s
- Propulsive Power: 9820.27 kW
- Propulsive Efficiency: 23.31 %

Fuel Information:

- Fuel Heating Value: 42700.0 Btu/lbm
- Fuel Mass Flowrate: 0.93519 lbm/s

Diagram: A schematic of a turbojet engine and a T-s diagram are shown. The T-s diagram shows the thermodynamic cycle with points 1 through 6. A red circle 6 points to the T-s diagram.

Update: A button at the bottom right of the interface.

- The velocity of exhaust is 3300 ft/s
- The propulsive power is 9,820 kW
- The propulsive efficiency is 23.3%
- The rate of fuel consumption is 0.93519 lbm/s

• All other results, in addition to the pressure and temperature throughout the engine, are presented.

Example 2 – Jet Propulsion Cycle [1]: Repeat the previous problem using a compressor efficiency of 80%, a turbine efficiency of 85%, and a nozzle efficiency of 90%.

In the completed form above, make the following modifications:

1. Change the compressor efficiency to 80%.
2. Change the turbine efficiency to 85%.
3. Change the nozzle efficiency to 90%.
4. Click **Update** to get the updated results.

Jet Propulsion

Input

Local Ambient Conditions

P1 psi

T1 F

[Use Altitude Tool](#)

Inlet Flow Information

Vaircraft mile/h

☒ mdot lbm/s

☐ D1 ft

Compressor Information

Pressure Ratio

Compressor Efficiency %

Cumbustion Chamber

☒ T4 R

☐ Qin Btu/s

Press.Drop psi

AuxiliaryPower Requirement

Waux Btu/s

Turbine_Nozzle

Turbine Efficiency %

Nozzle Efficiency %

Output

Properties psi R

No	Pressure	Temperature
1	6.75	447.35
2	10.74	510.86
3	139.57	1184.04
4	139.57	2400.00
5	34.63	1808.55
6	6.75	1246.17

Results

Compressor Power Btu/s

Turbine Power Btu/s

Engine Thrust lbf

Nozzle Exit Velocity ft/s

Propulsive Power kW

Propulsive Efficiency %

Fuel Information

Fuel Heating Value Btu/lbn

Fuel Mass Flowrate lbm/s

Units

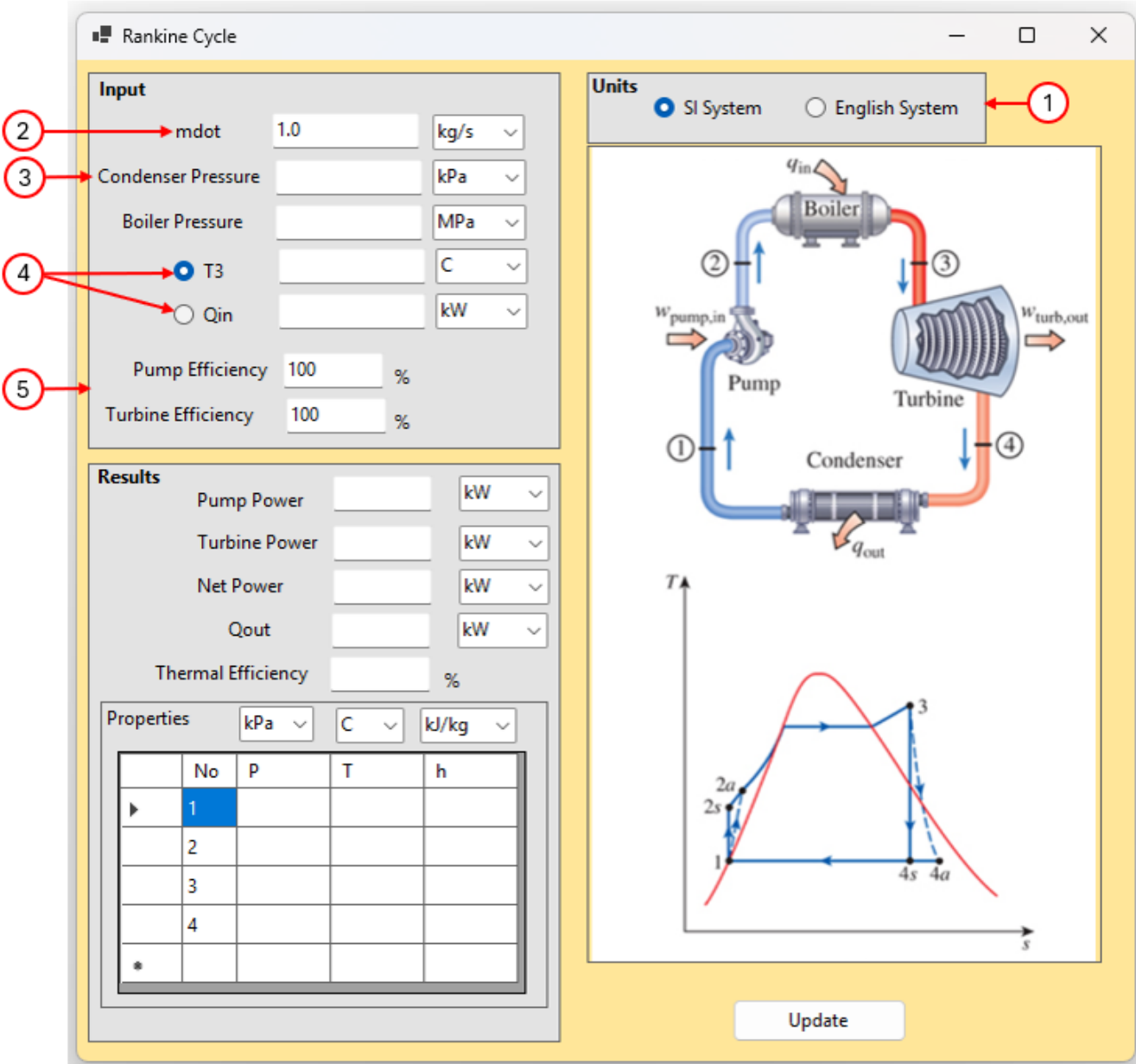
☐ SI System ☒ English System

[Update](#)

Updated reduced values for the exhaust velocity, the propulsive power, and the propulsive efficiency are: 2731 ft/s, 7517 kW, and 16.63%, respectively.

08: Vapor Cycles: Rankine Cycle

This tool is used to perform thermodynamic analysis of the Rankine cycle. The tool is accessed from the top menu: *Thermodynamic/Vapor Cycles/Tool: Rankine Cycle*.



The user must follow the following steps:

1. Choose the unit system.
2. Enter the mass flow rate if performing a total analysis; otherwise, keep the default to perform analysis per unit mass of the vapor.
3. Enter the Condenser (or compressor inlet) pressure, P_{low} , and the boiler pressure (or turbine inlet) pressure, P_{hi} . Note: the default unit is changed to MPa.
4. Enter either the temperature into the turbine (T_3) or the rate of heat transfer in the boiler (Q_{in}).
5. For non-ideal cases, enter the isentropic efficiencies of the pump and turbine.
6. Click **Update**.

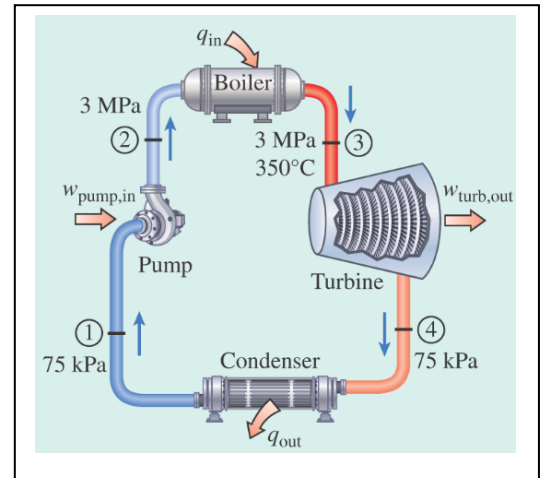
The pressure and temperature values at all state points are presented in the grid box, along with all relevant results.

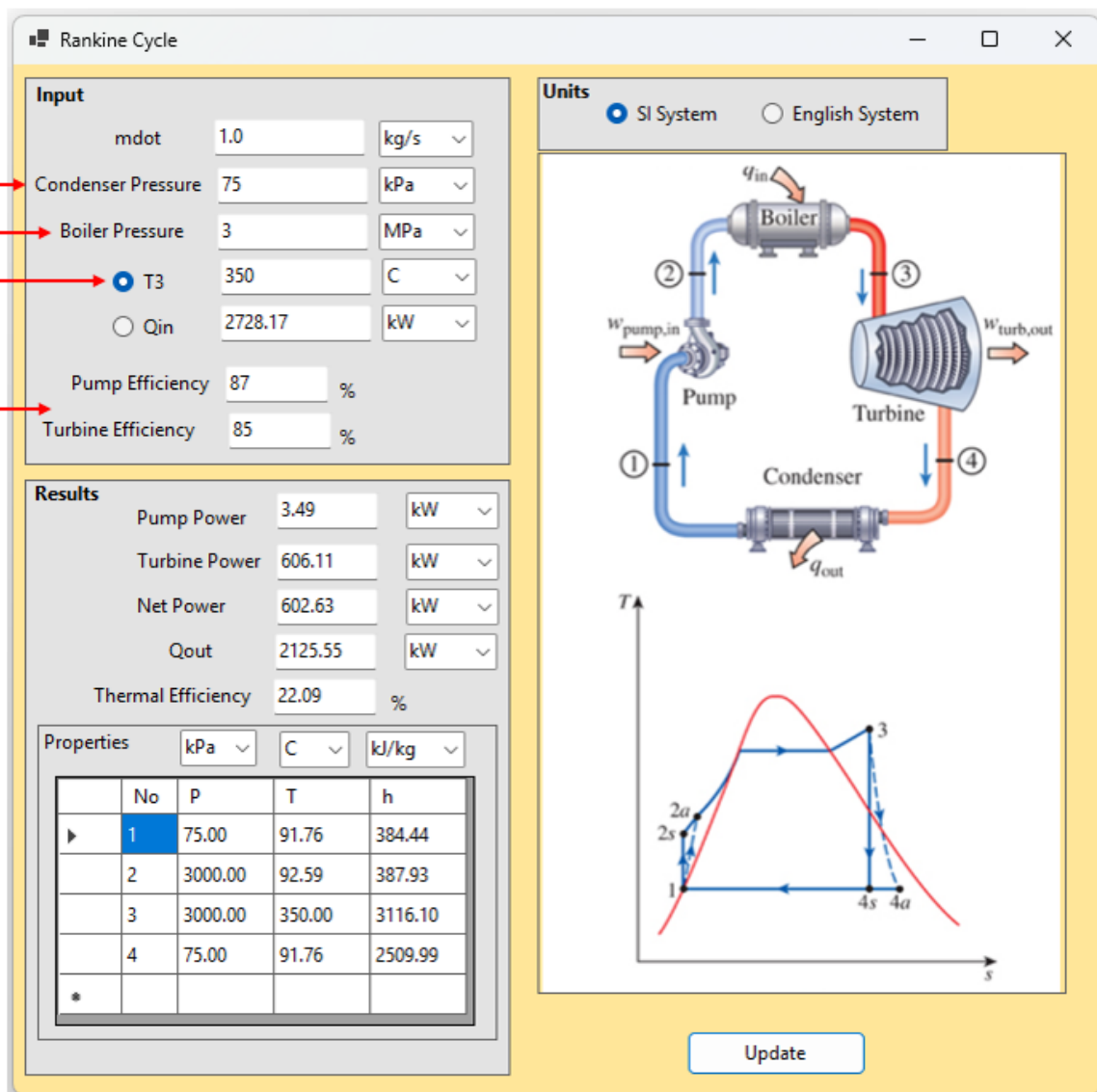
Example – Rankine Power Cycle [1]: Consider a steam power plant operating on a Rankine cycle shown below. Steam enters the turbine at 3 MPa and 350 °C and is condensed in the condenser at 75 kPa. Assuming isentropic efficiencies of 87% for the pump and 85% for the turbine, determine the thermal efficiency and the net work for this cycle.

Open the “Rankine Cycle” tool from the *Thermodynamic/Vapor Cycles* menu.

1. Enter **75** kPa for P1.
2. Enter **3** MPa for the turbine inlet pressure, T3.
3. Enter **350** °C for the high temperature, T3.
4. Enter **87%** and **85%** for the pump and turbine efficiencies.
5. Click **Update** to solve.

The thermal efficiency is 22%, and the net work is 602.6 kJ per kg of steam (note that kW for a 1 kg/s mass flow rate is equivalent to kJ/kg).





Vapor-Compression Refrigeration Cycle

Input

② $\dot{m}$ 1.0 kg/s

③ Compressor Inlet Saturated ☒ Inlet Superheated ☐

④ Inlet Temperature C

Inlet Pressure kPa

⑤ Exit Pressure MPa

⑥ Efficiency 100 %

Expansion Valve Inlet Saturated ☒ Inlet Subcooled ☐

③ Inlet Temperature C

Results

Comp Power kW

Q_H kW

Q_L kW

Quality at State 4 %

COP_r COP_{hp}

kPa C kJ/kg

No	P	T	h
1			
2			
3			

Units ☒ SI System ☐ English System ①

Diagram: Hot Space, Condenser, Expansion Valve, Evaporator, Cold Space, Compressor, Q_H , Q_L , W_{net}

T-s Diagram: Saturated Liquid, Saturated Vapor, Q_H , Q_L , W_{net}

Update

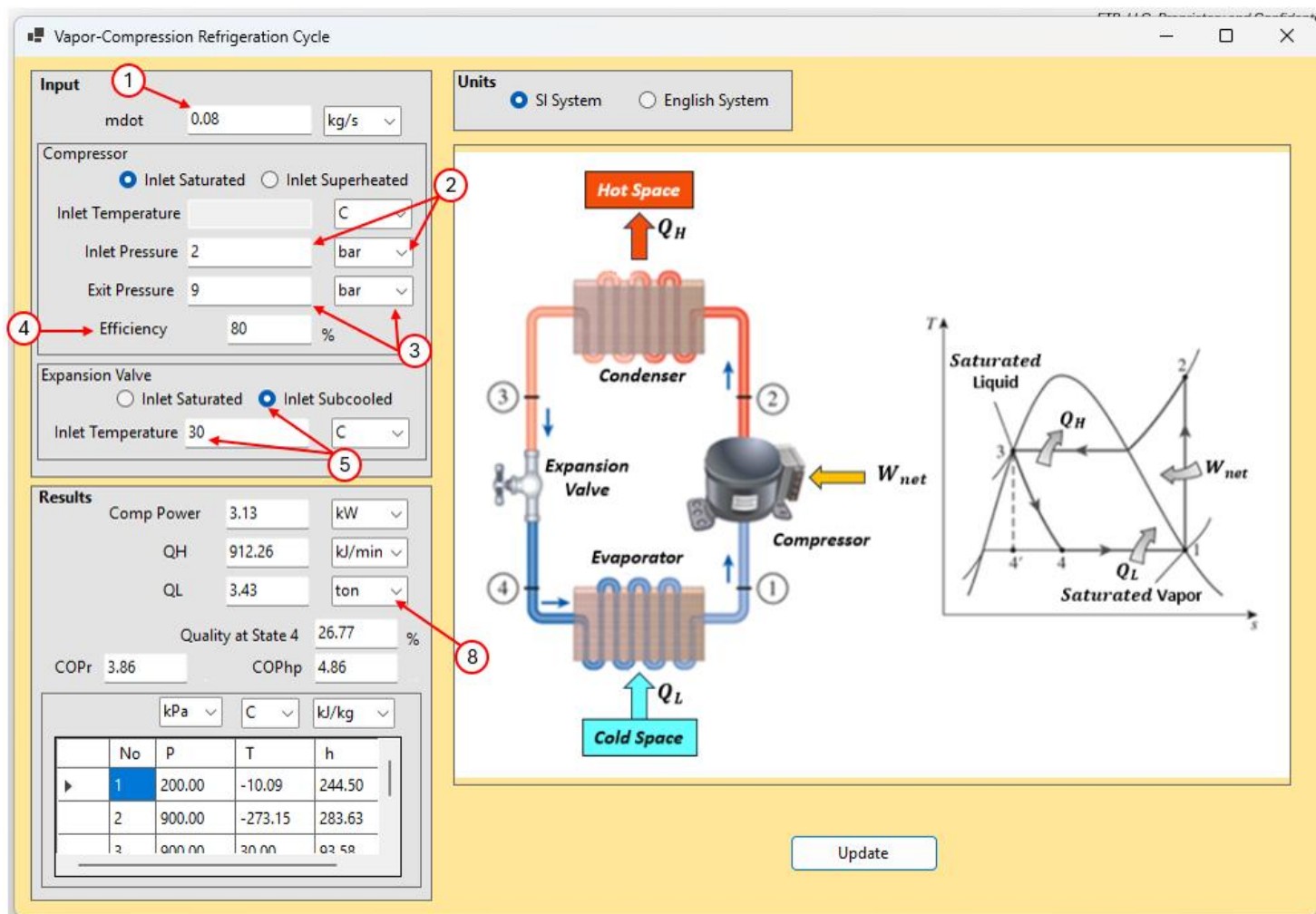
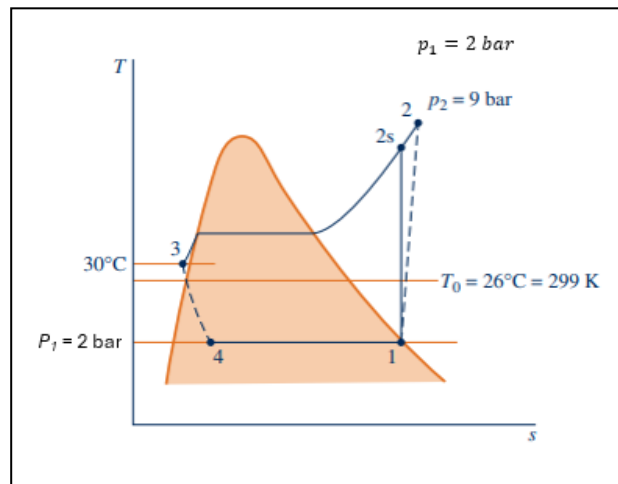
The sequence of operations is:

1. Choose the unit system.
2. Enter the mass flow rate if performing a total analysis; otherwise, keep the default to perform analysis per unit mass of the vapor.
3. Choose the condition for the compressor inlet. The "inlet saturated" condition represents an ideal system, while the "inlet superheated" condition signifies a practical cycle.
4. Enter the compressor inlet temperature (for the second option above) and the inlet pressure.
5. Enter the compressor exit pressure.
6. Provide the isentropic efficiency for non-ideal cycles.
7. Choose the state of refrigerant entering the expansion valve. For an ideal cycle, leave the default (Inlet Saturated); otherwise, for real cycles, the inlet may be subcooled, and the liquid refrigerant temperature must be specified.
8. Click **Update**.

Example – Analyzing an Actual Vapor-Compression Refrigeration Cycle [2]: Refrigerant 134a is the working fluid in an actual vapor-compression refrigeration cycle, entering the compressor as saturated vapor at 2 bar with a mass flow rate of 0.08 kg/s. The compressor's exit pressure is 9 bar. The refrigerant is then cooled in the condenser to 30 °C, entering the expansion valve as subcooled liquid. Assuming 80% efficiency for the compressor, determine (a) the compressor power, in kW, (b) the refrigeration capacity, in tons, (c) the coefficient of performance.

Open the “Vapor-Compression Refrigeration” tool from the Thermodynamic/Refrigeration Cycles menu.

1. Enter **0.08 kg/s** for the refrigerant mass flow rate.
2. Enter **2 bar** for the compressor inlet pressure.
3. Enter **9 bar** for the compressor exit pressure.
4. Change the efficiency of the isentropic to **80%**.
5. Change the expansion valve inlet option to Inlet Subcooled, and enter **30 °C** for inlet temperature.
6. Change the unit for Q_L (refrigeration capacity) to **ton**.
7. Click **Update** to solve.



Compressor power is 3.13 kW, the COP is 3.86, and the refrigeration capacity is 3.43 tons.

The screenshot shows a software window titled "Psychrometry". At the top, there is a "Units" section with two radio buttons: "SI System" (selected) and "English System". Below this, there are input fields for "Environment Pressure" (101.325 kPa) and "Dry Bulb Temperature" (25 C). A bracket on the left side groups three options: "Relative Humidity, ϕ " (selected), "Wet Bulb Temp", and "Humidity Ratio, ω ". Below these are several other input fields with units: "Dew Point Temperature" (C), "Mixture Enthalpy" (kJ/kg), "Spec. Volume - Dry Air" (m³/kg), "Spec. Volume - Vapor" (m³/kg), "Partial Press. - Dry Air" (kPa), and "Partial Press. - Vapor" (kPa). At the bottom center is an "Update" button. Red circles with numbers 1, 2, and 3 are placed over the "Units" section, the "Environment Pressure" and "Dry Bulb Temperature" fields, and the "Relative Humidity, ϕ " option respectively, with arrows pointing to them.

The sequence of operations is:

- 1. Choose the unit system.
- 2. Enter the environmental pressure and temperature (dry bulb temperature).
- 3. Enter the relative humidity, or wet bulb temperature, or the humidity ratio (also known as specific humidity).
- 4. Click **Update** to solve.

All other psychrometric properties will be calculated.

Example – The Specific and Relative Humidity of Air [1]: The dry- and wet-bulb temperatures of atmospheric air at 1 atm pressure are measured with a sling psychrometer and are determined to be 25 °C and 15 °C, respectively. Determine a) the specific humidity, b) the relative humidity, and c) the enthalpy of the air.

Open the “Heat Transfer”/Heat Conduction/Steady-State 1D/Tools: Heat Sink Analysis.

1. Enter “1” for the environmental pressure and change its unit to **atm**. Leave the dry-bulb temperature at the default value of 25 °C.
2. Enter **15** °C for the wet-bulb temperature.
3. Click **Update** to solve.

The screenshot shows the 'Psychrometry' window with the following settings and results:

- Units:** SI System (selected), English System
- Environment Pressure:** 1 atm (unit selected via dropdown, indicated by red circle 1)
- Dry Bulb Temperature:** 25 C (unit selected via dropdown)
- Relative Humidity, ϕ :** 32.68 %
- Wet Bulb Temp:** 15 C (unit selected via dropdown, indicated by red circle 2)
- Humidity Ratio, ω :** 0.00642
- Dew Point Temperature:** 7.40 C (unit selected via dropdown)
- Mixture Enthalpy:** 41.48 kJ/kg (unit selected via dropdown)
- Spec. Volume - Dry Air:** 0.85323 m³/kg (unit selected via dropdown)
- Spec. Volume - Vapor:** 132.85 m³/kg (unit selected via dropdown)
- Partial Press. - Dry Air:** 100.29 kPa (unit selected via dropdown)
- Partial Press. - Vapor:** 1.04 kPa (unit selected via dropdown)
- Update** button at the bottom.

- a) The specific humidity (or humidity ratio) is 0.00642
- b) The relative humidity is 32.68 %
- c) The mixture enthalpy is 41.48 kJ/kg.

Example 2 – Use of Psychrometry [1]: Consider a room that contains air at 1 atm, 35 °C, and 40% relative humidity. Determine a) the specific humidity, b) the enthalpy, c) the wet-bulb temperature, d) the dew point, and e) the specific volume of the air.

Open the “Psychrometry” tool from the *Thermodynamic/Gas-Vapor Mixtures and A/C* menu.

1. Enter **1** for the environmental pressure and change its unit to **atm**.
2. Enter **25** °C for the dry-bulb temperature.
3. Enter **40%** for the relative humidity.
4. Click **Update** to solve.

The screenshot shows the 'Psychrometry' tool interface. At the top, there are radio buttons for 'SI System' (selected) and 'English System'. Below this, the 'Environment Pressure' is set to '1' with a unit dropdown set to 'atm'. The 'Dry Bulb Temperature' is set to '35' with a unit dropdown set to 'C'. The 'Relative Humidity, ϕ ' is set to '40' with a unit dropdown set to '%'. Below these, there are several output fields: 'Wet Bulb Temp' (24.51), 'Humidity Ratio, ω ' (0.01414), 'Dew Point Temperature' (19.30), 'Mixture Enthalpy' (71.43), 'Spec. Volume - Dry Air' (0.89267), 'Spec. Volume - Vapor' (63.16), 'Partial Press. - Dry Air' (99.07), and 'Partial Press. - Vapor' (2.25). Each output field has a unit dropdown. Red circles and arrows highlight the input fields and the corresponding output fields: (1) for Environment Pressure, (2) for Dry Bulb Temperature, (3) for Relative Humidity, (c) for Wet Bulb Temp, (a) for Humidity Ratio, (d) for Dew Point Temperature, (b) for Mixture Enthalpy, and (e) for Spec. Volume - Dry Air. An 'Update' button is at the bottom.

Input/Output	Value	Unit
Environment Pressure	1	atm
Dry Bulb Temperature	35	C
Relative Humidity, ϕ	40	%
Wet Bulb Temp	24.51	C
Humidity Ratio, ω	0.01414	
Dew Point Temperature	19.30	C
Mixture Enthalpy	71.43	kJ/kg
Spec. Volume - Dry Air	0.89267	m ³ /kg
Spec. Volume - Vapor	63.16	m ³ /kg
Partial Press. - Dry Air	99.07	kPa
Partial Press. - Vapor	2.25	kPa

The results for cases a) through e) are shown in the completed form above.

11: Analyzing Air-Conditioning Processes

This toolset provides an environment for analysis of various air-conditioning processes. The user selects an A/C process type to start the analysis. Based on this selection, the user interface is modified to accommodate data entry. The interface for the “Simple Heating/Cooling” selection is shown below.

Air-Conditioning Processes

Select Case a) Simple Heating/Cooling

Inlet/Exit

P1

kPa

☒ Tdb1 C
☐ ϕ_1 %

☐ Twb1 C
☐ ω_1

h1 kJ/kg
va1 m³/kg

P2

kPa

☒ Tdb2 C
☐ ϕ_2 %

☐ Twb2 C
☐ ω_2

h2 kJ/kg
va2 m³/kg

Flow Info

☒ m_{da}

kg/s

☐ Vdot1

m³/s

☐ Vdot2

m³/s

☐ Q_{cv} kJ/min

☒ SI System
☐ English System

a) Simple Heating/Cooling

c) Cooling with Dehumidification

b) Heating with Humidification

d) Evaporative Cooling

Update

To enter an input value:

- Turn ON the variable's checkbox. This will enable editing of its textbox.
- Enter a value for the variable.

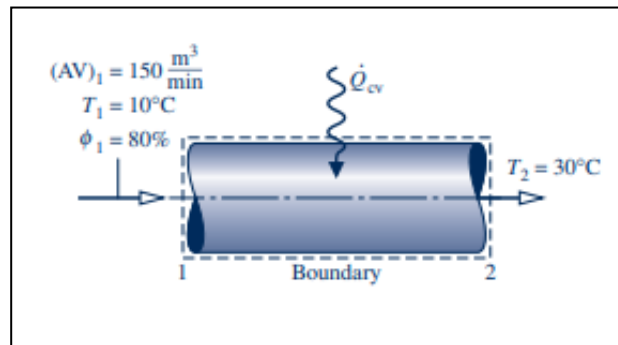
To solve for a variable:

- Uncheck the checkbox, which will disable text editing for the associated textbox.

Example 1 – Heating Moist Air in a Duct [2]: Moist air enters a duct at 10°C, 80% relative humidity, and a volumetric flow rate of 150 m³/min. The mixture is heated as it flows through the duct, exiting at 30 °C. No moisture is added or removed, and the mixture pressure remains approximately constant at 1 bar. For steady-state operation, determine (a) the rate of heat transfer, in kJ/min, and (b) the relative humidity at the exit. Changes in kinetic and potential energy can be ignored.

Open the “AC Processes” tool from the *Thermodynamic/Gas-Vapor Mixtures and A/C* menu.

1. Enter **10 °C** for the inlet temperature.
2. Check the checkbox On and enter **80%** for inlet relative humidity.
3. Enter **30 °C** for the inlet temperature.
4. Select the Vdot1 option and enter the value of 150 m³/min
5. Click **Update** to solve.



- The heat transfer rate into the control volume is calculated to be 3764 KJ/min.
- The exit relative humidity is 23.1 %.

Example 2 – Cooling and Dehumidification of Air [2]: Air enters a window air conditioner at 1 atm, 30 °C, and 80% relative humidity at 350 CFM, and it leaves as saturated air at 14 °C. The condensate is also removed at 14 °C. Determine

- the rate of moisture removed from the air, and
- the rate of heat transfer.

Open the “AC Processes” tool from the *Thermodynamic/Gas-Vapor Mixtures and A/C* menu.



- Select Option 3: **c) Cooling with Dehumidification**
- Enter **30 °C** for the inlet temperature.
- Check the checkbox On and enter **80%** for inlet relative humidity.
- Enter **14 °C** for the inlet temperature.
- Check the checkbox On and enter **100%** for exit relative humidity.
- Select the Vdot1 option and enter the value of 350 cfm.
- Change the unit for Vdot2 to cfm.
- Change the unit for mass flow rate of water to kg/min.
- Click **Update** to solve.

- 0.129 kg/min of moisture is removed from the air.
- The heat transfer rate into the control volume is calculated to be 519 KJ/min.

12: Combustion: Energy Analysis of Reacting Mixtures

AutoTherm's Reacting Systems automated tool provides an ideal environment for performing the extremely tedious and error-prone thermodynamic combustion calculations. This tool allows the user to select a fuel (or a mixture of fuels) and automatically determines the stoichiometric coefficient, calculates the combustion heat transfer, adiabatic flame temperature, or work (per mole of fuel or total).

1. Choose the oxidizer mixture: a) standard air, b) separate oxygen and nitrogen amounts can be pure oxygen).
2. Fuel mixture: defaults to a single fuel. Can use a mixture – this option allows entering the number of components. Upon clicking the **Initialize** button, the **Reaction** panel will modify to allow fuel selection.
3. Select a fuel (for each constituent if needed) from the list provided in the fuel combobox.
4. You can enter the coefficients manually, or alternatively, check the % Theoretical Air checkbox and enter the percent theoretical air value to automatically calculate the coefficients. Clicking the **Calculate Coefficient** button will fill in the text boxes for the coefficients, air-fuel mixture values, and the average fuel molar mass.
5. For heat transfer calculations, check the Qcv_bar box and enter a value for heat transfer; for product temperature calculations, check the Qcv_bar box and enter a value for heat transfer. *Note: 1) Enter zero value for Qcv_bar to calculate the adiabatic flame temperature. 2) For exothermic combustions, the heat transfer must have a negative sign.*
6. **Optional:** For total energy calculations, **check on** the “mdot” checkbox and enter a value for the fuel mass flow rate. As before, you can enter a value for Qcv and solve for the power generated (Wcv), or enter a value for the Wcv and solve for Qcv. For these calculations, the product temperature must be provided. Alternatively, values for Qcv and Wcv may be provided to solve for the product temperature. The “Prod Temp” checkbox must be unchecked to activate Solve for this option.

Example – Burning Natural Gas with Excess Air [2]: A natural gas has the following molar analysis: CH₄, 80.62%; C₂H₆, 5.41%; C₃H₈, 1.87%; C₄H₁₀, 1.60%; N₂, 10.50%. The gas is burned with 145% theoretical air. Determine a) the air–fuel ratio on a molar basis, and b), assuming products of combustion leaving at 1000 K, the rate of heat transfer per mole of fuel.

Open the “*Reacting Systems*” tool from the *Thermodynamic/Chemical Reactions* menu.

1. Change the fuel option to *Fuel Mixture*, enter **5** for the number of constituents, and click **Initialize**. The reaction panel will expand to accommodate five fuel lines.
2. For each fuel line, select the constituent from the list and enter its percentage in the percentage textbox.
3. Check **ON** the theoretical air check box, enter **145**, and click on **Calculate Coefficients**. The coefficients for air and combustion products are calculated and entered into the respective text boxes. Also shown are the air-fuel ratio, the equivalence coefficient, and the effective fuel molar mass.
4. Enter **1000 K** for the product temperature.
5. Click **Update** for energy analysis.

The screenshot shows the "Reacting Systems - Energy" window. The "Fuel" section has "Fuel Mixture" selected with a value of 5. The "Oxidizer" section has "Air Mixture" selected. The "Reaction" section shows the theoretical air percentage set to 145, and the "Calculate Coefficients" button is highlighted. The reaction equation is displayed as: 80.62 CH₄ + 2.90 (O₂ + 3.76 N₂) → 1.03 CO₂ + 1.93 H₂O + 11.05 N₂ + 0.90 O₂ + 0.00 CO. The air-fuel ratio (A/F_mole) is 13.80 and the air-fuel ratio (A/F_mass) is 20.68. The equivalence ratio is 0.68966. The "Mole Basis" section shows the fuel molar mass as 19.25, oxidizer temperature as 298 K, and product temperature as 1000 K. The "Mass Basis" section shows the heat transfer rate (Qcv_bar) as -461038.56 kJ/kmol. The "Units" section shows "SI System" selected. The "Update" button is at the bottom.

Note: The negative sign for $Q_{cv_bar} = 461038.56$ kJ/kmol indicates that heat is transferred out of the system, as expected for an exothermic reaction.

Example 2 – Adiabatic Flame Temperature: Propane (C₃H₈) at 25 °C, 1 atm, enters a furnace operating at steady state and burns completely with 100% theoretical air entering in a separate stream at 25 °C, 1 atm. Determine a) the heat transfer from the surroundings to the furnace, in kJ per kmol of fuel, when the combustion products exit at 1000 K, b) the adiabatic flame temperature for this reaction, and c) the adiabatic flame temperature when 25 % excess air is used.

Open the “Reacting Systems” tool from the *Thermodynamic/Chemical Reactions* menu.

1. Select propane, C₃H₈, from the fuel selection combobox.
2. Check **ON** the theoretical air check box, enter **100**, and click on **Calculate Coefficients**. The coefficients for air and combustion products are calculated and entered into the respective text boxes. The air-fuel ratio, equivalence coefficient, and effective fuel molar mass are also shown.
3. Enter **1000** K for the product temperature.
4. Click **Update** to solve.

The screenshot shows the 'Reacting Systems - Energy' software interface. The 'Fuel' section has 'Single Fuel' selected. The 'Oxidizer' section has 'Air Mixture' selected. The 'Reaction' section shows the reaction: C₃H₈ + 5.00 (O₂ + 3.76 N₂) → 3.00 CO₂ + 4.00 H₂O + 18.80 N₂. The '% Theoretical Air' is set to 100. The 'Calculate Coefficients' button is highlighted. The 'Mole Basis' section shows 'Fuel Molar Mass' as 44.09, 'Oxidizer Temp' as 298 K, and 'Prod Temp' as 1000 K. The 'Reactants Enthalpy' is -103850.00 kJ/kmol, and the 'Products Enthalpy' is -1.540E06 kJ/kmol. The 'Qcv_bar' is -1.436E06 kJ/kmol, which is circled in red and labeled 'a'. The 'Wcv_bar' is 0.000 kJ/kmol. The 'Units' section has 'SI System' selected. The 'Update' button is at the bottom.

Part a): The rate of heat transfer is 1.436×10^6 kJ/kmol from the furnace to the surroundings.

b) The adiabatic flame temperature for this reaction:

1. Uncheck the *Products Temperature* checkbox.
2. Check **ON** the Qcv_bar check box and enter **0** for its value.
3. Click **Update** to solve for the temperature of the products (the adiabatic flame temperature).

The screenshot shows the 'Reacting Systems - Energy' software interface. The 'Fuel' section has 'Single Fuel' selected. The 'Oxidizer' section has 'Air Mixture' selected. The 'Reaction' section shows the reaction: $\text{C}_3\text{H}_8 + 5.00 (\text{O}_2 + 3.76 \text{N}_2) \rightarrow 3.00 \text{CO}_2 + 4.00 \text{H}_2\text{O} + 18.80 \text{N}_2 + 0.00 \text{O}_2 + 0.00 \text{CO}$. The 'Mole Basis' section shows 'Reactants Enthalpy' as -103850.00 kJ/kmol and 'Products Enthalpy' as -103854.05 kJ/kmol. The 'Mass Basis' section shows 'mdot' as 0.000 kg/s, 'Qcv' as 0.000 kJ/min, and 'Wcv' as 0.000 kW. The 'Prod Temp' is 2394.43 K. The 'Units' section has 'SI System' selected. The 'Update' button is at the bottom right. Red circles and arrows highlight the 'Prod Temp' field (labeled '1'), the 'Qcv_bar' checkbox and value (labeled '2'), and the 'Units' section (labeled 'b').

Reacting Systems - Energy

Fuel
☒ Single Fuel ☐ Fuel Mixture
Initialize

Oxidizer
☒ Air Mixture ☐ O2, N2 Separate

Reaction
☒ % Theoretical Air 100 Calculate Coefficients
C3H8 + 5.00 (O2 + 3.76 N2) → 3.00 CO2 + 4.00 H2O + 18.80 N2 + 0.00 O2 + 0.00 CO
A/F_mole 23.80 A/F_mass 15.57 Equivalence Ratio 1.00000

Mole Basis
Fuel Molar Mass 44.09
Oxidizer Temp 298 K
☐ Prod Temp 2394.43 K
Reactants Enthalpy -103850.00 kJ/kmol
Products Enthalpy -103854.05 kJ/kmol
☒ Qcv_bar 0 kJ/kmol
☒ Wcv_bar 0.000 kJ/kmol

Mass Basis
☐ mdot kg/s
☐ Qcv kJ/min
☒ Wcv 0.000 kW

Units
☒ SI System ☐ English System
Update

The adiabatic flame temperature is calculated to be 2394.4 K.

c) The adiabatic flame temperature for this reaction with 25% excess air:

1. Change the Theoretical Air value to **125%** (25% excess air).
2. Click **Calculate Coefficients** to get the updated coefficients.
3. Click **Update** to solve for the temperature of the products (the adiabatic flame temperature).

The screenshot shows the 'Reacting Systems - Energy' software interface. The 'Fuel' section has 'Single Fuel' selected. The 'Oxidizer' section has 'Air Mixture' selected. The 'Reaction' section shows the reaction: $\text{C}_3\text{H}_8 + 6.25 (\text{O}_2 + 3.76 \text{ N}_2) \rightarrow 3.00 \text{ CO}_2 + 4.00 \text{ H}_2\text{O} + 23.50 \text{ N}_2 + 1.25 \text{ O}_2 + 0.00 \text{ CO}$. The '% Theoretical Air' is set to 125. The 'Calculate Coefficients' button is highlighted with a red circle and arrow labeled '2'. The 'Mole Basis' section shows the 'Prod Temp' as 2066.78 K, which is circled in red and labeled with a red circle and arrow labeled 'C'. The 'Update' button is highlighted with a red circle and arrow labeled '3'. The 'Mass Basis' section shows 'Wcv' as 0.000 kW. The 'Units' section has 'SI System' selected.

Reacting Systems - Energy

Fuel
☒ Single Fuel ☐ Fuel Mixture
 Initialize

Oxidizer
☒ Air Mixture ☐ O₂, N₂ Separate

Reaction
☒ % Theoretical Air 125
 Calculate Coefficients
 $\text{C}_3\text{H}_8 + 6.25 (\text{O}_2 + 3.76 \text{ N}_2) \rightarrow 3.00 \text{ CO}_2 + 4.00 \text{ H}_2\text{O} + 23.50 \text{ N}_2 + 1.25 \text{ O}_2 + 0.00 \text{ CO}$
 A/F_mole 29.75 A/F_mass 19.47 Equivalence Ratio 0.80000

Mole Basis
 Fuel Molar Mass 44.09
 Oxidizer Temp 298 K
☐ Prod Temp 2066.78 K
 Reactants Enthalpy -103850.00 kJ/kmol
 Products Enthalpy -103852.93 kJ/kmol
☒ Q_{cv_bar} 0 kJ/kmol
☒ W_{cv_bar} 0.000 kJ/kmol

Mass Basis
☐ m_{dot} kg/s
☐ Q_{cv} kJ/min
☒ W_{cv} 0.000 kW

Units
☒ SI System ☐ English System
 Update

The adiabatic flame temperature is reduced to 066.78 K.

Example 3 – Analyzing an Internal Combustion Engine Fueled with Liquid Octane [2]: Liquid octane enters an internal combustion engine operating at steady state with a mass flow rate of 0.004 lb/s and is mixed with the theoretical amount of air. The fuel and air enter the engine at 77 °F and 1 atm. The mixture burns completely, and combustion products leave the engine at 1140 °F. The engine produces 50 horsepower. Determine the rate of heat transfer from the engine, in Btu/s.

Open the “Reacting Systems” tool from the *Thermodynamic/Chemical Reactions* menu.

1. Select liquid octane, C₈H₁₈(l), from the fuel selection combobox.
2. Check **ON** the theoretical air check box, enter **100**, and click on **Calculate Coefficients**. The coefficients for air and combustion products are calculated and entered into the respective text boxes. The air-fuel ratio, equivalence coefficient, and effective fuel molar mass are also shown.
3. Change the unit to the English system
4. Enter **1140** °F for the product temperature.
5. Check the **ON** the mdot checkbox and enter the value of **0.004** lbm/s
6. Enter the output power of **50** Hp
7. Click **Update** to solve.

The screenshot shows the "Reacting Systems - Energy" window. The interface includes several sections:

- Fuel:** "Single Fuel" is selected.
- Oxidizer:** "Air Mixture" is selected.
- Reaction:** "% Theoretical Air" is checked and set to 100. The "Calculate Coefficients" button is visible. Below this, the reaction is shown: C₈H₁₈(l) + 12.50 (O₂ + 3.76 N₂) → 8.00 CO₂ + 9.00 H₂O + 47.00 N₂. Below the reaction, A/F_mole is 59.50, A/F_mass is 15.03, and Equivalence Ratio is 1.00000.
- Mole Basis:** "Reactants Enthalpy" is -107342.97 Btu/lbmol, "Products Enthalpy" is -1.751E06 Btu/lbmol, "Qcv_bar" is -634559.11 Btu/lbmol, and "Wcv_bar" is 1.009E06 Btu/lbmol. "Fuel Molar Mass" is 114.22. "Oxidizer Temp" is 77 F. "Prod Temp" is 1140 F.
- Mass Basis:** "mdot" is checked and set to 0.004 lbm/s. "Qcv" is unchecked. "Wcv" is checked and set to 50 Hp. The value -22.22 is circled in red and labeled with a circled 'a'.
- Units:** "English System" is selected.
- Buttons:** "Initialize", "Calculate Coefficients", and "Update" are present.

 Red numbered circles (1-7) and a circled 'a' point to specific elements as described in the instructions.

The rate of heat transfer from the engine is 2222 Btu/s.