3.5.2 Specific heat at constant pressure C_p:

It is the energy required to raise the temperature of the unit mass of substance by one degree as the pressure maintained constant.

$$Cp = \frac{\delta Q}{dT}$$

$\delta Q = CpdT$ at constant pressure.

$$\delta Q - \delta W = dU$$

$$\delta Q = dU + Pdv = dH$$

$$CpdT = dH$$

$$Cp = \left(\frac{dH}{dT}\right)_P$$

Note: That ***Cp*** and ***Cv*** are expressed in terms of other properties, thus they must be properties themselves. Like any other property, the specific heats of a substance depend on the state which, in general, is specified by two independent, intensive properties. That is, the energy required to raise the temperature of substance by one degree will be different at different temperatures and pressures.

Example 3.13

Determine the specific heats at constant pressure and volume for saturated water vapor at 200^o

Solution: Given_ sat. water vapor T=200^{o}C

$$Cv = \frac{\Delta u}{\Delta T}, \quad C_p = \frac{\Delta h}{\Delta T}$$

we can take the temperature around 200^{o}C at sat vapor state

$$T_1 = 195^o C, \quad u_g = 2592.8 kJ/kg, \quad h_g = 2790 kJ/kg$$

$$T_2 = 205^o C, \quad u_g = 2597.5 kJ/kg, \quad hg = 2796.kJ/kg$$

$$Cv = \frac{2597.5 - 2592.8}{205 - 195} = 0.47 kJ/kg.K, \quad Cp = \frac{2796 - 2790}{205 - 195} = 0.6 kJ/kg.K$$

3.6. Internal energy, enthalpy and specific heat of ideal gas:

The equation of state of ideal gas:

$$Pv = RT$$

It has been demonstrated mathematically (Chap. 12) and experimentally (Joule, 1843) that for an ideal gas the internal energy is a function of the temperature only. That is,

$$u = u(T)$$

The enthalpy is also defining as a combined property of internal energy plus the product of pressure and specific volume.

$$\left.\begin{aligned} h &= u + pv \\ pv &= RT \end{aligned}\right\} h = u + RT$$

The ideal gas constant ***R*** is a constant of all gases so the enthalpy is function of temperature only like internal energy.

$$h = h(T)$$

and from the equation of definition of specific heat at constant pressure and volume. We can find the relation of calculating ***h*** and ***u***.

$$du = CvdT \rightarrow \Delta u = Cv\Delta T \rightarrow \Delta U = mCv\Delta T \rightarrow (U_2 - U_1) = mCv(T_2 - T_1)$$

$$dh = CpdT \rightarrow \Delta h = Cp\Delta T \rightarrow \Delta H = mCp\Delta T \rightarrow (H_2 - H_1) = mCp(T_2 - T_1)$$

and sometimes the values of Cv and Cp is function of T

$$du = Cv(T)dT \rightarrow \Delta u = \int_1^2 Cv(T)dT \rightarrow \Delta U = m\int_1^2 Cv(T)dT$$

$$dh = Cp(T)dT \rightarrow \Delta h = \int_1^2 Cp(T)dT \rightarrow \Delta H = m\int_1^2 Cp(T)dT$$

The values of the ideal gas constants (Cp, Cv, R, and the specific heat ratio $k = \frac{Cp}{Cv}$) are represented in a table of the ideal gas properties.

3.7. specific heat relations of ideal gases:

A special relationship between Cp and Cv for ideal gases can be obtained by differentiating the relation $h = u + RT$,which yields.

$$dh = du + RdT$$

and replacing dh by $CpdT$ and du by $CvdT$ so:

$$CpdT = CvdT + RdT$$

$$Cp = Cv + R \quad (kJ/kg.K)$$

When the specific heats are given on a molar basis, ***R*** in the above equation should be replaced by the universal gas constant $\boldsymbol{R_u}$

$$\overline{C}p = \overline{C}v + R_u \quad (kJ/kmol.K)$$

and there is another ideal gas property called the specific heat ratio k.

$$k = \frac{Cp}{Cv}$$

there are author relations relates these four constants. That are

$$Cv = \frac{R}{k-1}$$

$$Cp = \frac{kR}{k-1}$$

Example 3.14

Air is in a rigid tank of volume $1m^3$ at initial pressure of 500kPa and temperature of 300K. It is heated to a final temperature of 700K.(a) find the final pressure in the tank, (b) the change in internal energy and enthalpy, (c) heat transfer to the system.

Solution: Given P_1=500kPa, T_1=300K, The tank is rigid with volume of $V=1m^3$, T_2 =700K, from table of ideal gas properties.

R=0.287kJ/kg.K, Cp=1.005kJ/kg.K, Cv=0.718kJ/kg.K

(a)

$$P_2 = P_1 \frac{T_2}{T_1} = 500 \times \frac{700}{300} = 1166.67 kPa$$

(b) $$m = \frac{P_1 V}{RT_1} = \frac{500 \times 1}{0.287 \times 300} = 5.807 kg$$

$$\Delta U = mCv(T_2 - T_1) = 5.807 \times 0.718 \times (700 - 300) = 1667.77 kJ$$

$$\Delta H = mCp(T_2 - T_1) = 5.807 \times 1.005 \times (700 - 300) = 2334.414 kJ$$

(c) because the tank is rigid, W=0

$$Q = \Delta U = 1667.77 kJ$$

Example 3.15

Nitrogen gas is heated in a piston-cylinder device from 30°C to 120°C at constant pressure of 200kPa. The mass of nitrogen in the system is 0.2 kg. Find the work done and heat transfer during the process.

Solution: Given N_2, m=0.2 kg, T_1=30°C=303K, T_2 =120°C=393K at P=200kPa, from table R=0.2968kJ/kg.K, Cp=1.039kJ/kg.K

$$W = mR\Delta T = 0.2 \times 0.2968 \times (120 - 30) = 5.3424 kJ$$

$$Q = mCp\Delta T = 0.2 \times 1.039 \times (120 - 30) = 18.702 kJ$$

There are tables to give the properties of gases as real gases. These are ***h*** and ***u*** as a function ***T***, also we can use the heat capacity to find the internal energy and enthalpy as a function temperature. These two method give more accurate values for the property of gases.

3.8. Internal energy-enthalpy, and specific heat of solids and liquids:

The substance which has constant specific volume is called an incompressible substance. The specific volume of solids and liquids remains constant during a process. Therefore, liquids and solids can be approximated as incompressible substance.

It can be mathematically shown that the constant-volume specific heat is equal to constant-pressure specific heat. Therefore, for solids and liquids the subscripts on ***Cp*** and ***Cv*** can be dropped, and both specific heats can be represented by a single symbol ***C***. That is

$$Cp = Cv = C$$

Therefore, the change in internal energy can be calculated as:

$$du = CvdT = C(T)dT$$

$$\Delta u = u_2 - u_1 = \int C(T)dT \quad (kJ/kg)$$

the change in enthalpy represented by

$$dh = du + d(Pv)$$

$$dh = du + vdP \quad v = constant$$

$$\Delta h = \Delta u + v\Delta P$$

$$h_2 - h_1 = u_2 - u_1 + v(P_2 - P_1)$$

so for compressed liquid

$$h = h_f + v_f (P - P_{sat})$$

Problems-3

3.1 Piston-cylinder device contains saturated liquid-vapor mixture of water at 100°C and volume of $0.1 m^3$, with 90% vapor and 10 % liquid. The system is heated at constant volume until the final state of saturated vapor. Find the work done, and the change in internal energy.

3.2 5kg of O_2 is heated at constant pressure in a closed system from 25°C to 300°C. If the initial volume $0.2 m^3$. find (a) the pressure in the system, (b) the final volume of the system, (c) the work done.

3.3 A piston-cylinder device contains 50kg of water at 200kPa with a volume of $0.1 m^3$. Stops in the cylinder restrict the enclosed volume to $0.5 m^3$, (Figure 41). The is now heated to 200°C. Find the final pressure, volume, and the work done by the water.

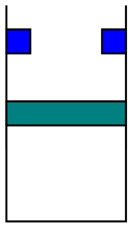

Figure41 . P3.3.

3.4 A piston cylinder device shown in Figure 42, initially contains air at 150kPa, 400°C. The setup is allowed to cool to the ambient temperature of 20°C. (a) Is the piston resting on the stops. What is the final pressure in the cylinder? (b) What is the specific work done by the air during this process.

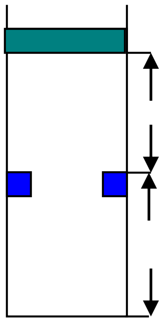

Figure 42. P3.4.

3.5 Saturated liquid water at 50°C is heated at constant temperature until it becomes saturated vapor. Find the work done per unit mass.

3.6 Piston-cylinder device contains 5kg of water liquid-vapor mixture with quality of 80% at 100kPa. It is compressed in such a process that (PV=c) until the final pressure is doubled. Find (a) the final state of vapor, (b) the work done.

3.7 A mass 1.5kg of air at 150kPa and 27°C is contained in a frictionless piston-cylinder device. The air is now compressed to a final pressure of 750kPa. During the process heat is transferred from the air such that the temperature inside the cylinder remains constant. Calculate (a) the initial and the final volume of the air, (b) the work done during the process.

3.8 Nitrogen at an initial state of 300K, 150kPa, and 0.2m^3 is compressed slowly in an isothermal process to a final pressure of 800kPa. Determine the work done during the process.

3.9 Water vapor at 300kPa and 300°C is compressed in hyperbolic process to 1000kPa. Find the final state of the vapor and the work done during this process per unit mass.

3.10 A gas is compressed from initial volume of 0.4m^3 to a final volume of 0.1m^3. During the quasi-equilibrium process, the pressure changes with volume according to the relation $P=aV+b$, where $a=-1000kPa/m^3$, and $b=600kPa$. Calculate the work done during this process.

3.11 A cylinder contains 0.085m^3 of a gas at 103.2kPa and 38°C. The gas is compressed according to the law $PV^{1.3}$=constant until the pressure is 550kPa. Determine the final temperature and the work done.

3.12 Carbon dioxide contained in a piston cylinder device is compressed from 0.3m^3 to 0.1m^3. During the process, the pressure and the volume are related by $P=aV^{-2}$, Where $a=8kPa.m^6$. Calculate the work done on the carbon dioxide during this process.

3.13 Hydrogen is contained in a piston-cylinder device at 100kPa and 1m^3. At this state, a linear spring($F\propto x$)with a spring constant of 200kN/m is touching the piston but exerts no force on it. The cross-sectional area of the piston is 0.8m^2. Heat is transferred to the hydrogen, causing it to expand until its volume doubles. Determine (a) the final pressure, (b)the total work done by the hydrogen, and (c) the fraction of the work done against the spring. Also show the process on a p-v diagram.

3.14 A piston-cylinder device contains 50kg of water at 150kPa and 25°C. The cross-sectional area of the piston is 0.1m^2. heat is now transferred to the water, causing part of it to evaporate and expand. When the volume reaches 0.2m^3, the piston reaches a linear spring whose spring constant is 100kN/m. More over heat is transferred to the water until the piston raises 20cm more.

Determine (a) the final pressure and temperature and (b) the work done during this process. Also show the process on a P-V diagram.

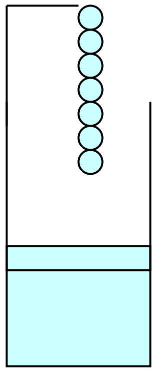

Figure 43. p3.14.

3.15 A paddle wheel supplies work at the rate of 0.75kW to a system, shown in figure P3.15. During a period of minute, the system expands in volume from $0.03m^3$ to $0.09m^3$ while the pressure remains constant at 500kPa. Find the net work done during this 1-min period.

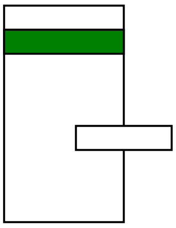

Figure 44. p3.15.

3.16 Consider the system shown in figure P3.16. The initial volume inside the cylinder is $0.1m^3$. At this state the pressure inside is 100kPa, which just balances the atmospheric pressure out side plus the piston weight: the spring is touching nut exerts no force on the piston at this state. The gas is now heated until the volume is doubled. The final pressure of the gas is 300kPa, and during the process the spring force is proportional to the displacement of the piston from the initial position.

(a) Show the process on a P-V diagram
(b) Considering the gas inside as the system, calculating the work done by the system. What percentage of this work is done against the spring?

3.17 The cylinder shown in figure P3.17, contains 1kg of saturated water at 30°C. The piston has a cross-sectional area of $0.065m^2$, a mass of 40kg, and is resting on the stops as shown. The volume at this point is $0.1m^3$. Atmospheric pressure outside is 94kPa, and the local gravitational acceleration is $9.75m/sec^2$. Heat is now transferred to the system until the cylinder contains saturated vapor. (a) What is the temperature of the water when the piston first rises from the stops? (b) Calculate the work by the water during the overall process.

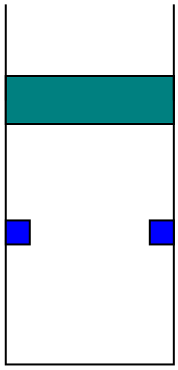

Figure 45. p3.17.

3.18 A balloon that is initially flat is inflated by filling it with air from a tank of compressed air. The final volume of the balloon is $5m^3$. The barometer reads 95kPa. Considering the tank, the balloon, and the connecting pipe as a system, calculate the work done during the process.

3.19 A spherical balloon contains 2kg of water at 250°C, 400kPa. The balloon material has an elasticity such that the pressure inside is always proportional to the balloon diameter. The water is now allowed to cool until the volume is one-half the initial volume.

3.20 Tank A shown in figure P.3.22 has a volume of 400L and contains argon gas at 250kPa, 30°C. Cylinder B contains a frictionless piston of a mass such that a pressure of 150kPa inside the cylinder is required to raise the piston. The valve connecting the two is now opened, allowing gas to flow into the cylinder. Eventually, the argon reaches a uniform state of 150kPa, 30°C throughout. Calculate the work done by the argon during this process.

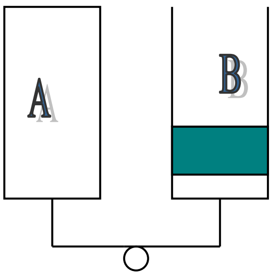

Figure 46. p3.22

3.21 A rigid tank containing $0.4m^3$ of air at 400kPa and 30°C is connecting by valve a piston-cylinder device with zero clearance. The mass of the piston is such that a pressure of 200kPa is required to raise the piston. The valve is now opened slightly, and air is allowed to flow into the cylinder until the pressure in the tank drops to 200kPa. During this process, heat is exchanged with the surroundings such that the entire air remains at 30°C at all times. Determine the work done during this process.

3.22 Water initially at 50kPa, 100°C is contained in a piston and cylinder arrangement with initial volume of $3m^3$. the water is then slowly compressed according to the relation PV=constant until a final pressure of 1MPa is reached. Determine the work done for this process.

3.23 Fill in the missing data for each of the following processes of a closed system between states 1 and 2. (every thing in kJ)

	Q	W	U_1	U_2	ΔU
(a)	20	-6		35	
(b)	-13			4	-15
(c)		15	3		32
(d)	20		14		10

3.24 A closed system undergoes a cycle consisting of two processes. During the first process, 50kJ of heat is transferred to the system while the system does 80kJ of work. During the second process, 45kJ of work is done on the system. (a) Determine the heat transfer during the second process, and (b) calculate the network and the net heat transfer for the cycle.

3.25 A closed system undergoes a cycle consisting of three processes. During the first process, which is adiabatic, 50kJ of work is done on the system. During the second process,210kJ of heat is transferred to the system while no work interaction takes place. And during the third process, the system does 90kJ of work as it return to its state.
(a) determine the heat transfer during the last process.
(b) determine the net work done during this process.

3.26 A radiator of a steam heating system has a volume of 25L. At a time when this radiator is filled with saturated vapor steam at 225kPa, both valves to the radiator are closed. How much heat will have been transferred to the room when the steam pressure in the radiator has dropped to 100kPa?

3.27 A rigid 500L tank contains R-134a at 500kPa, 60°C. The tank is now cooled to 0°C. Determine the heat transfer for this process.

3.28 A well-insulated rigid tank contains 5kg of saturated liquid-vapor mixture of water at 125kPa. Initially, three-quarters of the mass is in the liquid phase. An electric resistor placed in the tank is connected to a 110V source, and a current of 10A flows through the resistor when the switch is turned on. Determine how long it will take place to evaporate all the liquid in the tank. Also, show the process on a T-v diagram with respect to saturation liners.

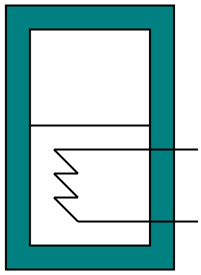

Figure 47. p3.32

An insulated tank is divided into two parts by a partition. One part of the tank contains 2.5kg of compressed liquid water at 50°C and 600kPa while the other part is evacuated. The partition is removed, and the water is expand to fill the entire tank. Determine the final temperature of the water and the volume of the tank for a final pressure of 10kPa.

3.29 An insulated piston-cylinder device contains 5L of saturated liquid water at a constant pressure of 150kPa. Water is stirred by a paddle wheel while a current of 10A flows for 40minuts through a resistor placed in the water. If one-half of the liquid is evaporated during this constant pressure process and the paddle wheel work amounts to 280kJ, determine the voltage of the source. Also, show the process on P-v diagram with respect to saturation lines.

3.30 A piston-cylinder device contains steam initially at 1MPa, 400°C, and 1.6m^3. Steam is allowed to cool at constant pressure until it first starts condensing. Show the process on T-v diagram with respect to saturation lines, and determine (a) the mass of the steam, (b) the final temperature, and (c) the amount of heat transfer.

3.31 A piston-cylinder device initially contains steam at 200kPa, 200°C, and 0.5m^3. At this state, a linear spring ($F \propto x$) is touching the piston but exerts no force on it. Heat is now slowly transferred to the system, causing the pressure and the volume to rise to 500kPa and 0.65m^3, respectively. Show the process on a P-v diagram with respect to saturation lines, and Determine

(a) the final temperature, (b) the work done by the steam, and (c) the total heat transfer.

3.32 Two rigid tanks are connected by a valve. Tank A contains $0.3m^3$ of water at 400kPa and 80% quality. Tank B contains $0.5m^3$ of water at 200kPa and 250^oC. The valve is now opened, and the two tanks eventually come to the same state. Determine the pressure and the amount of heat transfer when the system reaches thermal equilibrium with the surrounding at 25^oC.

3.33 A 4m x 5m x 7m room is heated by the radiator of steam heating system. The steam radiator transfer heat at a rate of 10000kJ/hr, and 100W fan is used to distribute the warm air in the room. The rate of heat loss from the room is estimated to be about 5000kJ/hr. If the initial temperature of the room air is 10^oC, determine how long it will take for the air temperature to rise to 20^oC.

3.34 An insulated rigid tank is divided into two equal parts by a partition. Initially, one part contains 3kg of an ideal gas at 800kPa and 50^oC, and the other part is evacuated. The partition is now removed, and the gas expands into the entire tank. Determine the final temperature and pressure in the tank.

3.35 An insulated piston-cylinder device contains 100L of air at 400kPa and 25^oC. A paddle wheel within the cylinder is rotated until 15kJ of work is done on the air while the pressure is held constant. Determine the final temperature of the air.

3.36 5kg of an ideal gas are heated by supplying 180kJ. During this process, the volume is held constant at $4m^3$ and the pressure increases from 100kPa to 120kPa. Compute (a) the work done; (b) internal energy change of the gas; (c) density of the gas before and after the process.

3.37 One kg of air is compressed in a piston-cylinder device from 80kPa and 300K to 120kPa according to the law P(v+0.2)=constant, where P is in kPa an v in m^3/kg. Calculate the heat transfer. Assume air to be an ideal gas.

3.38 A cylinder contains 0.28 m^3 of an air at 103.5kPa and 29^oC. the air is compressed according to the law $PV^{1.3}$=constant until the volume is reduced to $0.028m^3$. Heat is then supplied at constant pressure until the volume becomes $0.056m^3$. Determine; (a) the temperature and pressure at the end of each process, (b) the total change in internal energy, (c) the work done during each process, and (d) the total heat transfer.

3.39 During a polytropic process in a piston cylinder device, $0.182m^3$ of air at 1.035bar and 300K is compressed until the pressure and temperature becomes 12.4bar and 282°C respectively. Determine (a) the value of the index of compression, (b) the work done, (c) the change in internal energy, and (d) the heat transfer.

3.40 A balloon contains at the initial state 5kg of air at 100 kPa and 27°C. the pressure in the balloon is directly proportional to the diameter square of the balloon. The air in the balloon is heated until the temperature becomes 377°C. (a) find the final pressure and volume of the balloon, (b) the work done, and (c) the heat transfer.

3.41 A frictionless piston-cylinder device and a rigid tank initially contain 12kg of an ideal gas each at the same temperature, pressure, and volume. It is desired to raise the temperature of both systems by 15°C. Determine the amount of extra heat must be supplied to the gas in the cylinder, which is maintained at constant pressure, to achieve this result. Assume the molar mass of the gas is 25.

3.42 Helium which is contained in a cylinder fitted with a piston expands slowly according to the relation $PV^{1.5}$=constant. The initial volume of the helium is $0.1m^3$, the initial pressure is 500kPa, and the initial temperature is 300K. after expansion the pressure is 150kPa. Calculate the work done and heat transfer during the expansion.

3.43 An unknown mass of aluminum at 60°C is dropped into an insulated tank which contains 40L of water at 25°C and atmospheric pressure. If the final equilibrium temperature is 30°C, determine the mass of the aluminum. Assume the density of liquid water to be $1000kg/m^3$.

3.44 A 50kg mass of copper at 70°C is dropped into an insulated tank which contains 80kg of water at 25°.