

For mass; *m* of a fluid ; $Q=H_2-H_1$

For Ideal gas:

$$W = p(\hat{p}_2 - \hat{p}_1)$$

$$Q = h_2 - h_1 = c_p (T_2 - T_1)$$



Example(4.1):

A mass of 0.05 kg of a certain fluid is healed at a constant pressure of 2 bar until the volume occupied is 0.0658 m³. Calculate the heat supplied and the work done: (i) when the fluid is steam, initially dry saturated; (ii) when the fluid is air, initially at 130°C.

Solution:

m = 0.05kg, $p_1 = p_2 = 2$ bar, $V_2 = 0.0658 m^3$, Q = ?, W = ?

<u>(i):</u>



 $_{1}=0.578 m^{3}/kg$

 $_2=1.316 m^3/kg$

 $W=2*10^{5}(1.316-0.578)=147600 \text{ J/kg}$

Total work=147600*0.05=7380 J=7.38 kJ

Or

 $W = p(\hat{t}_2 - \hat{t}_1) = R(T_2 - T_1)$ $p_2 V_2 = mRT_2 \Longrightarrow T_2 = \frac{2*10^5 * 0.0658}{0.05*287} = 917K$ $W = mR(T_2 - T_1) = 0.05*0.287(917 - 403) = 7.38kJ$ $Q = mc_p(T_2 - T_1) = 0.05*1.005*(917 - 403) = 25.83kJ$

3-Constant temperature process (Isothermal process):-

A process at constant temperature is called an isothermal process.

For Steam:

W=shaded area

 $Q = (u_2 - u_1) + W$



<u>For Ideal gas:</u>

$$p^{2} = RT$$

$$p^{2} = cons \tan t \Rightarrow p^{2} = c$$

$$p_{1^{-}1}^{2} = p_{2^{-}2}^{2} = p_{3^{-}3}^{2} =$$

$$W = \int_{1}^{2} pd^{2} = \int_{1}^{2} \frac{c}{r} d^{2} = c \int_{1}^{2} \frac{d^{2}}{r} = p_{1^{-}1}^{2} \ln \frac{c}{r}$$

$$W = p_{1^{-}1}^{2} \ln \frac{c}{r}$$

$$W = p_{2^{-}2}^{2} \ln \frac{c}{r}$$



$$\hat{\frac{2}{n_1}} = \frac{p_1}{p_2}$$

$$W = p_1 \hat{\frac{2}{p_1}} \ln \frac{p_1}{p_2}$$

$$p_1 \hat{\frac{2}{p_1}} = RT$$

$$W = RT \ln \frac{p_1}{p_2}$$

$$Q = (u_2 - u_1) + W$$

$$u_2 - u_1 = c_1 (T_2 - T_1) \Rightarrow but T_2 = T_1 \Rightarrow \therefore u_2 = u_1$$

$$Q = W$$

Example(4.2):

Steam at 7 bar and dryness fraction 0.9 expands in a cylinder behind a piston isothermally and reversibly to a pressure of 1.5 bar. Calculate the change of internal energy and the change of enthalpy per kg of steam, The heat supplied during the process is found to be 400 kJ/kg, calculate the work done per kilogram of steam.

Solution:

At p=7 bar, $T_s=165^{\circ}C$ At p=1.5 bar and T=165°C is superheated Because at p=1.5 bar, $T_s=111.4^{\circ}C$

 $u_1 = (1 - x)u_f + xu_g$ $u_1 = (1 - 0.9) * 696 + 0.9 * 2573 = 2385.3kJ / kg$



Interpolation from superheated tables at 1.5 bar and 165°C

 $\frac{200 - 150}{2656 - 2580} = \frac{165 - 150}{u - 2580}$ $u = \frac{15}{50}(2656 - 2580) + 2580 = 2602.8kJ / kg$ $\therefore u_2 = 2602.8kJ / kg$

Gain in internal energy= u_2 - u_1 =217.5 kJ/kg

$$h_1 = h_f + xh_{fg} = 697 + 0.9 * 2067 = 2557.3 kJ / kg$$

Interpolation from superheated tables

 $h = \frac{15}{50} (2873 - 2773) + 2773 = 2803 \, kJ \, / \, kg$ $\therefore h_2 = 2803 \, kJ \, / \, kg$ $\therefore h_2 - h_1 = 245 \, .7 \, kJ \, / \, kg$

 $Q = (u_2 - u_1) + W$ $\therefore W = 400 - 217.5 = 182.5 kJ / kg$

Example(4.3):

1 kg of nitrogen (molar mass 28 kg / kmol) is compressed reversibly and isothermally from 1.01 bar, 20°C to 4.2 bar. Calculate the work done and the heat flow during the process. Assume nitrogen to be a perfect gas.

Solution:

 $\overline{m} = 1$ kg, N₂, M=28, T=C, p₁=1.01 bar, T₁=T₂=20°C p₂=4.2 bar, W=?, Q=?

$$W = RT \ln \frac{p_1}{p_2}$$

$$R = \frac{R_o}{M} = \frac{8314}{28} = 297 J / kg.K$$

$$W = 297 * 293 \ln \frac{1.01}{4.2} = -124 kJ / kg$$

The work input=124kJ/kg Q=W=-124kJ/kg The heat is rejected

4-Adiabatic process (Q=0):-

An adiabatic process is one in which no heat is transferred to or from the fluid during the process. Such a process can be reversible or irreversible.

For reversible adiabatic non-flow process:-

For Steam:

 $Q = (u_2 - u_1) + W$ $\therefore Q = 0$ $\therefore W = u_1 - u_2$

Note:- For an adiabatic process to take place, perfect thermal insulation for the system must be available.

For Ideal gas:

dQ = du + dW

For a reversible process, $dW = pd^{2}$ $dQ = du + pd^{2} = 0$ For a perfect gas ; $p^{2} = RT \Rightarrow du = c_{2}dT$

 $d(p^{\hat{}}) = d(RT)$ $pd^{\hat{}} + dp = RdT$ $\therefore du + pd^{\hat{}} = 0$

$$c \cdot dT + pd^{2} = 0$$

$$\frac{c}{R} [pd^{2} + dp] + pd^{2} = 0$$

$$c \cdot = \frac{R}{x - 1} \Longrightarrow x - 1 = \frac{R}{c}$$

$$\frac{1}{x - 1} [pd^{2} + dp] + pd^{2} = 0$$

$$pd^{2} + dp + (x - 1)pd^{2} = 0$$

$$pd^{2} + dp + xpd^{2} - pd^{2} = 0$$

$$[^{2}dp + xpd^{2} = 0] \div p^{2}$$

$$\frac{dp}{p} + x \frac{d}{2} = 0$$

$$\ln p + x \ln^{2} = C$$

$$p^{2} = e^{C} = cons \tan t$$

$$p^{2} = C$$
Adiabatic process for

or perfect gas

$$p_{1}^{n} \stackrel{x}{}_{1}^{x} = p_{2}^{n} \stackrel{x}{}_{2}^{x}$$

$$\frac{p_{1}}{p_{2}} = \left(\frac{2}{n}\right)^{x}$$

$$p^{n} = RT \Rightarrow p = \frac{RT}{n}$$

$$\frac{RT}{n} \stackrel{x}{}_{n}^{x} = C \Rightarrow T^{n} \stackrel{x-1}{}_{n}^{x-1} = \frac{C}{R} = cons \tan t$$

$$T^{n} \stackrel{x-1}{}_{n}^{x-1} = C$$

$$\frac{T_{1}}{T_{2}} = \left(\frac{2}{n}\right)^{x-1}$$

$$p^{n} = RT \Rightarrow \stackrel{n}{}_{n}^{x} = \frac{RT}{p}$$

$$p\left(\frac{RT}{p}\right)^{x} = C \Rightarrow \frac{T^{x}}{p^{x-1}} = \frac{C}{R} = cons \tan t$$

$$\frac{T_1}{T_2} = (\frac{p_1}{p_2})^{(\frac{x-1}{x})}$$

The work done in an adiabatic process per kg of gas

$$Q = (u_2 - u_1) + W$$

$$\therefore W = u_1 - u_2 = c_{-}(T_1 - T_2)$$

$$\because c_{-} = \frac{R}{\chi - 1}$$

$$\therefore W = \frac{R(T_1 - T_2)}{\chi - 1}$$

$$\therefore P^{-} = RT \implies p_{1-1}^{-} = RT_1, p_{2-2}^{-} = RT_2$$

$$\therefore W = \frac{p_{1-1}^{-} - p_{2-2}^{-}}{\chi - 1}$$



**: A reversible adiabatic process for a perfect gas is shown on a p- diagram.

$$W = \int_{-1}^{2} pd^{2} = \int_{-1}^{2} \frac{c}{2\pi} d^{2} = c \int_{-1}^{2} \frac{d^{2}}{2\pi} d^{2} = c \left[\frac{2\pi}{-1} - \frac{\pi}{2} + 1 - \frac{2\pi}{2} - \frac{\pi}{2} + 1 - \frac{\pi}{2} + \frac{\pi}$$

Example(4.4):

1 kg of steam at 100 bar and 375°C expands reversibly in a perfectly thermally insulated cylinder behind a piston until the pressure is 38 bar and the steam is then dry saturated. Calculate the work done by the steam.



 $\therefore u = h - p^{2}$ $u_{1} = 3017 - \frac{100 * 10^{5} * 0.02453}{1000} = 2771.7 kJ / kg$ $u_{2} = u_{g} atp = 38bar$ $\therefore u_{2} = 2602 kJ / kg$ $\therefore W = 2771.7 - 2602 = 169.7 kJ / kg$

Example(4.5):

Air at 1.02 bar, 22°C, initially occupying a cylinder volume of 0.015 m^3 , is compressed reversibly and adiabatically by a piston to a pressure of 6.8 bar. Calculate the final temperature, the final volume, and the work done on the mass of air in the cylinder. *Solution:*



5- Polytropic processes:-

It is found that many processes in practice approximate to a reversible law of the form $p^{n} = C$; where *n* is a constant. Both vapors and perfect gases obey this type of law closely in many non-flow processes. Such processes are internally reversible.

For Steam:

For any reversible process, $W = \int pd^{\hat{}}$

$$p^{n} = c$$

Where; n and c : constant

 $\therefore W = \int_{-1}^{2} \frac{c}{n} d^{n} = c \left[\frac{n}{-n+1} - \frac{1}{n} \right]_{-1}^{2} = c \left[\frac{n}{-1} - \frac{1}{2} - \frac{1}{2} - \frac{1}{2} - \frac{1}{2} \right]$ $c = p_{1}^{n} = p_{2}^{n} - \frac{1}{2}$ $\therefore W = \frac{p_{1}^{n} - \frac{1}{1} - p_{2}^{n} - \frac{1}{2} - \frac{1}{2} - \frac{1}{2}}{n-1}$ $W = \frac{p_{1}^{n} - \frac{1}{1} - p_{2}^{n} - \frac{1}{2}}{n-1}$ $\frac{p_{1}}{p_{2}} = \left(\frac{1}{2}\right)^{n}$

For Ideal gas:

$$p = RT$$

for polytropic process; $p^{n} = C$

$$p = \frac{RT}{2}$$

$$(\frac{RT}{2})^{n} = c \Longrightarrow T^{n-1} = \frac{c}{R} = c$$

$$T_{1\ 1}^{n-1} = T_{2\ 2}^{n-1}$$

$$\boxed{\frac{T_{1}}{T_{2}} = (\frac{2}{2})^{n-1}}_{1}$$
.....(1)

Note: It can be seen that these equations are exactly similar to the equations for a reversible adiabatic process for a perfect gas. This is mean that the reversible adiabatic process for a perfect gas is a particular case of a polytropic process with the index; n equal to \therefore

For polytropic process,
$$W = \frac{p_{1-1} - p_{2-2}}{n-1}$$

 $p_{1-1} = RT_1 \Rightarrow p_{2-2} = RT_2$
 $\therefore W = \frac{R(T_1 - T_2)}{n-1}$
Or for mass; m
 $\therefore W = \frac{mR(T_1 - T_2)}{n-1}$
 $Q = (u_2 - u_1) + W = c_{-}(T_2 - T_1) + \frac{R(T_1 - T_2)}{n-1}$
 $Q = \frac{R}{n-1}(T_1 - T_2) - \frac{R}{X-1}(T_1 - T_2)$
 $Q = R(T_1 - T_2) \left[\frac{1}{n-1} - \frac{1}{X-1} \right]$
 $Q = R(T_1 - T_2) \left[\frac{X - 1 - (n-1)}{(n-1)(X-1)} \right]$
 $Q = R(T_1 - T_2) \left[\frac{X - n}{(n-1)(X-1)} \right]$
 $Q = (\frac{X - n}{X-1}) \left[\frac{R(T_1 - T_2)}{n-1} \right]$

$$\therefore Q = (\frac{X - n}{X - 1})W$$

Example(4.6):

In a steam engine the steam at the beginning of the expansion process is at 7 bar, dryness fraction 0.95, and the expansion follows the law $p^{-1.1} = cons \tan t$, down to a pressure of 0.34bar. Calculate the work done per kg of steam during the expansion, and the heat flow per kg of steam to or from the cylinder walls during the expansion.

Solution:

 $p_1=7$ bar, x=0.95, $p^{-1.1} = c$, $p_2=0.34$ bar, W=?, Q=? $W = \frac{p_{11} - p_{22}}{n - 1}$ $\hat{x}_{1} = x \hat{x}_{g}$ $\hat{g} = 0.2728m^3 / kg(at7bar)$ $\therefore \hat{1} = 0.95(0.2728) = 0.259m^3 / kg$ $p_{1_{1}}^{n} = p_{2_{2}}^{n} \Longrightarrow \frac{2}{2} = (\frac{p_{1}}{p_{2}})^{\frac{1}{n}}$ $\therefore \hat{p}_2 = \hat{p}_1 \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} = 0.259 \left(\frac{7}{0.34}\right)^{\frac{1}{1.1}} = 4.05m^3 / kg$ $p_2 = 0.34 bar \Rightarrow \hat{}_g = 4.649 m^3 / kg$ $_{g} > _{2}$ the steam is wet at point 2 $W = \frac{7*10^5*0.259 - 0.34*10^5*4.05}{1.1 - 1} = 436kJ/kg$ $Q = (u_2 - u_1) + W$ $u_1 = u_{f1} + x_1(u_{g1} - u_{f1}) = 696 + 0.95(2573 - 696) = 2479.15kJ / kg$ $\hat{x}_2 = x_2 \hat{x}_s \Longrightarrow x_2 = \hat{\frac{2}{2}} = \frac{4.05}{4.649} = 0.871$ $u_2 = u_{f2} + x_2(u_{g2} - u_{f2}) = 302 + 0.871(2472 - 302) = 2192.1 kJ / kg$ $\therefore Q = (2192.1 - 2479.15) + 436 = 148.9 kJ / kg$

Heat is supplied

Example(4.7):

1 kg of a perfect gas is compressed from 1.1 bar, 27 °C according to law, $p^{-1.3} = cons \tan t$ until the pressure is 6.6 bar. Calculate the heat flow to or from the cylinder walls.

(i) When the gas is ethane (molar mass 30 kg/kmol), which has $c_p=1.75$ kJ/kg K. (ii) When the gal is argon (molar mass 40 kg/kmol), which has $c_p = 0.515$ kJ/kl K. Solution: (i)/M=30, c_p=1.75kJ/kg.K $\therefore Q = (\frac{X - n}{X - 1})W$ $X = \frac{c_p}{c_p} \Longrightarrow R = c_p - c_p$ $R = \frac{R_o}{M} = \frac{8.314}{30} = 0.277 kJ / kg.K$ $\therefore c_{-} = c_{p} - R = 1.75 - 0.277 = 1.473 kJ / kg.K$ $\therefore x = \frac{1.75}{1.473} = 1.188$ $W = \frac{R(T_1 - T_2)}{n - 1}$ $\frac{T}{p^{\frac{n-1}{n}}} = c \Longrightarrow \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} \Longrightarrow T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}$ $T_2 = (27 + 273)(\frac{6.6}{1.1})^{\frac{0.3}{1.3}} = 453.6K$ $\therefore W = \frac{0.277(300 - 453.6)}{1.3 - 1} = -141.8kJ / kg$ $\therefore Q = (\frac{1.188 - 1.3}{1.188 - 1})(-141.8) = 84.5 kJ / kg$ The heat is supplied (ii)/ use the same method for argon $R = \frac{8.314}{40} = 0.208 kJ / kg.K$ $c_{-} = 0.515 - 0.208 = 0.307 kJ / kg.K$ $x = \frac{0.515}{0.307} = 1.678$ $W = \frac{0.208(300 - 453.6)}{1.3 - 1} = -106.5 kJ / kg$ $Q = (\frac{1.678 - 1.3}{1.678 - 1})(-106.5) = 59.4 kJ / kg$ Heat is supplied

<u>Note:-</u> The various processes considered in previous sections are cases of the polytropic process for a perfect gas.

Where;

 $n = 0, p^{n} = c \Longrightarrow p = cons \tan t$ $n = \infty, p^{n} = c \Longrightarrow p^{\frac{1}{\infty}} = c^{\frac{1}{\infty}} \Longrightarrow = cons \tan t$ $n = 1, p^{n} = c \Longrightarrow T = cons \tan t$ $n = \chi, p^{n} = c$

State 1 A (constant pressure cooling; *n*=0)

State 1 B (Isothermal compression; *n*=1)

State 1 C (Reversible adiabatic compression; n=)

State 1 D (Constant volume heating; n=)

State 1 A' (constant pressure heating; *n*=0)

State 1 B'(Isothermal expansion; *n*=1)

State 1 C'(Reversible adiabatic expansion; n=)

State 1 D'(Constant volume cooling; n=)



<u>Note:-</u> () is always greater than unity, then process 1 C must lie between processes 1 B and 1 D similarly, process 1 C'must lie between processes 1 B' and 1 D'.

<u>Note:</u> A vapor may undergo a process according to a law p = c. In this case the process is not isothermal because the characteristic equation of state, p = RT, does not apply to vapor. Therefore tables must be used to find the properties at the end states, making use of the fact that $p_{1,1}^{2} = p_{2,2}^{2}$.

Example(4.8):

In the cylinder of a steam engine the steam expands from 5.5bar to 0.75bar according to a hyperbolic law. If the steam is initially dry saturated, calculate the work done per kg of steam, and the heat flow to or from the cylinder walls.

Solution:

 $p_1=5.5$ bar, $p_2=0.75$ bar, $p^2 = c$, W=?, Q=?

$$W = \int_{-1}^{2} pd^{2} = \int_{-1}^{2} \frac{c}{d^{2}} d^{2} = c \ln^{2} \int_{-1}^{2} p_{1-1} \ln \frac{2}{2} \int_{-1}^{2} p_{1-1} \ln \frac{2}{2} \int_{-1}^{2} p_{1-1} d^{2} d^$$

$$_2$$
 > $_g$ the steam is superheated at point 2

 $\frac{2585 - 2510}{2.588 - 2.271} = \frac{u - 2510}{2.513 - 2.271}$ $u_2 = 2567.3kJ / kg$ Q = (2567.3 - 2565) + 375.5 = 377.8kJ / kg

(B) Irreversible processes:-

<u>1-Unresisted, or free expansion:</u>

$$Q = (u_2 - u_1) + W$$
$$Q = 0$$
$$W = 0$$
$$u_2 - u_1 = 0$$

$$\therefore u_1 = u_2$$



**: In a free expansion process, the internal energy initially equals the internal energy finally.

(For ideal gas

 $u = c_{\uparrow} T$ $c_{\uparrow} T_{1} = c_{\uparrow} T_{2}$

$$\therefore T_1 = T_2$$

2-Throttling:

A flow fluid is said to be throttling when there is some restriction to the flow, such as, partly open valve, an orifice or any sudden reduction in the cross section of the flow.

$$h_{1} + \frac{C_{1}^{2}}{2} + Q = h_{2} + \frac{C_{2}^{2}}{2} + W$$
$$Q = 0, W = 0$$
$$h_{1} + \frac{C_{1}^{2}}{2} = h_{2} + \frac{C_{2}^{2}}{2}$$



When the velocities C_1 and C_2 are small, or when C_1 is very nearly equal to C_2 , then the kinetic energy can be neglected.

$$h_1 = h_2$$

Therefore for throttling process, the enthalpy initially is equal to the enthalpy finally.

(For ideal gas

$$h = c_p T$$
$$c_p T_1 = c_p T_2$$

$$\therefore T_1 = T_2$$

3- Adiabatic mixing:

The mixing of two streams of fluid is quite common in engineering practices, and can usually be assumed to occur adiabatically.

$$Q = 0$$

 $W = 0$

Neglecting change in kinetic energy.

$$H_1 + H_2 = H_3$$

 $m_1^{\bullet} h_1 + m_2^{\bullet} h_2 = m_3^{\bullet} h_3$

 $m_1^{\bullet}h_1 + m_2^{\bullet}h_2 = (m_1^{\bullet} + m_2^{\bullet})h_3$



(For ideal gas

 $h = c_n T$

$$m_1^{\bullet}c_pT_1 + m_2^{\bullet}c_pT_2 = (m_1^{\bullet} + m_2^{\bullet})c_pT_3$$

$$m_1^{\bullet}T_1 + m_2^{\bullet}T_2 = (m_1^{\bullet} + m_2^{\bullet})T_3$$

Example(4.9):

Air at 20 bar is initially contained in vessel A as shown in figure below, the volume of this vessel is $1m^3$. The valve is opened and the air expands to fill vessels A and B. Assuming that the vessels are of equal volume ,calculate the final pressure of the air.

Solution:

Air is a perfect gas The process is free expansion

$$u_{1} = u_{2}$$

$$\therefore T_{1} = T_{2}$$

$$p_{1}V_{1} = p_{2}V_{2}$$

$$V_{2} = 2V_{1} = 2 * 1 = 2m^{3}$$

$$\frac{p_{2}}{p_{1}} = \frac{V_{1}}{V_{2}} \Longrightarrow p_{2} = p_{1}(\frac{V_{1}}{V_{2}}) = 20(\frac{1}{2}) = 10bar$$

<u>Note:-</u> The point 1 and 2 lie on isothermal line, but the process between 1 and 2 cannot be called isothermal, since the intermediate temperatures are not the same throughout the process.

Example(4.10):

Steam at 19 bar is throttled to 1 bar and the temperature after throttling is found to be 150°C. Calculate the initial dryness fraction of the steam.

Solution:

The process is throttling, $\therefore h_1 = h_2$

Point 2 at superheated, at p=1bar T_s = 99.6°C

 $T_s\ <\ T$





From superheated table at p=1 bar and T=150°C.

h=2777 kJ/kg $h_1 = h_2 = 2777 \text{kJ} / \text{kg}$ $h_1 = h_f + xh_{fg}$ $2777 = 897 + x(1901) \Longrightarrow x = 0.989$

Note:- States 1 and 2 are fixed but the intermediate states are indeterminate, therefore for a vapor, throttling can be used as a means of finding the dryness fraction of wet steam, as in example.

Reversible Flow Processes:-

If the kinetic energy terms are negligible small;

$$W = (h_1 - h_2)$$

For ideal gas: $W = c_p (T_1 - T_2)$

<u>Note:-</u> The work done in a reversible adiabatic flow process between two states $W = (h_1 - h_2)$ is not equal to the work done in a reversible adiabatic non-flow process between the same states $W = (u_1 - u_2)$

Example(4.11):

A gas turbine receives gases from the combustion chamber at7 bar and 650°C, with velocity of 9 m/s. The gases leave the turbine at 1 bar with a velocity of 45 m/s. Assuming that the expansion is adiabatic and reversible in the ideal case, calculate the work done per kg of gas , For the gases take = 1.333 and $c_p = 1.11$ kJ/kg K.

Solution:

$$\frac{1}{h_{1} + \frac{C_{1}^{2}}{2} + Q} = h_{2} + \frac{C_{2}^{2}}{2} + W \Rightarrow Q = 0$$

$$W = (h_{1} - h_{2}) + (\frac{C_{1}^{2} - C_{2}^{2}}{2})$$
For gas; $h = c_{p}T$

$$\therefore W = c_{p}(T_{1} - T_{2}) + (\frac{C_{1}^{2} - C_{2}^{2}}{2})$$

$$\frac{T_{1}}{T_{2}} = (\frac{P_{1}}{P_{2}})^{\frac{x-1}{x}} \Rightarrow T_{2} = T_{1}(\frac{P_{2}}{P_{1}})^{\frac{x-1}{x}} = (650 + 273)(\frac{1}{7})^{\frac{0.333}{1.333}} = 567.7K$$

$$\therefore W = 1.11*10^{3}(923 - 567.7) + \frac{1}{2}(9^{2} - 45^{2}) = 393.4kJ / kg$$