AL-MAMON UNIVERSITY COLLAGE

DEPARTMENT OF ELECTRICAL POWER ENGINEERING TECHNIQUES

Part 2

Lecture notes 3 & 4

# THERMODYNAMIC

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# First Law of Thermodynamic

This lecture notes consist the following topics:

- Introduction.
- First Law of Thermodynamic.
- Energy Equation of Study Flow Open System.
- Application of Study Flow Energy Equation (S.F.E.E).
- Steam Turbine.
- Compressor.
- Nozzle.
- Diffuser.
- Condenser.
- Boiler.

## 2.1 INTRODUCTION

In these lecture notes, we begin the formal study of the first law of thermodynamics. The theory is presented first, then it is applied to a variety of closed and open systems of engineering interest.

تم تطوير القانون الأول للديناميكا الحرارية وتوازن الطاقة المرتبط به جنبًا إلى جنب مع مناقشة مفصلة لآليات نقل الطاقة للعمل والحرارة. لفهم فائدة القانون الأول للديناميكا الحرارية ، نحتاج إلى دراسة أوضاع نقل الطاقة والتحقيق في كفاءة تحويل الطاقة للتقنيات الشائعة.

## 2.2 First Law of Thermodynamic

The first law of thermodynamics is commonly called the conservation of energy.

Having discussed the concepts of work and heat, we are now ready to present the first law of thermodynamics. Historically, the first law of thermodynamics was stated: ***The net heat transfer is equal to the net work done for a system undergoing a cycle*.**

$$\sum W = \sum Q$$

when even heat is absorbed by a system it goes to increase its internal energy (U) plus to do some thermal works (Pdv).

يُطلق على القانون الأول للديناميكا الحرارية عمومًا اسم حفظ الطاقة.فبعد مناقشة مفاهيم العمل والحرارة ، نحن الآن على استعداد لتقديم القانون الأول للديناميكا الحرارية. تاريخيًا ، تم ذكر القانون الأول للديناميكا الحرارية: "صافي انتقال الحرارة يساوي صافي العمل المنجز لنظام يمر بدورة."حتى عندما يتم امتصاص الحرارة بواسطة نظام ما ، فإنه يذهب لزيادة طاقته الداخلية (U) بالإضافة إلى القيام ببعض الأعمال الحرارية (Pdv).

$$Q = \Delta U + W$$

the equation is for closed system.

Energy Supplied = Energy Rejected + Energy Stored

Example 1: A spring is stretched a distance of 0.8 m and attached to a paddle wheel (Fig 2-1). The paddle wheel then rotates until the spring is unstretched. Calculate the heat transfer necessary to return the system to its initial state.

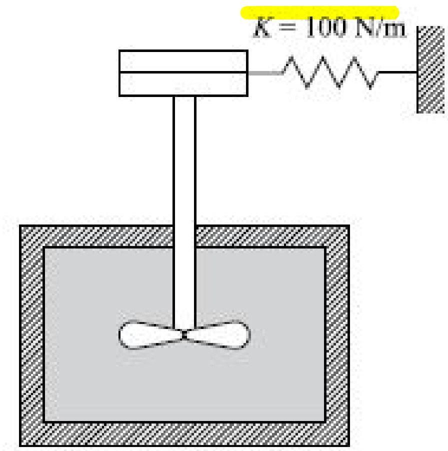


Fig 2.1

Solution: The work done by the spring on the system is given by

$$W_{1-2} = \int_0^{0.8} F dx = \int_0^{0.8} 100x dx = (100)\left[\frac{(0.8)^2}{2}\right] = 32\text{N} \cdot \text{m}$$

Since the heat transfer returns the system to its initial state, a cycle result. The first law then states that

$$Q_{2-1} = W_{1-2} = 32 \text{ J}/s$$

## 2.3 Energy Equation of Steady Flow Open System.

The principles used in the study of open systems are the conservation of mass (mass balance) and the First law of thermodynamics (energy balance).

$$Energy\ inlet = Energy\ outlet$$

$$Q + PE_1 + KE_1 + Wf_1 + U_1 = W + PE_2 + KE_2 + Wf_2 + U_2$$

$$Q - W = PE_2 - PE_1 + KE_2 - KE_1 + Wf_2 - Wf_1 + U_2 - U_1$$

$$Q - W = \Delta PE + \Delta KE + \Delta Wf + \Delta U$$

But $$\Delta Wf + \Delta U = \Delta H$$

$$\therefore \quad Q - W = \Delta PE + \Delta KE + \Delta H$$ this equation called:

*Study Flow Energy Equation (S.F.E.E)*

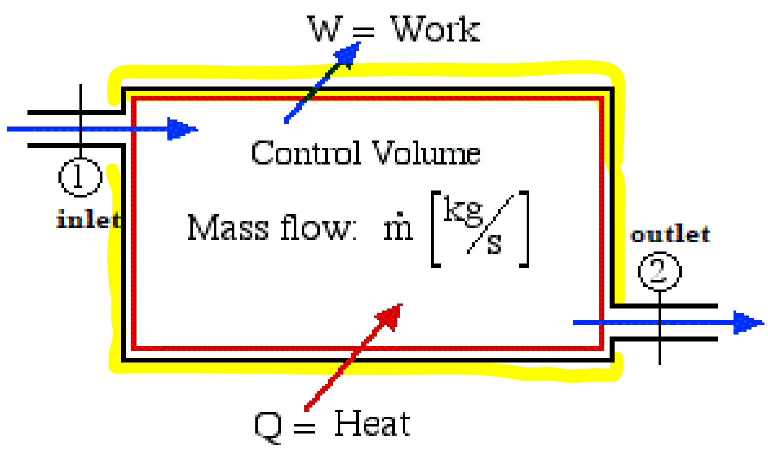


Figure 2-2 Study Flow Open System

the mass flow rate and energy flow rate are constant in steady flow process

$$mass\ flow\ rate\ m^{\circ}_{in} = mass\ flow\ rate\ m^{\circ}_{out}$$

$$Energy\ in = Energy\ out$$

Example 2: - A (5 hp) fan is used in a large room to provide for air circulation. Assuming a well-insulated, sealed room determine the internal energy increase after (1 h) of operation.

Solution: -

By assumption, $Q = 0$ . With $\Delta PE = KE = 0$

The first law becomes $-W = \Delta U$

The work input is

$$W = (-5\text{ hp})(746\text{ W/hp})(1h)(3600\text{ s/h}) = -1.343 \times 10^7\text{J}$$

The negative sign results because the work is input to the system. Finally, the internal energy increase is:

$$\Delta U = -(-1.343 \times 10^7) = 1.343 \times 10^7 J$$

## 2.4 Application of Steady Flow Energy Equation (S.F.E.E)

2.4.1 Steam Turbine: A steam turbine is a device with rows of blades mounted on a shaft could be rotated about its axis. Steam turbine is extracts thermal energy from the steam and converts it to mechanical work on a rotating output shaft.

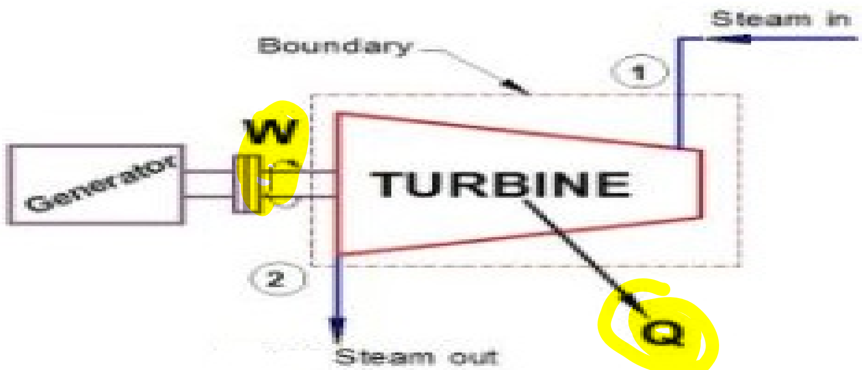


Figure 2-3 Steam Turbine

from S.F.E.E $$Q - W = \Delta PE + \Delta KE + \Delta H$$

$$Q - W = g\Delta z + \frac{\Delta \mathbf{v}^2}{2} + \Delta H$$

Where in Steam Turbine $Q = 0$ , $v_1 = v_2$ $and$ $z_1 = z_2$

$\therefore S.F.E.E$ $$-W = m^{\circ}(h_2 - h_1)$$

Example 3: - Steam is expanded isentropically in a turbine from ($30\ bar$ $400℃\ to\ 4\ bar$). Calculate the work done per unit mass flow of steam. Neglect changes as K.E and P.E.

Solution: -

$$Q = 0,\ K.E = P.E = 0,$$

Hence;

$$- W = m\ [h_2 - h_1]$$

By table, we get $h_1$ = 3230.9kJ/kg, $h_2$ = 2750kJ/kg & m = 1 kg/s

Hence, we get;

$$- W = 1\ [2750 - 3230]$$

$$W = 480\ J/s\ (W)$$

2.4.2 Compressor: The purpose of a compressor is to compress a gas or an air or vapor from a low-pressure inlet state to a high pressure exit state by utilizing mechanical work.

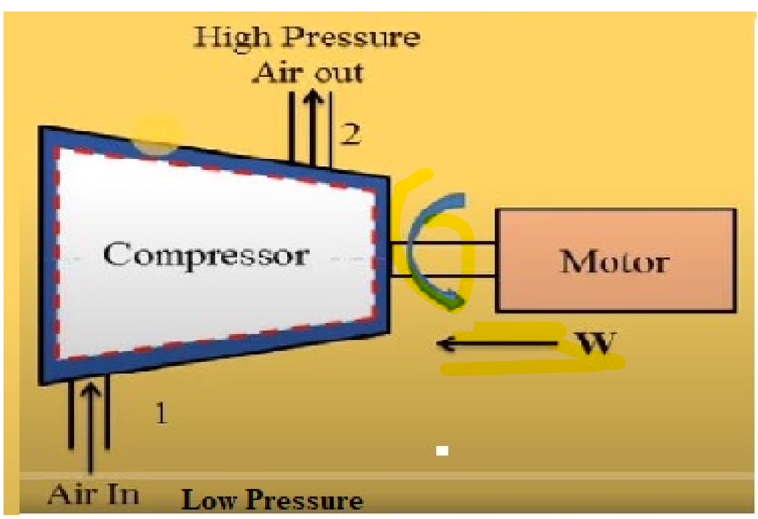


Figure 2.4 Compressor

from S.F.E.E $$Q - W = \Delta PE + \Delta KE + \Delta H$$

Where in Compressor $Q = 0$ , $\Delta PE = 0$ and $\Delta KE = 0$

$\therefore S.F.E.E$ $$-W = m^{\circ}(h_2 - h_1)$$

Example 4: - Freon R-134a at a mass flow rate of 0.015 kg/s enters an adiabatic compressor at 200 kPa and -10ºC and leaves at 1 MPa and 70ºC. Determine the Work done in compressor.

Solution: -

$$Q = 0, K.E = P.E = 0,$$

Hence;

$$- W = m [h_2-h_1]$$

By table, we get $h_1$ = 392.3 kJ/kg, $h_2$ = 452.3 kJ/kg

Hence, we get;

$$- W = 0.015 [425.3 – 392.3]$$

$$W = 49.5 \text{ J/s (W)}$$

2.4.3 Nozzle: - is a small device used to create a high kinetic energy or a high velocity fluid stream at the expense of its pressure. There is no means to do mechanical shaft work. A nozzle is usually modeled as adiabatic.

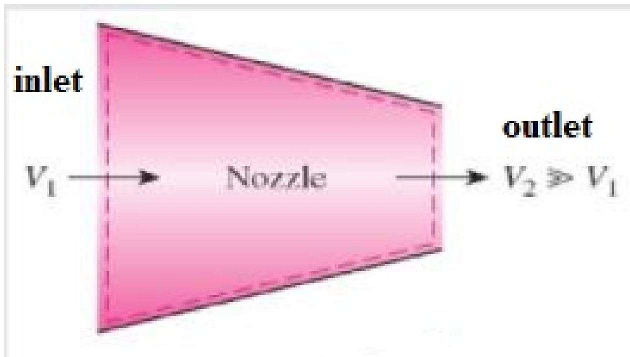


Figure 2.5 Nozzle

from S.F.E.E $$Q - W = \Delta PE + \Delta KE + \Delta H$$

Where in Nozzle $Q = 0$ , $W = 0$ $\Delta PE = 0$

$\therefore$ $S.F.E.E$ $$\Delta KE = -m^{\circ}(h_2 - h_1)$$

$$\frac{(V_2^2 - V_1^2)}{2} = -m^{\circ}(h_2 - h_1)$$

Example 5: - Steam at (5 MPa and 400°C) enters a nozzle steadily with a velocity of 80 m/s, and it leaves at (2 MPa and 300°C). The inlet area of the nozzle is (50 $cm^2$). Determine

(a) the mass flow rate of the steam,

(b) the exit velocity of the steam,

Solution: -

Steam is accelerated in a nozzle from a velocity of " 80m/s”. The mass flow rate, the exit velocity and the exit area of the nozzle are to be determined.

From Steam Tables we get:

$$\left.\begin{aligned} P_1 &= 5\text{MPa} \\ T_1 &= 400^\circ\text{C} \end{aligned}\right\} \quad => \quad h_1 = 3196.7\text{kJ/kg} \;, v_1 = 0.057838\text{m}^3/\text{kg}$$

$$\left.\begin{aligned} P_2 &= 2\text{MPa} \\ T_2 &= 300^\circ\text{C} \end{aligned}\right\} \quad => \quad h_2 = 3024.2\text{kJ/kg}$$

There is only one inlet and one exit, and $\dot{m}_1 = \dot{m}_2 = \dot{m}$ The mass flow rate of steam is

$$\dot{m} = \frac{1}{v_1} V_1 A_1 = \frac{1}{0.057838\frac{\text{m}^3}{\text{kg}}} \left(80\,\frac{\text{m}}{\text{s}}\right) (50 \times 10^{-4}\text{m}^2)$$

$$\dot{m} = 6.92\text{kg/s}$$

we take the nozzle as a system, which is a control volume since mass crosses the boundary. the energy balance for steady-flow can be expressed in the rate form as:

$$\therefore S.F.E.E \qquad \Delta\, KE = \; - m^\circ (h_2 - \; h_1)$$

$$\frac{(V_2^2 - V_1^2)}{2} = -m^\circ(h_2 - h_1)$$

$$\frac{(V_2^2 - 80^2)}{2} = -6.92\ \text{kg/s}\ (3024.2\frac{kJ}{kg} - 3196.7\frac{kJ}{kg}) \times 10^3$$

$$V_2 = 1547.2\ \frac{\text{m}}{\text{s}}$$

2.4.4. Diffuser: is a small device used to decelerate a high velocity fluid stream and raise the pressure of the fluid. There are no means to do work.

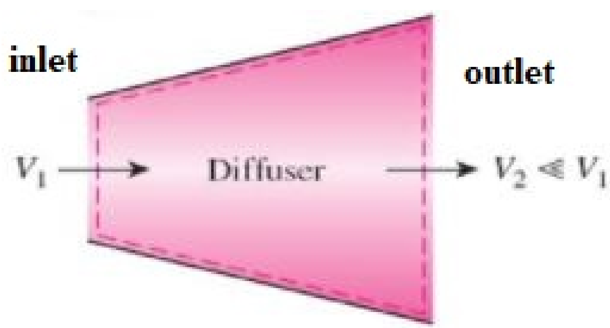


Figure 2.6 Diffuser

from S.F.E.E $\quad Q - W = \Delta PE + \Delta KE + \Delta H$

Where in Diffuser $\quad Q = 0\ ,\ W = 0\ \ \Delta PE = 0$

$\therefore S.F.E.E \quad \Delta KE = -m^\circ(h_2 - h_1)$

$$\frac{(V_2^2 - V_1^2)}{2} = -m^\circ(h_2 - h_1)$$

or more simplify $\quad h_1 + \frac{(V_1)^2}{2} = h_2 + \frac{(V_2)^2}{2}$

Example 6: - Air at (80 kPa, 27°C) and (220 m/s) enters a diffuser at a rate of (2.5 kg/s) and leaves at (42°C). The exit area of the diffuser is (400 $cm^2$). Determine the exit velocity.

Solution: -

Assumption:

1) This is a steady-flow process since there is no change with time.
2) Air is an ideal gas with variable specific heats.
3) Potential Energy changes are negligible.
4) There are no Work.
5) Heat loss can be neglected.

Properties The gas constant of air is $0.287 \mathrm{kPa.m^3/kgK}$, (Table A-1).

The enthalpies are (Table A-17)

$T_1 = 27^\circ\mathrm{C} = 300\mathrm{K} \quad \rightarrow h_1 = 300.19 \ \mathrm{kJ/kg}$
$T_2 = 42^\circ\mathrm{C} = 315\mathrm{K} \quad \rightarrow h_2 = 315.27 \ \mathrm{kJ/kg}$

$$h_1 + \frac{(V_1)^2}{2} = h_2 + \frac{(V_2)^2}{2}$$

$$\left(300.19 \ \frac{\mathrm{kJ}}{\mathrm{kg}} \times 1000\right) + \frac{\left(220 \ \frac{m}{s}\right)^2}{2} = \left(315.27 \ \frac{\mathrm{kJ}}{\mathrm{kg}} \times 1000\right) + \frac{(V_2)^2}{2}$$

$$V_2 = 99.2 \ \frac{m}{s}$$

2.2.5 Condenser: - is a device where heat is removed from the fluid to the surroundings, by flows simple single stream fluid through it. The fluid is cooled and may or may not change phases. The cooling process tends to occur at constant pressure, since a fluid flowing through the device usually undergoes only a small pressure drop due to fluid friction at the walls. There are no means for doing any shaft or electric work, and changes in kinetic and potential energies are commonly, negligibly small.

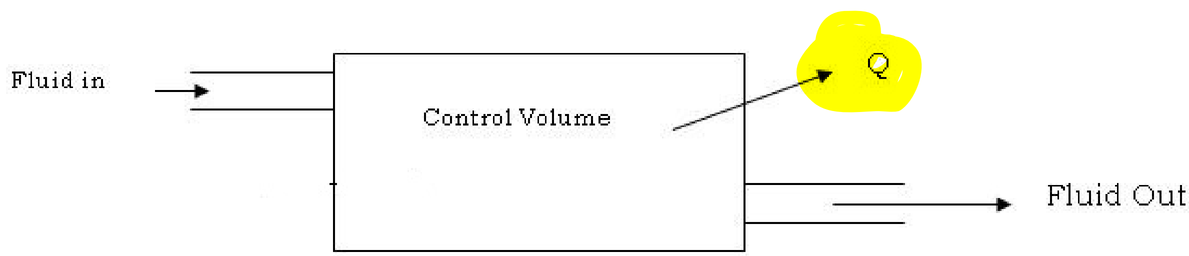


Figure 2.7 Condenser

Application of the First law of thermodynamics to a steady flow steady system Condenser gives:

from S.F.E.E $$Q - W = \Delta PE + \Delta KE + \Delta H$$

Where in Condenser $$W = 0,\ \Delta PE = 0,\ \Delta KE = 0$$

$\therefore S.F.E.E$ $$Q = m^{\circ}(h_2 - h_1)$$

Example 7: - Water inter a condenser at a mass flow rate of (2 kg/s) and (20 kPa and 60 C), and exit with (h= 251.5 kJ/kg). Find:

a) The mass flow rate of water flow at the exit section,

b) the rate of heat removed from the water in the condenser.

Solution: -

From Tables:

$T_1 = 60°\text{C} \quad \rightarrow h_1 = 2373 \ \text{kJ/kg}$
$P_1 = 20 \ \text{kPa}$

$h_2 = 251.5 \ \text{kJ/kg}$

Where in Condenser $W = 0 \ , \ \Delta PE = 0 \ , \ \Delta KE = 0$

$\therefore S.F.E.E \qquad Q = m^{\circ} \ (h_2 - h_1)$

$$Q = 2 \ \frac{kg}{s} \ (251.5 \ \frac{\text{kJ}}{\text{kg}} - 2373 \ \frac{\text{kJ}}{\text{kg}})$$

$$Q = 42.43 \ kJ \frac{kJ}{s}$$

2.2.6 Boiler: - is a vapor generator device in which a liquid is converted into a vapor by the addition of heat; a steam generator is the same as a boiler that heats liquid pure substance to vapor or superheated vapor phase. The heating process tends to occur at constant pressure, since a fluid flowing through the device usually undergoes only a small pressure drop due to fluid friction at the walls. There is no means for doing any shaft or electric work, and changes in kinetic and potential energies are commonly negligible small.

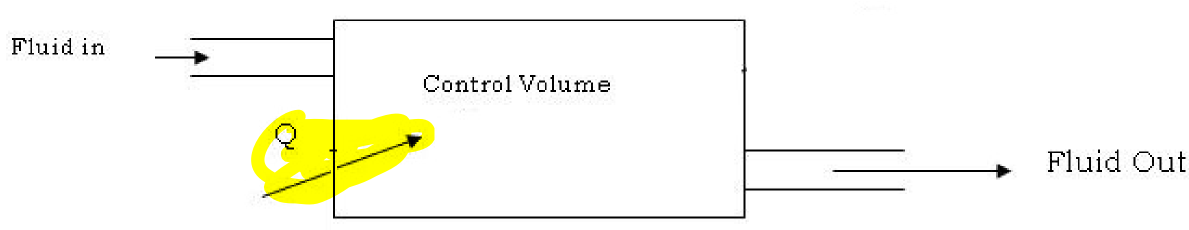


Figure 2.8 Boiler

Application of the First law of thermodynamics to a steady flow steady system Boiler gives:

from S.F.E.E $$Q - W = \Delta PE + \Delta KE + \Delta H$$

Where in Condenser $W = 0$ , $\Delta PE = 0$, $\Delta KE = 0$

$\therefore S.F.E.E$ $$Q = m^{\circ}\,(h_2 - h_1)$$

Example 8: - (0.1 kg/s) of water enters a boiler at (323°K & 5 Mpa), and leaves as steam at (673°K & 5 Mpa). For steady flow, what is the heat transferred and work added to the boiler?

Solution: -

From Tables:

$$\left.\begin{matrix} P_1 = 5\text{MPa} \\ T_1 = 323^\circ\text{K} \end{matrix}\right\} \quad => \quad h_1 = 218 \text{ kJ/kg} \ ,$$

$$\left.\begin{matrix} P_2 = 5\text{MPa} \\ T_2 = 673^\circ\text{K} \end{matrix}\right\} \quad => \quad h_2 = 3196.22 \text{ kJ/kg}$$

$$Q = m^\circ \, (h_2 - h_1)$$

$$Q = 0.1 \, \frac{kg}{s} \, \left(3196.22 \frac{\text{kJ}}{\text{kg}} - 218 \frac{\text{kJ}}{\text{kg}}\right)$$

$$Q = 297.822 \frac{\text{kJ}}{\text{s}}$$