جامعة تكريت

كلية الهندسة

قسم الهندسة الميكانيكية

ديناميك حرارة 1

الكورس الاول

اعداد

الدكتور المهندس

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Thermodynamics I – Lectures

By

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الكورس الاول – ديناميك حرارة 1

Weeks	hours	Unit name/subject
1	3	Chapter one: Basic Concepts Related to Thermodynamics - Introduction - Definition of Engineering Thermodynamics - Applications of Engineering Thermodynamics - Definition of Thermodynamics
2	3	- Definition of Thermodynamic Laws - Thermodynamic Systems
3	3	- Thermodynamic Systems System ,boundary and surroundings , closed system , open system , control volume and control surface , isolated system , adiabatic system, Macroscopic and Microscopic Approach , Thermodynamic equilibrium , properties of systems , state , process ,non-flow processes, flow processes, cycle
4	3	-Point functions, path functions, Temperature , Zeroth-Law of Thermodynamics -Pressure , Definition of pressure, Gauge pressure, Vacuum -pressure, Schematic diagram showing gauge ,vacuum and absolute pressures, unit of pressure, manometer, barometer, U-Tube manometer- Reversible and Irreversible processes , Energy, work and heat ,reversible work , Tutorial sheet- -Chapter one
5	3	First test
6	3	Chapter Two :The First Law of Thermodynamic and its applications , Corollaries of first law of thermodynamics, Perpetual motion machine of first kind -The perfect gas (Boyles law, Charles law, the characteristic equation of gas, Avogadro's hypothesis)
7	3	-Specific heats, Joule's law, internal energy, enthalpy, forms of energies
8	3	-Applications of First- Law of Thermodynamics to Non-Flow Processes -Steady Non-Flow Energy Equation(N.F.E.Q) -Reversible constant volume process(Isochoric process) -Reversible constant volume process(Isobaric process) -Constant temperature process(Isothermal process) -Adiabatic process

		-Polytropic process -Relationship between T and V and T and P, Tutorial sheet- chapter 2 ,
9	3	Second test
10	3	Chapter Three: Applications of First-Law to Steady-Flow Processes -Steady-Flow Energy Equation (S.F.E.E) -Engineering applications of steady flow energy equation -water turbine, steam or gas turbine, centrifugal water pump, centrifugal compressor, reciprocating compressor, Tutorial sheet- chapter 3
11	3	Third test
12	3	Chapter Four: Steam and Two-Phase Systems -Introduction -The formation of steam -Saturation of temperature and pressure -The triple point
13	3	-Enthalpy and the formation of steam at constant pressure -Enthalpy tables -Reference state of tables -Liquid enthalpy, enthalpy of evaporation, enthalpy of dry saturated vapor, enthalpy of superheated vapor
14	3	-Wet vapor and dryness fraction -Temperature-Enthalpy diagram -Volume of steam, volume of water, volume of dry saturated steam, volume of wet steam, volume of superheated steam, Density of steam, the internal energy of steam, Tutorial sheet- chapter 4
15	3	Fourth test

الكتاب المنهجي :

-Applied Thermodynamics for Engineering Technologists, Third edition ,by T.D.EASTOP مكتبة التعليم المجاني-قسم الميكانيك

الكتاب المصدري:

-Thermodynamics : An Engineering Approach, by Yunus A.Gengel

Chapter One

Basic Concepts Related To Thermodynamics

1.1 Introduction

Thermodynamics, like other physical sciences, is based on observation of nature.

- **The first law of thermodynamics**: is simply an expression of the conservation of energy principle, and asserts that energy is a thermodynamic property.

- **The second law of thermodynamics**: asserts that energy has quality as well as quantity, and actual processes occur in the direction of decreasing quality of energy.

- The term *thermodynamics* was first used in publication of Lord Kelvin in 1849.

- The first thermodynamic text book was written in 1859 by William Rankine a professor at the University of Glasgow.

1.2 Definition of Engineering Thermodynamics

Thermodynamic can be defined as the science of energy. The name thermodynamics stems from the Greek words **thermos** (heat) and **dynamics** (power).

Thermodynamics (Greek word) → Heat power

Today the same name is widely taken to include all parts of :

Energy and energy transformations, including power production, refrigeration, and relationships between the properties of matter.

Engineering thermodynamics is the subject that deals with the study of the science of thermodynamics and the usefulness of this science in the engineering design of processes, devices, and system involving the effective utilization of energy and matter for the benefit of humankind.

1.3 Applications of Engineering Thermodynamics

Some examples: electric , heating and air-conditioning systems, the refrigerator, the humidifiers, the pressure cooker, the water heater, the shower, the iron, the computer, the TV,

Engines,….etc.

1.4 Definition of thermodynamics

Thermodynamics may be defined as follows:

Thermodynamics is a clear science which deals with the relations between heat, work and properties of system which are in equilibrium. It describes state and change in state of physical system.

Thermodynamics is *the science that deals with the interaction between energy and material systems.*

Thermodynamics, basically includes four laws: Zeroth, First, Second and Third law of thermodynamics.

- The ***First law*** throws light on concept of internal energy

القانون الاول يلقي الضوء على الطاقة الداخلية

- The ***Zeroth law*** deals with thermal equilibrium and establishes a concept of temperature

يتعامل القانون الصفري مع التوازن الحراري ويؤسس مفهوم درجة الحرارة

- The ***Second law*** indicates the limit of converting heat into work and introduces the principle of increase of entropy.

يشير القانون الثاني الى حد تحويل الحرارة الى عمل ويقدم مبدأ زيادة الأنتروبيا

- The ***Third law*** defines the absolute zero entropy.

يحدد القانون الثالث أنتروبيا الصفر المطلق

These laws are based on experimental observations and have no mathematical proof. Like all physical laws, these laws are based on logical reasoning.

تستند هذه القوانيين الى الملاحظات التجريبية وليس لها دليل رياضي، مثل جميع القوانيين الفيزيائية تستند هذه القوانيين الى التفكير المنطقي.

1.5 Thermodynamic system

1.5.1 System, Boundary, and Surroundings

System, A system is a finite quantity of matter or a given region of space choose of study (Fig.1.1).

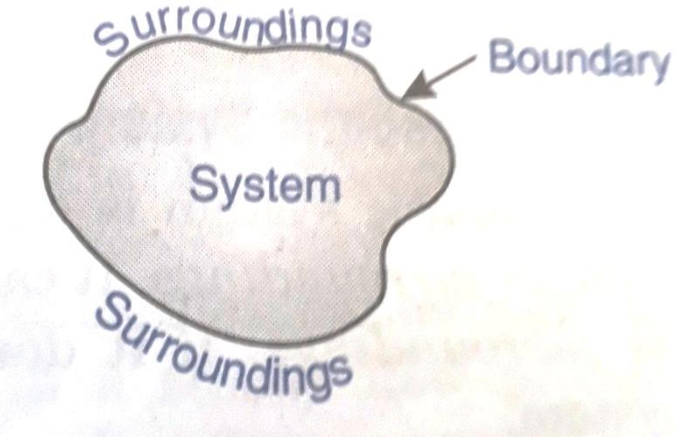


Fig. 1.1 The system

Boundary, The actual or hypothetical envelope enclosing the system is the boundary of the system. The boundary may be fixed or it may be move, as and when a system containing a gas is compressed or expanded. The boundary may be real or imaginary.

Surroundings, is those things outside the system.

1.5.2 Closed system

In system in which mass does not cross the system boundary, but energy may cross the system boundary (Fig.1.2). Closed system is also known as control mass.

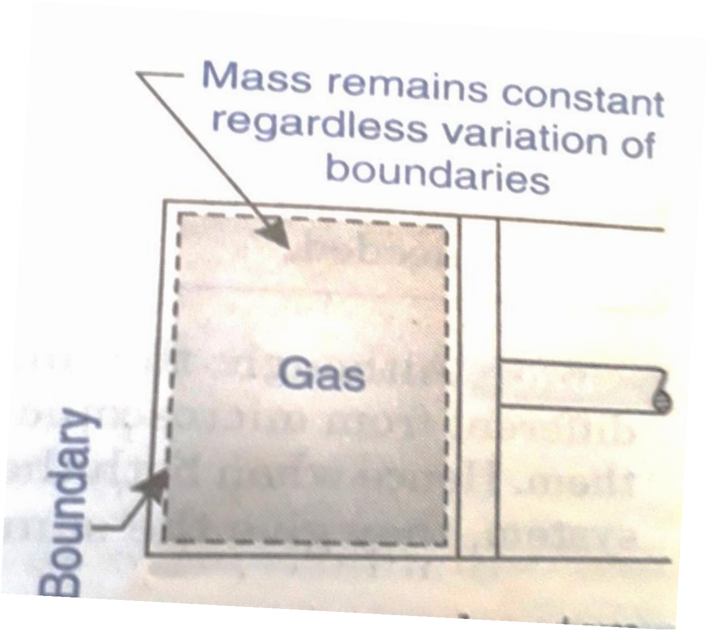


Fig. 1.2 Closed system

1.5.3 Open system

Any system in which both mass and energy may cross the system boundary (Fig.1.3).

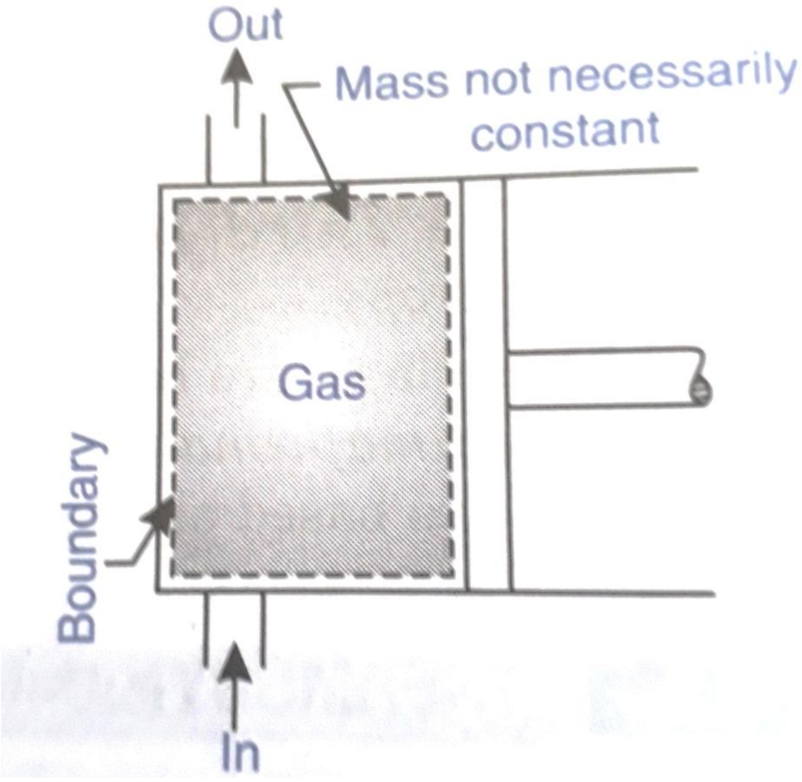


Fig. 1.3 Open system

1.5.4 Control volume and Control surface

Some author call an open system a control volume and its boundary a control surface.

1.5.5 Non-flow and flow processes

The processes undergone by the fluid in a closed system are described as non-flow processes, whereas those undergone by the fluid in an open system are referred to as flow processes.

1.5.6 Isolated system

Any system in which neither mass nor energy crosses the system boundary (Fig. 1.4).

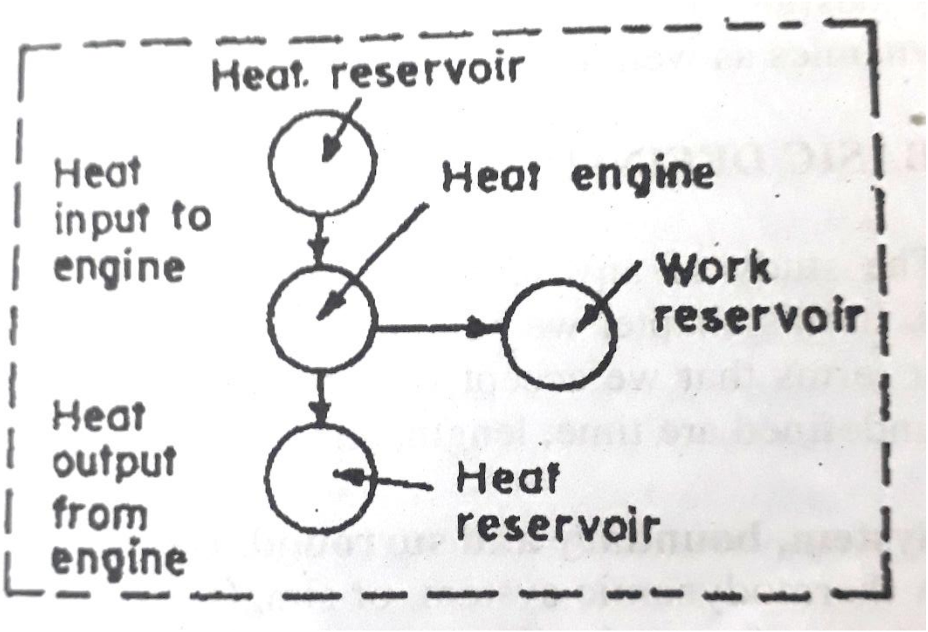


Fig. 1.5 Isolated system

1.5.7 Adiabatic system

A system which thermally insulated from its surroundings is called an adiabatic system. It can, exchange work with its surroundings . If it does not, it becomes an isolated system.

1.6 Macroscopic and Microscopic

System can be studied from macroscopic or a microscopic point of view.

Macroscopic approach : the macroscopic approach to thermodynamics is concerned with the gross or overall behavior. This sometimes called classical thermodynamics.

Microscopic approach: the microscopic approach to thermodynamics, known as statistical thermodynamics is concerned directly with the stricter of matter.

1.6.1 Macroscopic system analysis

The analysis of the systems at the continuum level (i.e molecular dimensions and time scales do not enter into the analysis). This is the domain of classical and non-equilibrium thermodynamics.

1.6.2 Microscopic system analysis

The analysis of the systems at the atomic level. This is the domain of statistical thermodynamics.

1.7 Thermodynamic equilibrium

A system is in ***thermodynamic equilibrium*** if the temperature and pressure at all points are same.

1. Thermal equilibrium : the temperature of the system does not change with time and has same value at all points of the system.

2. mechanical equilibrium : there are no unbalanced forces within the system or between the surroundings. The pressure in the system is same at all points and does not change with respect to time.

3. chemical equilibrium : no chemical reaction takes place in the system and the chemical composition which is same throughout the system does not vary with time.

1.8 Properties of systems

A property of a system is a characteristic of the system which depends upon its state, but not upon how the state is reached. There are two types of property :

1. Intensive properties : these properties do not depend on the mass of the system. Examples, Temperature and pressure.

2. Extensive properties : these properties depend on the mass of the system . Example. Volume . Extensive properties are often divided by mass associated with them to obtain the intensive properties. For example, if the volume of the system of mass m is V , then the specific volume of matter within the system is $\frac{V}{m} = v$, which is an intensive property.

1.9 State

State : is the condition of the system at an instant of time as described or measured by its properties. All properties are state or point functions.

1.10 Process

A process occurs when the system undergoes a change in a state or an energy transfer at a steady state.

A process may be :

1. non-flow process : in which a fixed mass(i.e closed system) within the defined boundary is undergoing a change in state. Example : a substance which is being heated in a closed cylinder undergoes a non-flow process.

2. flow process : in which mass is entering and leaving through the boundary of an open system .

1.11 Cycle

Any process or series of processes whose end states are identical is termed a cycle.

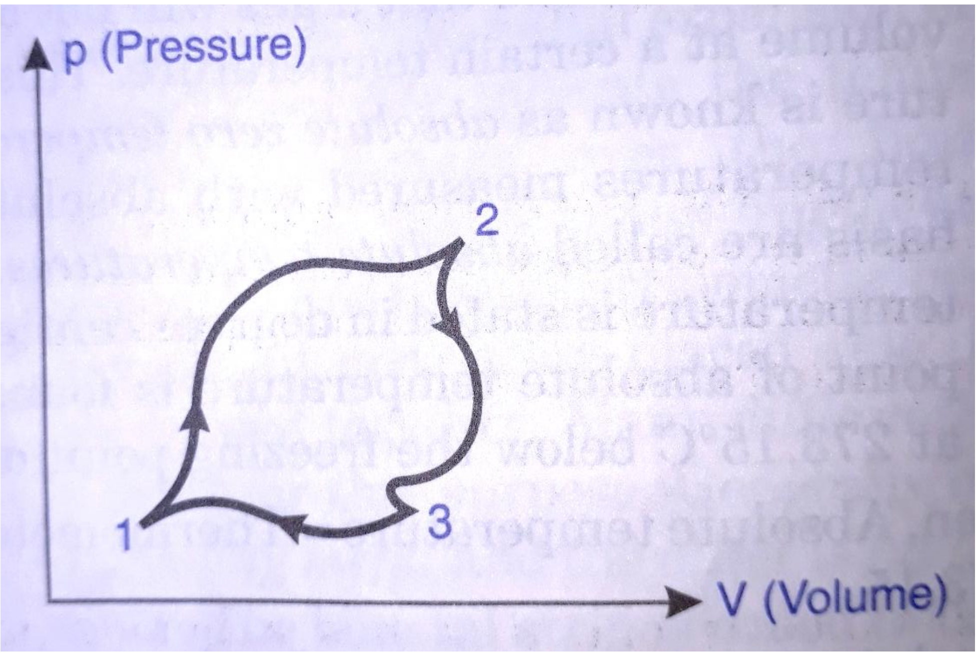


Fig. 1.5. Cycle in operations.

1.12. Point Function

When two properties locate a point on the graph, (coordinate axes) then those properties are called as point function.

Examples, pressure, temperature, volume , etc.

$$\int_{V_1}^{V_2} dV = V_2 - V_1 \quad (an\ exact\ differential)$$

1.13 Path Function

There are certain quantities which cannot be located on the graph by a point but are given by the area or so, on that graph. In that case, the area on the graph , related to the particular process, is a function of the path of the process. Such quantities are called **path functions**.

Examples, Heat , Work, etc.

Heat and work are *inexact differentials.* Their change cannot be written as difference between their end states.

Thus ${}_1Q_2$ or $Q_{1\text{-}2}$

Similarly $\int_1^2 \delta W \neq W_2 - W_1 \quad and\ is\ shown\ as$ ${}_1W_2$ or $W_{1\text{-}2}$

Note:

The operator

$\delta\ is\ used\ to\ denote\ inexact\ differentials\ and\ operator\ d\ is\ used\ to\ denote\ exact\ differential$

1.14 Temperature

-The temperature is a thermal state of a body which distinguishes a hot body from a cold body.

-The temperature of a body is proportional to the stored molecular energy.

- A particular molecule does not have a temperature, it has energy

ملاحظة: الجزيئة ليس لديها درجة حرارة ، تمتلك طاقة

- النظام له درجة حرارة اما جزيئة معينة داخل النظام ليس لديها درجة حرارة لديها طاقة حركية.

- The gas as a system has a temperature. **- الغاز مثل النظام لديه درجة حرارة**

-Instruments for measuring ordinary temperatures are known as ***thermometers*** and those for measuring high temperatures are known as ***pyrometers.***

-It has been found that a gas will note occupy any volume at a **certain temperature**. This temperature is known as ***absolute zero temperature.***

لقد وجد أن الغاز لن يشغل أي حجم عند درجة حرارة معينة،وتعرف درجة الحرارة هذه باسم درجة حرارة الصفر المطلق

-The point of absolute zero temperature is found to occur at 273 · 15℃ **below** the freezing point of water. Then

$$\text{Absolute temperature} = \text{Thermometer reading in } ℃ + 273$$

Absolute temperature can also be represented in degree Kelvin denoted by K (SI unit).

1.15 Zeroth Law of Thermodynamics

-***Zeroth Law of Thermodynamics***: states that if two systems are each equal in temperature to a third, they are equal in temperature to each other.

1.16 Pressure

1.16.1 Definition of pressure

Pressure is define as a force per unit area. Pressures are exerted by gasses, vapors and liquids.

جهاز قياس الضغط يسجل الفرق بين ضغطين وهذا الفرق بين الضغط المسلط من قبل المائع والضغط الجوي ambient atmospheric pressure . وتلك الجهاز يستدل على الضغط اما فوق الضغط الجوي او اقل من الضغط الجوي ، اما الفوق الضغط الجوي يسمى ضغط المقياس gauge pressure والاقل من الضغط الجوي يكون سالب negative pressure ويسمى vacuum pressure .

A schematic diagram showing the gauge pressure pressure, vacuum pressure and the absolute pressure is given in Fig.1.6.

Gauge pressure: the pressure which is above the atmospheric pressure is known as gauge pressure; the atmospheric pressure is zero gauge pressure.(Fig.1.6)

Vacuum pressure: the pressure which is below the atmospheric pressure is known as a vacuum pressure.(Fig.1.6)

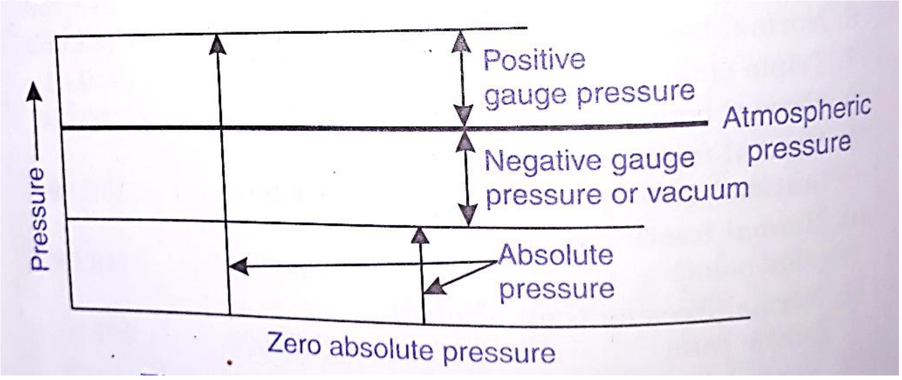


Fig.1.6. Schematic diagram showing gauge, vacuum and absolute pressures.

Mathematically:

(i) Absolute pressure= Atmospheric pressure + Gauge pressure

$$P_{abs} = P_{atm} + P_{gauge}$$

(ii) Vacuum pressure = Atmospheric pressure – Absolute pressure

Note:

Vacuum is defined as the absence of pressure. A perfect vacuum is obtained when absolute pressure is zero, at this instant molecular momentum is zero.

Atmospheric pressure is measured with the help of barometer.

Manometer: it is a device which measures either gauge pressure or vacuum pressure.

Barometer: the atmospheric pressure is measured by a device called a barometer.

1.16.2 Unit of pressure

1. The fundamental SI unit in N/m^2 (sometimes called *Pascal*, Pa)

2. Pressure is also measured in bar, 1bar= 10^5 N/m^2

3. Standard atmospheric pressure = 1.01325 bar =0.76 m Hg(or 760 mmHg).

The pressure unit Pascal is too small for pressure; therefore kilopascal, Mega Pascal and bar commonly used.

1 kPa = 10^3 Pa

1 MPa = 10^6 Pa =10^3 kPa

1 bar = 10^5 Pa =100 kPa

Atmospheric pressure varies with location on the earth, a standard reference can be defined and used to express other pressures

1 standard atmosphere (atm.) =101.325 Pa

=101.325 kPa

=1.01325 bar

Absolute pressure = atmospheric pressure $\pm$ $Gauge\ pressure$

Or, $p_{abs} = p_a + p_{gauge}$

$p_{gauge} = \rho g h$

Where,

$\rho = density$; $g = acceleration = 9.81\, m/s^2$;

$h = high\ of\ liquid\ coluum$

Analysis

Using the relation

$p = \rho g h$

Let p=1 bar=10^5 N/m^2 ; $\rho = 1000\ kg/m^3\ for\ water$; $g = 9 \cdot 81\, m/s^2$

For water

$$1 \times 10^5 = 1000 \times 9 \cdot 81 \times h$$

$$h = \frac{1 \times 10^5}{1000 \times 9.81} = 10 \cdot 2\, m\ of\ water$$

$$or \quad 1\, mm\ of\ water = 9 \cdot 81 \frac{N}{m^2} = 9 \cdot 81\, Pa$$

By using the relation

$$h_{water} \times S_{water} = h_{mercury} \times 13 \cdot 6$$

Therefore, 1 bar= 750 mm of Hg

1.16.3 U-tube manometer

Low pressures are generally determined by manometers which employ liquid columns. A U-tube manometer is in the form of U-tube and is made of glass (Fig.1.7).

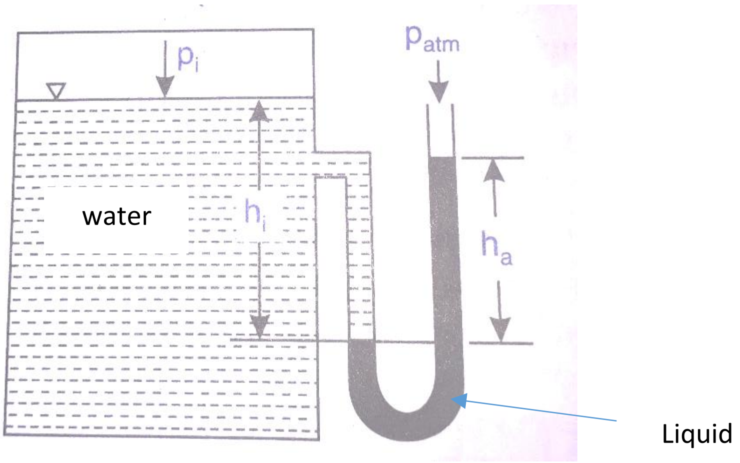


Fig.1.7. Principle of U-tube manometer.

Considering equilibrium condition, we have

$$p_{atm} + w_a h_a = p_i + w_i h_i$$

Where, $p_{atm} = Atmospheric\ pressure$

$p_i = Pressure\ over\ water\ surface\ in\ the\ container$

$h_a = Heigh\ of\ liquid\ in\ U - tube\ manometer$

$h_i = Difference\ between\ water\ surface\ and\ lower\ surface\ of\ the\ liquid\ in\ manometer$

$w_a = Specific\ weight\ of\ liquid$

$w_i = Specific\ weight\ of\ water$

1.17 Specific volume

The specific volume of a system is the volume occupied by the unit mass

$$Specific\ volume = v = \frac{Total\ Volume}{mass} = \frac{V}{m} \qquad (m^3/kg)$$

Example 1.1. ***Convert the following readings of pressure to kPa assuming that barometer read 760 mm of Hg.***

ملاحظة: البارومیتر (barometer) جهاز لقياس الضغط الجوي

(i) 80 cm of Hg

(ii) 30 cm Hg vacuum

(iii) 1.35 m H_2O gauge

(iv) 4.2 bar

Solution. Assuming density of Hg

$\rho_{Hg} = 13600 \;\; kg/m^3$

Where $\rho_{hg} = density\ of\ Hg$

Pressure of 760 mm of Hg will be

$$p = \rho_{Hg} gh = 13600 \times 9 \cdot 81 \times \frac{760}{1000} \approx 101 \cdot 325\, kPa$$

i.e **760 mm of Hg =101.325 kPa**

(i) pressure of 80 cm of Hg

Pressure in mm of Hg	pressure in kPa
760	101.325
800	p

$$p = \frac{101 \cdot 325 \times 800}{760} = 106 \cdot 65\, kPa \quad (Ans\, \cdot)$$

(ii) 30 cm Hg vacuum

$$= 76 - 30 = 46\ cm\ of\ Hg\ absolute$$

$$= \frac{101 \cdot 325 \times 460}{760} = 61 \cdot 328\, kPa \quad (Ans\, \cdot)$$

(iii) pressure due to 1.35 m H_2O gauge

$$p = \rho_{H_2O} \times g \times h = 1000 \times 9 \cdot 81 \times 1 \cdot 35 = 13 \cdot 238\, kPa \;\; (Ans\, \cdot)$$

(iv) 4.2 bar

$$= 4 \cdot 2 \times 10^5 = 420000\, Pa = \frac{420000}{10^3} = 420\, kPa \quad (Ans\, \cdot)$$

Note.

Pressure of 1 atmospheric = 760 mm of Hg = 101325 N/m^2

Example 1.2. *On a piston of 10 cm diameter a force of 1000 N is uniformly applied .Find the pressure on the piston.*

Solution. Diameter of the piston, d=10 cm=0.1 m

$\therefore \;\; Pressure\ on\ the\ piston$

$$p = \frac{Force}{Area} = \frac{F}{A} = \frac{F}{\pi d^2/4} = \frac{1000}{\pi(0.1)^2/4} = 127307\ N/m^2 = 127 \cdot 307\ kN/m^2$$

Example 1.3. *A tube contains an oil of specific gravity 0.9 to a depth of 120 cm. Find the gauge pressure at this depth* $(in\ kN/m^2)$.

Solution.

Specific gravity of oil =0.9

Depth of oil in the tube, h=120 cm=1,2 m

We know that

$p = \rho g h \qquad \rho = density\ in\ kg/m^3$

$$Specific\ gravity = S = \frac{density\ of\ matter}{density\ of\ water} = \frac{\rho_{matter}}{\rho_{water}}$$

In this example the matter is the oil, hence

$\rho_{oil} = S \times \rho_w = 0 \cdot 9 \times 1000$

$p = (0 \cdot 9 \times 100) \times g \times h = (0 \cdot 9 \times 1000) \times 9 \cdot 81 \times 1 \cdot 2 = 10 \cdot 595\, kN/m^2$

Example 1.4. *A U-tube manometer is connected to a gas pipe. The level of the liquid in the manometer arm open to the atmosphere is 170 mm lower than the level of the liquid in the arm connected to the gas pipe. The liquid in the manometer has specific gravity of 0.8. find the absolute pressure of the gas if the manometer reads*

760 mmHg.

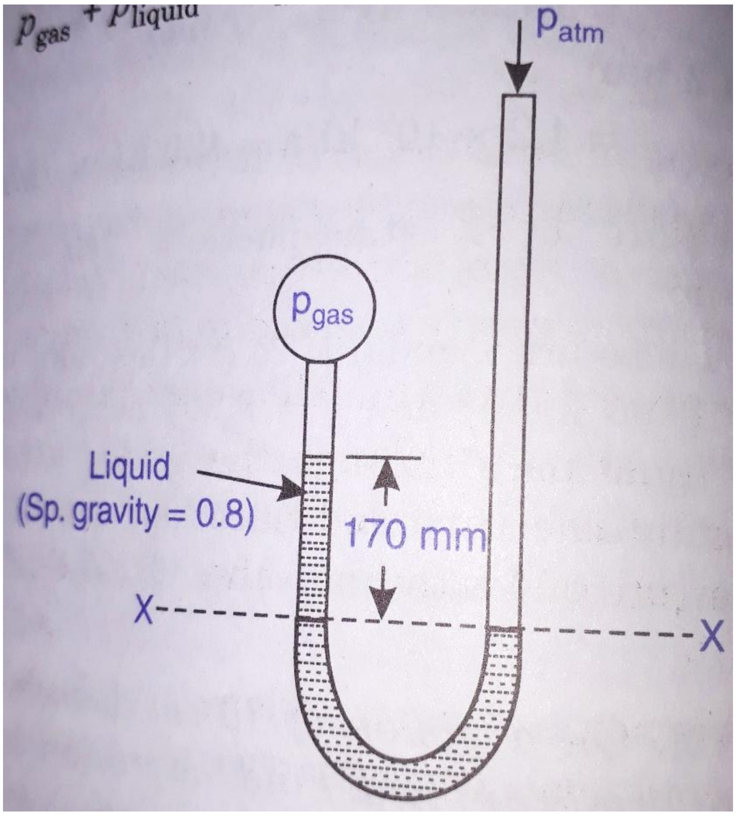


Fig.1.8

Solution.

Equating pressure on both arms above the line XX, Fig.1.8

$$p_{gauge} + p_{liquid} = p_{atm} \qquad (i)$$

Now $\quad p_{liquid} = \rho gh = (0\cdot 8 \times 1000) \times 9\cdot .81 \times \frac{170}{1000} = 1334.16\ N/m^2 = \frac{1334.16}{10^5} = 0\cdot 0133416\ bar$

Substituting these value in eqn.(i) above, we have

$$p_{gas} + 0\cdot 0133416 = 1\cdot 01325$$

$\therefore \quad p_{gas} = 1\cdot 01325 - 0\cdot 0133416 = 0\cdot 9999\ bar \qquad (\boldsymbol{Ans}\cdot)$

1.17. Reversible and Irreversible Processes

Reversible process: *A reversible process (also sometimes known as quasi-static process) is one which can be stopped at any stage and reversed so that the system and surroundings are exactly restored to their initial states.*

عملية قابلة للعكس (تعرف أحيانا باسم عملية شبه ثابتة)هي عملية يمكن أيقافها في أي مرحلة وعكسها بحيث يتم استعادة النظام والمناطق المحيطة به الى حالتها الأولية

This process has the following *characteristics:*

1.It must pass through the same states on the reversed path as were initially visited on the forward path.

الاجراء يجب ان يمر عبر نفس الحالات states على المسار المعكوس كما تم المرور عليه في البداية على المسار الامامي

2.It must pass through a continuous series of equilibrium states.

يجب ان يمر عبر سلسلة مستمرة من حالات التوازن

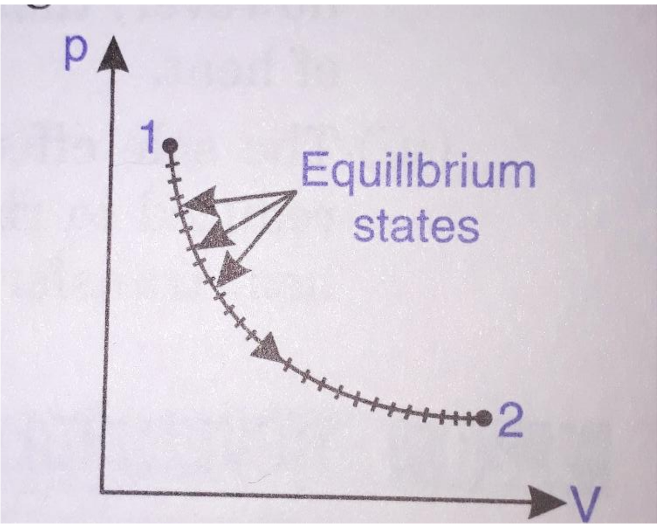


Fig.1.9 .Reversible process

Examples. Some examples of nearly reversible processes are:

(i) Frictionless relative motion.

(ii) Expansion and compression of spring

(iii) Frictionless adiabatic expansion or compression of fluid.

(iv) Polytropic expansion or compression of fluid.

(v) Isothermal expansion or compression

(vi) Electrolysis التحليل الكهربائي

Irreversible process: *An irreversible process is one in which heat is transferred through a finite temperature.*

العملية التي لا رجعة فيها هي العملية التي تنتقل فيها الحرارة من خلال درجة حرارة محدودة

Examples.

(i)Relative motion with friction

(ii)Combustion

(iii)Diffustion

(iv)Free expansion

(v)Throttling

(vi) Electricity flow through a resistance

(vii)Heat transfer

(viii)Plastic deformation

An irreversible process is usually represented by a dotted(or discontinuous)line joining the end states to indicate that the intermediate states are indeterminate(Fig.1.10).

عادة ما يتم تمثيل عملية لا رجعة بخط منقط ينظم الى الحالات النهائية للاشارة الى ن الحالات الوسطية غير محددة

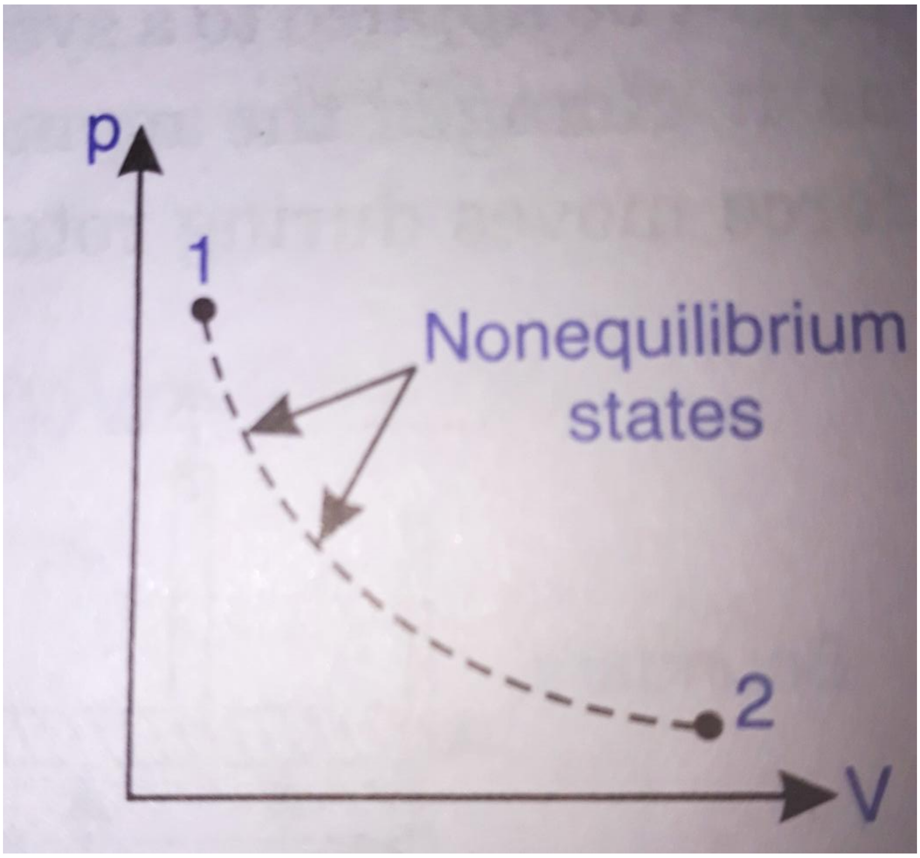


Fig.1.10.Irreversible process

Irreversibilities are of *two types:*

1. External irreversiblilities. *These are associated with dissipating effects outside the working fluid.*

هذه ترتبط بتأثيرات تبديد dissipating خارج مائع التشغيل(النظام)

2. Internal irreversibilities. *These are associated with dissipating effects within the working fluid.*

هذه ترتبط بتأثيرات تبديد داخل مائع التشغيل(النظام)

1.18 Energy, Work and Heat

1.18.1. Energy

Energy is a general term embracing energy in transition and stored energy.

الطاقة مصطلح عام يشمل الطاقة التي تمر بمرحلة انتقالية والطاقة المخزنة

The stored energy of a substance may be in the forms of *mechanical energy* and *internal energy* (other forms of stored energy may be chemical energy and electrical energy).

Part of the stored energy may take the form of either potential energy (due to high above a chosen datum line) or kinetic energy (due to velocity).

*in a **non-flow process** usually there is no change in potential or kinetic energy hence mechanical energy will not enter the calculations.*

In a flow process, however, they may changes in both potential and kinetic energy and these must be taken into account.

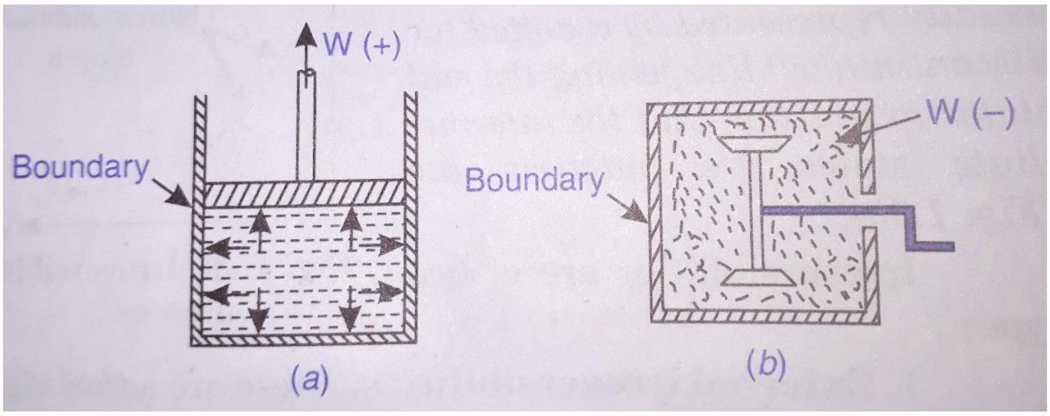
***Heat and work** are the forms of energy in transition.*

ملاحظة : الطاقة عندما تنتقل (تعبر جدار النظام system boundary) يكون شكلها اما شغل او حرارة

1.18.2 Work and Heat

$$Work = Force \ \times distance = F \times L$$

عادتا في ديناميك الحرارة يدرس النظام وللنظام جدار يسمى boundary of system وعندما يحدث لهذا الجدار ازاحة نتيجة القوة المسلطة عليه والناتجة عادتا من الضغط المسلط على جدران النظام وهذه الازاحة تكون باتجاه القوة المسلطة وكما موضح في الشكل (1−11)(أ) والذي يوضح اسطوانة يتحرك داخلها مكبس piston وتسمى هذه المنظومة piston−cylinder arrangement وهو نفس ما موجود في محرك احتراق داخلي(محرك السيارة)، يسمى الشغل الناتج من الازاحة لجدران النظام boundary work ويكون موجب عندما تكون الازاحة موجبة(حالة التمدد expansion process) وسالب عندما تكون الازاحة سالبة (compression process)



(a) (b)

Fig.1.11

الشكل (a) النظام يسلط ضغط على المكبس ويحركه الى الاعلى وينتج تمدد في الحجم وبالتالي يكون الشغل موجب كونه مسلط من قبل النظام (خارج من النظام)

Sign convention:

(i) if the work is done by the system on the surroundings , the work is said to be positive

(ii) if the work is done on the system by the surroundings, the work is said to be negative.

الشكل(b) شغل ميكانيكي مصدره من الخارج surroundings مسلط على النظام ، الشغل في هذه الحالة يكون سالب

Heat

Heat denoted by the symbol Q, may be, defined in an analogous way to work as follows:

" Heat is 'something' which appears at the boundary when a system changes its state due to a difference in temperature between the system and its surroundings".

Heat, like work, is a transient quantity, which only appears at the boundary while a change is taking place within a system.

الشغل والحرارة ليس exact differentials *وتكاملهما يجب ان يكون بهذه الصيغة:*

$\int_1^2 \delta W = W_{1-2}\ 0r\ {}_1W_2$ (or W) and

$\int_1^2 \delta Q = Q_{1-2}\ or\ {}_1Q_2$ (or Q)

Sign convention :

(i) if the heat flows into a system from the surroundings, the quantity is said to be positive

(ii) if the heat flows from the system to the surrounding it is said to be negative.

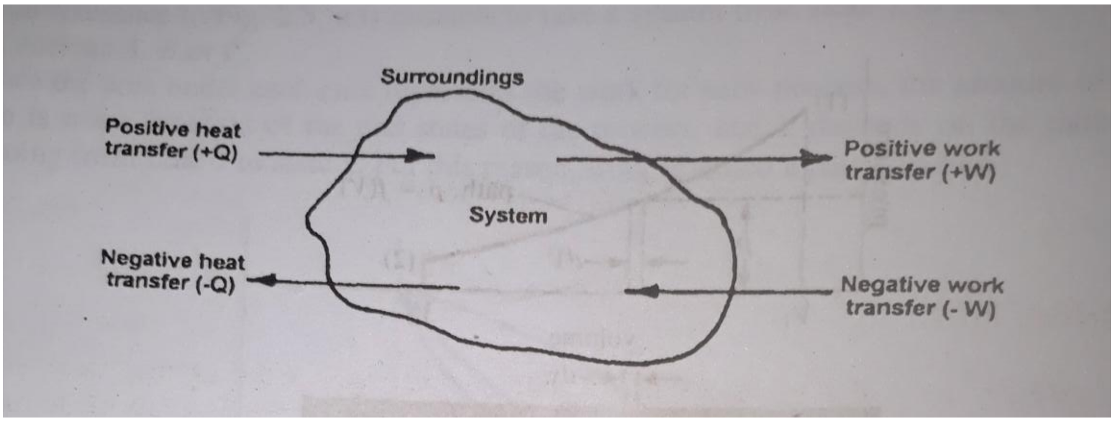


Fig.1.12.Sign convention for work and heat

Comparison of Work and Heat

Similarities:

(i) Both are path functions and inexact differentials.

(ii) Both are boundary phenomenon i.e, both are recognized at the boundaries of the system as they cross them.

(iii) Both are associated with a process, not a state. Unlike properties , work and heat has no meaning at a state.

(iv) systems possess energy, but not work or heat.

تمتلك الأنظمة الطاقة ولا تمتلك شغل او حرارة

Dissimilarities:

(i) In heat transfer temperature difference is required.

(ii) In a stable system there cannot be work transfer, however, there is no restriction for the transfer of heat.

في نظام مستقر لا يمكن ان يكون هناك نقل شغل، ومع ذلك، لا توجد قيود على نقل الحرارة

1.19 Reversible Work

الشكل((1.13(a) افترضناه يحتوي على مائع مثالي بدون احتكاك اثناء الجريان ، والشكل عبارة عن مكبس يتحرك داخل اسطوانة من دون احتكاك (عملية ارجاعية reversible process) وتسمى ايضا frictionless process ، لتكن :

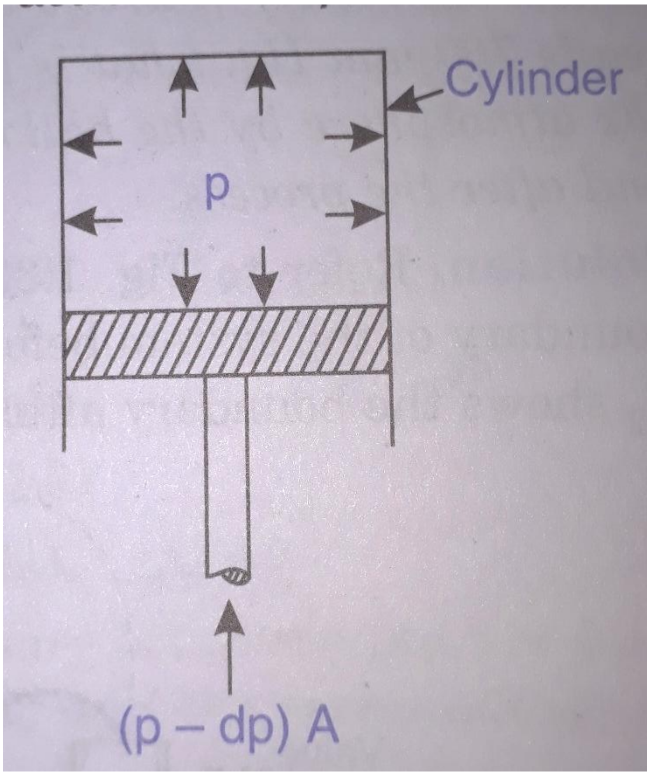


Fig.1.13(a)

A= Cross−sectional area of the piston,

P= pressure of the fluid at any instant,

dl= the distance moved by the piston under the action of the force exerted.

$$p = \frac{F}{A} \quad or \quad F = pA$$

Work done by the fluid=$(pA) \times dl = pdV$

Where dV = a small increase in volume, or considering unit mass

$$Work\ done = pdv$$

Where $v = specific\ volume$

Note that $specific\ volume = \frac{Total\ volume}{mass}$

Or $v = \frac{V}{m}$ $\quad \therefore V = mv$

This is only true when

(a) the process is frictionless

(b) the different in pressure between the fluid(or system) and its surroundings during the process is infinitely small. Hence when a reversible process takes place between state 1 and state 2 , we have

$$work\ done\ by\ the\ unit\ mass\ of\ fluid = \int_1^2 pdv$$

The work done by the fluid during any reversible process is therefore given by the area under the line of process plotted on a $p - v$ diagram [Fig.1.13(b)].

$$i.e\ Work\ done = Shaded\ area\ on\ Fig \cdot 14(b)$$

$$= \int_1^2 pdv$$

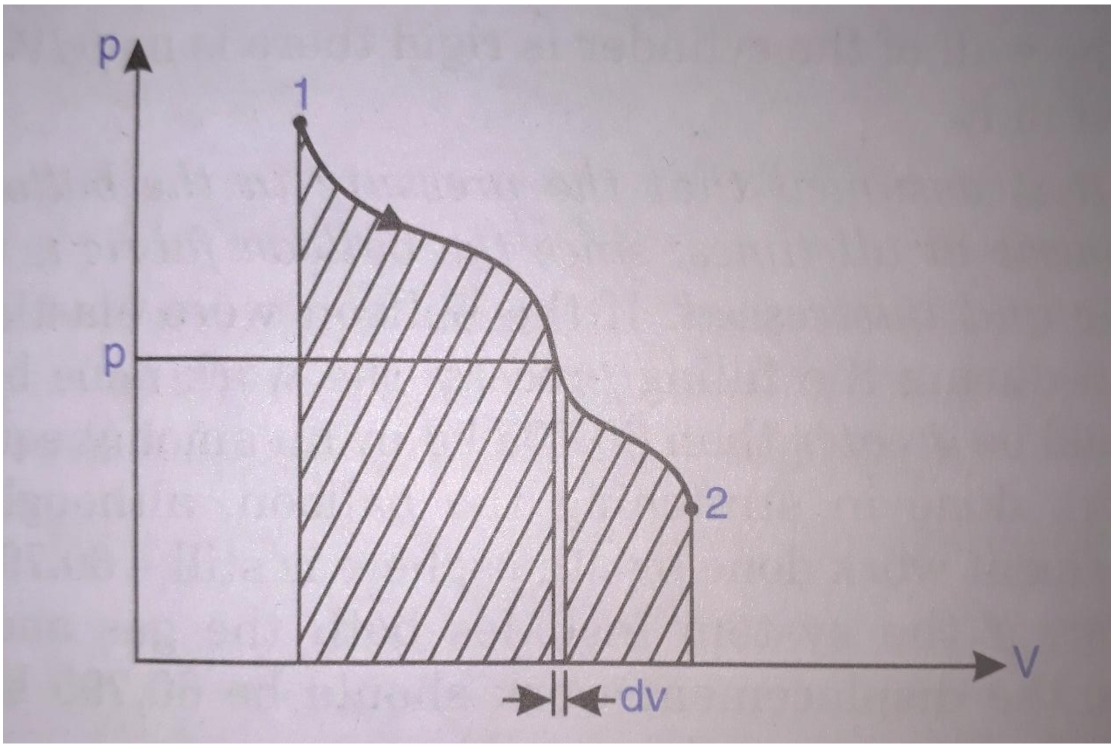


Fig.1.13 (b)

Example 1.5. *The properties of a closed system change following the relation between pressure and volume as $pV = 3$, where p is in bar V is in m^3. Calculate the work done when the pressure increases from 1.5 bar to 7.5 bar.*

Solution.

Initial pressure, p_1=1.5 bar

Finial pressure, p_2= 7.5 bar

Relation between p and V, pV=3.0

Work done, W=?

The work done during the process is given by

$$W = \int_{V_1}^{V_2} pdV$$

From the above relation $V_1 = \frac{3}{p_1} = \frac{3}{1.5} = 2\, m^3$

$$V_2 = \frac{3}{2} = \frac{3}{7.5} = 0\cdot 4\, m^3$$

From the relation pv=3 , **we find** $p = \frac{3}{V}$

$$W = 10^5 \times \int_2^{0\cdot 4} \frac{3}{V} dV = 10^5 \times 3[LnV]_2^{0.4}$$

$$= 10^5 \times 3[Ln0\cdot 4 - Ln2]$$

$$= -3 \times 10^5\, Ln\left(\frac{2}{0\cdot 4}\right)$$

$$= -3 \times 10^5\, Ln\, 5$$

$$= -3 \times 10^5 \times 1.61$$

$$= -4\cdot 83 \times 10^5\, Nm$$

$$= -4\cdot 83 \times 10^5 J = -4\cdot 83\, \frac{10^5}{10^3} = -4\cdot 83 \times 10^2 kJ = -483kJ \quad (Ans\cdot)$$

Example 1.6. *To a closed system* $150\ kJ$ *of work is supplied. If the initial volume is* $0\cdot 6\ m^3$ *and pressure of the system changes as* $p = 8 - 4V$, *where p is in bar and V is in* m^3, *determine the final volume and pressure of the system.*

Solution.

Amount of work supplied to a closed system = 150 kJ

Initial volume, $V_1=0.6\ m^3$

Pressure−volume relationship, p=$8-4$V

The work done during the process is given by

From the relation p=$8-4$V , substitute from p in this relation:

$$W = \int_{V_1}^{V_2} pdV = 10^5 \int_{0\cdot 6}^{V_2} (8-4V)dV$$

ملاحظة: ضرب التكامل اعلاه في 10^5 لتحويل الضغط من البار الى الباسكال حيث ان (1 bar=10^5 Pa) علما ان (1Pa=$1\frac{N}{m^2}$)

$$W = 10^5[8V - 4\frac{V^2}{2}]_{0\cdot 6}^{V_2}$$

$$= 10^5[8(V_2 - 0\cdot 6) - 2(V_2^2 - 0\cdot 6^2)]$$

$$= 10^5[8V_2 - 4\cdot 8 - 2V_2^2 + 0\cdot 72]$$

$$= 10^5[8V_2 - 2V_2^2 - 4\cdot 08]$$

But this work is equal to -150kJ, as this work is supplied to the system

Note: 1kJ = 10^3 J

$$\therefore\ -150\times 10^3 J = 10^5[8V_2 - 2V_2^2 - 4\cdot 08]$$

$$-150 = 10^2[8V2 - 2V_2^2 - 4\cdot 08$$

$$or \quad 2V_2^2 - 8V_2 + 2\cdot 58 = 0$$

الحل بطريقة الدستور لايجاد الحجم المطلوب

$$V_2 = \frac{8 \pm \sqrt{64 - 4\times 2\times 2\cdot 58}}{4}$$

$$= \frac{8 \pm 6 \cdot 585}{4} = 0 \cdot 354\, m^3$$

اشارة الجمع تهمل في هذا المثال ، وضح لماذا ؟

Final volume, $V_2 = 0 \cdot 354 m^3$ $(Ans \cdot)$

And, Final pressure, $p_2 = 8 - 4V = 8 - 4 \times 0 \cdot 354 = 6 \cdot 584\, bar$ (Ans)

Reversible Work

Example 1.7. A fluid at a pressure of 3 bar, and with a specific volume of 0.18 m^3/kg, contained in a cylinder behind a piston expands reversibly to a pressure of o.6 bar according to a law, $p = \frac{C}{v^2}$, where C is a constant. Calculate the work done by the fluid on the piston.

Solution. Refer to Fig.1.15.

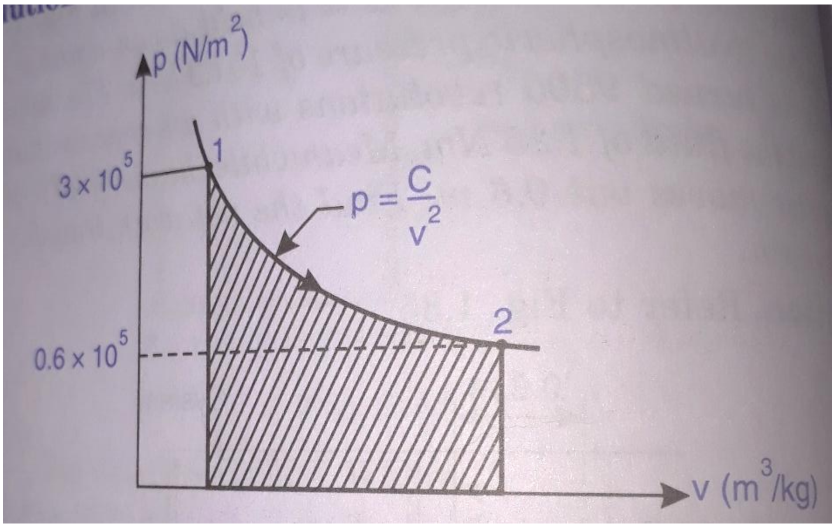


Fig 1.15. Example 1.8

$$p_1 = 3bar = 3 \times 10^5\, N/m^2$$

$$v_1 = 0.18 m^3/kg$$

Work done =shaded area=$\int_1^2 pdv$

i.e, work done, $W = \int_1^2 \frac{C}{v^2} dv = C \int_1^2 \frac{dv}{v^2} = C \left| \frac{v^{-2+1}}{-2+1} \right|_{v_1}^{v_2}$

$$= C[-v^{-1}]_{v_1}^{v_2} = C\left[-\frac{1}{v}\right]_{v_1}^{v_2} = C\left[\frac{1}{v_1} - \frac{1}{v_2}\right] \quad (i)$$

Also $C = pv^2 = p_1 v_1^2 = 3 \times 10^5 \times 0.18^2 = 0.0972 \times 10^5$

Substituting the values of C, v_1 *and* v_2 *in eqn* $\cdot (i)$. *we get*

$$v_2^2 = \frac{C}{p} = \frac{0 \cdot 0972 \times 10^5}{3 \times 10^5} = 0 \cdot 0324$$

Or, $v_2 = 0 \cdot 18\, m^3$

Work done, $W = 0.0972 \times 10^5 \left[\frac{1}{0.18} - \frac{1}{0.402}\right] = 29840 \frac{J}{kg}$

$$W = 29 \cdot 840\, kJ/kg \quad (Ans \cdot)$$