

International Association Of Certified Practicing Engineers	 INTERNATIONAL ASSOCIATION OF CERTIFIED PRACTICING ENGINEERS www.iacpe.com	Page : 1 of 107
		Rev: 01
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IACPE No 19, Jalan Bilal Mahmood 80100 Johor Bahru Malaysia	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	

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International Association Of Certified Practicing Engineers	 IACPE INTERNATIONAL ASSOCIATION OF CERTIFIED PRACTICING ENGINEERS www.iacpe.com	Page : 2 of 107
		Rev: 01
		Rev. 01- August 2014
IACPE No 19, Jalan Bilal Mahmood 80100 Johor Bahru Malaysia	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	

TABLE OF CONTENT

INTRODUCTION	4
Scope	4
Basic Concepts	4
Thermodynamic System	5
The Law of Thermodynamics	9
Heat Transfer	10
DEFINITIONS	16
NOMENCLATURE	17
THEORY	18
Thermodynamics	18
Properties of Pure Substance	18
Phases	18
Behavior	19
Equation of State (EOS)	26

International Association Of Certified Practicing Engineers	 www.iacpe.com	Page : 3 of 107
		Rev: 01
		Rev. 01- August 2014
IACPE No 19, Jalan Bilal Mahmood 80100 Johor Bahru Malaysia	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	

Ideal Gas Equation	29
Virial Equation	30
Beattie-Bridgeman Equation	31
Benedict-Webb-Rubin Equation	32
Other Cubical Equation of State	33
Pitzer's Correlation	34
Specific Heat	36
The First Law of Thermodynamics	40
Heat Effects	45
Sensible Heat	46
Latent Heat	47
Standard Heat of Reaction	48
Standard Heat of Formation	48
Standard Heat of Combustion	49

International Association Of Certified Practicing Engineers	 www.iacpe.com	Page : 4 of 107
		Rev: 01
		Rev. 01- August 2014
IACPE No 19, Jalan Bilal Mahmood 80100 Johor Bahru Malaysia	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	

The Second Law of Thermodynamics	50
Identifying Process	52
Heat Engines	53
Entropy	60
The Carnot Refrigerator and Heat Pump	62
Heat Transfer	64
Mechanism of heat transfer	64
Conduction	64
Equation of Conduction Heat	68
Convection	79
Dimensionless Numbers	81
Forced Convection	83
Natural Convection	93
Radiation	96
Radiation of Blackbody materials	98

International Association Of Certified Practicing Engineers	 www.iacpe.com	Page : 5 of 107
		Rev: 01
		Rev. 01- August 2014
IACPE No 19, Jalan Bilal Mahmood 80100 Johor Bahru Malaysia	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	

Thermal Resistance	98
Concept	98
Thermal Resistance Cases	100
Thermal Insulation	104
Material Choices	104
REFERENCES	106

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	Page 6 of 107
		Rev: 01
		August, 2014

LIST OF TABLE

Table 1 : Constants in Beattie-Bridgeman Equation	32
Table 2 : Constants in Benedict-Webb-Rubin Equation	32
Table 3 : Equation of State	34
Table 4 : Value of Thermal Conductivity	66
Table 5 : Thermal diffusivities of common material	68
Table 6 : Conduction Shape Factors	76
Table 7 : Prandtl Number for Common fluids	82
Table 8 : Empirical correlations for the average Nusselt number	87
Table 9 : Nusselt number correlations for tube banks	89
Table 10: Correction Factor (F)	90
Table 11: Nusselt number and friction factor for ducts and conduits	92
Table 12: Nusselt number for natural convection over surfaces	95
Table 13: The wavelength ranges of color	97
Table 14: Expressions for Thermal Resistance	103

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	Page 7 of 107
		Rev: 01
		August, 2014

LIST OF FIGURE

Figure 1 : A simple example of thermodynamic system	10
Figure 2 : Criterion of Thermodynamic Properties	11
Figure 3 : Steady state Process	12
Figure 4 : An example of pure substance	18
Figure 5 : The atoms – arrangement in diffrenet phases	19
Figure 6 : T-v diagram for water phase-change processes	20
Figure 7 : Critical Point of Water	21
Figure 8 : P-v Diagram	22
Figure 9 : P-v Diagram of Pure Substance	23
Figure 10 : P-T diagram	24
Figure 11 : P-v-T surface	25
Figure 12 : Comparison of Z factors for various gases	27
Figure 13 : Illustration of Specific Heat	37
Figure 14 : Control Volume	41
Figure 15 : Example of Heat Engines	53
Figure 16 : Steam Power Plant	54
Figure 17 : Heat Transfer between two reservoirs	55
Figure 18 : Carnot cycle processes	58
Figure 19 : Illustration of Heat Conduction experiment	65
Figure 20 : Heat Conduction through a plane wall	69
Figure 21 : Heat Conduction in a Long Cylinder	72
Figure 22 : Heat Conductin in a spherical element	75
Figure 23 : Average C_D for flow across smooth cylinder and sphere	85

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	Page 8 of 107
		Rev: 01
		August, 2014

Figure 24 : Heat transfer in pipe flow	90
Figure 25 : Temperature profile in the compoosite wall	100
Figure 26 : Thermal resistance of conduction heat in circuit form	101
Figure 27 : Convective resistances in series	102
Figure 28 : Heat transfer in parallel form	103

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	Page 9 of 107
		Rev: 01
		August, 2014

INTRODUCTION

Scope

This Training Module provides an overview one of the basic fundamentals of engineering; The knowledge of the thermodynamics and heat transfer is essential to design efficient process equipment.

At the first part of this module will deal with the science of thermodynamics. The science of thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another, and makes no reference for how long the process will take.

The fundamental concepts of thermodynamics form the framework for heat transfer. Based on this thermodynamic framework the module will present the three basic mechanisms of heat transfer, which consists of: (1) Conduction, (2) Convection, and (3) Radiation.

Basic Concepts

The word thermodynamics stems from the Greek words *therme* (heat) and *dynamis* (force). The formal study of thermodynamics began in the early 19th century through consideration of the motive power of heat, the capacity of hot bodies to produce work. Thermodynamics could be define simply as the science of energy.

Engineers use principles drawn from thermodynamics and other engineering sciences, in example fluid mechanics and heat and mass transfer, to analyze and design equipment intended to meet industrial needs. One of the fundamentals laws of nature is the conservation of energy principle. The conservataion of energy differs from that of mass in the energy can be generated in a chemical process.

Energy can exist in several forms, including chemical energy, heat, mechanical energy and electrical energy. The total energy is conserved, but energy can be transformed from one kind of energy to another. The change in the energy content of a body or any other system is equal to the difference between the energy input and the energy output, and the energy balance could be formulated as

$$E_{in} - E_{out} = \Delta E$$

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	Page 10 of 107
		Rev: 01
		August, 2014

The first law of thermodynamic is cites an expression of the conservation of energy principle, and it 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.

There is an important consideration that thermodynamics do not establish the rates of chemical of physical processes. Rates are depend on driving force and resistance. Although driving forces are thermodynamic variables, resistance are not. Neither can thermodynamics (a macroscopic – property formulation) reveal the microscopic mechanisms of physical or chemical processes. On the other hand, knowledge of the microscopic behavior or matter can be useful in the calculation thermodynamic properties. Thus, property values are important to the practical application thermodynamic properties.

Thermodynamic System

A system is could be defined as a quantity of matter or a region in space chosen for study. A system could be a closed or open system. A closed system consists of a fixed amount of mass, and no mass can across its boundary. On the other hand, an open system is usually encloses a device that involves mass flow such as compressor, nozzle or turbine. Both of thecase, energy transfer can occur across the system boundary in any of irs various forms, in example like : Heat, Work, Electrical / Magnetic Energy. Unlike closed and open system, isolated system is enclosed by a boundary that allows neither mass nor energy to transfer.

All matter external to the system constitutes the surroundings. The combination of the system and the surroundings is what made of the universe. The real or imaginary surface that separates the system from its surroundings is called the boundary. For practical purposes, in any thermodynamic analysis of a system it is necessary to include only the immediate surroundings in which the effects are felt.

Figure 1 shows a very common example of thermodyanmic system. The system consists of gas contained in a piston-and-cylinder arrangement derived from the idea of steam engines, which may typically exchange heat or work with its surroundings.

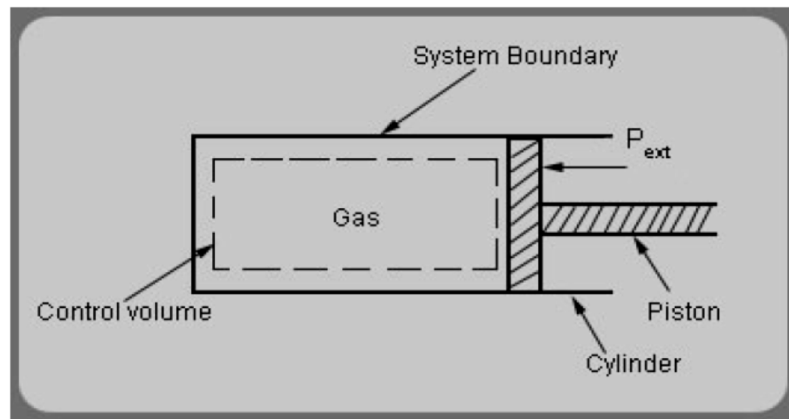


Figure 1. A simple example of thermodynamic system.

The dotted rectangle represents the 'control volume' which essentially encloses the mass of gas in the system and walls from the boundary of the system. If the internal gas pressure and the external pressure from the acting of moveable piston is the same, there is no net force operates that work on the system.

However, if there is an imbalancing force event, the piston would move until the internal and external pressures equalize. In the process some net work would be either delivered to or by the system, depending on whether the initial pressure of the gas is lower or higher than the externally applied pressure. In addition, if there is a temperature differential between the system and the surroundings the former may gain or lose energy through heat transfer across its boundary.

Any characteristic of a system is called a property. Some familiar properties that often heard in industrial application including : Pressure (P), Temperature (T), Volume (V) and also mass (m). The thermodynamic properties are typically classified as extensive and intensive. Intensive properties are those that are independent of the mass of a system, such as Temperature (T), Pressure (P), and Density (ρ). While extensive properties are those whose values depend on the size of the system. Total mass, total volume and total momentum are several examples of an extensive properties. Extensive properties per unit mass are called specific properties. Specific volume and specific total energy are the example of specific properties.

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER	Page 12 of 107
		Rev: 01
	CPE LEVEL I TRAINING MODULE	August, 2014

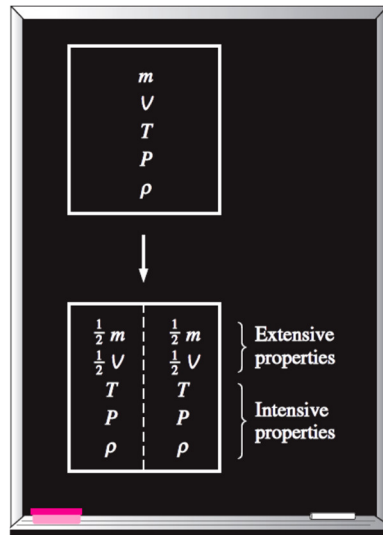


Figure 2. Criterion of Thermodynamic Properties.

The 'state' refers to the condition of a system as described by its properties. Since there are normally relations among the properties of a system, the state often can be specified by providing the values of a subset of the properties. All other properties can be calculated in terms of these few. When any of the properties of a system change, the state changes and the system is said to have undergone a 'Process'.

A 'process' is a transformation from one state to another. If a system exhibits the same values of its properties at two different times, it is in the same state at these times. A system is said to be at 'Steady state' if none of its properties changes with time (Figure 3).

A thermodynamic cycle is a sequence of processes that begins and ends at the same state. At the conclusion of a cycle all properties have the same values they had at the beginning. Consequently, over the cycle the system experiences no net change of state. Cycles that are repeated periodically play prominent roles in many areas of application. Steam circulating through an electrical power plant is a common example that could be found in industrial application.

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER	Page 13 of 107
		Rev: 01
	CPE LEVEL I TRAINING MODULE	August, 2014

Thermodynamics deals with equilibrium states. The term of 'equilibrium' implies a state of balance. In an equilibrium state there are no unbalanced potentials (or driving forces) within the system. A system in equilibrium experiences no changes when it is isolated from its surroundings.

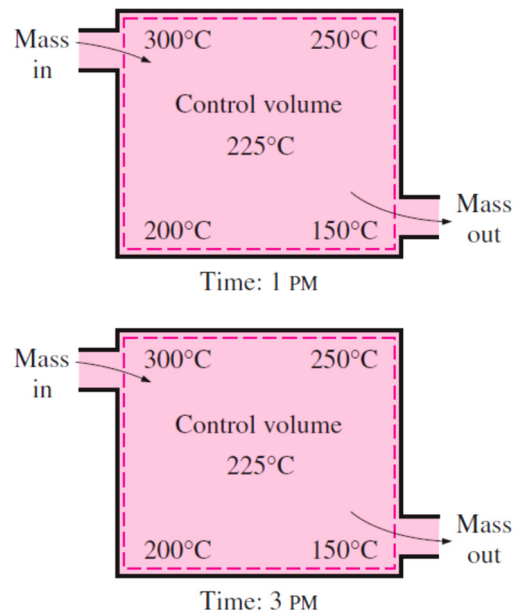


Figure 3. Steady state Process.

Processes are sometimes modeled as an idealized type of process called a 'quasiequilibrium'. A quasiequilibrium process is one in which the departure from thermodynamic equilibrium is at most infinitesimal. Because nonequilibrium effects are inevitably present during actual processes, systems of engineering interest could be at best an approximation but never realize, a quasiequilibrium process. The main interest in the quasiequilibrium process concept stems from two major considerations :

- Simple thermodynamic models giving at least qualitative information about the behavior of actual systems of interest often can be developed using the quasiequilibrium process concept. This is akin to the use of idealizations such as the point mass or the frictionless pulley in mechanics for the purpose of simplifying an analysis.
- The quasiequilibrium process concept is instrumental in deducing relationships that exist among the properties of systems at equilibrium.

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	Page 14 of 107
		Rev: 01
		August, 2014

There are many types of equilibrium and a system is not thermodynamic equilibrium unless the conditions of all the relevant types of equilibrium are satisfied. In example, a system is in 'Thermal equilibrium' if the temperature is the same throughout the entire system. The system involves no temperature differential, which is the driving force for heat flow. Mechanical equilibrium is related to pressure and a system is in mechanical equilibrium if there is no change in pressure at any point of the system with time.

On the other hand, if a system involves two phases, it is in phase equilibrium when the mass of each phase reaches an equilibrium level and stays there. A system could be in 'Chemical equilibrium' if its chemical composition does not change with time, that is, no chemical reactions occur. A system will not be in equilibrium unless all the relevant equilibrium criteria are satisfied.

The Law of Thermodynamics (General review)

The Zeroth Law of Thermodynamics

The level of temperature qualitatively measured with words like cold, warm, and hot. Nevertheless, the measurement of things qualitatively could be misleading due to the material properties, at same temperature, a metal could be colder than the woods.

The zeroth law of thermodynamics states that if two bodies are in thermal equilibrium with a third body, they are also in thermal equilibrium with each other. The zeroth law was first formulated by R. H. Fowler in 1931, it was cited a century after the formulation of the first and the second laws of thermodynamics. It was named 'the zeroth'; since it should have preceded the first and the second laws of thermodynamics.

First Law of Thermodynamics

The energy change of any system together with its surrounding is zero. Implicit in this declaration is the affirmation that there exists a form of energy, known as internal energy, which for systems in equilibrium states is an intrinsic property of the system. Internal energy is separate from the external energy forms. Nevertheless, internal energy originates in the kinetic and potential energies of molecules and submolecular particles. In applications of the first law of thermodynamics energy at its forms (internal and external) should also be considered.

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER	Page 15 of 107
		Rev: 01
		August, 2014
CPE LEVEL I TRAINING MODULE		

The Second Law of Thermodynamics

The use of the second law of thermodynamics is not limited to identifying the direction of processes. However, the second law also asserts that energy has quality as well as quantity. The first law is concerned with the quantity of energy and the transformations of energy from one form to another with no regard to its quality.

Preserving the quality of energy is a major concern to engineers, and the second law provides the necessary means to determine the quality as well as the degree of degradation of energy during a process. The second law of thermodynamics is also used in determining the theoretical limits for the performance of commonly used engineering systems, such as heat engines and refrigerators, as well as predicting the degree of completion of chemical reactions.

The Third Law of Thermodynamics

Nernst and Planck at the beginning of the twentieth century lead a postulate that: "The absolute entropy is zero for all perfect crystalline substances at absolute zero temperature" by recent studies at very low temperatures have increased confidence in this postulate which is now accepted as the third law of thermodynamics.

The 'Heat' could be described as an energy that is transferred because of the existence of a temperature difference between two systems or two parts of a system. Heat usually refer to energy in transit. It cannot be said that a system accumulates heat. Heat is only transferred to a system and once it enters the system, this type of energy is transformed in other types of energy like kinetic energy or mechanical work.

Heat Transfer

At the first part of this module, the engineer will deal with the science of thermodynamics. The science of thermodynamics deals with the amount of heat transfer as a system undergoes a process from one equilibrium state to another, and makes no reference for how long the process will be taken.

The fundamental concepts of thermodynamics form the framework for heat transfer. Based on this thermodynamic framework the module will present the three basic mechanisms of heat transfer, which consists of: (1) Conduction, (2) Convection, and (3) Radiation

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER	Page 16 of 107
		Rev: 01
		August, 2014
CPE LEVEL I TRAINING MODULE		

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent, less energetic ones as a result of interaction between the particles. Meanwhile, convection is the mode of heat transfer between solid surface and the adjacent liquid or gas that is in motion event, and it involves the combined effects of conduction and fluid motion. Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.

Heat exchangers, Heaters, Refrigerators, Solar collectors, Boilers, Condensers, Radiators, Furnaces, Boilers are a common example of Heat transfer equipment that widely used in industrial application. Every equipment design is basically designed on the basis of heat transfer analysis. As in general, the heat transfer problems encountered in practice could be considered in two main groups

- Rating problems.
- Sizing problems.

The rating groups will deal with the determination of the heat transfer rate for an existing system at a specified temperature difference. Nonetheless, the sizing problems deal with the determination of the size of a system in order to transfer heat at a specified rate for a specified temperature difference.

A heat transfer process or equipment can be studied either experimentally or analytically. The experimental approachment has the advantage that deals directly with the actual physical system and also the desired quantity. On the on contrary, the experimental approachment will cost a a expensive budget, very time-consuming and also often impractical. Hence, The analytical approachment has the advantage such as fast data-track, cheap, but sometimes leak of the accuracy of the assumptions and idealizations made in the analysis.

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER CPE LEVEL I TRAINING MODULE	Page 17 of 107
		Rev: 01
		August, 2014

DEFINITION

Conduction – The transfer of internal energy by microscopic diffusion and collisions of particles or quasi-particles within a body due to a temperature gradient.

Convection – The concerted, collective movement of groups of aggregates of molecules within fluids and solids.

Entropy – A quantity of the number of specific ways in which a thermodynamic system may be arranged, commonly understood as a measure of disorder.

Equation of State – A relation between state variables such as Temperature, Pressure and Specific Volume of substance.

Heat Balance – Often called an ‘energy balance’, a version of law of conservation of energy adapted thermodynamic systems.

Heat Transfer – Exchange of thermal energy between physical systems depending on the temperature and pressure of substance.

Phase - Region of space throughout which all physical properties of a material are essentially uniform.

Radiation – A process in which electromagnetic waves (EMR) travel through a vacuum or through matter-containing media..

Specific Heat – Physical quantity unit that determine the ratio of the added to (or subtract from) an object to the resulting temperature change.

Thermal Insulation – The reduction of heat transfer between objects in thermal contact or in range of radiative influence.

Thermal resistance – A heat property and a measurement of a temperature difference by which an object or material resists a heat flow.

Thermodynamic – A branch of physics that concerned with heat and temperature and relation to energy and work.

International Association Of Certified Practicing Engineers	THERMODYNAMICS AND HEAT TRANSFER	Page 18 of 107
		Rev: 01
	CPE LEVEL I TRAINING MODULE	August, 2014

NOMENCLATURE

A	: Area perpendicular of the x direction (m ²)
C _p	: Specific heat at constant pressure
C _v	: Specific heat at constant volume
COP	: Coefficient of Performance (%)
g	: Gravitational Acceleratio (m/s ²)
H	: Enthalpy (Joule)
k	: Thermal conductivity (W/m.K)
L	: Length of substances or materials (m).
P	: Pressure (kPa)
P _{cr}	: Critical Pressure (kPa)
P _R	: Reduced Pressure (kPa)
P ^{sat}	: Vapor pressure
Q	: Heat (Joule)
\dot{Q}	: The rate of heat transfer (W)
R	: An Ideal Gas Constant (8.314 J/mol.K)
S	: Entropy (J/K)
T	: Temperature (K)
T _{cr}	: Critical Temperature (K)
T _R	: Reduced Temperature (K)
U	: Internal Energy (Joule)
v	: Volume of substances (m ³)
W	: Work (Joule)
Z	: Compressibility factor
Δx	: The thickness of the plane (m)

SYMBOLS

β	: Volume expansivity
κ	: Isothermal compressibility
γ	: Specific heat ratio
η _{th}	: Thermal Efficiency