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CHAPTER 1

THERMODYNAMICS AND REFRIGERATION CYCLES

THERMODYNAMICS: First Law of Thermodynamics; Second Law of Thermodynamics; Equations of State; COMPRESSION REFRIGERATION CYCLES: The Ideal Basic Vapor Compression Refrigeration Cycle; The Reversed Carnot Cycle; The Actual Basic Vapor-Compression Refrigeration Cycle; Complex Vapor Compression Refrigeration Cycles; ABSORPTION REFRIGERATION CYCLES: Basic Absorption Refrigeration Cycle; Thermodynamic and Physical Data Required; Practical Cycles; Cycle Analysis

THE purpose of this chapter is to discuss the principles of thermodynamics and the application of these principles to refrigeration cycles. Part I of the chapter deals with the general laws of thermodynamics, Part II and Part III discuss the two most common methods used in the transfer of thermal energy, the compression refrigeration cycle, and the absorption refrigeration cycle.

A working knowledge of the fundamentals of thermodynamics is presumed of the reader, but it may be desirable to consult a recent textbook on the subject. Several recently developed texts are included in References 1-10 at the end of the chapter.

PART I: THERMODYNAMICS

The field of science concerned with relationships between heat and work, and properties of systems is called *thermodynamics*. The subject as discussed here is a classical presentation based on two general laws of nature: the *first* and *second laws of thermodynamics*.

Although the engineer is primarily interested in thermodynamics as a study of macroscopic phenomena, and may limit his study to an empirical science, thermodynamics is actually an extension of conventional mechanics to include temperature. By the acceptance of quantum mechanics it is possible to explain many of the phenomena hitherto the subject of inadequate theories, and to determine many of the properties by calculations, some of which are limiting values.

Thermodynamics in its broadest sense includes changes in systems involving energy transport in non-equilibrium states. However, thermodynamics, as discussed in this chapter, is limited to a study of equilibrium states and changes of state from one equilibrium state to another.[1]

A *thermodynamic system* is a collection of matter, bounded by surfaces, either real or imaginary. A system may be *closed* or *open*, i.e., mass flow into and out of an open system is permitted. That portion of the universe contiguous to the outside of the boundaries of the system is known as the surroundings.

FIRST LAW OF THERMODYNAMICS

The *first law of thermodynamics* is based on the results of experiments that attempted to measure the mechanical equivalent of heat. These experiments dissipated mechanical work by friction into thermal energy, to demonstrate an equivalence in a cyclic process between energy transport by work and energy transport in the form of heat, independent of the state path that was followed. It was postulated that there existed an internal energy function which would describe stored thermal energy. As a consequence, the first law of thermodynamics for a stationary *closed* system for any process is stated as:

$$ {}_1Q_2 - A\,{}_1W_2 = U_2 - U_1 \quad (1)$$

where

${}_1Q_2$ = the energy transfer to the system due to a temperature difference between the surroundings and the system, while the system changes from the initial state 1 to the final state 2, Btu.
U = internal energy, Btu.
${}_1W_2$ = work done by the system as it changes from the initial to the final state, foot pounds.
A = the thermal equivalent of work = 1/778, Btu per foot pound.

In differential form this equation becomes:

$$dQ = dU + AdW \quad (2)$$

and per unit mass:

$$dq = du + Adw \quad (3)$$

Then

$$U = um \quad (4)$$

where

m = mass of the system.
u = internal energy per unit mass, Btu per pound.

The total work ${}_1W_2 = \int_1^2 dW$ represents all of the work done by the system on its surroundings. In a system in which the forces exerted on the system are in equilibrium with the forces exerted by the system accompanied by an increase in volume of the system:

$$ {}_1W_2 = \int_{V_1}^{V_2} PdV$$

where

P = force exerted by the surroundings per unit area on the boundaries of the system, i.e. pressure, pounds per square foot.
V = volume of system, cubic feet.

For the *open* system, the corresponding statement of the first law in differential form is:

$$dE = dQ - AdW + \sum^{i}(e_i + AP_iv_i)dm_i \quad (5)$$

where

E = sum of the potential energy, kinetic energy, and internal energy of the system, Btu.
e = sum of the potential energy, kinetic energy, and internal energy per unit mass of the fluid crossing the boundary of the system, Btu per pound.
dm = mass flow penetrating the boundary of the system, pounds.

If the system is limited to a single flow of mass entering and a single flow leaving the system, the properties are desig-

The general responsibility for this chapter is assigned to TC 1.1, Thermodynamics.