

FIRST LAW OF THERMODYNAMICS

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Abstract: The paper analyze the first law of thermodynamics, the state of the first law, analyze an open system including all energy transfer processes, cyclic processes for a thermodynamic system, perform energy balances on all major components in the system, identify the path(s) on a T-s diagram that represents the thermodynamic processes occurring in a fluid system.

First Law of Thermodynamics is a balance of the various forms of energy as they pertain to the specified thermodynamic system (control volume) being studied.

Key words: thermodynamics first law, sytem, processes, energy.

1. INTRODUCTION

The First Law of Thermodynamics states: Energy can either be created or destroyed, only altered in a form.

For any system, energy transfer is associated with mass and energy crossing the control boundary, external work and/or heat crossing the boundary, and the change of stored energy within the control volume. The mass flow of fluid is associated with the kinetic, potential, internal, and "flow" energies that affect the overall energy balance of the system. The exchange of external work and/or heat complete the energy balance.

The first law of thermodynamics is referred to as the conservation of energy principle, meaning that energy can neither be created nor destroyed, but rather transformed into various forms as the fluid within the control volume is being studied. The energy balance spoken of here is maintained within the system being studied. The system is a region in space (control volume) through which the fluid passes.

The various energies associated with the fluid are then observed as they cross the

boundaries of the system and the balance is made.

2. EQUATION FORM OF THE FIRST LAW OF THERMODYNAMICS

A system may be one of three types: isolated, closed, or open. The open system, the most general of the three, indicates that mass, heat, and external work are allowed to cross the control boundary. The balance is expressed in words as: all energies into the system are equal to all energies leaving the system plus the change in storage of energies within the system. Recall that energy in thermodynamic systems is composed of kinetic energy (KE), potential energy (PE), internal energy (U), and flow energy (P_L); as well as heat and work processes.

$$\Sigma (\text{all energies in}) = \Sigma (\text{all energies out}) + \Delta(\text{energy stored in system})$$

$$\Sigma E_{in} = \Sigma E_{out} + \Delta E_{storage}$$

For most industrial plant applications that most frequently use cycles, there is no change in storage.

In equation form, the balance appears as:

Q = heat flow into the system

\dot{m}_{in} = mass flow rate into the system

u_{in} = specific internal energy into the system

$\frac{P_{in} v_{in}}{2g_c}$ = pressure-specific volume energy into the system

$\frac{\bar{v}_{in}^2}{2g_c}$ = kinetic energy into the system ,where:

\bar{v}_{in} = average velocity of fluid

g_c = the gravitational constant

$\frac{g}{g_c} Z_{in}$ = potential energy of the fluid entering the system, where:

Z_{in} = height above reference level

g = acceleration due to gravity

g_c = the gravitational constant

W = work flow out of the system

\dot{m}_{out} = mass flow rate out of the system

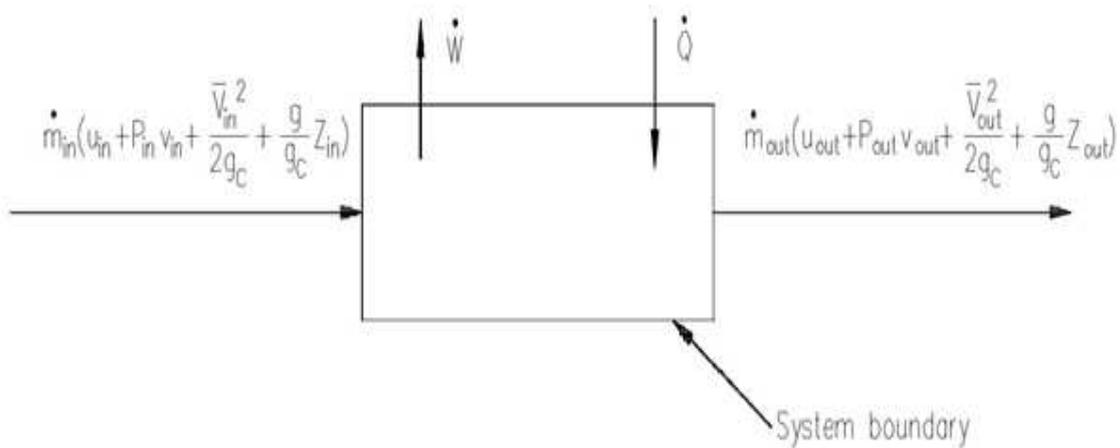
u_{out} = specific internal energy out of the system

$\frac{P_{out} v_{out}}{2g_c}$ = pressure-specific volume energy out of the system

$\frac{\bar{v}_{out}^2}{2g_c}$ = kinetic energy out the system

$\frac{g}{g_c} Z_{out}$ = potential energy out of the system

g_c



$$\dot{Q} + \dot{m}_{in} \left(u_{in} + P_{in} v_{in} + \frac{\bar{v}_{in}^2}{2g_c} + \frac{g}{g_c} Z_{in} \right)$$

$$= \dot{W} + \dot{m}_{out} \left(u_{out} + P_{out} v_{out} + \frac{\bar{v}_{out}^2}{2g_c} + \frac{g}{g_c} Z_{out} \right)$$

Figure 1 First law of thermodynamics

Heat and/or work can be directed into or out of the control volume. But, for convenience and as a standard convention, the net energy exchange is presented here with the net heat exchange assumed to be into the system and the net work assumed to be out of the system. If no mass crosses the boundary, but work and/or heat do, then the system is referred to as a "closed" system. If mass, work and heat do not cross the boundary, then the system is referred to as an isolated system. Isolated and closed systems are nothing more than specialized cases of the open system. In this text, the open system approach to the first law of thermodynamics will be emphasized because it is more general. Also, almost all practical applications of the first law

require an open system analysis.

An understanding of the control volume concept is essential in analyzing a thermodynamic problem or constructing an energy balance. Two basic approaches exist in studying thermodynamics: the control mass approach and the control volume approach. The former is referred to as the LeGrange approach and the latter as the Eulerian approach. In the control mass concept, a "clump" of fluid is studied with its associated energies. The analyzer "rides" with the clump wherever it goes, keeping a balance of all energies affecting the clump.

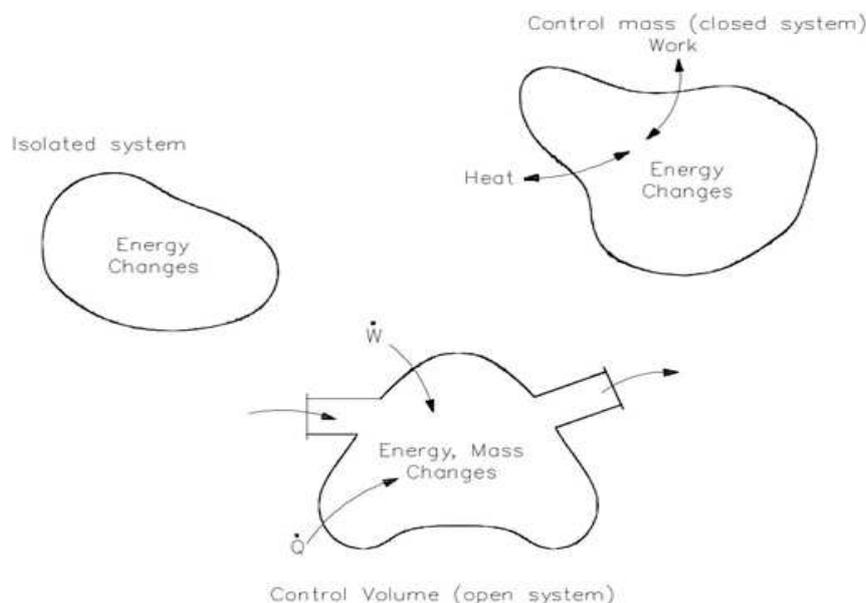


Figure 2 Control Volume Concepts

The forms of energy that may cross the control volume boundary include those associated with the mass (m) crossing the boundary. Mass in motion has potential (PE), kinetic (KE), and internal energy (U). In addition, since the flow is normally supplied with some driving power (a pump for example), there is another form of energy associated with the fluid caused by its pressure. This form of energy is referred to as flow energy (Pv -work). The thermodynamic terms thus representing the various forms of energy crossing the control boundary with the mass are given as $m(u + Pv + ke + pe)$.

In open system analysis, the u and Pv terms occur so frequently that another property, enthalpy, has been defined as $h = u + Pv$. This results in the above expression being written as $m(h + ke + pe)$. In addition to the mass and its energies, externally applied work (W), usually designated as shaft work, is another form of energy that may cross the system boundary.

In order to complete and satisfy the conservation of energy relationship, energy that is caused by neither mass nor shaft work is classified as heat energy (Q). Then we can describe the relationship in equation form as follows.

$$m(h_{in} + pe_{in} + ke_{in}) + Q = m(h_{out} + pe_{out} + ke_{out}) + W$$

where:

- m = mass flow rate of working fluid
- h_{in} = specific enthalpy of the working fluid entering the system
- h_{out} = specific enthalpy of the working fluid leaving the system
- pe_{in} = specific potential energy of working fluid entering the system
- pe_{out} = specific potential energy of working fluid leaving the system
- ke_{in} = specific kinetic energy of working fluid entering the system
- ke_{out} = specific kinetic energy of working fluid leaving the system
- W = rate of work done by the system
- Q = heat rate into the system

When the system changes its properties (temperature, pressure, volume) from one value to another as a consequence of work or heat or internal energy exchange, then it is said that the fluid has gone through a "process." In some processes, the relationships between pressure, temperature, and volume are specified as the fluid goes from one thermodynamic state to another.

The most common processes are those in which the temperature, pressure, or volume is held constant during the process. These would be classified as isothermal, isobaric, or isovolumetric processes, respectively. Iso means "constant or one." If the fluid passes through various processes and then eventually returns to the same state it began with, the system is said to have undergone a cyclic process. One such cyclic process used is the Rankine cycle, two examples of which are shown in figure 3. The processes that comprise the cycle are described below.

- ab: Liquid is compressed with no change in entropy (by ideal pump).
- bc: Constant pressure transfer of heat in the boiler. Heat is added to the compressed liquid, two-phase, and superheat states.
- cd: Constant entropy expansion with shaft work output (in ideal turbine).
- da: Constant pressure transfer of heat in the sink. Unavailable heat is rejected to the heat sink (condenser).

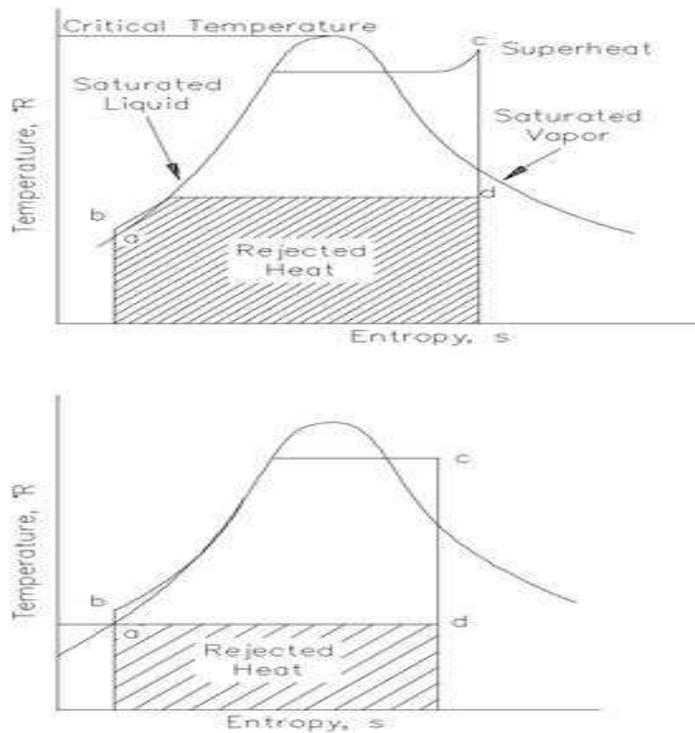


Figure 3 T-s Diagram with Rankine Cycles

3.TYPICAL STEAM PLANT CYCLE

Figure 4 shows a typical steam plant cycle. Heat is supplied to the steam generator (boiler) where liquid is converted to steam or vapor. The vapor is then expanded adiabatically in the turbine to produce a work output. Vapor leaving the turbine then enters the condenser where heat is removed and the vapor is condensed into the liquid state. The condensation process is the heat-rejection mechanism for the cycle. Saturated liquid is delivered to the condensate pump and then the feed pump where its pressure is raised to the saturation pressure corresponding to the steam generator temperature, and the high pressure liquid is delivered to the steam generator where the cycle repeats itself.

A typical steam plant system consists of: a heat source to produce the thermal energy (fossil fuel); a steam generator to change the thermal energy into steam energy; pumps to transfer the fluid back to the heat source; a pressurizer to ensure that the primary system maintains its desired pressure and the

necessary piping to ensure the fluid passes through each stage of its cyclic process. Of necessity, the steam plant is a large "closed" system. Each component of the system is thermodynamically analyzed as an open system as the fluid passes through it. Of primary importance is the process of dissipating the energy created by the heat source. This process takes place in the steam generator, which acts as a giant two-phase heat generator.

The hot fluid from the heat source passes through the primary side of the steam generator where its energy is passed to the secondary side of the heat exchanger in such a manner as to create steam. The fluid, with its energy removed from the primary side, leaves the steam generator at a lower temperature, and is pumped back to the heat source to be "re-heated." Each major component of a steam plant can be treated as a separate open system problem. A thermodynamic analysis, using the various forms of energies discussed, can be applied to the particular component in studying its behavior.

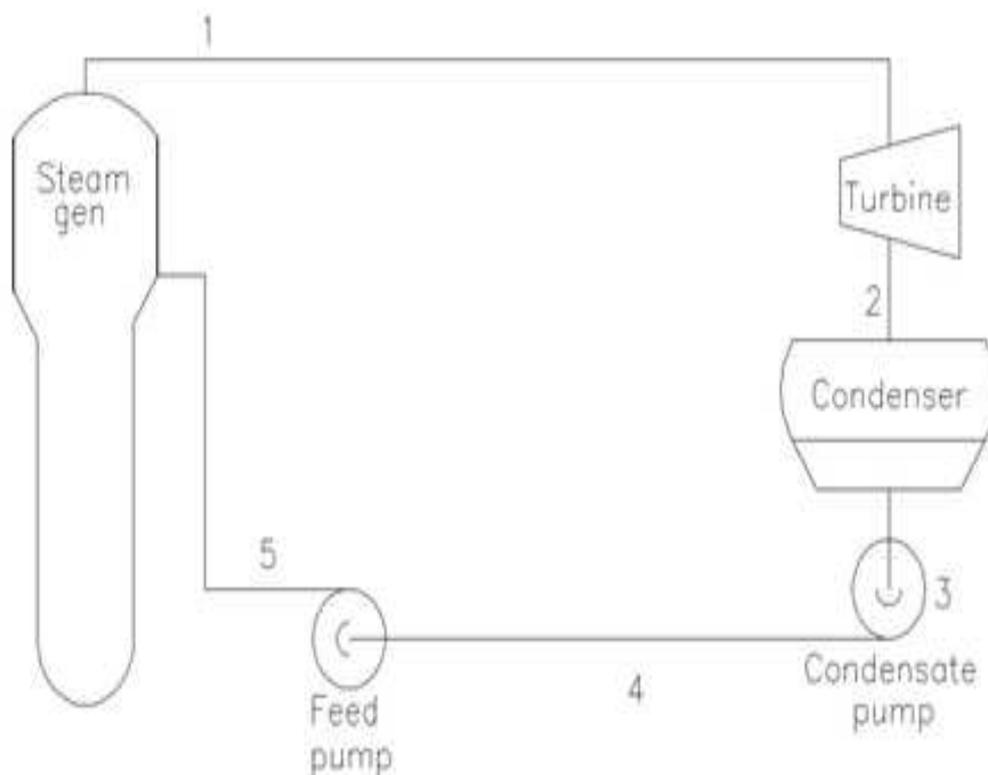


Figure 4 Steam Plant Cycle

4.CONCLUSION

The first law of thermodynamics states that energy can either be created or destroyed, only altered in a form.

In analyzing an open system using the first law of thermodynamics, the energy into the system is equal to the energy leaving the system.

The amount of energy transferred across a heat exchanger is dependent upon the temperature of the fluid entering the heat exchanger from both sides and the flow rates of these fluids.

If the fluid passes through various processes and then eventually returns to the same state it began with, the system is said to have undergone a cyclic process. The first law is used to analyze a cyclic process.

The energy entering any component is equal to the energy leaving that component at steady state.

A T-s diagram can be used to represent thermodynamic processes.

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