Principles of Thermodynamics

Lecture # 2

Module Outline

- Introduction
- Basic properties and units
- Thermodynamic processes and properties
- Fundamental laws and principles
- Heat engine
- Rankine cycle for power plants
- Energy and power
- Examples of applications
- Conclusions

Introduction

- Fluids play an important role in the modern storage and energy conversion systems with the definition of open and closed systems.
- A system can be open if it exchanges matter and energy with its surroundings, it can be isolated if there is no interaction with its surroundings and be considered as a closed system if it exchanges energy with its surroundings but not matter.
- Working fluid is the matter contained within boundaries of a system. Matter can be in solid, liquid, vapor or gaseous and plasmatic phases. The working fluid in applied thermodynamic problems is approximated by either a perfect gas or a substance, which exists as liquid and vapor.

Introduction

Thermodynamics deals with the transformation of energy. In engineering thermodynamics the emphasis is on processes involving transformations of work, heat, and internal energy as found in boilers, steam turbines, internal combustion engines, refrigeration, air conditioning, and other thermal/mechanical processes.

Basic Properties and Units

- State of Working Fluid - Working fluid is the matter contained within boundaries of a system. Matter can be in solid, liquid, vapor or gaseous phase. The working fluid in applied thermodynamic problems is either approximated by a perfect gas or a substance which exists as liquid and vapor. The state of the working fluid is defined by certain characteristics known as properties. Some of the properties which are important in thermodynamic problems are:
  - Pressure (P)
  - Temperature (T)
  - Specific enthalpy (h)
  - Specific entropy (s)
  - Specific volume (v)
  - Specific internal energy (u)
- The state of a substance and all of its thermodynamic properties are fixed by a knowledge of (at most) its pressure, temperature, and specific weight.

Energy

- Energy is an extensive property and thermodynamic principles provide ways to calculate the change in energy for a closed system.
- The dimensions of energy are the same for work. Although the dimensions are the same, engineers may use the SI system where the unit is joule (J) where 1 J = 1 N.m = 1 W/s.
- In the USCS system there are two main units, the British thermal unit (Btu) that was used in the study of heat and the foot-pound-force (ft.lbf) that was used in the study of the mechanical work.
- One British thermal unit approximately equals the amount of energy required to raise the temperature of one pound-mass of liquid water one degree Fahrenheit at room temperature. Some of the properties, which are important in thermodynamic problems, are described next.

Basic Properties and Units

- Temperature (T) is taken simply as the relative hotness or coldness of a substance. Temperature is not a form of energy and should not be confused with the heat output of a device. A fundamental SI base unit is the absolute temperature or thermodynamic temperature (degree Kelvin, K).
- Pressure (P) is a force acting on a unit area with common units being pounds per square inch gauge (psig). Absolute pressure, the pressure above the lowest possible pressure, is the sum of the gauge pressure and the atmospheric pressure. The notation for pressure differences will be simply psi.
- Specific Volume - The specific volume, v, of a system is the volume occupied by unit mass of the system. The relationship between the specific volume and density is:
  - The SI unit of specific volume is m3/kg (cubic meter per kilogram). Other units are:
  - 1 m3/t= 1 m3/ton= 0.001 m3/kg
  - 1 L/kg=1 lit/kg= 1 dm3/kg= 0.001 m3/kg
  - 1 cm3/g= 0.001 m3/kg
  - 1 in3/lbm= 3.6175E-5 m3/kg
  - 1 ft3/lbm= 0.0625 m3/kg

Basic Properties and Units

- Specific weight (w) is the weight of a unit volume of a substance, generally in units of pounds per cubic foot (lb/ft3).
- Weight rate of flow (W) will be in pounds per hour (lb/hr). Liquid flows are usually specified in gallons per minute (gpm), so the conversion W = 500 (Gpm) is required. Air flow is generally measured in cubic feet per minute (cfm) and the conversion is W = 60(w) (cfm).
- Specific Entropy - Specific entropy of a system is the entropy of the unit mass of the system and has the dimension of energy/ mass/temperature. The SI unit of specific entropy is J/(Kg . K). Other units are:
  - 1 KJ/kg,K= 1000 J/(Kg . K)
  - 1 erg/g,K= 1E-4 J/(Kg . K)
  - 1 Btu/lbm,F= 4186.8 J/(Kg . K)
  - 1 cal/g,C= 4186.8 J/(Kg . K
- Enthalpy - Enthalpy of a system is defined as the mass of the system (m) multiplied by the specific enthalpy of the system, (h) : H = m h
- Velocity (V) is the volume rate of flow (F) per unit area (A) and the units vary with the application.

Basic Properties and Units

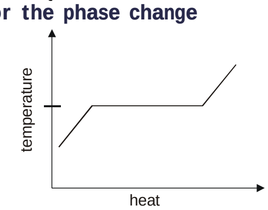
- Specific Enthalpy - **Specific enthalpy of a working fluid (h) is a property of the fluid which is defined as: h=u + Pv**
  where u= Specific internal energy , P= Pressure, v= Specific volume
  - Specific enthalpy has the same dimension as [energy/mass]. The SI unit of specific enthalpy is J/kg. Other units are:
  - 1 kJ/kg= 1000 J/kg
  - 1 erg/g= 1E-4 J/kg
  - 1 Btu/lbm= 2326 J/kg
  - 1 cal/g= 4184 J/kg
- Specific Internal Energy - **Internal energy of a system, is the energy content of the system due to its thermodynamic properties such as pressure and temperature. The change of internal energy of a system depends only on the initial and final states of the system and not in any way by the path or manner of the change. This concept is used to define the first law of thermodynamics.**
  - Specific internal energy is defined as the internal energy of the system per unit mass of the system and naturally has the same dimension as [energy/mass] or enthalpy

Basic Properties and Units

- **Heat Capacity - It is defined by the ratio of heat ΔQ required to raise the temperature of an object to a small amount ΔT, i.e.** $C = \frac{\Delta Q}{\Delta T}$
- **The specific heat C is heat capacity divided by the mass m of the object, thus** $c = \frac{\Delta Q}{m\Delta T}$
- **Since an infinitesimal variation in entropy dS may be expressed as the ratio of an infinitesimal amount of the absorbed heat divided by the system temperature, i.e.** $dS = dQ/T$ **the following expression for entropy in terms of specific heat capacity holds:** $dS = \frac{dQ}{T} = \frac{mcdT}{T}$

Basic Properties and Units

- **When two phases (solid/liquid or liquid/gas) are present during heat transfer at constant pressure a temperature change will not occur and the change in heat content of the substance must be obtained from tables of properties of the substance. The heat required to change the phase of an object with mass m is $Q = \pm mL$ where L is the heat required for the phase change**



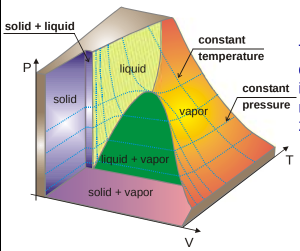
Heating Value

- **Heating Value - The chemical energy stored in a fuel is measured by burning a small sample of the fuel in an oxygen environment and noting the heat transferred to a water jacket surrounding the sample. This value is termed the higher heating value (HHV) of the fuel.**
- **When a fuel is burned, the moisture present is converted into water vapor. The latent heat of vaporization must be subtracted from the HHV and the result is reported as the lower heating value (LHV).**

Fuel	HHV
Anthracite coal	13,000 Btu/lb
Bituminous coal	13,500 Btu/lb
Lignite	6,500 Btu/lb
Peat	1,200 Btu/lb
Fuel oil	137,000 Btu/gal
Natural gas	1,050 Btu/ft^3
Propane	92,000 Btu/gal
Butane	102,050 Btu/gal
Wood varieties	7,200 Btu/lb
Hardwoods	$25x10^{-6}$ Btu/cord
Softwoods	$16x10^{-6}$ Btu/cord
Carbon (C)	14,600 Btu/lb
Hydrogen (H_2)	62,000 Btu/lb
Sulfur (S)	4,050 Btu/lb

Thermodynamic Properties

- **The thermodynamic properties for a pure substance can be related by the general relationship,** f(P,v,T)=0**, which represents a surface in the** (P,v,T) **space. The thermodynamic laws do not give any information about the nature of this relationship for the substances in the liquid and vapor phases.**



The state of any pure working fluid can be defined completely by just knowing two independent properties of the fluid. This makes it possible to plot state changes on 2D diagrams such as:

- **pressure-volume (P-V) diagram,**
- **temperature-entropy (T-s) diagram,**
- **enthalpy-entropy (h-s) diagram**

What processes are involved?

- **When considering a transition between two points of thermodynamic state, the following processes are often used:**
  - Adiabatic — dq = 0 — no heat transfer
  - Isentropic — ds = 0 — constant entropy
  - Isothermal — dT = 0 — constant temperature
  - Isochoric — dv = 0 — constant volume
  - Isobaric — dP = 0 — constant pressure
- **The following table lists specific weights of a number of substances that we may encounter in residential and commercial energy problems. The specific weight of gases and vapors (and to a lesser extent, liquids) depends on both pressure and temperature.**

Thermodynamic Properties

Thermodynamic Properties

Substance	Specific Weight w, lb/ft^3	Specific Heat Cp, Btu/(lb-^{o}F)
Air	0.075 (O psig, 70 ^{o}F)	0.24
Aluminum	165	0.22
Brick	125	0.20
Cast iron	450	0.12
Concrete	144	0.22
Flue gas	0.041 (O psig, 500 ^{o}F)	0.26
Glass	155	0.19
Ice	57.5	0.49
Steam	0.037 (O psig, 212 ^{o}F)	0.48
Steel	490	0.12
Stone	165	0.21
Water	62.5	1.00
White pine	27	0.67

Fundamental Laws and Principles

- *Law of Conservation of Energy*
  "Energy can be neither created nor destroyed." **- the total energy within the universe remains constant. Energy can be stored in a number of ways and can be transferred from one system to another by various processes.**
- *First Law of Thermodynamics*
  "The net heat added to a system minus the net work produced by the system must be equal to the increase in stored energy within the system." **- we will use the first law in a more general manner, considering in addition to work and heat, electrical energy and chemical energy as distinct energy forms which can move into or out of systems and must be balanced by corresponding changes in other energy forms.**

Fundamental Laws and Principles

- *Second Law of Thermodynamics*

  The second law is a straightforward law of physics with the consequence that, in a closed system, you can't finish any real physical process with as much useful energy as you had to start with — some is always wasted. This means that a perpetual motion machine is impossible. The second law was formulated after nineteenth century engineers noticed that heat cannot pass from a colder body to a warmer body by itself.
- Clausius Statement of the Second Law is: **"Heat cannot of itself pass from a cold to a hot body. "**
- The Kelvin-Planck Statement of the Second Law is: **"It is impossible for any device to operate in a cycle and produce work while exchanging heat only with bodies at a single fixed temperature. "**

Carnot Principle

- **An important consequence of the Second Law is the Carnot Principle, in which it is shown that with heat supplied at a temperature TH and rejected at a temperature TL the maximum efficiency (h) at which the heat supplied can be converted into work is :**

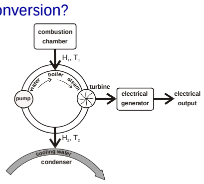
$$\eta = \frac{T_H - T_L}{T_H + 460}$$

where the temperatures are in degrees Fahrenheit.

- In a steam boiler the efficiency of conversion of energy from the fuel to the steam is limited by the First Law to 100% - practical considerations set the limit at around 90%. If the steam is used for space or process heat the limitation is again 100%, a value that can be approached as closely as desired. If the steam is used to produce work (and indirectly, electrical energy) with a heat engine the maximum efficiency is limited by the Second Law.

Example In a Nutshell

- In a steam/electric power station heat is supplied at 1000 ºF (steam temperature) and rejected to the condenser cooling water at a temperature of 60 ºF. What is the maximum possible efficiency of conversion?

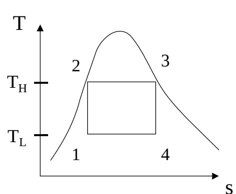


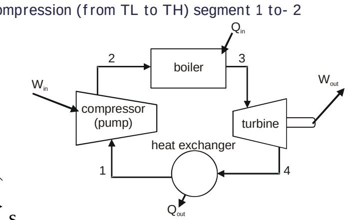
$$\eta = \frac{1000 - 60}{1000 + 460} = 64\%$$

36% of the energy supplied is lost to the cooling water. Actual efficiency is considerably less, and when combined with the boiler conversion efficiency and losses in the conversion from shaft work to electrical energy, the overall efficiency of the modern steam/electric station is around 35%. By the time the electrical energy is delivered to the point of use less than one-third of the energy in the fuel remains.

Heat Engine

- **Device that converts heat energy into mechanical energy, only heat and work may pass across its boundaries (Otto, Diesel, Brayton, Stirling and Rankine cycles). The *Carnot cycle* is an idealized representation of the operation of a steam engine:**
  - Reversible isothermal expansion at TH segment 2 to 3
  - Reversible adiabatic expansion (from TH to TL) segment 3 to 4
  - Reversible isothermal compression at TL segment 4 to 1
  - Reversible adiabatic compression (from TL to TH) segment 1 to- 2





Heat Engine

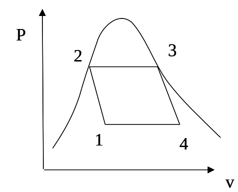
- **Heat absorbed by the working fluid during the isothermal process 2 - 3 (High temperature reservoir) is**
  - q23 = TH(s3– s2) => Qin
- **During isothermal process 4 - 1, (low temperature reservoir) the heat given up by the working fluid is**
  - q41 = TL(s1 – s4) = TL(s2 – s3) = - TL(s3 – s2)
- **The work produced by the cycle is :**
  - wcy = q23 + q41 = TH(s3– s2) - TL(s3 – s2)
- **The thermal efficiency can be calculated by :**

  (Work produced by the cycle) / (Heat supplied to the cycle)

$$\eta = \frac{q_{23}+q_{41}}{q_{23}} = \frac{T_H - T_L}{T_H}$$

Heat Engine

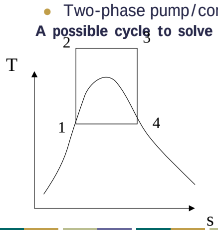
- **The product of pressure and volume represents a quantity of work. This is represented by the area below a p-V curve, i.e. the area enclosed by the four curves represents the net work done by the engine during one cycle.**



- By using the second law of thermodynamics it is possible to show that no heat engine can be more efficient than a reversible heat engine working between two fixed temperature limits. Due to mechanical friction and other irreversibilities no cycle can achieve this efficiency .

Practical Problems

- **Carnot cycle is not practical due :**
  - Isentropic expansion in a turbine from 3-4. What is the quality of the steam inside the turbine? High moisture content => blade erosion
  - Isentropic compression process in a pump from 1-2. Can one design a condenser and transmission line system that precisely control the quality of the vapor in order to achieve an isentropic compression?
  - Two-phase pump/compressor needed
- **A possible cycle to solve some problems would be :**



However, this cycle requires the compression (1-2) of liquid at a very high pressure (exceeding 22 MPa for a steam) which is not practical. Also, to maintain a constant temperature above the critical temperature is also difficult since the pressure will have to change continuously.

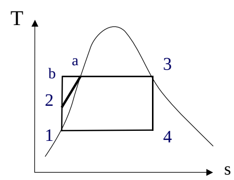
=> Maximum temperature limitation for cycle

Rankine Cycle for Power Plants

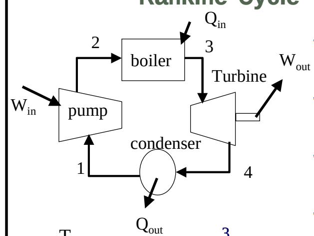
- **The cornerstone of modern steam power plants was possible due to a thermodynamic cycle proposed by W.J.M. Rankine. The main components of a Rankine cycle steam plant are:**
- **a boiler which generates steam, usually at a high pressure and temperature;**
- **a turbine which expands the steam to a low pressure and temperature thereby producing work;**
- **a generator driven by the steam turbine;**
- **a condenser which cools the steam to a liquid so that it may be pumped back into the boiler;**
- **a feed pump;**
- **feed heaters which preheat the water before it enters the boiler; and**
- **a reheater which is part of the boiler and which reheats the steam after it has been partially expanded.**

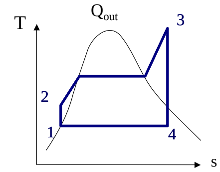
Rankine Cycle for Power Plants

- It is evident in the T-s diagram that the **Ideal Rankine** cycle is less efficient than a Carnot cycle for the same maximum and minimum temperatures. The Rankine cycle work is represented by the area 2-a-3-4-1-2 which is smaller than the Carnot cycle work represented by the area 2-b-3-4-1-2



Rankine Cycle for Power Plants



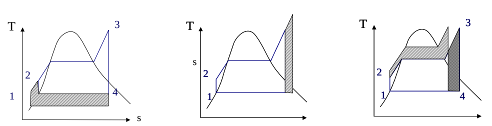


- 1-2: Pump (q=0) Isentropic compression (Pump)
  - Wpump = h2 - h1 = v(P2-P1)
- 2-3: Boiler (W=0) Isobaric heat supply (Boiler)
  - qin = h3 - h2
- 3-4: Turbine (q=0) Isentropic expansion (Steam turbine)
  - Wout = h3 - h4
- 4-1: Condenser (W=0) Isobaric heat rejection (Condenser)
  - qout = h4 - h1

By **increasing the steam temperature** the point 3 is shifted up. Increasing the steam temperature increases the cycle efficiency and reduces the moisture content at the turbine exhaust end

Rankine Cycle for Power Plants

- **Thermal efficiency can be further improved by:**
  - (a) Lowering the condensing pressure (lower condensing temperature, lower TL)
  - (b) Superheating the steam to higher temperature
  - (c) Increasing the boiler pressure (increase boiler temperature, increase TH)



- The optimal way of increasing the boiler pressure but not increase the moisture content in the exiting vapor is to reheat the vapor after it exits from a first-stage turbine and redirect this reheated vapor into a second turbine. The description of such improvements and the reheating process is outside the scope of this introductory information

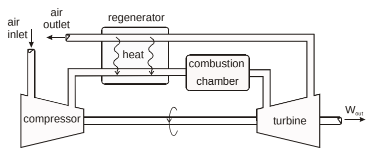
Brayton Cycle for Power Plants

- The basic gas turbine cycle was first proposed by George Brayton around 1870 and is currently applied for gas-turbine engines based aircraft propulsion and electric power generation.
- Gas turbines may be used as stationary power plants to generate electricity as stand-alone units or in conjunction with steam power plants on the high-temperature side. In these plants, the exhaust gases serve as a heat source for the steam.

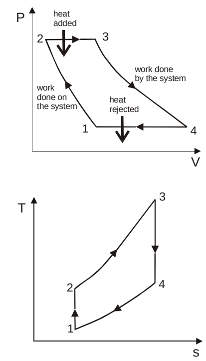
Home

Gas Turbine

- **Steam power plants are considered external-combustion engines, in which the combustion takes place outside the engine.**
- **The diagram shows a gas turbine where air is drawn into a compressor, making the temperature and pressure to be raised. The high-pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure.**



Ideal Brayton Cycle

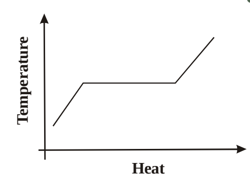


Energy and Power

- **Energy (E) may be defined as "the capacity to do work," such as the lifting of a weight. To lift a 10-lb weight a distance of 5 ft requires (5)*(10) = 50 foot-pounds (ft-lb) of energy. Energy takes a variety of forms - chemical, electrical, mechanical (work, kinetic, potential, flow), and thermal (heat, internal).** Industrial problems **: chemical energy, electrical energy, and heat.**
  - Chemical energy (CE) is the energy, as stored in fuels, usually identified by the term higher heating value (HHV) and measured in British thermal units (Btu). One Btu is the energy required to increase the temperature of 1 lb of water 1 oF.
  - Electrical energy (EE) is a form of energy entering the system as electricity. It is measured in kilowatt-hours (kwh). One kilowatt-hour is equal to 3413 Btu.
  - Heat (Q) is a form of thermal energy that is transferred across system boundaries by a temperature difference. It is measured in Btu.

  Heat content = MCPT, where M is the weight of the body in pounds, T is the temperature in degrees Fahrenheit, and Cp is the specific heat in Btu/(lb-oF). The term heat content is no longer used in modern thermodynamics, although it is still common. The preferred term is enthalpy.

Energy and Power



- **When two phases (solid/liquid or liquid/gas) are present during heat transfer at constant pressure a temperature change will not occur and the change in heat content of the substance must be obtained from tables of properties of the substance.**

- **When ice is heated from O ºF to 32 ºF the heat required is (0.49) (32 - 0) = 15.7 Btu/lb. As more heat is added the temperature remains at 32 ºF until all of the ice has been changed into water. The energy required to effect the change is termed the latent heat of fusion and is equal to 144 Btu/lb. As more heat is added, at atmospheric pressure, the temperature rises to 212 ºF. The heat required to raise the water temperature is (1.0) (212 - 32) = 180 Btu/lb. For further addition of heat the temperature remains at 212 ºF until all of the water has been converted into steam. The energy required for this change of phase is called the latent heat of vaporization and is equal to 970 Btu/lb at an atmospheric pressure of 14.7 psia.**

Energy and Power

- Power is the rate of energy transfer or conversion. Horsepower (hp), kilowatts (kW), and Btu/hr are units of power, not energy. Application of the first law involves energy balances – energy rates can also be used and are generally more convenient. The following table gives some useful energy and power conversion factors.

Energy and Power Conversion Factors	
Energy	**Power**
1 kwh = 3413 Btu	1 hp = 2545 Btu/hr
1 Btu = 778 ft-lb	1 kw = 3413 Btu/hr
1 hp-hr = 2545 Btu	1 hp = 0.746 kw
1 kwh = 1.34 hp-hr	1 hp = 33,000 (ft-lb)/min

Application of First Law

- The First Law of Thermodynamics as applied to residential and commercial energy problems is most conveniently stated a:
  "The energy added to a system equal the energy leaving the system plus the increase in stored energy within the system."
  $E_I = E_2 + \Delta E_S$
  Subscripts 1, 2, and s refer to energy entering, leaving, and stored, respectively.

Expanding that equation for the forms of energy we will be concerned with and using energy rates gives :

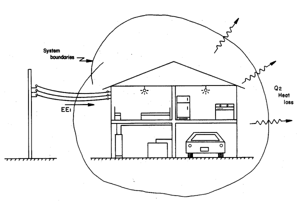
$$Q_1 + CE_1 + EE_1 + H_1 = Q_2 + CE_2 + EE_2 + H_2 + \Delta H_S$$

where:

Q = Heat transferred by temperature difference across system boundaries, Btu/hr
CE = Chemical energy, Btu/hr = (W) (HHV of fuel in Btu/lb)
EE = Electrical energy in Btu/hr = 3413 (kw)
H = Heat content of fluids crossing system boundaries, Btu/hr = $W(C_p)$ (T)
ΔH = Change in stored heat content, Btu/hr = M(Cp) (T'/t)
M is the weight of the storage material in pounds.
(T'/t) is the change in temperature T, °F in a time period t, hours.

Simple Residential Energy Balance

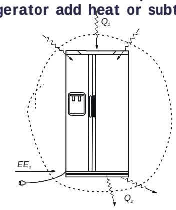
- Consider a residence, maintained at a constant temperature with no change in energy stored and only two energy flows crossing the boundaries. Assume an average electrical power usage of 1.5 kW. What is the heat loss from the house?



- Using the equation :
  $EE_1 = Q_2$ (all other terms are zero)
  (1.5) (3413) = Q_2

Refrigerator Energy Balance

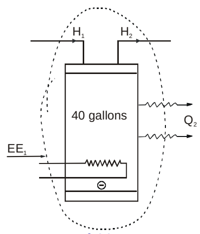
- In using energy balances the boundaries can be drawn around any device, group of devices, or components of a device like a refrigerator. Electrical energy is flowing in, as is the heat gain Q1 through the insulated walls. The heat flow Q2 from the condenser is out of the system. Suppose that the electrical input averages 150 watts (0.15 kw). Does the refrigerator add heat or subtract heat from the house? How many Btu/hr ?



- From the equation we have $EE_1 + Q_1 = Q_2$
  $Q_2 - Q_1 = EE_1 = (3413)\ (0.15) = 512$ Btu/hr
  The net effect is to heat the house, since the heat given off by the condenser (Q_2) exceeds the cooling (Q_1) by 512 Btu/hr

Energy Balance for a Water Heater

An electric water heater offers a good example of the use of stored energy and heat content in the energy balance. The 4.5-kw water heater shown is supplied with cold water at 60 ºF and delivers hot water at a thermostat setting of 130 ºF. Loss through the insulation (Q2) is 300 Btu/hr. Use 8.3 lb of water per gallon.



1. Can the unit supply the 130 ºF water continuously at a rate of 20 gal/hr? (166 lb/hr)
2. If the cost of electrical energy is **4 cents/kwh,** what does it cost to heat 1 gallon of water at these conditions?
3. If the heater is initially at 70 ºF, how long will it take for the temperature to reach 130 ºF? Neglect water usage during the warm-up period.

Energy Balance for a Water Heater

1. **From Equation : H_1 + EE_1 = H_2 + Q_2**

H_1 = (166) (1.0) (60) = 9960 Btu/hr

H_2 = (166) (1.0) (130) = 21,600 Btu/hr

so that 9960 + (3413) (Power_kw) = 21,600 + 300

- **Solving for the required power gives 3.5 kw. Since this is less than the 4.5 kw available, the 20 gal/hr rate is no problem.**

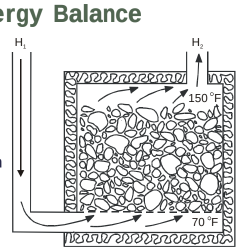
2. **Since 20 gal/hr requires 3.5 kw, 1 gal requires 3.5/20 = 0.18 kWh and the cost is (0.18)*(0.04) = \$0.72**
3. **There is no flow under these conditions, but there is an increase in stored energy. From Equation : EE_1 = Q_2 + ΔH_S**

$$3413 * 4.5 = 300 + \frac{40 * 8.3 * 1.0 * (130 - 70)}{t}$$

Solving for t gives t = 1.32 hr

Rock Bed Energy Balance

A 30,000 lb, well-insulated rock bed shown in the figure is used for energy storage in a solar air system. If the bed is initially at 150 ºF and the average air flow required to heat the building is 100cfm, calculate the average temperature of the rock bed after 24 hours of operation. Assume an ideal bed such that the outlet temperature remains at 150 ºF until the average temperature drops to the return air temperature of 70 ºF.



From Equation : H_1 = H_2 + ΔH_S

H_1 = (100) (4.5) (0.24) (70) = 7560 Btu/hr

H_2 = (100) (4.5) (0.24) (150) = 16,200 Btu/hr

$$\Delta H_S = (30{,}000)(0.21)\frac{T'}{24} = 262.5(T')$$

Solving for the temperature change gives = -33 ºF. The negative sign indicates a temperature decrease. Since is the change in temperature, the final temperature of the bed is 150 - 33 = 117 ºF.

Array of Solar Collectors

- **In a 300 ft² array of solar collectors the fluid absorbs energy at a maximum rate of 160 Btu/(ft²-hr). What airflow rate should be used in order to increase the air temperature by 50 ºF?**
- **For liquid cooled collectors what water flow would give a 10 ºF rise?**

From the First Law the increase in heat content of the flowing fluid must equal the heat added. H_2 -H_1 = Q_1

$$WC_P(T_2 - T_1) = Q_1$$

- **For air** $W = \frac{(160)(300)}{(0.24)(50)}$ = 4000 lb/hr

4000/4.5 = 889 cfm

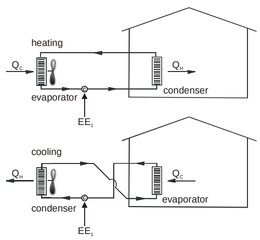
$$W = \frac{Q_1}{C_p \Delta T}$$

- **For water** $W = \frac{(160)(300)}{(1.0)(10)}$ = 4800 lb/hr

4800/500 = 9.6 gpm

Heat Pump

- In the cooling mode the indoor heat exchanger functions as an evaporator with heat flow from the room to the cold evaporating refrigerant. In the outdoor heat exchanger (condenser) heat is removed from the hot compressed vapor and liquid refrigerant is returned through a restriction to the indoor unit. In the heating mode the roles of heat exchangers are reversed.
- In the heating mode application $Q_H = Q_C + EE_1$
- The ratio of the useful energy output to the electrical energy input is determined by the coefficient of performance $(COP)_{heat} = Q_H/EE_1$
- In the cooling mode application $Q_C = Q_H - EE_1$ and $(COP)_{cool} = Q_C/EE_1$



Planet Earth: A closed but not isolated system

- From the beginning of life on earth until the last several hundred years, all organisms on earth including human beings, utilized the available energy of the sun to provide the necessities of life.
- During this period of time, energy from the sun was used to maintain the entropy in our planetary system. As long as life on earth used sunlight in an evenly distributed manner, and at a rate which was less than that of incoming solar radiation, order was maintained, all over the planet.
- As populations increased in certain parts of the world, in the past couple of thousand years, humans started to cut down more trees, build up their houses and roads, and harvest more crops in a year than could be regenerated through the natural process of photosynthesis. Such practices led to deforestation and desertification of previously fertile land. Human population increases and the use of fossil fuels since the industrial revolution have greatly increased the rate at which humans are adding to the entropy of the planet.

Conclusions

- This module discussed the principles of thermodynamics as applied to residential and industrial applications of distributed generation.
- Basic properties and units, thermodynamic processes and properties were related to fundamental laws and principles.
- Some cycles for power plants and the production of energy and power were discussed.
- Examples and applications were presented.