



Fundamentals of HVAC

Thermodynamics



What you will Learn in this Lesson

- Introduction: What is Thermodynamics?
- Fundamentals
- Properties of a substance
- Zeroth Law of Thermodynamics
- First Law of Thermodynamics
- Second Law of Thermodynamics
- Third Law of Thermodynamics

What is Thermodynamics?

ther•mo•dy•nam•ics: noun 1) physics that deals with the mechanical action or relations of heat 2) thermodynamic processes and phenomena

- Thermodynamics is the science devoted to the study of energy, its transformations, and its relation to status of matter
- Since every engineering operation involves an interaction between energy and materials, the principles of thermodynamics can be found in all engineering activities
- Thermodynamics can be considered the description of the behavior of matter in equilibrium and its changes from one equilibrium state to another

Fundamentals

- There are two fundamental kinds of entity in thermodynamics, states of a system, and processes of a system
- A thermodynamic system can be defined in terms of its states. In this way, a thermodynamic system is a macroscopic physical object, explicitly specified in terms of macroscopic physical and chemical variables which describe its macroscopic properties. The macroscopic state variables of thermodynamics have been recognized in the course of empirical work in physics and chemistry

Fundamentals

- A thermodynamic system can also be defined in terms of the processes which it can undergo. Of particular interest are cyclic processes. This was the way of the founders of thermodynamics in the first three quarters of the nineteenth century
- Classical thermodynamics is characterized by its study of materials that have equations of state that express relations between mechanical variables and temperature that are reached much more rapidly than any changes in the surroundings

Fundamentals

- Thermodynamic facts can often be explained by viewing macroscopic objects as assemblies of very many microscopic or atomic objects that obey Hamiltonian dynamics
- Statistical methods can be used to account for the macroscopic properties of the thermodynamic system in terms of the properties of the microscopic species, such explanation is called statistical thermodynamics

Systems and Surroundings

- A system can be an object, any quantity of matter, or any region of space selected for study and set apart (figuratively) from everything else, which then becomes the surroundings
- In classic thermodynamics, only the macroscopic parameters are considered in establishing the state of the system
- The system and the surroundings are separated by a boundary which is either movable or fixed, real or imagined

Properties and State

- Common properties:
 - Temperature
 - Pressure
 - Specific volume (density)
 - Internal energy
 - Enthalpy
 - Entropy
- Each property of a substance in a given state has only one value
- The state of a substance is defined by its properties
- In classic HVAC thermodynamics, we use equilibrium states

Thermal Equilibrium

Thermodynamic equilibrium occurs when a system is incapable of a spontaneous change to another state without a finite change in the state of the surroundings.

Processes and Cycles

- A cycle is a process, or a series of processes wherein the initial and final states of the system are identical.

Processes and Cycles

- A process is a change in state which can be defined as any change in the properties of a system
- The process is described, in part, by the series of states passed through by the system
- Sometimes, an interaction occurs between the system and surroundings during the process and then the process definition is completed by a description of this interaction

Processes and Cycles

- ***isobaric***
 - The pressure doesn't change
- ***isothermal***
 - The temperature doesn't change
- ***isometric***
 - The volume doesn't change
- ***adiabatic***
 - There is no heat transferred
- ***isentropic***
 - The entropy doesn't change

Reversibility

- All naturally occurring processes are irreversible
- A waterfall only goes one way
- Water can be pumped back up hill but only at the expense of energy
- A process is reversible only if its direction can be changed at any point by an infinitesimal change in external conditions
- Reversible processes can be drawn as a line on a thermodynamic diagram

Conservation of Mass

- Energy and mass are related!

$$\mathbf{E = mc^2}$$

Conservation of Mass

- Mass changes but only on a microscopic scale (except for nuclear reactions)
- Mass conservation is most important in mass flow rates

$$m = A * V / v$$

Where:

m = mass flow rate of a fluid

A = cross sectional area of conduit

V = average fluid velocity

v = specific volume

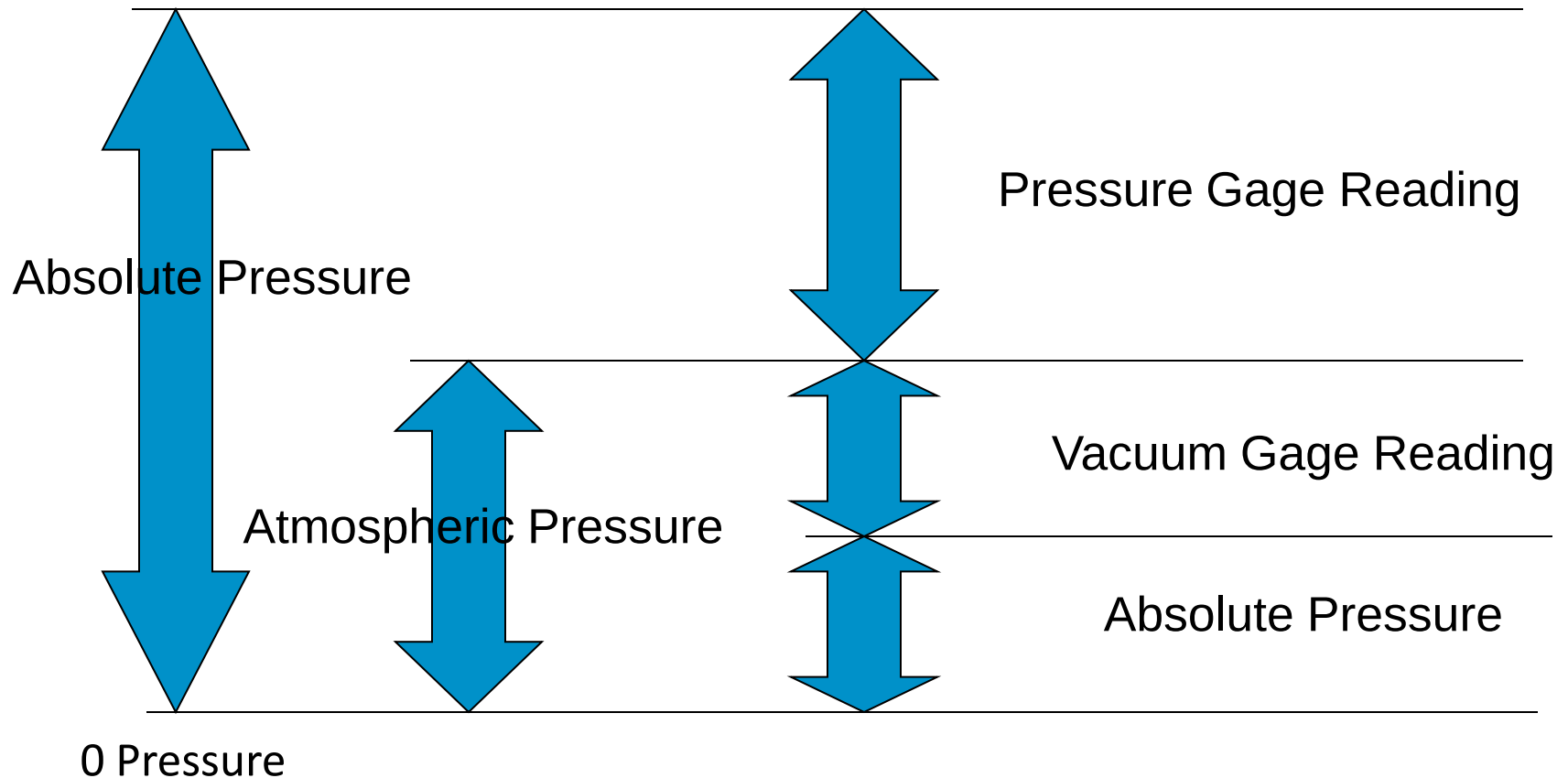
Conservation of Mass

- In a process, the mass of fluid entering the system must equal the mass leaving the system

Properties of a Substance

- Specific volume and density
 - Volume per unit mass
 - Mass per unit volume
- Pressure
 - Force per unit area (normal to the boundary)
 - In a gas, it is equal in all directions

Properties of a Substance



Barometric Pressure

- The [standard atmosphere](#) (symbol: atm) is a [unit of pressure](#) and is defined as being equal to 101.325 [kPa](#). The following units are equivalent, but only to the number of decimal places displayed: 760 [mmHg](#) ([torr](#)), 29.92 [inHg](#), 14.696 [psi](#), 1013.25 [millibars/hectopascal](#).

$$P = 101.325 * (1 - 2.25577 * 10^{-5} * h)^{5.256}$$

Properties of a Substance

- Temperature
 - Several scales exist for temperature
 - Absolute temperature scale is Kelvin (K) in SI units
 - Absolute temperature scale is Rankine (R) in IP units

$$K = ^\circ C + 273.15$$

$$^\circ R = ^\circ F + 459.67$$

Properties of a Substance

- Internal energy
 - Internal energy refers to the energy possessed by a material due to the motion and/or the position of the molecules
 - Kinetic energy: the velocity of the molecules
 - Potential internal energy: the attractive force between molecules
 - Changes in the average velocity of the molecules is indicated by the temperature changes of the system
 - Variations in the relative distance between molecules are denoted by changes in the phase of the system
 - U is the internal energy of a specific mass; u is the internal energy per unit mass

Properties of a Substance

- Enthalpy
 - Enthalpy is a property which is composed of three other substance properties
 - Specific enthalpy is enthalpy per unit mass
- More about this in the section on Psychrometrics

$$h = u + (p * v)$$

Properties of a Substance

- Entropy
 - A measure of molecular disorder
 - High disorder = high entropy
 - Boltzmann made an equation

$$S = k \ln W$$

Properties of a Substance

- Specific Heat
 - A thermodynamic property of a substance
 - Defined in two different ways

Constant Volume

$$c_v = (\Delta u / \Delta T)_v$$

Constant Pressure

$$c_p = (\Delta h / \Delta T)_p$$

Pure Substance

- A substance that has a homogeneous and invariable chemical composition
- The chemical composition remains the same regardless of the phase
- Therefore, water is a pure substance even if:
 - It is in both liquid and vapor phase
 - It is in both liquid and solid (ice) phase
- Is air a pure substance?

Zeroth Law of Thermodynamics

- *If two systems are each in thermal equilibrium with a third, they are also in thermal equilibrium with each other.*
- The law provides an empirical definition of temperature and justification for the construction of practical thermometers.

First Law of Thermodynamics

Energy in – Energy out = Increase in Energy in the System

First Law of Thermodynamics

- A change in the internal energy of a closed thermodynamic system is equal to the difference between the heat supplied to the system and the amount of work done by the system on its surroundings
- When a system is at thermodynamic equilibrium under a given set of conditions of its surroundings, it is said to be in a definite thermodynamic state, which is fully described by its state variables
- The first law observes that the internal energy obeys the principle of conservation of energy, which states that energy can be transformed (changed from one form to another), but cannot be created or destroyed

First Law of Thermodynamics

- First Law of Thermodynamics:

(Conservation) Energy can be changed from one form to another, but it cannot be created or destroyed. The total amount of energy and matter in the universe remains constant, merely changing from one form to another

First Law of Thermodynamics

- Constant pressure process
- Both energy and mass are conserved

Second Law of Thermodynamics

- Heat cannot spontaneously flow from a colder location to a hotter location
- There are many versions of the second law, but they all have the same effect; to explain the phenomenon of irreversibility in nature

Second Law of Thermodynamics

- The [Second Law of Thermodynamics](#) states that "in all energy exchanges, if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state." This is also commonly referred to as [entropy](#).

Irreversible Process

- Irreversible adiabatic process: If the cylinder is a perfect insulator, the initial top-left state cannot be reached anymore after it is changed to the one on the top-right. Instead, the state on the bottom left is assumed when going back to the original pressure because energy is converted into heat

Second Law of Thermodynamics

- Entropy always increases
- In any cycling system, heat cannot be continuously and completely converted into work
- Entropy is a measure of the random mix of a given state

Irreversible Entropy: So What?

- Why is this important?
 - The increased work above the ideal Carnot refrigeration cycle is a function of I and the absolute temperature

$$W_{\text{actual}} = W_{\text{reversible}} + T_0 \Sigma I$$

- The vapor compression refrigeration process is not 100% efficient because of this effect

Third Law of Thermodynamics

- *As a system approaches absolute zero, all processes cease and the entropy of the system approaches a minimum value.*

Third Law of Thermodynamics

- In the late 1800's, Guillaume Amontons, a French scientist investigated the relationship between pressure and temperature in gases
- Amontons found that a given volume of air, when heated or cooled, expands or contracts by the same amount for each degree of temperature change.
- He determined that this change as about $1/240$ of the gas volume at 0°C
- Therefore, he supposed the volume drops to 0 at -240°C
- But, since that is impossible he determined that an absolute zero temperature exists: it is -273.15°C

Third Law of Thermodynamics

- In 1889, Walther Nernst developed the 3rd Law.

The entropy of a system at absolute zero is a well-defined constant.

- The third law states that the entropy of a perfect crystal approaches zero as the absolute temperature approaches zero.
- Any other substance will have a non-zero entropy at 0K.

End of Lesson

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