**Energy conservation and the first law of thermodynamics**

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**Abstract**

The first law of thermodynamics is an extension of the law of conservation of energy, which asserts that energy cannot be created or destroyed but can only change forms. This principle applies to the entire universe: the amount of energy present at the beginning will remain unchanged at the end. However, delving into thermodynamics reveals that the first law is more intriguing than this simple explanation suggests. It also serves as a key to understanding the concept of "energy."

Utilizing the first law, an energy balance framework is constructed to enhance our comprehension of processes. It aids in process design, control, identification of areas for improvement, and eventual optimization. By comparing a process's energy utilization efficiency with other similar systems or the most efficient ones currently achievable, we can identify areas for optimization. This comparison helps prioritize optimization efforts, whether they target excessive energy consumption or particularly low efficiency.

Nevertheless, the energy approach has limitations. It generally doesn't consider the process's assumed direction; energy analysis allows heat to flow spontaneously from a higher temperature to a lower one. Energy doesn't differentiate between its forms either; for instance, 1 watt of heat is treated the same as 1 watt of work or electricity.

**Introduction**

The first law of thermodynamics, in essence, asserts that a system's total energy remains constant, even as it transforms from one form to another. For instance, when a moving car's kinetic energy is converted into heat energy by applying brakes, the total energy remains unchanged. This law establishes a connection between the various forms of energy within a system, the work it can perform, and the heat transfer it undergoes. In some contexts, it serves as the definition of internal energy and introduces a state variable known as enthalpy. While the first law allows for a range of potential states for a system, empirical evidence indicates that only specific states are realized.

David Ting discussed the ideal Carnot cycle, a theoretical thermodynamic process that operates between two temperature reservoirs for maximum efficiency [1]. The sources of irreversibility within the DCHE (Direct Contact Heat Exchanger) system and quantify the extent of useful work lost during its cyclic operation has been identified. This framework integrates both the first law of thermodynamics (conservation of energy) and the second law of thermodynamics (entropy increase) to provide a holistic perspective on the system's efficiency and effectiveness [2]. Ventsislav D. Zimparov et.al. establishes that other forms of the Bejan number, which are based on the first law of thermodynamics and associated with convective heat or mass transfer, are combinations of the unique Bejan number with Prandtl (Pr) or Schmidt (Sc) numbers respectively [3]. Applying the first and second laws to practical engineering problems necessitates understanding the interplay between a substance's pressure, volume, and temperature. We outline the provision of such relationships, which can be accomplished through the use of equations of state or phase diagrams [4]. Dumitru Astefanesei et. al, investigation reveals a novel contribution to the total energy, contingent upon the scalar field's asymptotic value. This finding prompts a discussion on the significance of scalar charges in the context of the first law of thermodynamics [5]. Chen and Li derive both the differential and integral forms of the first law of thermodynamics for a holographic screen enclosing a spherically symmetric black hole. This formulation aligns with the equipartition principle and takes into account the structure of the Komar mass [6]. The first law of thermodynamics states that the total energy of a system remains constant, even if it is converted from one form to another [7]. Wassim M. Haddad presents a novel approach that combines energy-based modeling and hybrid dynamical systems to create a versatile framework for understanding and analyzing hybrid thermodynamic systems. This comprehensive methodology contributes to advancing the comprehension of critical thermodynamic behaviors and transitions, and extends the applicability of classical thermodynamic laws [8]. The evaluation of every power generation technology relies on the application of thermodynamic laws, which include the principles of energy conservation (the first law) and entropy generation (the second law). The utilization of these laws is imperative to attain a profound comprehension of the behavior and characteristics of power systems [9]. Jurgen M. Honig has significant emphasis on the significance of the surroundings in the context of heat and work transfers. This role of the surroundings is highlighted as a crucial factor in organizing and understanding the interactions involving heat and work within a thermodynamic system [10]. Bastian E. Rapp involves deriving the energy equation as an integral part of the process for solving for the various field variables. This equation solidifies the framework for analyzing fluid dynamics by integrating the principles of conservation of mass, momentum, energy, and thermodynamics [11].

**Mathematical Modeling**

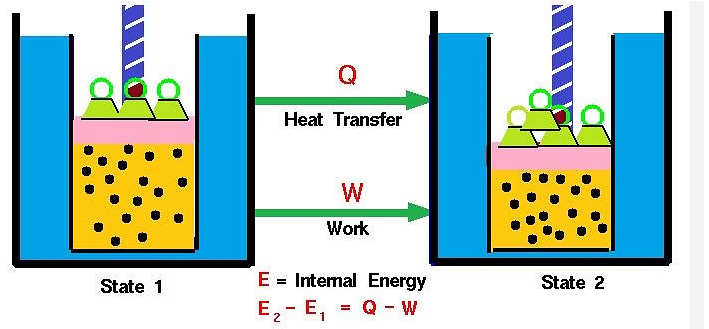


Figure 1 First Law of Thermodynamics

**Conservation of Energy**

The first law of thermodynamics articulates the principle of energy conservation. When applied to a system, it describes how the change in the system's internal energy is related to the total input energy, which is the sum of energy transferred as heat and energy involved in doing work. The power system encompasses both the internal energy stored within the system and the kinetic energy associated with its motion.

The following diagram visually illustrates this concept:

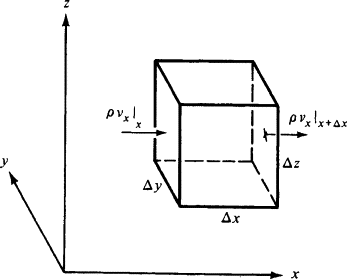


Figure 2 Control Volume for the energy conservation

In this representation, the internal energy and kinetic energy of the system play integral roles in determining the total power involved in the system's energy dynamics. The first law of thermodynamics ensures that energy is not lost within the system; instead, it is transferred between various forms such as heat and work. This principle forms the foundation for understanding energy transformations and exchanges within physical systems.

When a system moves from state 1 to state 2, its internal energy changes from U1 to U2. Then change in internal energy

ΔU = U2 – U1 (1)

This internal energy change is brought about by the either absorption or evolution of heat and/or by work being done by/on the system.

Because the total energy of the system must remain constant, we can write the mathematical statement of the First Law as:

ΔU = q + w (2)

Where,

q - The amount of heat supplied to the system;

w - Work done on the system

Other statements of first law of thermodynamics

1. Whenever an energy of a particular type disappears, an equivalent amount of another type must be produced.
2. The total energy of a system and surrounding remains constant (or conserved).
3. "Energy can neither be created nor destroyed, but may be converted from one form to another".
4. "The change in the internal energy of a closed system is equal to the energy that passes through its boundary as heat or work".

The mathematical statement of the first law of thermodynamics is

∆U = q + w

**Case 1:** For a cyclic process involving isothermal expansion of an ideal gas,

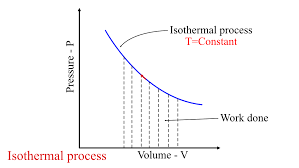


Figure 3 Isothermal Process

∆U = 0.

q = -w (3)

In simpler terms, for a cyclic process (a process where the system returns to its initial state), the heat absorbed by the system is equal to the work done by the system. This principle is known as the First Law of Thermodynamics and is often summarized as "energy cannot be created or destroyed, only converted from one form to another." In the context of a closed cycle, the energy input as heat is transformed into the energy output as work, and vice versa.

**Case 2:** For an isochoric process there is no work of expansion. i.e. ΔV = 0

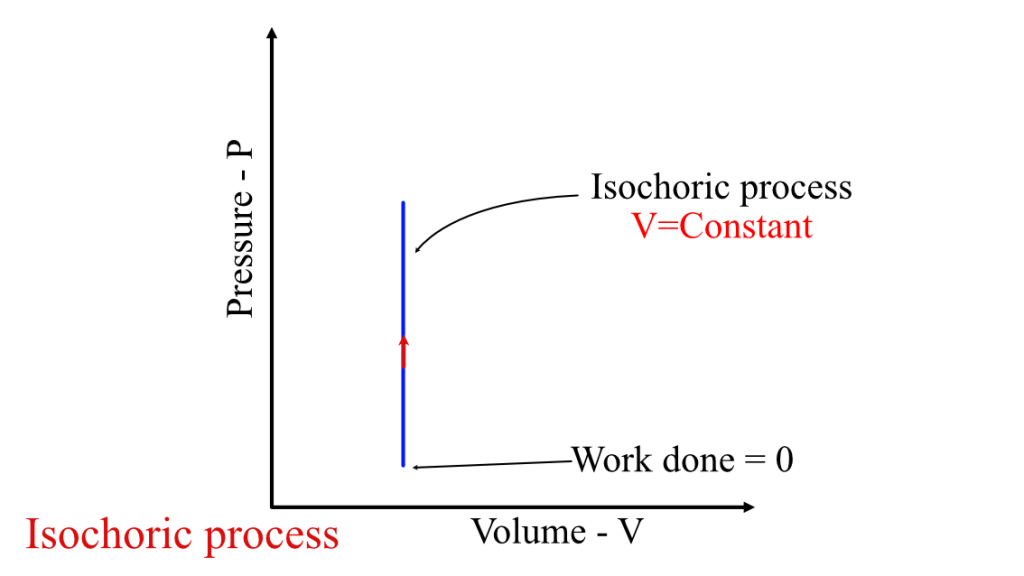


Figure 4 Isochoric Process

ΔU = q -w

ΔU = q – PΔV (4)

ΔV =0

ΔU = q (5)

During an isochoric process, which is also known as an isovolumetric process (constant volume process), the volume of the system remains constant while the pressure and temperature can change. In this type of process, no work is done by the system because there is no change in volume.

As a result, any heat supplied to the system is used solely to increase its internal energy. The internal energy of a system includes the kinetic energy of its particles (due to their motion) and potential energy (due to interactions between particles). So, in an isochoric process, any heat added to the system contributes to raising the internal energy, leading to an increase in temperature.

It's important to note that in an isochoric process, the internal energy change corresponds directly to the heat supplied, as no work is being done to change the volume.

**Case 3:** For an adiabatic process there is no change in heat. i.e. q= 0.

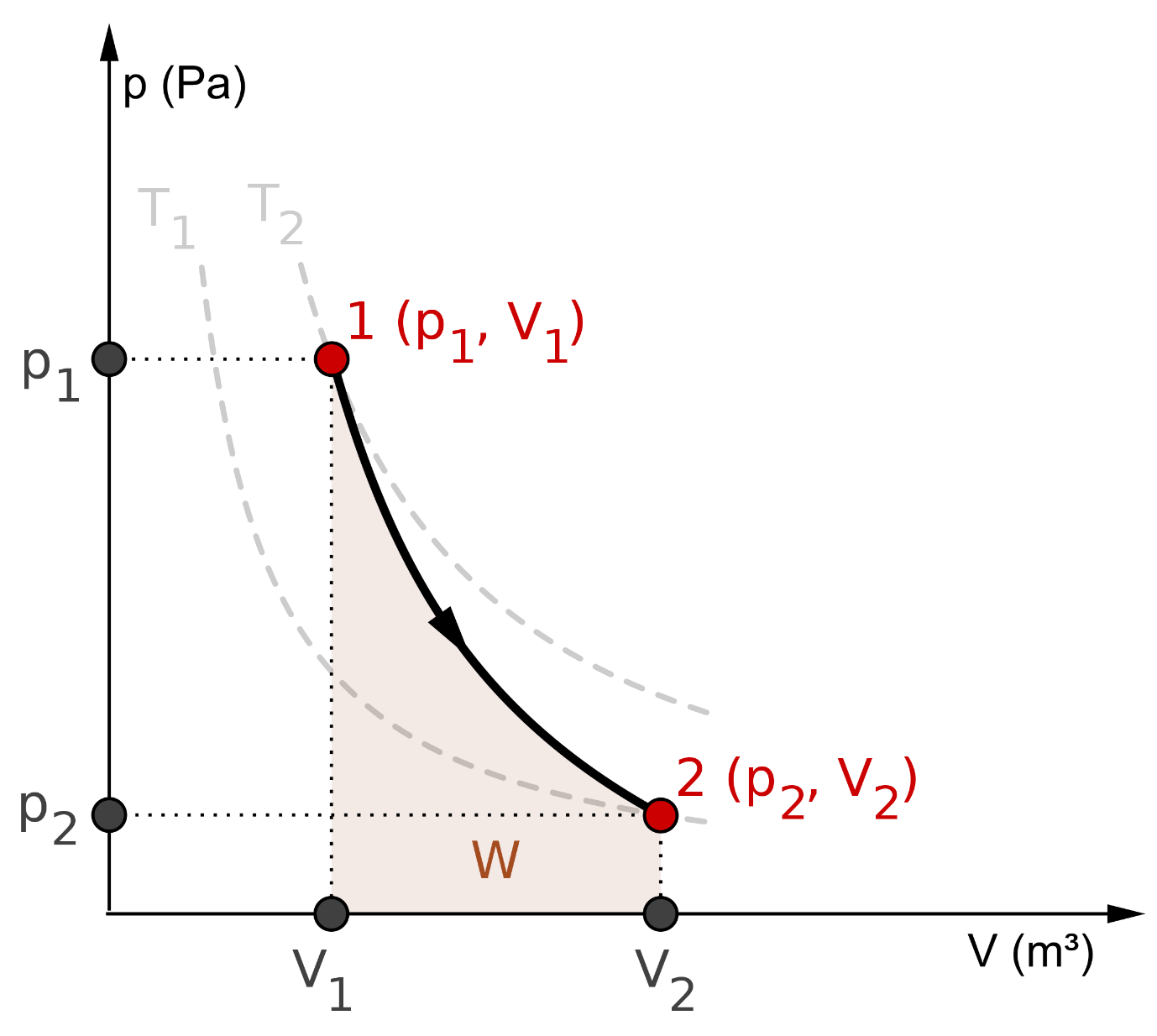


Figure 5 Adiabatic Process

As , q = 0

ΔU = w (6)

In an adiabatic process, which is a process where there is no heat exchange with the surroundings (Q = 0), the decrease in the internal energy of the system is equal to the work done by the system on its surroundings. This relationship is a consequence of the First Law of Thermodynamics, which states that the change in internal energy of a system is the sum of the heat added to or removed from the system and the work done on or by the system.

Since there is no heat exchanged (Q = 0) in an adiabatic process, the entire change in internal energy is accounted for by the work done. This often occurs in processes that happen rapidly or in well-insulated systems where heat transfer is negligible. Adiabatic processes are commonly found in thermodynamic engines and compressors.

**Case 4:** For an isobaric process. There is no change in the pressure

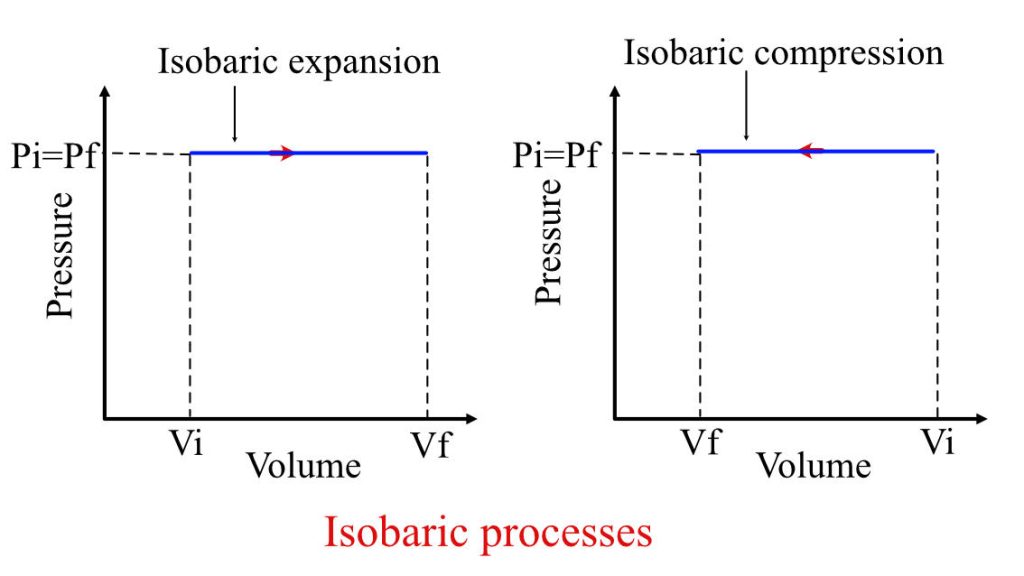


Figure 6 Isobaric Process

In an isobaric process, which is a process that occurs at constant pressure, heat can be exchanged with the surroundings. During such a process, a portion of the heat absorbed by the system is utilized to perform pressure-volume (PV) expansion work, while the remainder contributes to increasing the internal energy of the system.

Mathematically, for an isobaric process:

Q = ΔU + W

Where:

Q = Heat added to the system

ΔU = Change in internal energy

W = Work done by the system

Since pressure is constant in an isobaric process, the work done is given by:

W = PΔV (7)

Where:

P = Constant pressure

ΔV = Change in volume

So, during an isobaric process, the heat added (Q) is divided into two components: one part is used to do the PV expansion work (PΔV), and the other part contributes to the change in internal energy (ΔU). This is a result of the First Law of Thermodynamics, which accounts for the balance between heat transfer, work done, and change in internal energy in various thermodynamic processes.

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