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A review of the second law of thermodynamics and its application

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Abstract. Over thousands of years, many great physicists, such as Carnot, Boltzmann, Plank, Clausius, to name only a few, have put great endeavor into unwinding the mysteries of thermodynamic studies. In recent decades, many innovations have been made by groundbreaking modern technologies, such as refrigerators and air conditioning, and both recent findings and formerly discovered concepts of thermodynamics have been explained deeply by modern scientists. The paper briefly introduces the definition of the second law of thermodynamics and the relative concepts and their application. This paper delves into the history and definition of the Carnot Theorem, the Irreversible Carnot engine and refrigerator principle, as well as the Coefficient of Performance (COP). After that, this paper will introduce a few relative concepts, including entropy, exergy, and the Clausius-Duhem inequality. In summary, this paper covers a basic overall explanation of the aforementioned concepts, as well as drawing conclusions about the experimental achievements of the early explorers of thermodynamics.

Keywords: The Second Law Of Thermodynamics, Entropy, Physics, Thermodynamics.

1. Introduction

It is well known that three laws of thermodynamics have been found by great physicists in history. Classical thermodynamics is primarily used to determine how well the heat engine performs. The first law of thermodynamics is a cassone of the basic laws in the physics, and it is taught to every school student, as it is a necessary tool in every case and question. Whereas, for the second law of thermodynamics, numerous great physicists, like Carnot, Kelvin, Plank, Boltzmann, and others, are put great endeavor to figure out the truth of the second law of thermodynamics. Based on notions discovered by those forerunners, a sheer volume of inventions form, like heat pump and refrigerators. The rise of the core of the second law of thermodynamics, which is something called ‘entropy’, led to an evolution, not only in the science field, but also in the sociology field. Today, there are many problems related to entropy still unsolved or solved in recent years. The principle of entropy increase, result from the second law of thermodynamics, is one of the greatest principles in the science field. In this paper, the basic concept for the second law of thermodynamics is shown, as well as some history of the concepts. The principle of the irreversible Carnot heat engine and irreversible Carnot refrigerator will be explained, and the entropy and exergy will be told briefly in the paper.

2. The second law of thermodynamics

According to Clausius's principle and Kelvin's principle, the second law of thermodynamics expresses that it is difficult to move heat from a colder body to a sultrier body with next to no other change, and moving intensity from an intensity supply and convert all into work with no change are impossible [1]. These two concepts are based on Carnot's theorem. The theorem is discovered by Carnot, who analyzed the performance of the 'Carnot cycle' [2].

2.1. Carnot's Theorem

Lazare Carnot was an army engineer in France, and he was one of the ruling people in France in the revolutionary years. He did many things during that age. Besides that, he published articles about the most general statement of the principles of mechanics, and thus the impossibility of perpetual motion machines [3]. His son, Sadi Carnot, based on what Lazare discovered, turned the idea subtly to deduce a new principle. There were many problems unsolved and many misunderstandings in that age, so his new principle solved hundreds of questions [3]. He assumed a generalized heat engine with a cold reservoir, which can provide useful work W by taking heat Q1 from a source that is at thermal equilibrium at temperature t1, and to maintain the operation, the cold reservoir, t2<t1, so that an amount of heat, Q2, can be released [3]. A reversible engine just bumps into Carnot's head. Depending on that, the Carnot figured out the principle, which is the Carnot's Theorem.

According to Carnot's Theorem, the reversible Carnot cycle has the greatest efficiency regardless of the mode of operation or the materials used. It just depends on the temperature of the heat source [4]. Although Carnot used an incorrect concept of 'heat', he used two different notions to connect with 'heat' when he did the experiment, which was 'chaleur' (refers to 'heat') and 'calorique'(alludes to something that intended to be not quite the same as 'heat') [5]. According to after study, what Carnot found is still valid, despite he used the wrong notions [5]. Carnot's Theorem plays a non-substitutable role in the contemporary thermodynamics, which acts as an ancestor. It basically portrays a romanticized reference cycle of a genuinely thermodynamic interaction to look at the feasible cycle in nature in examination with a glorified cycle, or at least, a reversible interaction relating to a genuine cycle.

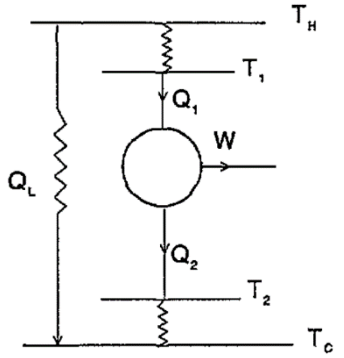


Figure 1. Schematic diagram of an irreversible Camot heat engine [4].

2.2. The irreversible Carnot Heat Engine

The graph [4] above shows an irreversible Carnot heat engine. In reality, heat engines are extremely complex, and the conditions are more complicated than the theoretical conditions, so there are many sources of irreversibility. This graph, shows the heat transfer with a finite rate between the heat engine and reservoirs, heat leaking between the reservoirs, and the inner dissipation of the fluid. The fluid flows in the hot reservoir at temperature TH and the cold reservoir at temperature TC (TH >TC), and the fluid temperature in the hot reservoir and cold reservoir are T1 and T2 respectively. The engine works with cyclic motion in time t for each cycle. The fluid will back to the initial state after time t. The energy Q1 transfers from the hot reservoir to the heat engine in time t1 with thermal conductance K1, and then energy Q2 transfers from the heat engine to the cold reservoir in time t2 with thermal conductance K2.

QL is the heat Leakage from the hot reservoir to the cold reservoir in a full cycle with time t and thermal conductance KL.

In the cycle, the entropy of the fluid in two thermoresistant branches rises. The entropy production in the branches is defined as ΔS1 and ΔS2. Base on the second law of thermodynamics, an inequality is formed:

$$\frac{Q_2}{T_2}-\frac{Q_1}{T_1}>0 \tag{1}$$

Base on Chen(1994)'s calculation [4] , the expressions of the power output and efficiency are formed (1)

$$P=\frac{Q_H-Q_C}{t}=\frac{Q_1-Q_2}{t}=\frac{1-I_Sx}{\left[\frac{1}{K_2(T_H-T_1)}\right]+\left[\frac{I_sx}{K_2(xT_1-T_e)}\right]} \tag{2}$$

$$\eta=1-\frac{Q_C}{Q_H}=(1-I_Sx)\Bigg[\bigg[1+K_L(T_H-T_C)\times\bigg\{\bigg[\frac{1}{K_1(T_H-T_1)}\bigg]+\bigg[\frac{I_Sx}{K_2(xT_1-T_C)}\bigg]\bigg]\bigg\}\bigg]\Bigg]^{-1} \tag{3}$$

which IS is the ration of ΔS2 over ΔS1, and x is equal to T2 over T1. This cyclic model is a general model. The heat engine is internal irreversibility when KL=0 or IS=1 (endoreversible heat engine with limited-rate heat transfer is only formed when KL=0 and IS=1).

2.3. *Irreversible refrigerator cycle:*

The schematic graph below shows the Carnot refrigeration cycle. According to Yan(1989)'s deduction [5] , the irreversible cycle has different suitable configurations and characters in different heat transfer law. So, we assume that the heat transfer law is a general law, and the cycles are only irreversibly arisen from finite-rate heat conduction.

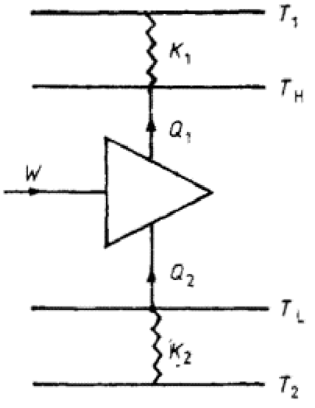


Figure 2. A Carnot refrigeration cycle affected by thermal resistance [5].

When the internal isothermal process is carried out, the temperature T1 and T2 is different from the temperature inside hot reservoir TH and cold reservoir TL, and the relationship between T1, T2, TH, and TL is T1 > TH > TL > T2 [5] . Additionally, in the isentropic cycle, the interaction happens in an unimportant time. According to specific perspectives, this model is like the Curzon-Ahlborn cycle model [5] , however it's still a few distinctions. K1 and K2 represent the heat conductance between the working fluid and the two heat reservoirs. According to the Yan(1989)'s deduction [5] :

$$Q_2=K_2(T_L^n-T_2^n)t_2 \tag{4}$$

which n is a non-zero integer. The heat transfer law would be different when different value of n is taken. For instance, when n is equal to 1, the Newton's law is presented; when n is equal to 4, the heat radiation law is presented. After the deduction [5] , the average rate of refrigerator of the cycle is:

$$R = \frac{Q_2}{\tau} = \frac{K_2(T_L^n - T_2^n)}{1 + \frac{t_1}{t_2}} = \frac{K_2}{\frac{1}{T_L^n - T_2^n} + \frac{K_2 T_1}{K_1 T_2}\left(\frac{1}{T_1^n - T_H^n}\right)} \tag{5}$$

which τ is the cycle time that τ = t1+t2. Beside this equation, the rate of refrigerator of the cycle can be deduced from another equation [5] :

$$R = \frac{K_2\left[T_L^n - \frac{T_H^n}{(1+\varepsilon^{-1})^n}\right]}{\left\{1 + \left[\frac{K_2}{K_1(1+\varepsilon^{-1})^{n-1}}\right]^{\frac{1}{2}}\right\}^2} \tag{6}$$

which ε is the coefficient of performance. The condition above is the general and fundamental connection for the model cycle, and the various exhibitions for this sort of model cycle can be in every way reasoned from this situation. For instance, when the n is equal to 1, the relationship between the R and ε can be determined.

3. The application of second law of the thermodynamics

3.1. Coefficient of Performance (COP)

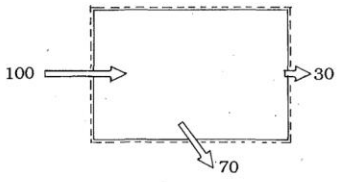
According to the aforementioned notions, the coefficient of Performance, which is known as COP, is mentioned in the irreversible refrigerator cycle. The COP is defined as the ratio of energy conversion efficiency.

Like refrigerators, there are many cooling systems used in daily life, not only for ordinary, but also for some special regions like military, aerospace, and industrious, to name only a few. In past few decades, thermoelectric devices have been used extensively, but the shortage of the devices is the low COP, especially in large capacity application. According to the research by Riffat(2004) [6] and his team, they have emphasized how to improve the COP value of thermoelectric cooling system, by developing new material, optimizing module system design and fabricating and improving the heat exchange (heat sink and heat rejector) efficiency [6].

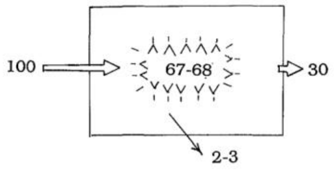
3.2. Exergy

Based on the first and the second law of thermodynamics, exergy is present. Exergy is the greatest hypothetical work that can be extricated from a consolidated framework [7] . The definition [7] of exergy states that exergy is the base hypothetical shaft work or electrical work expected to shape an amount of issue from substances present in the climate and carry the make a difference to a predefined state [7] . Taking everything into account, isn't saved yet is annihilated. When a system spontaneously achieves equilibrium with the environment without providing work—a special case—the energy is completely destroyed [7] .Exergy has few properties: In the dead state, the exergy is 0; for all states, the exergy is always larger or equal to 0. Also, exergy in a system can somehow equal to the sum of chemical exergy and thermodynamic exergy.

The term 'energy' and 'exergy' is easy to be confused by investigators, so they should be distinguished carefully. Energy, for instance, is conserved in all circumstances and cannot be destroyed or formed. The figure [7] underneath shows a power cycle that has energy premise and exergy premise individually, so the distinctions between the energy and exergy can be obviously shown.



(a) Energy Basis



(b) Exergy Basis

Figure 3. Power cycle [7].

The exergy can be used in multiple ways [7] . One of the ways is the exergy analysis. Exergy analysis can help to find out the nonidealities of the system, like the irreversibility of combustion. Also, the exergy analysis can help to design better industrious products or processes. Lastly, it can assist the government in determining the location and relative importance of key non-idealities, thereby enhancing conversion efficiency and reducing unnecessary resource waste.

3.3. *Clausius inequality:*

The second law of thermodynamics is fascinating in thermodynamics. As per the previously mentioned thoughts, the meaning of the subsequent regulation has been shown. Clausius and Kelvin's principle are identical to Carnot's Theorem, and Poincaré demonstrated the equality of Clausius and Kelvin principle to Carnot's Theorem [8] . Clausius utilized the proportionality of the Clausius principle and Carnot principle to name an inequation with his name, called 'Clausius inequality'. The mathematical expression of the second law of thermodynamics has been regarded as the Clausius inequality.

The Clausius inequality [8] is

$$N = -\oint \frac{dQ}{T} \geq 0 \tag{7}$$

Which N is ‘uncompensated heat’(generally sure and disappears provided that a reversible interaction structures. The uncompensated heat was found via Carnot, when he was finding his theorem. It is one of the fundamental focal quantities for the development of a thermodynamic hypothesis of irreversible interaction with the goal that it should be explained), dQ is ‘compensated heat’(heat move between the framework and environmental factors), and temperature T alludes to the intensity stockpiling of the places being referred to in a progression of minute cycles that make up the cycle under consideration [8] . Based on the C.M. Dafermos’s deduction [8], the Clausius inequality is satisfied by a smooth process, which is equality.

3.4. *Entropy*

The core notion of the second law of thermodynamics is what is called ‘entropy’. Entropy is the vital notion of thermodynamic mechanics. Generally speaking, the entropy is equal to 0 only if one has complete information, like a pure state, otherwise the entropy is always greater than one in a system. Entropy is not the same as general physical quantities, like length, mass, and density. In quantum mechanics, entropy is certainly not a perceptible. It’s more likely a state. The entropy can be defined when the state is described by the density matrix ρ [9].

$$S < \rho >= -k_B Tr_\rho ln_\rho \tag{8}$$

Which kB refers to Boltzmann's constant (1.38x106 erg/K).

This equation was first formed by Von Neumann in the time of 1927, which advanced the classical articulation of Boltzmann and Gibbs to quantum mechanics [9].There is more general form of definition, which is 'a measure of the "amount of chaos" in a system [9]'.

Entropy is also normally defined with the other equation [10].

$$\Delta S = \frac{\Delta Q}{T} \tag{9}$$

Where Δ S refers to the increment in the entropy of a system with temperature T and obtain several heat Δ Q.

Clausius first formulated the concept 'entropy', as he expected that such a quantity existing would vanish in a reversible process, which is called ' Clausius entropy'. An extremely essential point is that the Clausius entropy only exist in reversible processes [11].

To mention the entropy, we have to consider the maximum entropy principle. The maximum entropy principle originated from the principle of insufficient reason [12].The case in which the expectation value of some function f has a given value [12]is the most straightforward type of constraint, as determined by Uffink's deduction [12]

$$< f >= \sum_{i} f(x_i)\, p(x_i) = a \tag{10}$$

The probability distribution with maximum entropy is of the form [12].

$$p_\beta(x) = \frac{e^{-\beta f(x)}}{Z(\beta)} \tag{11}$$

For which β is the parameter.

As per Uffink's view, the rule of maximum entropy gives explanation or progress to all complaints that have demonstrated lethal to the standard of inadequate explanation [12]. Uffink's paper [12] laid out in 1996 shows plainly whether the Maximum Entropy Principle be made sense of as a Consistency requirement or not, perusing his paper is blissful.

4. Conclusion

In this paper, the author introduces briefly what is the second law of thermodynamics. After that, the author shows the Carnot theorem, which is the basic theorem to the second law of thermodynamics. The author briefly shows the irreversible Carnot heat engine and refrigerator, at the same time demonstrating some equations that are related to them. Also, the author expounds the COP from the rate of the refrigerator, introducing the definition of COP and its application in reality. The author inserts 'exergy' after introducing the COP and showing the application of exergy analysis. Back to the topic, the author introduces briefly the Clausius inequality and entropy. The limitation of the paper is clear either: most of the reference is from ages ago, so most of the concepts may not be fresh new, and cutting-edged; also, some parts of the explanation are lack of using professional lexical resources, which the explanation is not accurate. The field of thermodynamics has great potential to study and explore in the future. Many of the unsolved problems in this field are waiting to be solved in the future.

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