Proposal to test the validity of the second law of thermodynamics

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Abstract

The concept of '*thermal heating efficiency'*, G, considered as a duel of Carnot efficiency, offers a suitable method to test the validity of second law of thermodynamics. This concept claims to offer us many practical (therefore, experimentally testable) advantages, specifically, economy in heating houses, cooking, besides others. For example, if one unit of fuel when burnt inside the house gives Q joules of heat, the thermodynamic method based on this concept offers as much as 10 Q joules for the same one unit of fuel, giving a 10 fold economy in heating houses. We show in this article that the economy claimed is a myth and we can get no more heat into the house using this method than that we get by burning the fuel inside the house. We propose, the concept of thermal heating efficiency as a suitable method to test the validity of the second law of thermodynamics.

Introduction

The thermodynamic process of heating houses more economically than burning the fuel directly inside the house was originally conceived by Lord Kelvin[1], who was one of the founders of thermodynamics and one who postulated the second law. The economy arises due to '*thermal heating efficiency'*[2], sometimes referred to as '*Heat multiplication factor'*[3,4]. In more recent times it is referred to as the duel of Carnot efficiency that completes the logical structure of classical thermodynamics[2]. The concept is based on the compound cyclic process of two Carnot heat engines (CHEs) combined in series (that is, with a heat reservoir (HR) common to both engines). The first engine, CHE1, interacts with HRs at temperatures T_1 and T_2 and the second engine, CHE2, interacts with HRs at temperatures T_2 and T_3 ($T_1 > T_2 > T_3$) and operates in the reverse direction so as to act as a heat pump. We call such a device '***Heat Multiplying Device'*** (***HMD***). Here, HR at T_1 is the boiler which is maintained at constant temperature by transferring heat obtained from burning the fuel. HR at T_2 is the house to be heated so as to maintain it at a temperature suitable for comfortable living. HR at T_3 is the surroundings. The compound cyclic process absorbs Q_1 units of heat from the boiler at T_1, (we have to pay for this heat by way of cost of fuel used to maintain the boiler at constant temperature T_1), Q_3 units of heat from the atmosphere (surroundings) at T_3 (we get this heat free of cost), and supplies the whole heat of ($Q_1 + Q_3$) units into the house at T_2 with no work interaction involved and at no extra cost whatever. All processes are reversible.

Several challenges appeared in the recent literature, highlighted by the several conferences[5] and by Capeck and Sheehan[6]. However, most challenges are quantum mechanical in nature or are sophisticated in experiment.

'Thermal heating efficiency' G, is defined as the ratio of heat supplied into the house ($Q_1 + Q_3$) by employing HMD to the heat Q_1 obtained from burning the same amount of fuel inside the house. It is the efficiency of the HMD. We show in this article that the concept of thermal heating efficiency, or heat multiplication factor, is a myth. That is, that it is impossible to get any more heat into the house by the thermodynamic process using HMD than that which can be obtained by directly burning the fuel inside the house. Since this process is practical, we propose it as a test to validate the second law of thermodynamics.

Analysis

Q, T, W, S and η refer to heat, absolute temperature, work, entropy, and Carnot efficiency respectively, in this paper.

There are two variants of HMD. Each follows a cycle which is a combination of two Carnot cycles. In both variants the first CHE interacts with HRs at the highest and the intermediate temperatures and runs in the forward direction as a heat engine. The second CHE interacts with HRs at the intermediate temperature and the lowest temperature and runs in the reverse direction as a heat pump. In the first variant the cycle operates along two adiabats, say, S_1 and S_2 and in the second variant the cycle operates along three adiabats, S_1, S_2 and S_3. In both cases there are three HRs where heat interaction occurs. The HR at the intermediate temperature is common to both CHEs. We analyze the two variants under case (i) and case (ii) below. We depict the different CHEs and their combinations in Fig. 1. The T-S diagrams of different CHEs and their combinations that we use in the analysis are depicted in Fig. 2.

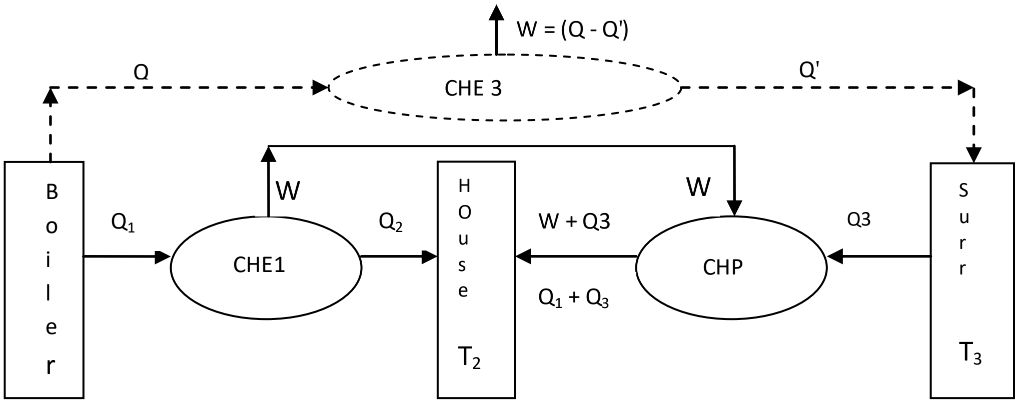

Fig. 1. A schematic diagram depicting Combination of two CHEs proposed by Kelvin, to heat houses economically. CHE1 works in the clockwise direction as a heat engine and the other CHE works in the anticlockwise direction as a CHP. The combined cycle of CHE1 and CHP produces no net work interaction with surroundings. CHE3 interacts with HRs at T_1 and T_3.

If we have three HRs, using any two we can operate a CHE. Thus we have three possible CHEs: CHE1, CHE2 and CHE3. If we have four or more HRs we can operate more CHEs. With different values for each CHE we get variants of these CHEs. We consider several CHEs and their combinations in this analysis. To facilitate easy understanding we show them in Fig. 2 and list them below.

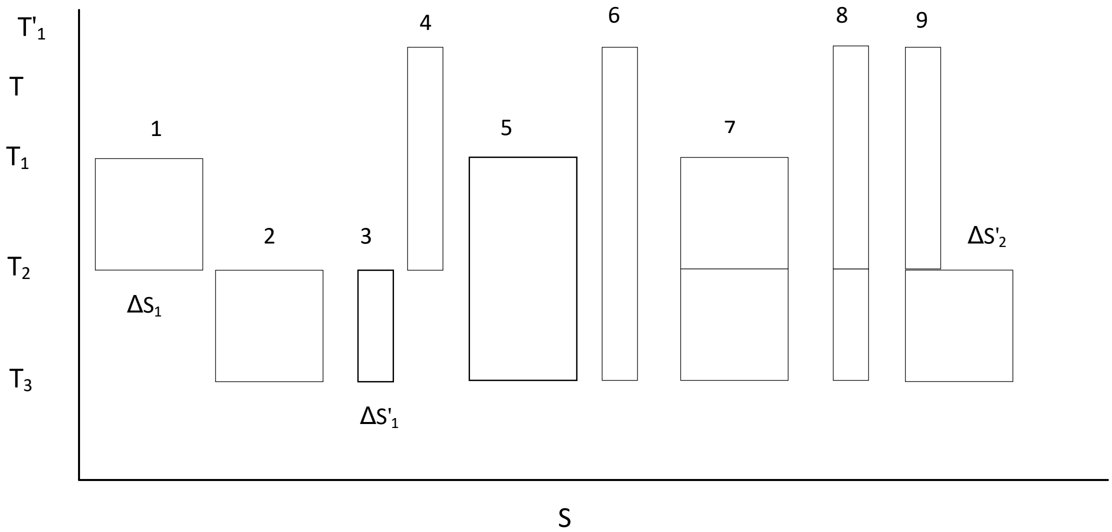

Fig. 2. T-S diagrams of Different CHEs (the first six) and their combinations (last three) considered in this analysis are depicted individually here. $\Delta S_1 = (S_1 - S_2)$, $\Delta S_2 = (S_2 - S_3)$, $\Delta S'_1 = (S'_1 - S_1)$, $\Delta S'_2 = (S'_1 - S_2)$. The CHEs and their combinations depicted in Fig. 2 are listed below.

1. CHE1 works along adiabats $S_1$and S_2, and along isotherms at T_1 and T_2,
2. CHE2 works along adiabats $S_1$and S_2, and along isotherms at T_2 and T_3,
3. CHE'1 works along adiabats $S_1$and S'_1, and along isotherms at T'_1 and T_2,
4. CHE'2 works along adiabats $S_1$and S'_1, and along isotherms at T_2 and T_3,
5. CHE3 works along adiabats $S_1$and S_2, and along isotherms at T_1 and $T_{3.}$
6. CHE3' works along adiabats $S_1$and S'_1, and along isotherms at T_1 and T_3
7. Combination of CHE1 and CHE2 (HMD-1)
8. Combination of CHE'1 and CHE'2 and (not useful as HMD)
9. Combination of CHE'1 and CHE2 (HMD-2)

We note that CHE2 and CHE'2 work in the reverse direction, as CHPs.

Necessary conditions for combination of two CHEs to produce a resultant HMD.

CHE working at the higher temperatures operates in the clock-wise direction and the CHE working at the lower temperatures operates in the reverse direction as CHP. (ΔS_1/ ΔS_2) = 1. The HMD produces no net work interaction with the surroundings.

It can be seen from Fig. 2 that only 7 satisfies both these conditions; 8 satisfies the second condition but not the first; 9 satisfies the first condition but not the second. Combination 8 is included because it would be useful later in our analysis. Let us now proceed forward with the analysis. We consider the combination 7 under case (i) below.

Case (i): This is the first variant of HMD. We consider the combination of CHE1 and CHE2, keeping in mind that CHE2 operates as CHP. The T-S diagram of the combination is shown in Fig. 3 (7 in Fig. 2).

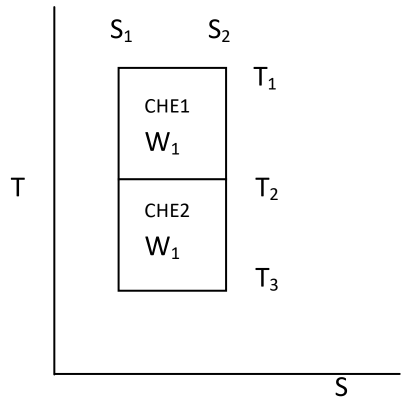

Fig. 3. Two CHEs combined in series with HR at T_2 common to both. Both operate between the same two adiabats $S_1$and S_2. CHE2 works as a CHP. The net work interaction with surroundings is zero.
For the combined CHE1 and CHE2, Qs are related to Ts as:

$$Q_1\colon Q_2\colon Q_3 = T_1\colon T_2\colon T_3 \tag{1}$$

$$\Delta S_1 = \frac{Q_1}{T_1} = \frac{Q_2}{T_2} = \frac{Q_3}{T_3},\ \ (Q_1 - Q_2) = (Q_2 - Q_3) = W \tag{2}$$

From Eq. (2) we get,

$$\frac{(Q_1 - Q_2)}{(T_1 - T_2)} = \frac{(Q_2 - Q_3)}{(T_2 - T_3)}\ and\ (T_1 - T_2) = (T_2 - T_3)\ or\ (T_1 + T_3) = 2T_2 \tag{3}$$

$$\frac{(T_1 - T_2)}{T_1} = \frac{(Q_1 - Q_2)}{Q_1} = \frac{W_1}{Q_1} = \eta_{12} < 1 \quad (4)$$

$$G = \frac{Q_1 + Q_3}{Q_1} = 1 + \frac{Q_3}{Q_1} > 1 \quad (5)$$

$$\eta_{13} = \frac{Q_1 - Q_3}{Q_1} = 1 - \frac{Q_3}{Q_1} < 1 \quad (6)$$

Thermal heating efficiency is the duel of Carnot efficiency

We can see from Eqs. (5) and (6) why thermal heating efficiency is called the duel of Carnot efficiency. Neither G nor η_{13} is equal to one. Their values lie on either side of one on the number line. It may be surmised if either of them is equal to one the other would also be equal to one. In fact that is the truth. We made η less than one by definition! Therefore, we have to face the consequence of countenancing G > 1.

$$G = \frac{Q_1 + Q_3}{Q_1} = 1 + \frac{Q_3}{Q_1} = 1 + (1 - \eta_{13}) = 1 < (2 - \eta_{13}) < 2 \quad (7)$$

Again, we find from Eq. 7 that G < 2. Therefore, values of G > 2 are based on irrational arguments. η_{ij}, represents the efficiency of CHE interacting with HRs at temperatures T_i and T_j.

η = ½ paradox

Since η_{12} can have any value between 0 and 1, let us assume, η_{12} =1/2. Then we get,

$$\frac{Q_1}{2} = W_1 = W = W_2 = Q_2, (Q_2 - W_2) = Q_3 = 0 = \eta_{23} \quad (8)$$

$Q_3 = 0 = \eta_{23}$, is impossible as it violates the Kelvin's postulate of second law. When $Q_3 = 0$, G = 1. But, since $Q_3 = 0$ is impossible, G = 1 is impossible. If $\eta_{12} \neq ½$, then $\Delta T_1 = \Delta T_2$ and $\eta_{12} \neq ½$ will not be consistent. In other words, it is impossible to satisfy the conditions $\eta_{12} \neq ½$ and $W_1 = W_2$ simultaneously. Therefore, for no value of η_{12} can we satisfy Eq. (5). Therefore, G ≥ 1 is a myth.

Case (ii): This is the second variant of HMD. Let us consider the combination of CHE'1 and CHE2 keeping in mind that CHE2 operates as CHP. The T-S diagram of the combination is shown in Fig. 4(9 in Fig. 2).

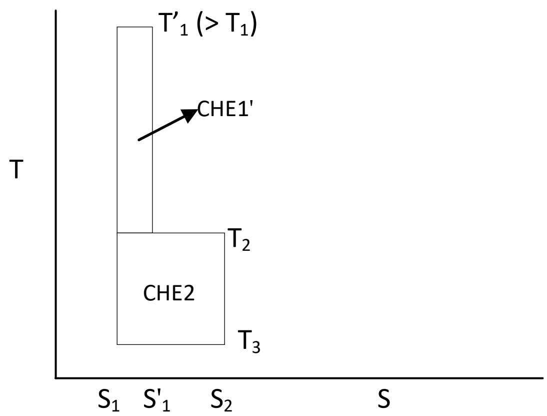

Fig. 4. CHE1' and CHE2 are combined with HR at T_2 common to both. CHE2 works as a CHP. The net work interaction with surroundings is zero.

For CHE1', CHE2', CHE3' (Fig. 2) the following relations between Qs and Ts apply.

$$Q'_1 : Q'_2 = T'_1 : T_2 \qquad CHE1' \tag{9}$$

$$Q'_2 : Q'_3 = T_2 : T_3 \qquad CHE2' \tag{10}$$

$$Q'_1 : Q'_3 = T'_1 : T_3 \qquad CHE1'' \tag{11}$$

For the combination of CHE1' and CHE2' (CHE 8 in Fig. 2) we have,

$$Q'_1 : Q'_2 : Q'_3 = T'_1 : T_2 : T_3 \tag{12}$$

Now the question is: How are the Q's and Ts related for the combined CHEs: CHE1' and CHE2 shown in Fig. 4 (9 in Fig. 2)?

There is no way the Q's and Ts are related for this combination, because the combination does not have a unique value of efficiency either as a heat engine or as a HMD according to classical thermodynamics.

However, Kelvin's proposition[1] and Jane's advocacy of the method[2] that offers heating efficiency greater than one, implicitly or explicitly suggest the relations:

$$Q'_1 : Q_2 : Q_3 = T'_1 : T_2 : T_3 \tag{13}$$

$$\frac{Q'_1 + Q_3}{T'_1 + T_3} = \frac{Q'_1}{T'_1} \; or \; \frac{Q'_1 + Q_3}{Q'_1} = \frac{T'_1 + T_3}{T'_1} = G > 1 \tag{14}$$

However, in view of the fact that Eq (13) is inconsistent with Eqs. (9) to (12), Eq. (14) is also inconsistent with Eqs (9) to (12). If Eqs (9) to (12) are in accordance with the second law, then Eqs (13) and (14) violate the second law. Conversely, if Eqs (13) and (14) are in accordance with the second law then, Eqs (9) to (12) violate the second law.

Note that Eq. (14) would be true only if :

$$\frac{Q'_1 - Q_3}{T'_1 - T_3} = \frac{Q'_1}{T'_1} \; or \; \frac{Q'_1 - Q_3}{Q'_1} = \frac{T'_1 - T_3}{T'_1} = \eta < 1 \tag{15}$$

But Eq. (15) would be true only if $S'_2 = S_2$. Eq and Eq (14) would be true only if $S'_2 \neq S_2$. Therefore, it is impossible to satisfy Eqs (14) and (15) simultaneously. Therefore either Eq. (14) is true or Eq. (15) is true but not both. If Eq (15) is true, then heat multiplication is a myth, on the other hand, if Eq. (14) is true then second law is a myth.

Therefore, this process of deriving economic advantage out of Kelvin's thermodynamic process can be a very practical candidate to test the validity of the second law of thermodynamics.

Note: In literature, we find the theoretical analysis follows Fig. 3 but numerical examples follow Fig. 4. See for example [1]: T_1 = 1000K, T_2 = 298K, T_3 = 273K and G = 10.9.

Disproportionation of heat

We have another interesting aspect of this HMD cycle. Since all the processes are reversible, the HMD cycles when operate in the reverse direction lead to disproportionation of heat. That is, a given quantity of heat of Q units from a HR at certain temperature T, is transferred to two HRs. Q_1units of heat to HR at a temperature T_1 (higher than T) and Q_2 units of heat to HR at a temperature T_2 (lower than T), where $Q = (Q_1 + Q_2)$ with no other change elsewhere.

Just as heat multiplication is a myth, disproportionation of heat is also a myth! Many a standard result in thermodynamics depends on disproportionation of heat, including Clausius theorem.

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