



SDI FINAL EVALUATION FORM 1.1

PART 1:

Journal Name:	British Journal of Applied Science & Technology
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PART 2:

FINAL EVALUATOR'S comments on revised paper (if any)	Authors' response to final evaluator's comments
It follows from the first and second law that the highest efficiency any heat engine operating between two thermal reservoirs is given by the carnot efficiency. This is easily proven. You have not presented a valid proof for why a heat engine operating between two thermal reservoirs can have a higher efficiency than the Carnot efficiency. Your cycle is operating between two thermal reservoirs and is therefore bound by the Carnot efficiency. If you have constructed an engine that operates between two thermal reservoirs and has a higher efficiency than the Carnot efficiency you are in violation of the laws of thermodynamics.	Please find below the response to the Reviewer comments, which contributed to the enhancement of the paper From the first and second laws the highest efficiency any (Carnot based) heat engine operating between two thermal reservoirs is given by the Carnot efficiency. We agree with you that this is easily proven. However, from the first and second laws only is easily proved that the highest efficiency any heat engine operating between two thermal reservoirs is lower than 100% (Kelvin-Plank). In what follows there are answered your reasonable doubts. The comparison of the Carnot cycle with a Non Carnot cycle 1. Introduction Carnot proposed a specific cycle, known as the Carnot cycle, consisting of two isothermal and two adiabatic processes in which whenever the working fluid exchanges energy with either reservoir, the temperature of the working fluid is kept the same as that of the reservoir. Whenever the temperature of working fluid differs from the temperatures of the reservoirs, the working fluid is thermally insulated. He argued that this cycle is the most efficient of all cycles that convert heat to work by using two reservoirs of different temperatures. 1.1. The two propositions concerning the Carnot cycle. The relevance of the Carnot cycle is appreciated in terms of two propositions. 1) . It is impossible to construct an engine that operates between two given reservoirs and is more efficient than a reversible engine operating between the same two reservoirs. 2) All engines that operate on the Carnot cycle between two given constant-temperature reservoirs have the same efficiency. This cycle is relevant due to various reasons. However the most relevant concerns to the fact that Carnot argued without any consistent demonstration that this cycle is the most efficient of all thermal cycles that convert heat to work by using two reservoirs of different temperatures. 2. Efficiency of a Carnot engine The Carnot engine is implemented by means of an ideal single effect reciprocating piston-cylinder designed to transfer a load of a given weight. The p-V, and T-s diagrams depicted in Fig. 1sketches the operation of a Carnot engine, where the “working fluid” that expands and contracts within the cylinder is an ideal gas.



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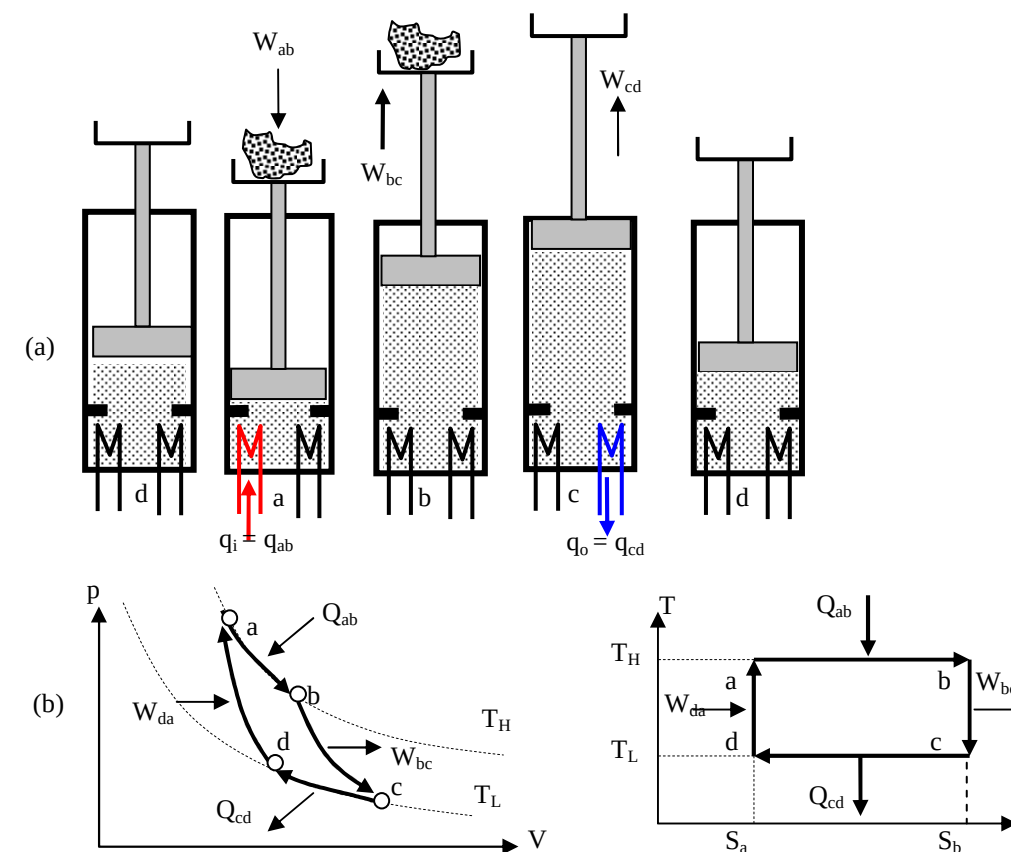


Fig. 1. The structure of a Carnot engine working with an ideal gas and the p-V, and T-s diagrams.

Here the high temperature T_H and the low temperature T_L are temperatures as measured on an ideal gas thermometer, that is

$$T = \frac{pV}{RT}$$

One cycle of the Carnot engine acts as follows:

- **Leg (a-b):** Isothermal expansion at high temperature from state point (a) to state point (b). As the gas expands, it lifts a big pile of sand that is, it does work W_1 . We've seen that expansion normally sends the temperature down. To keep the same temperature, the gas must absorb heat Q_1 from its surroundings.
- **Leg (b-c):** Adiabatic expansion from state point (b) to state point (c). As the gas expands, it lifts a big pile of sand | that is, it does work W_2 . The expansion sends the temperature down. Because it's adiabatic, no heat is absorbed or ejected.
- **Leg (c-d):** Isothermal compression at low temperature from state point © to state point (d). As the gas contracts, it lets down a small pile of sand | that is, work W_3 is done on the gas. We've seen that compression normally sends the temperature up. To keep the same temperature, the gas must eject heat Q_2 into its surroundings.
- **Leg (d-a):** Adiabatic compression from state point (d) to state point (a). As the gas contracts, it lets down a small pile of sand | that is, work W_4 is done on the gas. The compression sends the temperature up. Because it's adiabatic, no heat is absorbed or ejected.

Overall, the gas absorbs some heat and ejects some heat. The gas does some work and some work is done on it. The “net work done by the gas” is the work done by the gas minus the work done on the gas.

We're interested in getting as large a net work as possible for a given amount of heat absorbed. That is, we're interested in getting a large efficiency η defined as



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$$\eta = \frac{W_n}{Q_{ab}} = \frac{W_{ab} + W_{bc} - W_{cd} - W_{da}}{Q_{ab}} \quad (1)$$

In order to evaluate the efficiency of the Carnot cycle let's consider the work performed in every leg of the cycle

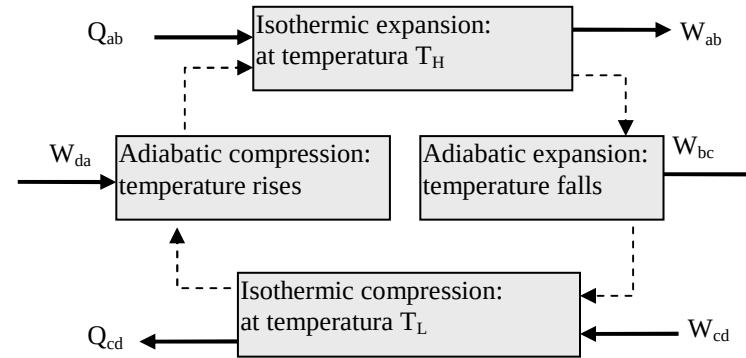


Fig. 2. Energy flow diagram

Leg (a-b): On this isothermal expansion leg, the temperature is T_H so

$$p(V) = \frac{RT_H}{V} \quad (2)$$

The work done by the ideal gas is then

$$W_{ab} = \int_a^b p(V)dV = \int_a^b \frac{RT_H}{V} dV = RT_H \int_a^b \frac{dV}{V} = RT_H [\ln(V)] = RT_H \ln \frac{V_b}{V_a} \quad (3)$$

With $V_b > V_a$, so that (3) is positive. Along the leg (a-b) the gas does mechanical work by lifting some weight for instance. Since the internal energy is constant, the heat absorbed merely counteracts the effect of the work done. That is, $Q_{ab} = W_{ab}$.

This obeys to the fact that the energy of a given sample of an ideal gas is a function of temperature alone.

Leg (b-c): On this adiabatic expansion leg, the pressure and volume are related through

$$pV^\gamma = \text{constant} = p_b V_b^\gamma = p_c V_c^\gamma \quad (4)$$

The following relations are useful to calculate the work done

$$\begin{aligned} p_b V_b^\gamma &= p_c V_c^\gamma \\ p_b V_b V_b^{\gamma-1} &= p_c V_c V_c^{\gamma-1} \\ RT_H V_b^{\gamma-1} &= RT_L V_c^{\gamma-1} \\ \frac{T_H}{T_L} &= \left(\frac{V_c}{V_b} \right)^{\gamma-1} \end{aligned} \quad (5)$$

With this piece of bookkeeping out of the way, we go ahead and find the work done by the gas:

$$W_{bc} = \int_b^c p(V)dV = C \int_b^c \frac{1}{V^\gamma} dV = C \left[\frac{1}{-\gamma+1} V^{-\gamma+1} \right]_b^c = \frac{1}{-\gamma+1} \left[\frac{C}{V_c^{\gamma-1}} - \frac{C}{V_b^{\gamma-1}} \right]$$



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$$= \frac{1}{-\gamma+1} \left[\frac{p_c V_c^\gamma}{V_c^{\gamma-1}} - \frac{p_b V_b^\gamma}{V_b^{\gamma-1}} \right] = \frac{1}{-\gamma+1} [p_c V_c - p_b V_b] = \frac{1}{-\gamma+1} R[T_L - T_H]$$

$$= \frac{1}{\gamma-1} R[T_H - T_L] \quad (6)$$

This quantity is also positive.

Leg (c-d): In this isothermal expansion leg, the calculation of work done by the gas is performed exactly as it was in the leg (a-b), but obviously with different variables inserted. With respect to equation (3) follows that

$$W_{cd} = RT_L \ln \frac{V_d}{V_c} \quad (7)$$

Since $V_d < V_c$, the quantity (7) is negative

$$|W_{cd}| = -RT_L \ln \frac{V_d}{V_c} = RT_L \ln \frac{V_c}{V_d} \quad (8)$$

Since the internal energy is constant, the heat rejected equals the work done. That is, $Q_{cd} = W_{cd}$.

Leg (d-a): In this adiabatic compression leg, the calculations are performed exactly as it was they were in leg (b-c), but obviously with different variables inserted. Referring to equations (5) and (6) follows that

$$\frac{T_L}{T_H} = \left(\frac{V_a}{V_d} \right)^{\gamma-1} \quad (9)$$

Consequently

$$W_{da} = \frac{1}{\gamma-1} R[T_L - T_H]$$

And

$$|W_{da}| = -W_{da} = \frac{1}{\gamma-1} R[T_H - T_L] \quad (10)$$

2.1. Carnot Efficiency η_C

$$\eta_C = \frac{W_n}{Q_{ab}} = \frac{W_{ab} + W_{bc} - W_{cd} - W_{da}}{Q_{ab}} = \frac{|W_{ab}| + |W_{bc}| - |W_{cd}| - |W_{da}|}{|Q_{ab}|}$$

$$\eta_C = \frac{W_n}{Q_{ab}} = 1 + \frac{|W_{bc}| - |W_{cd}| - |W_{da}|}{|Q_{ab}|} = 1 - \frac{|W_{cd}|}{|Q_{ab}|} \quad (11)$$

Since $|W_{bc}| = |W_{da}|$

Using the calculated values for W_{ab} and Q_{ab} follows that

$$\eta_C = \frac{W_n}{Q_{ab}} = 1 - \frac{|W_{cd}|}{|Q_{ab}|} = 1 - \frac{RT_L \ln \frac{V_c}{V_d}}{RT_H \ln \frac{V_b}{V_a}} = 1 - \frac{T_L \ln \frac{V_c}{V_d}}{T_H \ln \frac{V_b}{V_a}} = 1 - \frac{T_L}{T_H} \quad (12)$$

Since

$$\frac{T_H}{T_L} = \left(\frac{V_c}{V_b} \right)^{\gamma-1} = \left(\frac{V_d}{V_a} \right)^{\gamma-1} \text{ and } \left(\frac{V_c}{V_b} \right) = \left(\frac{V_d}{V_a} \right) \text{ or } \left(\frac{V_c}{V_d} \right) = \left(\frac{V_b}{V_a} \right)$$

From (12) follows that the efficiency of a Carnot based engine can be expressed only as function of the ratio of temperatures. The bigger



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the temperature ranges the bigger efficiency. However note that as T_L tends to zero the thermal efficiency tends to 1 or the 100% independently of the value of $T_H > 0$.

This means that the thermal efficiency of a Carnot engine operating near the absolute zero, for instance in an artificial space platform operating in the deep space where the temperature T_L of the heat sink is 1 (K) and the temperature T_H of the heat source is 500 (K), yields a maximum thermal efficiency that approaches

$$(1 - T_L/T_H) = (1 - 1/500) = 99.8 \%$$

This means that as lower the heat sink the higher the limit of the Carnot efficiency

3. A Non Carnot cycle model

Considering the possibility of the existence of several different Non Carnot (NC) cycle types, let's assume a NC cycle in which, as in the analysed Carnot cycle, the working fluid cycles through four closed transformation based reversible processes according to the engine structure shown in Fig. 3:

-Leg (1-2), Adiabatic compression. The system is fully insulated, and the weight compresses the fluid. The energy of the fluid increases so that the temperature of the fluid increases.

-Leg (2-3), Isobaric expansion. The base of the cylinder is in thermal contact with a reservoir of temperature and the fluid expands.

-Leg (3-4), Adiabatic expansion. The system is fully insulated, and fluid expands. The energy of the fluid decreases, and the temperature of the fluid decreases.

-Leg (4-1), Isobaric compression. The base of the cylinder is in thermal contact with a reservoir of temperature T_L , and the fluid is compressed.

The structure of a NC cycle to be analysed is represented on the (p, V) diagram, and on the (T, S) diagram depicted in Fig. 3.

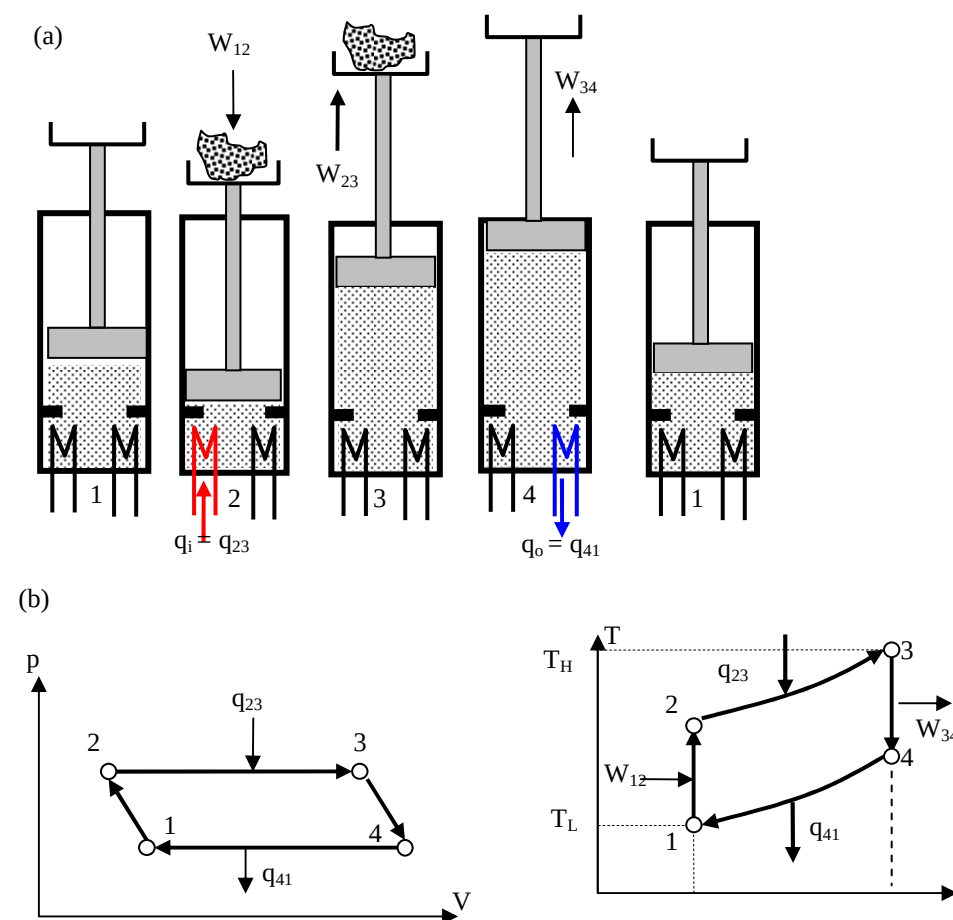




Fig. 3. The structure of a NC engine working with an ideal gas and the p-V, and T-s diagrams.

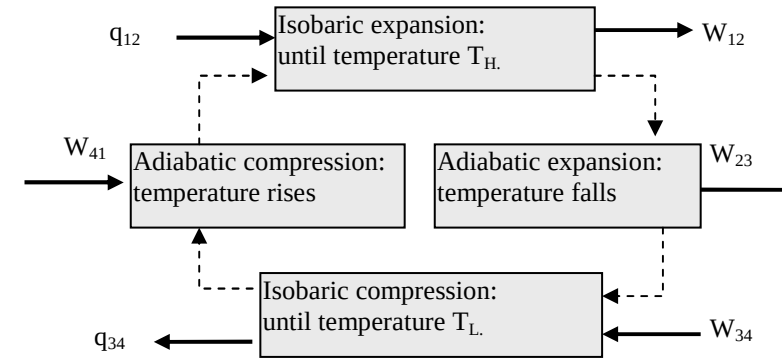


Fig. 4. Energy flow diagram of a NC engine type

3.1. The efficiency of a NC cycle implemented by means of a reciprocating engine

Consider a cylinder filled with gas at a pressure equal to the atmospheric pressure p_1 . With reference to the Fig. 3 follows that if a determined weight is placed on the piston, the system changed from state (1) to state (2). Furthermore, it is observed that the cylinder volume is compressed causing the pressure to increase from p_1 to p_2 , while the volume decreases and the temperature increases till T_2 . The first principle for closed transformations where irreversibilities, potential and kinetic energy are neglected yields

$$\sum q + \sum W - \Delta u = 0 \quad (13)$$

Leg (1-2), Adiabatic compression:

Assuming that the process (1)-(2) is a closed transformation follows that since there is not exchange of matter, the energy balance according to the first principle states that the amount of specific energy added from an external heat source is defined as

$$q_{12} + W_{12} - \Delta u_{12} = 0 \quad (14)$$

In this transformation there is not heat transfer so that q_{12} is zero yielding

$$W_{12} - \Delta u_{12} = 0 \quad (15)$$

The work is then

$$W_{12} = \Delta u_{12} = (u_2 - u_1) \quad (16)$$

Equation (15) means that the work transferred to the system is entirely converted to internal energy, increasing the temperature and pressure at constant entropy.

If in the state conditions (2) an amount of heat energy is supplied to the balloon the temperature increases from T_2 to T_3 , its volume increases at constant pressure p_2 from V_2 to V_3 , and the internal energy increases from u_2 to u_3 .

Leg (2-3), Isobaric expansion:

Thus, assuming that the process (2)-(3) is a closed transformation, since there is not exchange of matter, the amount of specific energy added from an external heat source is defined as

$$q_i = q_{23} = -W_{23} + \Delta u_{23} = p_2 \cdot (V_3 - V_2) + u_3 - u_2 = Cp(T_3 - T_2) \quad (17)$$

Thus, the mechanical work performed along the transformation (2) (3) is

$$W_{23} = \int_{V_2}^{V_3} p dV = p_2 (V_3 - V_2) = p_3 (V_3 - V_2) \quad (18)$$

Since $dW = F \cdot dx = m \cdot g \cdot dx = p \cdot A \cdot dx = p \cdot dV$

$$\text{and } W = \int_2^3 F \cdot dx = \int_2^3 m \cdot g \cdot dx = \int_2^3 p \cdot A \cdot dx = \int_2^3 p \cdot dV = p_2 \cdot (V_3 - V_2)$$



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Leg (3-4), Adiabatic expansion:

In the state (3) if the load (weight) is removed from the balloon, it causes the balloon to expand increasing its volume from V_3 to V_4 and the pressure to decrease from $p_3 = p_2$ to $p_4 = p_1$ so that this transformation yields.

$$q_{34} + W_{34} - \Delta u_{34} = 0 \quad (19)$$

In this transformation there is not heat transfer so that q_{34} is zero yielding

$$W_{34} - \Delta u_{34} = 0 \quad (20)$$

The work is then

$$W_{34} = \Delta u_{34} = (u_3 - u_4) \quad (21)$$

Leg (4-1), Isobaric compression:

Finally if some heat from the balloon is extracted by cooling the working fluid contained into the balloon, till reaching the original temperature T_1 , at constant pressure p_1 the volume returns to its original volume. For the process (4)-(1) the amount of heat rejected to the low temperature heat sink assumed also as a closed transformation yields

$$q_o = q_{41} = -W_{41} + \Delta u_{41} = 0 + \Delta u_{41} = u_4 - u_1 \quad (22)$$

The mechanical work is zero along the transformation (4)-(1) because the load associated to this transformation is zero.

The net work Wn performed by the cycle is the difference $q_i - q_o$.

$$Wn = q_i - q_o = -W_{23} + \Delta u_{23} - \Delta u_{41} \quad (23)$$

3.2. The thermal efficiency of a NC cycle type η_{NC}

The thermal efficiency of a NC cycle type is then

$$\eta_{NC} = \frac{q_i - q_o}{q_i} = \frac{Wn}{q_i} = 1 - \frac{q_o}{q_i} = 1 - \frac{\Delta u_{41}}{|W_{23}| + \Delta u_{23}} = 1 - \frac{\Delta u_{41}}{Cp(T_3 - T_2)} \quad (24)$$

Considering the high and low temperatures of the heat source and the heat sink, follows that

$$\eta_{NC} = 1 - \frac{Cv_{41}(T_4 - T_1)}{Cp_{23}(T_3 - T_2)} = 1 - \frac{Cv_{41}(T_4 - T_L)}{Cp_{23}(T_H - T_2)} \quad (25)$$

Taking into account that the fraction

$$\frac{(T_4 - T_L)}{(T_H - T_2)}$$

approaches the unity, follows that the expression (25) can be expressed as

$$\eta_{NC} = 1 - \frac{Cv_{41}}{Cp_{32}} = 1 - \frac{1}{\gamma} \quad (26)$$

Many others NC cycles are possible, so that (26) is not a general expression of the ideal thermal efficiency, but a particular solution for the NC cycle type described in the present demonstration, which is based on closed transformations. However, open transformations based cycles than doesn't obey the Carnot factor can also be implemented.

As can be observed, the maximum theoretical thermal efficiency is not dependent on any cycle temperature, but on the adiabatic expansion coefficient, so that this efficiency cannot be related although compared with the Carnot factor. Furthermore, as shown bellow, there is a range and ratio of operating temperatures for which a flagrant violation of Carnot statement without violating the Clausius or Kelvin-Planck statements (second law) exist.



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4. Thermal cycle's analysis by considering the 2d principle (Kelvin-Plank).

On losing energy Q_H , the high-temperature reservoir changes entropy by

$$\Delta S_H = -\frac{Q_H}{T_H} \quad (27)$$

On gaining energy Q_L , the low-temperature reservoir changes entropy by

$$\Delta S_L = +\frac{Q_L}{T_L} \quad (28)$$

The composite of the fluid, the weight, and the two reservoirs is an isolated system where the entropy of the composite is the sum of the entropies of all the involved parts.

After the fluid completes the cycle, then the entropy of the fluid returns to its initial value. Consequently, after a cycle, the entropy of the system changes by

$$\Delta S_{sys} = \Delta S_L + \Delta S_H \quad (29)$$

Inserting the above expressions, we obtain that

$$\Delta S_{sys} = \frac{Q_L}{T_L} - \frac{Q_H}{T_H} \quad (30)$$

According to the second principle or fundamental postulate, upon removing constraints internal to the isolated system, the entropy of the isolated system increases, so that

$$\Delta S_{sys} \geq 0, \quad (31)$$

which implies that

$$\Delta S_L \geq \Delta S_H \text{ or } \frac{Q_L}{T_L} \geq \frac{Q_H}{T_H} \quad (32)$$

which means that

$$\frac{Q_L}{Q_H} \geq \frac{T_L}{T_H} \quad (33)$$

The condition of equality holds when all the processes are reversible. For example, when the fluid and a reservoir is in thermal contact, the transfer of energy approaches reversibility when the temperature of the fluid equals that of the reservoir.

4.1. Analysis of the efficiency of a thermal engine on the basis of the second principle.

The thermal efficiency of an engine is defined as the ratio of the net work to the absorbed heat energy as

$$\frac{W}{Q_H} \quad (34)$$

According to the principle of the conservation of energy, $W = Q_H - Q_L$, so that the efficiency of any thermal engine is written as

$$\frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} \quad (35)$$

This is absolutely true for every possible thermal engine according to the first principle.

However, for the special case of a Carnot cycle (two adiabatic legs and two isothermal legs) where all the processes are reversible follows that

$$\frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H} \quad (36)$$

Consequently, using the thermodynamic inequality derived from the Kelvin-Plank (second principle) which states that

$$\frac{Q_L}{Q_H} \geq \frac{T_L}{T_H}, \quad (37)$$



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the efficiency of a Carnot cycle must satisfy the inequality

$$\frac{W}{Q_H} \leq \left[1 - \frac{T_L}{T_H} \right], \tag{38}$$
 which suggests us that the maximum obtainable thermal efficiency of a Carnot cycle is

$$\frac{W}{Q_H} = 1 - \frac{T_L}{T_H}. \tag{39}$$
 Consequently, the expression of the thermal efficiency obtained in (39) can only be applied on Carnot cycles since for other different thermal cycles the thermal efficiency cannot be expressed as

$$1 - \frac{T_L}{T_H} \tag{40}$$
 but

$$1 - \frac{Q_L}{Q_H} \tag{41}$$
 Summarising, for every thermal cycle the maximum thermal efficiency is achieved as

$$\eta_{NC} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} \tag{42}$$
 However for a Carnot cycle is

$$\eta_C = \frac{W}{Q_H} = 1 - \frac{T_L}{T_H} \tag{43}$$
 According to the analysis carried out so far, there is no evidence that this cycle is the most efficient of all cycles that convert heat to work by using two reservoirs of different temperatures.

5. The comparison of Carnot cycle and closed processes based NC cycle.

This section compares the results of expression (12) for Carnot cycle with that of expression (26) for a NC cycle in order to highlight some differences between the Carnot cycle and NC cycle.

Table 1. The results achieved wit the data shown in Table 2 with $T_L = 295$, $p_2=p_3= 400$ bar, $P_4=p_1= 395$ bar.

$T_H=T_3(K)$	305	310	315	320
$\eta_C(\%) = \text{Carnot}(\%)$	3.28	4.84	6.35	7.81
$\eta_{NC}(\%) \text{ He}$	28.88	32.79	36.7	36.63
$\eta_{NC}(\%) \text{ Ar}$	29.11	30.52	31.28	31.79
$\eta_{NC}(\%) \text{ H}_2$	20.35	23.25	24.61	25.39



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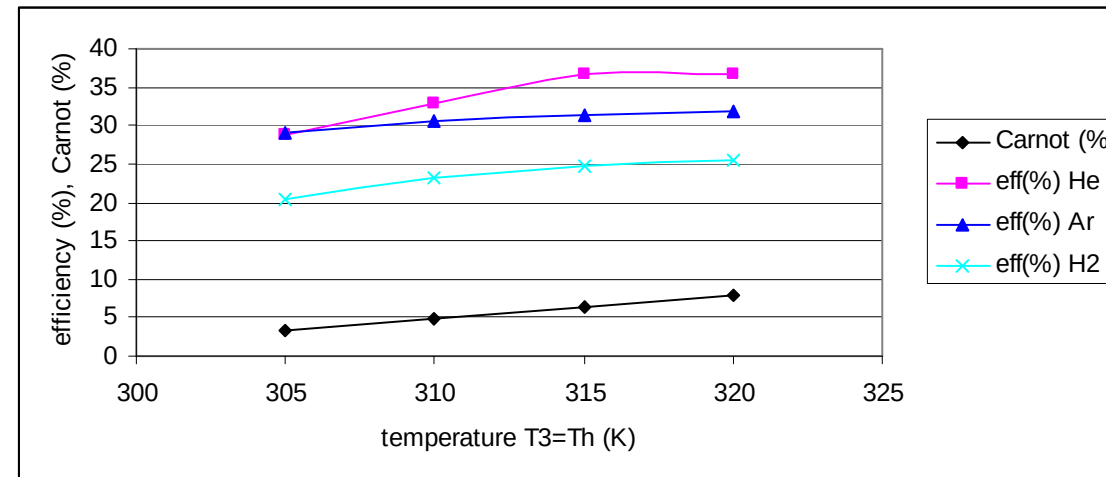


Fig. 5. The results also shown in Table 1 with $T_L = 295$, $p_2=p_3= 400$ bar, $P_4=p_1= 395$ bar

Table 2. Data applied on the case study for He, Ar and H₂ as working fluids.

Point	T ₃ (K)	h(kJ/kg)	u(kJ/kg)	s(kJ/kg.K)	p(bar)	v(m ³ /kg)
He						
1=T _L	295	1663	936.72	15.561	395	0.018387
2=T _H	296.4	1673.71	941.39	15.561	400	0.018267
3=T _H	320	1794.2	1015.3	15.957	400	0.019471
3=T _H	315	1768.3	999.66	15.876	400	0.019296
3=T _H	310	1742.4	983.96	15.793	400	0.018960
3=T _H	305	1716.4	968.27	15.709	400	0.018704
Ar						
1=T _L	295	104.13	39.074	2.4809	395	0.001647
2	296.2	105.11	39.324	2.4809	400	0.001641
3=T _H	320	124.25	52.228	2.5436	400	0.001801
3v	315	120.28	49.601	2.5311	400	0.001767
3=T _H	310	116.27	46.931	2.5182	400	0.001734
3=T _H	305	112.21	44.215	2.5050	400	0.001700
H₂						
1=T _L	295	4112.8	2588.6	28.380	395	0.038587
2	296.1	4135.51	2599.4	28.380	400	0.038319
3=T _H	320	4488.8	2854.7	29.538	400	0.040853
3=T _H	315	4414.3	2801.3	29.304	400	0.040325
3=T _H	310	4339.8	2748.0	29.065	400	0.039796
3=T _H	305	4265.3	2694.6	28.823	400	0.039266

Thank you for your effort and interest in the discussed topic.