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Necessary conditions for achieving energy self-sufficient thermal engines and the roadmap for achieving them

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Abstract

The fundamental objective of this work is to find the necessary and sufficient conditions for achieving energy self-sufficient thermal engines. It begins with the premise that this is impossible with the thermal efficiencies of actual conventional thermal cycles. Therefore, it follows that it is necessary to achieve greater thermal efficiency than has been possible to date. It is also known that perpetual motion is impossible with conventional technologies. And it is also known that perpetual motion alone is insufficient, as it is necessary to overcome all resistances and perform useful work. Therefore, it is reasonable to suspect that it is necessary to explore unusual heat-work interactions and heat manipulation strategies to disruptively improve existing technologies and overcome the CF. Therefore, it is reasonable to suspect that it is necessary to explore unknown heat-work interactions and heat manipulation strategies without violating any fundamental law to disruptively improve existing technologies. Therefore, it is reasonable to suspect that it is necessary to explore unknown feasible heat-work interactions and heat manipulation strategies to disruptively improve existing technologies. These two actions define the research path undertaken in this endeavor. The article addresses this challenge and successfully achieves the established milestones, for which it has to violate two fundamental statements of classical physics: a) exceeding the Carnot factor and b) violating the first law of thermodynamics.

Keywords: Cascaded Coupled Power Units, Self-Sufficiency conditions, Self-Sustaining Power Generation, Thermodynamic Disruption, and Vacuum-Induced useful work.

Nomenclature related to general VsVs and Vsp cycles	
Acronyms	**Description/Context**
cont	Subscript of contraction process: A form of compression (volume decrease) achieved by cooling a TWF, which generates a **pull** force while increasing internal energy and pressure.
CTF	HTF for cooling: Cooling Transfer Fluid (conventionally, thermal oil)
CF	Carnot Factor (thermal efficiency of a Carnot cycle): $\eta_{Carnot}=(T_H-T_L)/T_H=(T_2-T_1)T_2=1-(T_L/T_H)$
DARA	Double-acting reciprocating actuator
E_i	Energy input (heat and/or work)
E_o	Energy output (heat and/or work)
exp.	Subscript of expansion process: A form of expansion (volume increase) achieved by heating a TWF, which generates a **push** force while decreasing internal energy and pressure.
FLT	First law of thermodynamics. Closed processes: $E_i-E_o=\Delta u$. closed processes cycle: $E_i-E_o=0$
FCF	Forced Convection Fan to reinforce heat transfer by recalculating the TWF
H, L	Subscript of High, Low: i.e. T_L with L subscript of T_{low}, T_H, with H subscript of T_{high}
HTF	HTF for heating: Heating transfer fluid (conventionally, thermal oil)
HWI	Heat-work interaction
PU	Power Unit driven by the thermal cycle VsVs or Vsp cycle
SARA	Single-acting reciprocating actuator
SLT	Second law of thermodynamics according to statements of Kelvin-Planck: and Clausius: -- It is impossible to convert 100% of the available heat into mechanical work output.

	-- It is impossible to spontaneously transfer heat from a colder body to a hotter body.
suct.	Subscript of suction process: A form of expansion (volume increase) achieved by adding useful work to the system by means of a **pull** force, while decreasing internal energy and pressure.
TWF	Thermal Working fluid (a gas with high adiabatic expansion coefficient such as helium or argon)
VsVs	sequential processes of the cycle sVsVs: Isochoric **V**, adiabatic **s**, Isochoric **V**, adiabatic **s**: [**VsVs**]
Vsp	sequential processes of the cycle Vsp
η_{th} (%)	process or cycle thermal efficiency [w_n/q_i]
Symbols/units	***description***
p(bar)	pressure
p_i	Initial pressure (bar
p_F	Final pressure
p_{surr}	Surroundings pressure (bar)
q_i(kJ/kg)	specific heat in to a cycle process
q_{i12} (kJ/kg)	Input heat to cycle process 2-3
q_{o23}(kJ/kg)	specific heat out from a cycle process 2-3
Cp(kJ/kg-K)	specific heat capacity at constant pressure
Cv(kJ/kg-K)	specific heat capacity at constant volume
s(kJ/kg-K)	specific entropy
S_{sys}(kJ/kg-K)	specific entropy of a thermodynamic system
S_{surr}(kJ/kg-K)	specific entropy of the system's surroundings
S_{gen}(kJ/kg-K)	specific entropy generated in a thermodynamic process
S_{qrec}(kJ/kg-K)	specific entropy exhibited by the recovered heat to be regenerated to feed the first PU
h(kJ/kg)	specific enthalpy; $h=f(T)$ h=Cp.T
T(K)	Absolute temperature
T_H(K)	top cycle temperature
T_L(K)	bottoming cycle temperature
T_D	Temperature drop between cascaded PUs
u(kJ/kg)	specific internal energy
v(m^3/kg)	specific volume
V(m^3)	volume
w(kJ/kg)	specific work
w_i(kJ/kg)	specific work input
w_o(kJ/kg)	specific work out
w_{oexp} (kJ/kg)	Output expansion work due to previously added heat
w_{ocont} (kJ/kg)	Output contraction work due to previously extracted heat
w_{oexp23} (kJ/kg)	Output expansion work w_{o34} due to previously added heat
$w_{ocont41}$ (kJ/kg)	Output contraction work w_{o51} due to previously extracted heat

w_n (kJ/kg)	Net useful work ($w_{oexp} + w_{ocont}$) = ($w_{o34} + w_{o51}$) in an VsVs thermal cycle
η_{th} (%)	Cycle thermal efficiency (w_n/qi)
CF	Carnot factor = T_H-T_L/T_H = net $w_o/qi_{(H)}$

1. Introduction

To achieve a heat engine capable of meeting the self-sufficiency criterion, several previously insurmountable challenges must be overcome: thermodynamic and physical-structural challenges.

Among the thermodynamic challenges, the need to overcome the Carnotn factor (CF) [1-2] stands out, as well as the need to achieve thermal cycles with processes that are currently nonexistent in technology because they are not considered in thermodynamics, despite having always existed in nature. Such processes are counterintuitive with standard thermodynamics and therefore have not been explored [3-4]

Among the physical-structural challenges challengers [5-7], [10-15], the strategy for recovering the heat rejected in each upstream cycle, to be regenerated and fed back into the heat addition system, is particularly noteworthy. Furthermore, certain relevant heat-work interactions (HWI) for achieving energy self-sufficiency had never been considered prior to the studies in [16-20]. They prove to be essential for satisfying certain necessary (but not sufficient) conditions for achieving energy self-sufficiency.

Judging by the article's title, we must ask ourselves: What conditions need to be met, and what resources can be used to meet them? To contextualize the HWI that, after more than two centuries, have led to self-sufficient heat engines, let's begin by understanding the roadmap followed since Sadi Carnot's contributions around 1825. Sadi Carnot's contributions were groundbreaking for his time in thermodynamics. His work was based on experiments with the piston-based steam engine, where he considered HWI, manipulating the thrust or pushing forces derived from the expansion of steam in a single-acting piston cylinder, as well as the thrust or pushing forces used to compress gases such as air or steam. Entropy was not yet understood, yet he made some contributions that were later incorporated into the second law of thermodynamics by Clausius and Kelvin-Planck. After analyzing Carnot's contributions, the reader should be able to understand why machines subject to the limitations established by Carnot's theorem are not capable of being self-sufficient. However, even without being subject to the limitations established by Carnot's theorem, the criterion for achieving self-sufficiency requires more conditions. In the following section, we will analyze a summary of Carnot's findings published in 1825 [1].

1.1 Review of Carnot's fundamental contributions

Let's discuss the summary of Carnot's fundamental contributions and their theoretical and practical relevance to the science of thermodynamics and the engineering of heat engines according to his work. To select the most important points, priority was given to those principles and discoveries that have had the greatest impact on science and engineering, according to the text itself and its historical analysis.

The following commentary is taken from a summary of Sadi Carnot's work, "Reflections on the Motive Power of Fire, and on Machines Fitted to Develop That Power" (Sadi Carnot, 1825) [1], and deals with the motive power of heat, especially in the form of the steam engine, and its impact on industry and society.

1.1.1 A review of Carnot's main findings

The following points summarize Carnot's fundamental contributions and their theoretical and practical relevance to the science of thermodynamics and the engineering of heat engines. Therefore, reviewing Carnot's findings, the following points stand out:

1. **The principle of work production by heat**: Carnot established that the work (motive power) produced by a heat engine does not depend on the nature of the working fluid, but only on the temperature difference between the hot and cold reservoirs. Example: It doesn't matter if steam, air, or any other gas is used; maximum efficiency depends only on the temperature difference between the boiler and the condenser.

2. **The concept of a reversible cycle and its importance:** Carnot introduced the idea that the most efficient process is one that can be reversed without energy loss, that is, a reversible cycle — No ideal engine can behave like a real engine—. This laid the foundation for the second law of thermodynamics. Example: The Carnot cycle, where the gas expands and compresses in a controlled manner, can function as an engine or as a refrigerator if the process is reversed.

3. **The maximum efficiency of a heat engine:** Carnot demonstrated that the efficiency of a heat engine increases with the greater the temperature difference between the hot and cold reservoirs, and that there is a theoretical limit that no engine can exceed. For example, an engine operating between 500 °C and 100 °C will be more efficient than one operating between 200 °C and 100 °C, even if both use the same working fluid.

4. **The equivalence between heat and work:** Although Carnot worked before the equivalence between heat and work was formally established (Joule), his writings anticipated the idea that heat can be transformed into mechanical work and vice versa, and that there is a quantitative relationship between the two. For example, Carnot calculated that a certain amount of heat could lift a specific weight to a certain height, anticipating the concept of heat as a form of energy.

5. **Practical Impact and Limitations of Efficiency:** Carnot cautioned that, while maximizing the motive power of heat is desirable, in practice there will always be losses and technical limitations (such as material strength, safety, cost, and machine size). For example, although theoretically a temperature drop of 1000 °C could be harnessed, in practice boilers and materials cannot withstand such conditions, and there will always be losses due to friction, heat transfer, isentropic efficiency, among the most important losses.

1.2 On the review and scope of Carnot's work

After trying to understand the summary of Carnot's most relevant findings, one might wonder why it is not possible to find another heat engine capable of exceeding the limit established by Carnot's theorem. As consequence, let's analyze the question regarding the attribution to Carnot of the phrase "Is it impossible to achieve a heat engine that exhibits greater efficiency than Carnot's?" and how this principle is expressed in his original writings.

1.2.1 Approach and reasoning:

1. It is assumed that I am looking for the original or equivalent formulation of this principle in Carnot's work, and whether he actually expressed it in that way, and

2. I use the translated and annotated document from Sadi Carnot's "Reflections on the Motive Power of Heat" (1897) [1], which includes both the original text and historical and scientific analyses.

1.2.2 Evidence and explanation

1. On the basis of the original contribution [1], I believe that Carnot did not literally write the modern phrase "It is impossible to achieve a heat engine that exhibits greater efficiency than Carnot's". However, he did establish the fundamental principle that gives rise to that interpretation.

2. In the text (*pages 12-13* of the document), Carnot states:

"The maximum power resulting from the use of steam is also the maximum motive power achievable by any means whatsoever." and

"The motive power of heat is independent of the agents employed to produce it; its quantity is determined solely by the temperatures of the bodies between which the heat transfer ultimately takes place".

3. Later, he develops the idea that "if a more efficient machine than the Carnot cycle existed, perpetual motion could be created", which is inadmissible according to the laws of physics (*pages 55-56*):

"If there were some means of utilizing heat preferable to those we have employed, that is, if it were possible by any method to make heat produce a greater quantity of motive power than we have made it produce...this would be not only perpetual motion, but an unlimited creation of motive power without the consumption of heat or any other agent. Such a creation is entirely contrary to now accepted ideas, to the laws of mechanics and sound physics. It is inadmissible". This statement is absolutely true if and only if the HWI involved in the cycle are due to adiabatic expansion and/or compression. No other possible heat-work interaction (HWI) has been demonstrated, such as the production of useful work due to an induced vacuum when cooling a TWF by extracting heat.

1.2.3 Example and potential application

1. The Carnot cycle is the theoretical model of maximum efficiency for a heat engine operating between two given temperatures. No real machine operating solely by the addition of heat, using any working substance, can achieve the efficiency of a Carnot cycle operating between the same temperatures.

2. For example, if you have two heat engines, one real and one ideal Carnot, both operating between 500 K and 300 K, the maximum possible efficiency is given by Carnot's: $(T_H - T_L)/T_H = (500-300) / 500 = 0.4$ or 40%. No real machine based on adiabatic expansion and contraction-based HWI can exceed that 40%.

1.2.4 Conclusion about Carnot's work comments

1. Under my opinion, the modern phrase is a synthesis of Carnot's fundamental principle, which he expressed rigorously and logically, although not in those exact words. The original document confirms that Carnot established that "**no heat engine can be more efficient than a reversible (Carnot) engine operating between the same temperatures**". This statement is absolutely true, that is, axiomatically irrefutable, if and only

if the machine operates by adding heat to open processes cycles with state changes such as Rankine cycles. No other thermal cycle has been tested because it did not exist in Carnot's time. Later Kelvin Planck established the statement "It is impossible to convert 100% of the available heat into mechanical work output" which is clearly derived from the Carnot statement meaning. However, this observation is self-consistent without Carnot's findings.

2. This is absolutely true in all cases of expansion and compression forces based on **thrust**-type forces, which means performing output work by adiabatic expansion and increasing internal pressure and energy by adiabatic compression through volume reduction while performing input work on the system.

3. In Carnot's work [1] there is no reference to the thermal efficiency that any heat engine operating under HWI and strategies different from those of heat engines based on adiabatic expansion and compression could exhibit.

1.2.5 Textual references from Carnot's summary [1]

1. "The maximum power resulting from the employment of steam is also the maximum motive power achievable by any means whatsoever." (*Carnot, Reflections**, p. 12***)

2. "The motive power of heat is independent of the agents employed to affect it; its quantity is fixed solely by the temperatures of the bodies between which, in the final result, the transport of heat takes place." (*Carnot Reflections, **p. 13***)

Therefore, the attribution is correct in spirit and content, although the modern phrase is a later formulation based on Carnot's original reasoning.

2. Essential heat-work interactions (HWI)

In conventional thermodynamics, the energy balance for any thermal cycle is given by $q_i - q_o = w_o$, and the thermal efficiency is $\eta_{th} = w_o/q_i$. According to Carnot's theorem, η_{th} cannot exceed the CF $(T_H - T_L)/T_H$, and this value is achieved only by the Carnot cycle, which satisfies both the first and second laws of thermodynamics in the case of real engines. However, it will be shown in sections of the article that it is possible to exceed the Carnot Factor in special cycles and suitable conditions are highlighted.

2.1 Special capabilities of the reciprocating actuators

Capabilities of the single-acting reciprocating actuator (SARA).

Special abilities refer to how both forces can be used simultaneously to operate in the same direction and with the same intent.

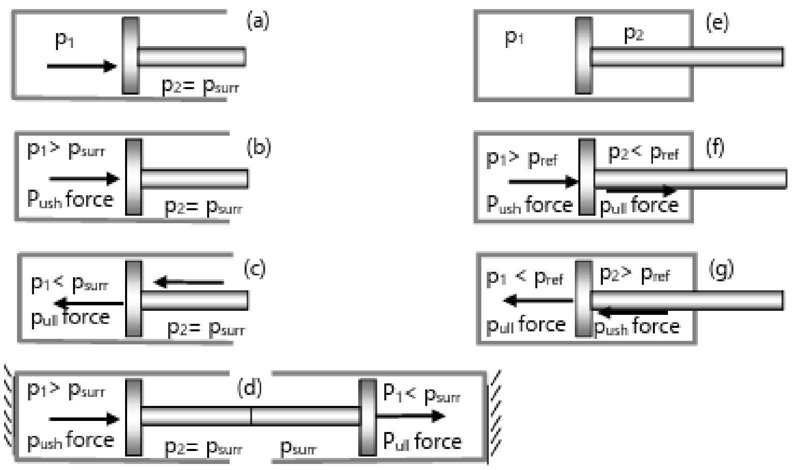

Figure 1. Illustration of two mechanical reciprocating actuators enabled to perform mechanical pushing and pulling forces

Fig. 1(d) illustrates two SARAs operating in opposition to give rise to a net force that is the sum of both forces acting in the same direction.

In each SARA Fig. 1(d), two pressures, p_1 and p_2, inevitably interact, generating two forces aligned with each other. The force in the SARA chamber is due to pressure p_1, obtained by adding or removing heat from the working heat fluid. To perform useful mechanical output work, two conditions must be met: the difference between p_1 and p_{surr}, and the piston displacement. If p_1 differs from the ambient pressure (p_{surr}) and the piston movement cannot overcome the resistances, no work can be performed. As shown in Fig. 1 (a), p1 is obtained by adding heat to the working heat fluid, while the complementary force corresponds to the ambient pressure $p_2 = p_{surr}$. Figures x(b) and (c) illustrate the possible modes of operation:

In Fig 1 (b), it is shown how work is performed by the adiabatic expansion of the previously heated, constant-volume working heat fluid.

Figure x(c) shows how work is performed by the adiabatic contraction of the previously cooled, constant-volume thermal working fluid.

Fig.1(d) shows how a dual effect can be achieved by combining two SARAs, with the left SARA acting as a push actuator and the right SARA as a pull actuator. This configuration performs a function equivalent to that of a DARA.

Operation of a SARA

If $p_1 > p_{surr}$ then the SARA exerts a **pushing** force in the p_1-p_2 direction.

If $p_1 < p_{surr}$ (vacuum in the cylinder chamber), then the SARA exerts a **pulling** force in the p_2-p_1 direction.

Capabilities of the double-acting reciprocating actuator (DARA)

In every DARA, two pressures inevitably interact resulting in two forces aligned with each other. Both forces are caused by thermo-mechanical effects, which give rise to the corresponding pressures p_1 and p_2. They are linear functions of his respective pressures.

Operation of a DARA

If $p_1 > p_2$, then the DARA actuator exerts a **pushing** force in the p_1-p_2 direction.

If $p_1 < p_2$ (vacuum in cylinder chamber 1), then the DARA actuator exerts a **pulling** force in the p_2-p_1 direction.

In a DARA device, there must be a reference pressure (p_{ref}). Therefore, $p_{ref,}$ is defined as the pressure at the beginning and end of the cycle. For there to be potential energy capable of performing useful mechanical work output, pressures p_1 and p_2 must be different from p_{ref}. Such difference is produced by means of heating, adding heat to a thermal working fluid or cooling by extracting heat from a thermal working fluid. Therefore, if p1 > p_{ref}, thrust or push forces are generated due to adiabatic expansion. If p2 < p_{ref} (vacuum), adiabatic contraction or traction or pull forces are generated.

In a DARA the mechanical net work output can be achieved by addictive association of both, push and pull forces aligned with the same direction.

Furthermore, everyday experimental observations involving certain heat-work interactions (HWI)—such as those that convert heat into work via tensile or **pulling** forces— yield results that deviate from Carnot's predictions. In fact, these results shift from logical to counterintuitive. The following text of this section address this phenomenon.

2.2 Fundamental Forces

Heat-work interactions give rise to essential forces capable of producing dynamic changes in thermo-physical and, in particular, thermo-mechanical systems (i.e., enabled to generate useful mechanical work) or in physical systems that respond to such forces.

In thermodynamic, mechanical, electrical, electromagnetic, and gravitational phenomena, only two fundamental types of forces have been observed, both relevant for producing dynamic changes and, therefore, useful mechanical work through various strategic procedures. Among mechanical devices special capabilities of the mechanical reciprocating actuators

(a) Push, thrust, or repulsion forces

Examples of pushing forces: gas pressure on a piston (expansion work); two like magnetic poles or like electric charges repelling each other or any thrust force among others:

(b) Pull, traction, or attraction forces

Examples of pull forces: the vacuum (pressure lower than that of the surrounding medium) inside an actuator cylinder that produces contraction; two opposite magnetic poles or opposite electric charges that attract each other; gravitational interactions, strong pulling forces exhibited by gluons or any other mechanical pulling force.

These forces (push and pull) become extraordinarily relevant when they are articulated or combined to act together in the same sense and direction. Furthermore, these phenomena should be taken into account when dealing with systems dynamics governed by quantum mechanics. i.e Casimir push-pull (repulsion-attraction) forces due to quantum vacuum fluctuations and Van der Waal froces as push and pull interactions.

2.3 Analyzing the thermodynamic characteristics of suction and contraction through simulated experiments

Among a vast set of heat-work interactions (more than 22), only two have been characterized by their counterintuitive thermodynamic behavior due to their misalignment with the FLT. These are suction and contraction. Heat-work interactions based on suction and contraction operate through traction (pulling) andforces.

(a) **Suction** is achieved by doing work on a system (e.g., adding work via **pulling** forces).

(b) **Contraction** is achieved by extracting heat to create a vacuum, which then performs useful work output via **pulling** forces.

To distinguish between these, consider industrial common cases:

(a) A double-acting suction-discharge reciprocating pump or compressor [Fig.2(a)], and

(b) A single-acting bellows-type actuator [Fig. 2(b–d)], fixed at one end and connected to a spring at the other.

2.3.1 The thermodynamic behavior of suction process

The double-acting compressor Fig. 2(a) converts rotary motion into reciprocating linear piston motion, drawing in and compressing gas.

(a) Left-to-right stroke: left chamber suctions, right chamber discharges/compresses.

(b) Right-to-left stroke: right chamber suctions, left chamber discharges/compresses.

During the suction process, the gas in the chamber cools below the original temperature of the fluid due to expansion as the volume increases, requiring external work (**pull force**) to perform this expansion. Ideally, suction process is an adiabatic-isentropic expansion where *external work reduces internal energy*. This everyday observation —*reducing internal energy while absorbing external work input*— is counterintuitive under standard thermodynamics and does not conform to the traditional statement of the first FLT. Summarizing, in suction mode, temperature, internal energy, and pressure inside the suction chamber decrease while volume increases, as work is done ***on*** the piston. Adding work while internal energy decreases contradicts the conventional FLT, as such a process has not been accounted for in standard thermodynamic analysis.

Fig.2(a) Illustration of a double-acting reciprocating suction-discharge compressor, showing the action of suction/pulling forces due to the application of external work. Fig. 2(b–d) Illustrates the actuator enabled to perform contraction work due to the pulling forces generated in a bellows by the vacuum induced by cooling. This actuator acts on a spring (by elongation) due to the pre-cooling of the gas inside the bellows, thus creating a vacuum responsible for pulling forces through heat extraction.

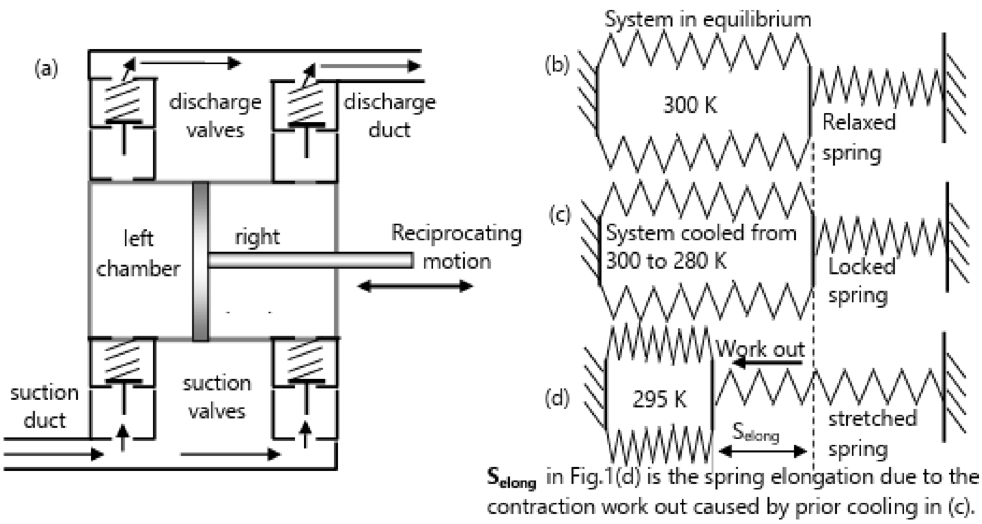

Figure 2. (a) Illustration of a double-acting reciprocating suction-discharge compressor, showing the action of suction/pulling forces due to the application of external work. (b–d) Illustration of the actuator enabled to

perform contraction work due to the pulling forces generated in a bellows by the vacuum induced by cooling. This actuator acts on a spring (by elongation) due to the pre-cooling of the gas inside the bellows, thus creating a vacuum responsible for the pulling forces through heat extraction.

2.3.2 Thermodynamic behavior of the contraction process

Consider a single-acting bellows actuator (Fig.2(b–d). Cooling a gas inside the bellows creates a vacuum (by heat extraction). This vacuum can perform useful mechanical work by contracting a spring via a **pulling** force.

Example: A bellows filled with helium at **1.1** bar and 300 K, fixed at one end and attached to a spring at the other. Cooling the gas from 300 K to 280 K causes contraction, producing a traction force that extends the spring—i.e., useful work output.

(a) Fig. 2(b): System immobilized, equilibrium at 300 K.

(b) Fig. 2(c): System blocked, cooled at constant volume to 280 K. The gas is now at lower pressure (vacuum relative to initial), exerting a contraction (pull) force on the spring. The system is then unlocked.

(c) Fig. 2(d): Under free movement, the bellows contract adiabatically, increasing pressure, temperature, and internal energy while delivering useful work output.

Ideally, this is an adiabatic-isentropic thermal contraction process where work output follows prior heat extraction. Again, this behavior is counterintuitive and not included in the conventional FLT.

2.4 Analysis of Contraction Behavior

Contraction forces are generated by a vacuum induced by cooling the TWF through heat extraction—which is cost-free, as cooling requires no energy input. Such forces can produce useful work without energetic cost. Conventional thermodynamics (including Carnot's work) has only considered HWI involving thrust/pushing forces. While this has enabled self-sustaining power engines, it is not sufficient condition.

The simultaneous increase in internal energy *and* useful work output has not been addressed in conventional analysis. Correctly understanding the single-acting actuator's operation [Fig.2(d–f)] is essential; otherwise, the energy balance in contraction work will appear misaligned not only with the FLT but also with the second law (SLT).

2.4.1 Thermal-Contraction Effects

For a thermal cycle involving HWI driven by thermal contraction [Fig.1, 2 and 3], two distinct pressure regimes must be considered:

(a) **Expansion work** occurs when expansion pressure exceeds a reference pressure, achieved by adding heat to the TWF.

(b) **Contraction work** occurs when contraction pressure falls below the reference pressure (relative vacuum), achieved by cooling via heat extraction.

2.5 Experimentally Observed Behavior

As shown in Fig.4(c), the vacuum induced by cooling during process 3–4 is responsible for:

(a) An increase in internal energy during process 4–1, and

(b) The performance of useful work output during process 4–1.

Because these two simultaneous phenomena (internal energy rise + work output) have not been previously considered, Section 2 presents a modeling analysis of thermodynamic processes involving mechanical work by thermal contraction, using an appropriate test bench device. The analysis of the VsVs thermal cycle is based on the FLT, yielding energy balances derived from the test bench described herein.

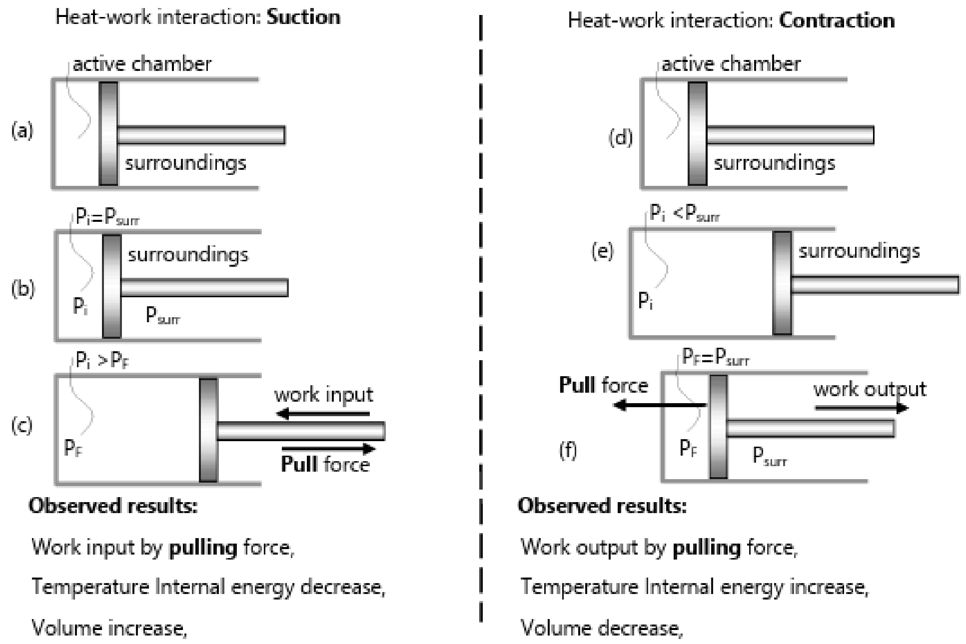

Figure 3. Illustration of suction vs. contraction HWI. (a-c) SARA showing a suction stroke by applying a pulling force on the piston rod. (d-f) SARA showing a contraction stroke by delivering useful work by a pulling force on the piston rod exerted by a vacuum.

2.6 Experimental Setup for Investigating Heat-to-Work Conversion in a Double-acting reciprocating cylinder Actuator (DARA)

As a preliminary step, we must take into account a clear concept of suction and thermal contraction previously described —common yet counterintuitive phenomena relative to the FLT.

2.6.1 What Is Being Tested with the Proposed Test Bench?

To achieve a self-sufficient machine, the suction concept is not required. Instead, thermal contraction is essential: generating useful work output via vacuum-induced contraction achieved by extracting heat from the TWF, then recovering that heat and feeding it back into the plant.

Let's remember that to distinguish the HWI characterized by their ability to perform suction in intake-exhaust compressors and to convert heat into useful output work by cooling the TWF, a comparison is made using Fig.3, which shows the essential differences between both interactions and their potential applications. Furthermore, their misalignment with the FLT is deduced. To gain a clear understanding of both HWI (suction and contraction), the concept of suction and contraction processes misaligned with FLT and SLT is illustrated by the detailed behavior of a single-acting cylinder shown in Fig.3, where two different applications (suction and contraction) highlight its distinct characteristics.

Fig.3 depicts the experimental behavior of two HWI carried out by means of a single-acting reciprocating cylinder. Suction effects are depicted in (a), (b) and (c) Figs, while (d), (e) and (f) represents the consequence of contraction effects of a heat-to-work converter. Both cases are characterized by its inherent misalignment with FLT and SLT. In Fig.3 (a-c) it is indicated that a suction process is useful in the phase of gas inlet for suction-discharge compressors while In Fig.3 (d-f) contraction process converts heat into useful work by previously cooling at constant volume the TWF. Both HWIs are misaligned with the FLT.

2.6.2 Operation Modes of the single-acting actuator depicted in Fig.2

(a) **Fig. 3(c):** Applying work to move the piston left-to-right via a pulling force increases volume, lowers pressure, temperature, and internal energy—while external work is applied.

(b) **Fig. 3(f):** Starting from a vacuum state Fig. 3(e), the piston moves right-to-left, producing contraction work. Volume decreases; pressure, temperature, and internal energy increase—while useful output work is produced.

Since thermal contraction work is necessary (though not sufficient) for self-sufficiency, this study focuses on actuators capable of both thermal expansion and thermal contraction. Suction processes are not relevant for heat-to-work converters aiming to produce useful work.

2.6.3 Experimental Test Bench Architecture

The test bench studies a DARA to analyze and optimize heat-to-work conversion efficiency. It demonstrates converting both heat and "cold" (via thermal contraction without energy expenditure) into useful work—solely through cooling, not heat addition.

A conceptual effort regarding closed thermodynamic transformations is required to understand how useful mechanical work output and internal energy increase can occur simultaneously in an adiabatic-isentropic manner, following constant-volume heat extraction. The test bench results are irrefutable. If they appear counterintuitive or violate fundamental principles, those principles must be revised to align with experiment.

Fig.4(a), indicates a DARA in motionless state with piston located at left side; chamber A heating during the adiabatic-isochoric process 1-2 forcing temperature and pressure to increase; chamber B cooling during the adiabatic-isochoric process 3-4 forcing temperature and pressure to decrease. Fig.4(b), indicates a DARA in motionless state with piston located at right side; chamber A cooling B cooling during the adiabatic-isochoric process 3-4 forcing temperature and pressure to decrease; chamber B heating during the adiabatic-isochoric process 1-2 forcing temperature and pressure to increase. Fig.4(c), illustrates the T-s diagram of a VsVs cycle showing the temperatures and pressures evolution as function of heat transfer. From the given description, it can be deduced that two VsVs cycles are being executed simultaneously, offset from each other by half a cycle.

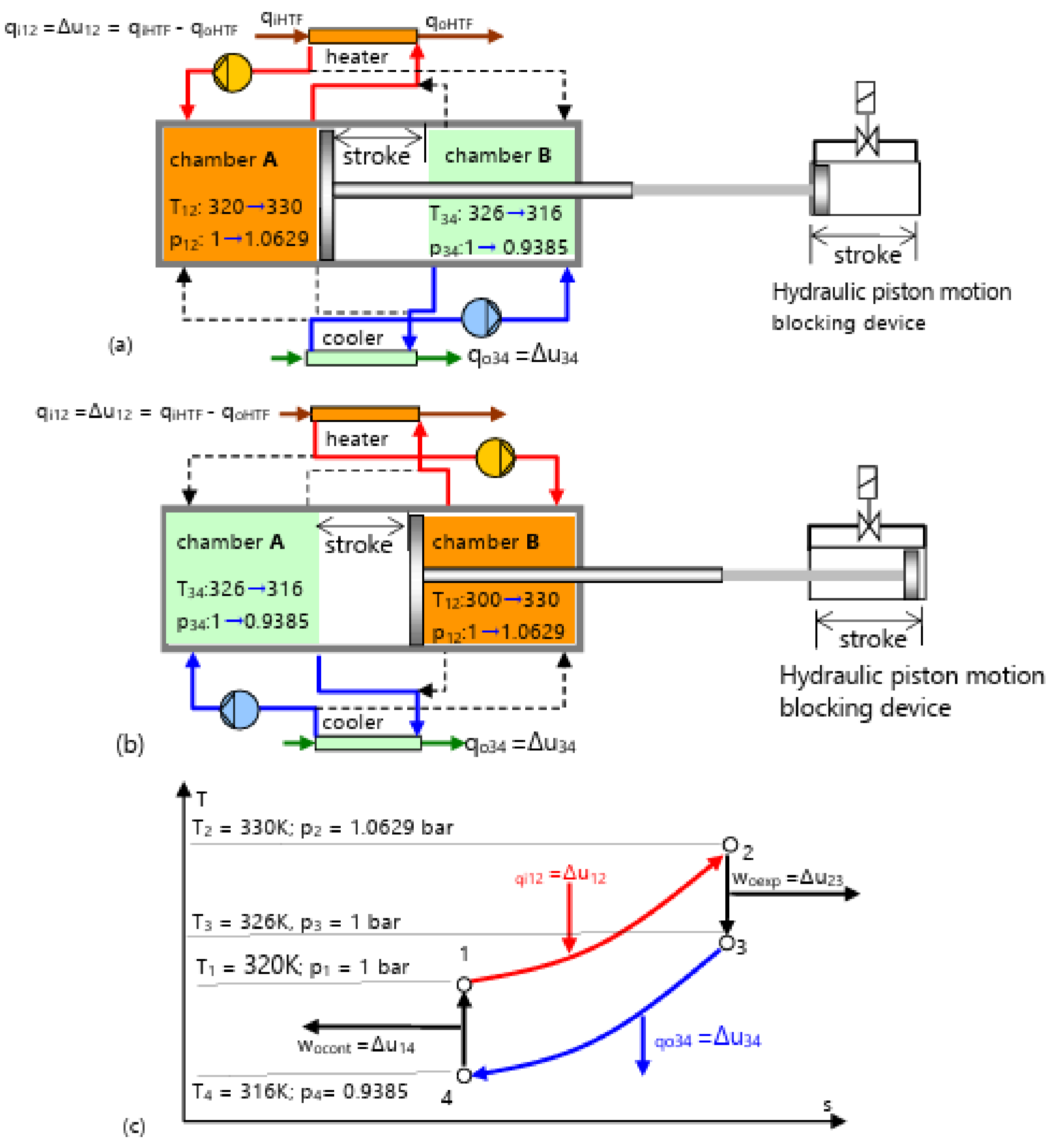

Figure 4. Test bench structure and operation modes of a semi-PU with DARA. (a) DARA motionless, piston left: chamber A heats (isochoric 1–2), chamber B cools (isochoric 3–4). (b) DARA motionless, piston right: chamber A cools (3–4), chamber B heats (1–2). (c) T-s diagram of a VsVs cycle, showing temperature/pressure evolution with heat transfer. Two VsVs cycles run simultaneously, half a cycle apart.

2.6.4 Main Components of the Test Bench

The DARA is adapted to demonstrate heat-to-work conversion via expansion and vacuum-induced contraction, both achieved by isochoric heat addition and extraction, respectively. Among the main components of the test bed is:

(a) Heat transfer accessories: heat addition (heating TWF) and heat extraction (cooling TWF). Both heat transfer modes (heating and cooling) require heat exchangers for heating and cooling the TWF under forced convection transfer modes. Closed heat transfer circuits are equipped with a recirculation pump to activate heat transfer via forced convection for both heat addition and heat extraction.

(b) Actuator: double-acting reciprocating cylinder to convert heat to work both by expansion or contraction. The double-acting reciprocating cylinder with a piston and rod are connected to a hydraulic locking cylinder operating as a motion blocking device.

(c) Motion blocking device: keeps piston motionless during simultaneous heat addition and extraction.

2.6.5 Operation Mode

The double-acting, intermittently moving reciprocating cylinder performs functional tests with thermal cycles. It includes subsystems for heating and cooling the TWF, plus a motion blocker to enable constant-volume heat transfer during both heating and cooling phases.

As shown in the T-s diagrams depicted in Fig.4 (c) and Fig 4 (b), each PU includes two DARAs operating intermittently and alternately. While the TWF in chamber A is heated (temperature and pressure increase), the TWF in chamber B is cooled (temperature and pressure decrease).

Fig.4(a) DARA piston locked (ready for heat transfer), piston at left side; motion blocked by a hydraulic device at the right extreme of the piston rod.

Fig.4 (b) DARA piston locked, piston at right side.

2.6.6 Description of the operation modes for a DARA following a VsVs cycle according to the data of Tables 1, 2 and Fig.5

The DARA operating mode following a double VsVs cycle simultaneously in the two actuator chambers is summarized in the following 4 phases:

State 1-2: Cylinder piston motion is locked at left side

-- Table 2: (1-2): chamber A heating,

while T changes from (T_1=320 to T_2=330); p changes from (1 to 1.0629); heat added

q_{i12} = $Cv(T_2\text{-}T_1)$ = $(u_2\text{-}u_1)$. (1)

-- Table 2: (3-4): chamber B cooling;

while T changes from (326 to 316), p changes from (1 to 0.9385) and heat extracted is

q_{o34} = $Cv(T_3\text{-}T_4)$ = $(u_3\text{-}u_4)$ (2)

State 2-3: Cylinder piston motion is unlocked at left side

As consequence, piston displaces along its stroke (left-right) doing work by expansion into chamber A due to the heat previously added, while simultaneously is doing work by contraction into chamber B due to the heat previously extracted.

-- work done due to expansion of the working fluid in chamber A Table 1(2-3):

w_{oexp} = w_{o23} = $Cv(T_3\text{-}T_2)$ = $(u_3\text{-}u_2)$ = 12.60 (3)

-- work done) due to contraction of the working fluid by chamber B Table 2 (4-1):

w_{ocont}= w_{o41} = $Cv(T_1\text{-}T_4)$ = $(u_1\text{-}u_4)$= 12.47 (4)

The net useful work done by expansion and contraction in chambers A and B as consequence of previously adding and extracting heat is

$w_o = w_{oexp} + w_{ocont}$ (5)

State 3-4: Cylinder piston motion is locked at right side

-- Table 2: (3-4): chamber A cooling; while T changes from (T_1=326 to T_2=316); p changes from (1 to .0.9385); heat extracted

$q_{io134} = Cv(T_3-T_4) = (u_3-u_4)$ (6)

-- Table 2: (1-2): chamber B heating; while T changes from (320.96 to 330); p changes from (1 to 0.0629); heat added

$q_{oi12} = Cv(T_2-T_1) = (u_2-u_1)$ (7)

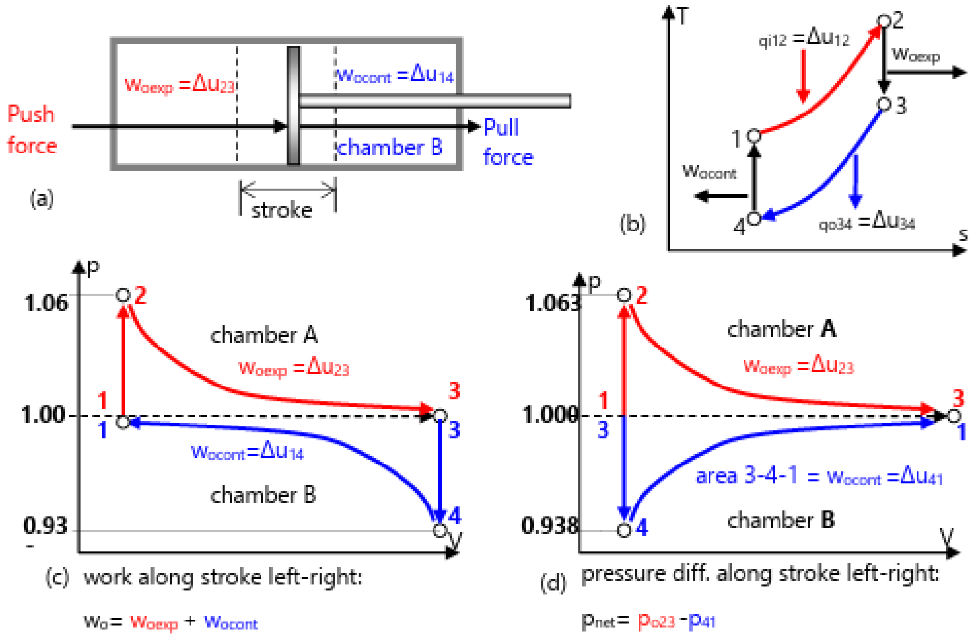

Figure 5. Description of the operating conditions of the DARA under a VsVs cycle in response to isochoric heat addition and extraction. (a) Illustrates the DARA. (b) Illustrates the T-s diagram for an ideal closed process-based VsVs cycle. (c) and (d) represent the T-s and p-V diagrams of a double-acting simultaneous operating mode.

State 4-1: Cylinder piston motion is unlocked at right side

As consequence, piston displaces along its stroke (right-left) doing work by contraction into chamber A due to the heat previously extracted, while simultaneously doing work by expansion into chamber B due to the heat previously added.

-- work out done due to expansion of the working fluid in chamber A Table 2 (2-3):

$w_{oexp} = w_{o23} = Cv(T_3-T_2) = (u_3-u_2) = 12.60$ (8)

-- work out done due to contraction of the working fluid by chamber B Table 2 (4-1):

$w_{ocont} = {}_{so41} = Cv(T_1-T_4) = (u_1-u_4) = 12.47$ (9)

The net useful work done by expansion and contraction in chambers A and B as consequence of previously adding and extracting heat is

$w_o = w_{oexp} + w_{ocont}$ (10)

Fig.3(a), illustrates a DARA structure representing cylinder chamber A doing work in expansion mode, while simultaneously, cylinder chamber B doing work in contraction or (vacuum –based) work. Fig.3(b) depicts the T-s diagram of the VsVs cycle. Fig.3(c) shows the p-V diagram of the VsVs cycle depicting expansion work in red color and contraction work in blue color and Fig.3(d) illustrate the pressure difference along a left-right piston stroke. The net work (w_n) done by the DARA during one stroke due to previous heat extraction is the sum of the single work done simultaneously in both cylinder chambers which includes an expansion and a contraction works. That is,

$w_n = w_{oexp} + w_{ocont} = \Delta u_{23} + \Delta u_{41}$. (11)

2.7 The cycle VsVs execution data

The data corresponding to the state points of the VsVs cycle operating between temperatures 316 and 330 K is illustrated in Table 1. The analysis of the data depicted in Table 1 yields the results regarding with heat transfer, and works output (w_{oexp} and w_{ocont}) in Table 2. for both cylinder chambers A and B.

Table 1: Test data and state conditions carried out in the closed processed-based VsVs cycle into each cylinder chamber A or B of a DARA with real helium as TWF [12-13]

	T[K]	*p*[bar]	*v*[m³/kg]	*u*[kJ/kg]	s[kJ/kg.K]	Alignment with SLT
1	320.00	1	3.3047	1002.20	26.889	Δs_{14}=0: meets SLT
2	330.00	1.0629	3.3047	1033.40	26.985	s_3-s_2=0
3	325.96	1	3.3661	1020.80	26.985	Δs_{23}=0: meets SLT
4	316.00	0.9385	3.3661	989.73	26.889	s_4-s_1=0

According to the rightmost column of Table 1, the ideal closed processes-based VsVs cycle satisfies the Kelvin-Planck and Clausius statements, despite the significant controversy surrounding the energy balance affecting the FLT, since for meet FLT (according to Eqs. (8), (9) and (10) the accounted output work is only the expansion work (w_{o23}) while in the case of Table 1 the net useful work output is w_{o23} + w_{o41}, (work out due to both expansion plus contraction). Since (w_{o23} + w_{o41}) > (w_{o23}), then, FLT efficiency is also greater than in the case of only expansion work, which in the general case surpasses CF, so that the energy balance-based model also satisfying energy conservation principle, is misaligned with FLT. These results are counterintuitive and controversial.

2.7.1 Results of the test

It is observed in Table 2 that the closed-processes-based VsVs cycles in chambers A and B are equal, simultaneous, and symmetrical and operate half a cycle out of phase with each other. The thermodynamic model used to describe heat transfer and work output is described in Eqs. (1-11)

For continuous movement, each power unit must be equipped with two DARA. offset by half a cycle. This ensures that while one power unit is at rest during the heat transfer phase, the complementary power unit is in motion, providing output work, and vice versa.

Table 2: Closed thermodynamic transformations carried out simultaneously in the cylinders chamber A and chamber B as response to heat transfer by adding and extracting heat during a closed processes-based VsVs cycle.

Changes carried out into the cylinder chamber A				
SPs	heat transfer/work	changes in T	changes in p	work/motion
1-2	q_{i12}= CvΔT_{12} =Δu_{12}=31.20	ΔT_{12}=320→330	Δp_{12}=1→1.0629	blocked
2-3	expansion work w_{o23}	ΔT_{23}=330→326	Δp_{23}=1.0629→1	w_{o23}=Δu_{23}=12.60
3-4	q_{o34}= CvΔT_{34} =Δu_{34}=31.07	ΔT_{34}=326→316	Δp_{34}=1→0,9385	blocked
4-1	contraction work w_{o41}	ΔT_{41}316→320	Δp_{41}=0,9385→1	w_{o41}=Δu_{41}=12.47
Changes carried out into the cylinder chamber B				
SPs	heat transfer/work	changes in T	changes in p	work/motion
3-4	q_{o34}= CvΔT_{34} =Δu_{34}=31.07	ΔT_{34}=316→320	Δp_{34}=1→0,9385	blocked
4-1	contraction work w_{o41}	ΔT_{41}=316→320	Δp_{41}=0,9385→1	w_{o41}=Δu_{41}=12.47
1-2	q_{i12}= CvΔT_{12} =Δu_{12}=31.20	ΔT_{12}=320→330	Δp_{12}=1→1.0629	blocked
2-3	expansion work w_{o23}	ΔT_{23}=330→326	Δp_{23}=1.0629→1	w_{o23}=Δu_{23}=12.60

2.8 Comparison between both thermal efficiencies: based on expansion and based on expansion and contraction

Let's analyze the thermal efficiency of a VsVs cycle that operates with both adiabatic expansion work and adiabatic contraction work. This corresponds to an unconventional thermal cycle that converts heat into work using both, a converter or actuator that employs a cylinder or turbine to convert heat into work output by adiabatic expansion and work output by adiabatic contraction. Therefore, both options consist of the thermal efficiency using Eq. (9) to define expansion work and Eq. (10) to define contraction work yields

Thermal efficiency for a Vsp cycle exhibiting expansion only,

$$\eta_{th(\exp)} = \frac{w_n}{q_i} = \frac{w_{o23}}{q_{12i}} \tag{12}$$

Thermal efficiency for a VsVs cycle exhibiting both: expansion end contraction

$$\eta_{th(\exp+cont)} = \frac{w_n}{q_i} = \frac{w_{o23} + w_{o41}}{q_{12i}} \tag{13}$$

The result of comparing Eq. (13) and (14) yields

$$\frac{w_{o23}}{q_i} < \frac{\left|w_{o23} + |\, w_{o41}\,|\right|}{q_i} \quad or$$

$$\eta_{th(\exp)} < \eta_{th(\exp+cont)} \tag{14}$$

Simply because

$$\left|w_{o23}\right| < \left|w_{o23} + |\, w_{o41}\,|\right| \tag{15}$$

The thermal efficiency of a cycle that operates by performing useful work output only through an adiabatic expansion in a converter or actuator based on the adiabatic heat-work interaction is:

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o23}}{q_i} \tag{16}$$

This corresponds to a conventional thermal cycle that converts heat into work using a converter or actuator that employs a cylinder or turbine as the converter.

When comparing the thermal efficiency (13) between that of a conventional thermal cycle in which the work output is due only to the expansion work induced by the addition of heat and the thermal efficiency (14) of a non-conventional and therefore disruptive thermal cycle that involves the addition of two useful work outputs —expansion work and contraction work generated by vacuum induced by heat extraction— it can be observed that the thermal efficiency of the cycle equipped only with expansion exhibits a thermal efficiency lower in any case than that of Eq. (14). Such thermal efficiency is always lower than the thermal efficiency of the disruptive cycle enabled to produce work by expansion and contraction, which not only does it exceed the thermal efficiency limit established by Carnot, but its energy balance does not align with the useful energy balance for conventional cycles —cycles that convert heat to work only by adiabatic or isothermal expansion— that is, they lack the ability to do useful work by contraction, which affects the definitions of the FLT. The restrictions on thermal efficiency imposed by Carnot's theorem are inviolable. This is because it is only applicable to Carnot cycles and related cycles such as real Ericsson and Stirling which undergoes irreversibilities. Their affinity stems from the common characteristic of operating between two isotherms, one of high temperature and the other of low temperature. However, Carnot's theorem does not impose any efficiency limits on cycles other than Carnot, Ericsson, or Stirling. However a real Carnot cycle, Ericsson, or Stirling cycles cannot approach CF; firstly, because they require a thermal working fluid, and secondly, because both involve irreversibilities.

Some characteristics of the VsVs cycle related to expansion versus expansion plus contraction include the efficiencies of expansion-only and expansion-plus-contraction scenarios. From Tables 1 and 2 the following parameters characterize the VsVs ideal cycles:

Ratio of expansion to contraction works (WR)

$$WR = \frac{w_{ocont}}{w_{o23}} = \frac{12.47}{12.60} = 0.98968 \tag{17}$$

CF —Carnot cycle efficiency

$$CF = \frac{T_H - T_L}{T_H} = \frac{330 - 316}{330} = \frac{14}{330} 0.04242 \quad (18)$$

Thermal efficiency for expansion only

$$\eta_{th(\exp)} = \frac{w_{o\exp}}{q_i} = \frac{w_{o23}}{q_{12i}} = \frac{12.60}{31.20} = 0.4038 \quad (19)$$

Thermal efficiency for contraction only

$$\eta_{th(cont)} = \frac{w_{ocont}}{q_i} = \frac{w_{o41}}{q_{i12}} = \frac{12.47}{31.20} = 0.3996 \quad (20$$

Thermal efficiency for a cycle including both expansion plus contraction

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o23} + |w_{o41}|}{q_{i12}} = \frac{12.6 + 12.47}{31.20} = \frac{25.08}{31,2} = 0,8038 \quad (21)$$

Comparing CF in Eq. (18) with the thermal efficiency in Eq. (19) it is observed that the thermal efficiency in equation (19) is greater than the CF in equation (18). This evidence leads to the following statements [16]:

1-Thermal cycles based on closed processes-based thermal cycles without changes of state can exceed the CF under certain conditions

2-In the cycles mentioned by statement 1 CF is misaligned with the thermal efficiency of cycles based on closed processes without changes of state.

3-The CF is independent of the Kelvin-Planck and Clausius statements and therefore of the SLT. In fact the SLT is applicable in all real systems.

2.9 On the misalignment of the thermal efficiency of closed-process cycles according to the generalized CF [16]

Comparing the results of Eq. (18) on CF with those of Eq.(19) on thermal efficiency, it turns out that CF = **0.04242** is noticeably lower than thermal efficiency η_{th} = **0.4038**, when at least, according to Carnot's theorem, it should be higher.

To analyze this controversial and counterintuitive case, an empirically based test is proposed to determine if it is possible to overcome the limits imposed by CF using conventional thermodynamics —without violating any principle of thermodynamics.

For this purpose, we consider a single-acting reciprocating cylinder enabled to produce work by adiabatic expansion as a result of previously adding heat at constant volume.

Figure 5 shows the schematic of a single-acting reciprocating actuator (SARA) capable of completing a cycle by performing useful work through the adiabatic expansion of a thermal working fluid, returning to the origin in a closed isobaric process while simultaneously moving the piston back to the origin.

During the piston's return stroke 2-3, no useful work is absorbed or performed, as the ambient (ambient or surroundings pressure = 1 bar) and cylinder pressures are equal under zero resistive loads. Consequently, the piston moves solely due to a slight vacuum induced by additional cooling, where the difference of pressures between the surroundings and cylinder chamber is negligible. The return movement or displacement of the piston is achieved by means of a slight sub-cooling by means of heat extraction during process 3-1 of the Vps cycle.

However, note that if it cools even more, which entails significantly greater subcooling through increased heat extraction, a certain amount of useful work output is performed by contraction (closed polytropic process, neither adiabatic nor isobaric), which inherently leads to a decrease in entropy.

Irrefutable evidence: Useful work output is performed while entropy decreases: This is unacceptable, meaning that this would not be possible according to the second law of thermodynamics (SLT).

The necessary conditions for mechanical work to occur are two: displacement and net force on the displaced object. Therefore, if the net force is zero due to an equilibrium of forces (zero pressure difference resulting in a zero net force) or the displacement is zero, then no work is done. n the case of the Vsp cycle depicted in Fig.6 (b) and (c), there is displacement but no force.

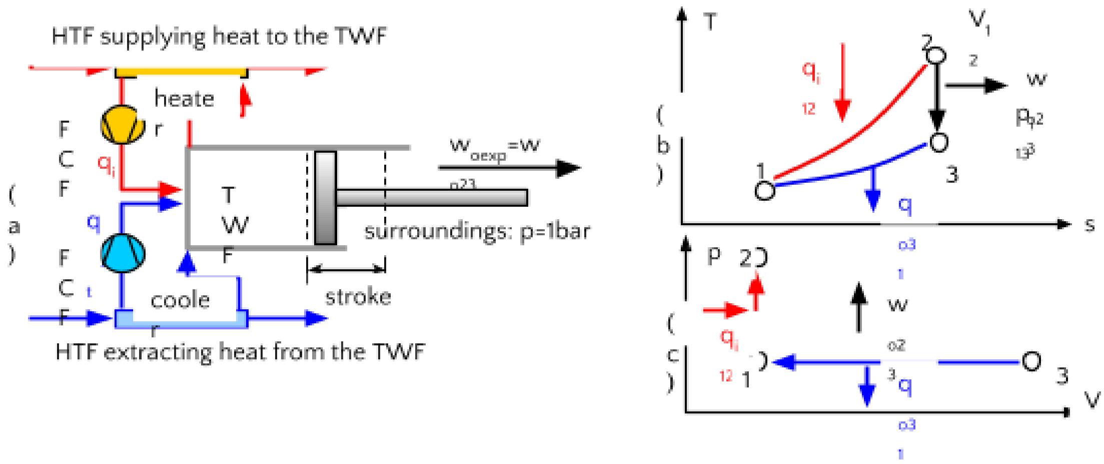

Figure 6. Schematic of a SARA depicted in (a), to illustrate the operating modes during the execution of a closed-process Vsp cycle, using helium as TWF [16-20]. The T-s and p-V diagrams depicted in (b) and (c) indicate us the sequences of processes carried out between state points. Notation: Heat transfer fluid (HTF), working thermal fluid (WTF), forced convection fan FCF

In the following section, the test device consisting of a SARA-type actuator shown in Fig.6 is subjected to tests susceptible to rigorous and consistent empirical analysis to verify the misalignment of the CF with the observed empirical results.

2.9.1 Results of an empirical study of cycles based on discontinuous closed processes showing misalignment with the CF limits.

Let's analyze an expansion only-based cycle through an empirical study showing misalignment with the CF in cycles based on closed processes without state changes (vaporization and condensation) operating -doing useful work- by adiabatic expansion only.

The reason a thermal cycle operates discontinuously is that during an isochoric process, the piston remains stationary to maintain a constant volume during heat addition or extraction.

To achieve constant motion (without intermittent motion), there are at least two options:

1- Operating with a DARA characterized by inherently using two simultaneous cycles offset by half a cycle from each other.

2- Implementing two SARA operating with simultaneous cycles offset by half a cycle from each other, such that when one remains stationary, the complementary one is in motion.

2.9.2 Vsp cycle

The study of a Vsp cycle is carried out by means of a test bed where the thermodynamic behavior of a Vsp thermal cycle is studied. Table 3 illustrates the closed processes carried out during the cycle Vsp applied on the test bed depicted in Fig.6.

Table 3: Illustration of the closed processes carried out during the execution of the Vsp cycle with reference to the T-s and p-V diagrams depicted in Fig.6.

SP	Process type	Process model	Piston motion
1-2	Isochoric heat addition	No work: $q_{i12}=\Delta u_{12}=Cv.(T_2-T_1)$	Motionless
2-3	Adiabatic expansion	Work output: $w_{o23}=u_2-u_3=Cv.(T_2-T_3)$	Outwards stroke
3-1	Quasi-Isobaric cooling	No useful work: p_{cyl} -p_{sourr} $q_{o31}=\Delta u_{31}=Cv.(T_3-T_1)$	Inwards stroke

The energy balance in the Vsp cycle obeys to FLT considering heat input-output and work output

$$\sum q - \sum w = 0 \rightarrow q_{i12} - q_{o31} - w_{o23} = 0 \tag{22}$$

As consequence of (22) the work output is

$$w_{o23} = q_{i12} - q_{o31} \tag{23}$$

The thermal efficiency η_{th} is

$$\eta_{th} = \frac{w_{o23}}{q_{i12}} = \frac{q_{i12} - q_{o31}}{q_{i12}} = 1 - \frac{q_{o31}}{q_{i12}} = \frac{w_{o23}}{q_{i12}} \tag{24}$$

Thus, according to the FLT and applying Eq (23) and (24) the useful work output and thermal efficiency are obtained for several tests in order to represent the results both by means of tables and graphs.

Table 4: Test data and state conditions carried out in the closed processed-based **Vsp** cycle of a SARA with real helium and nitrogen as real TWF [13]

sp	T (K)	p(bar)	V(m³/kg	u(kJ/kg)	s(kJ/kg-K)	sp	T (K)	p(bar)	V(m³/kg	u(kJ/kg)	s(kJ/kg-K)
			Vsp-He.1						Vsp- N2-1		
1	300	1	62.347	939.84	28.008	1	300	1	0.89025	222.17	6.8457
2	325	10.833	62.347	1017.7	28.257	2	325	10.835	0.89025	240.76	6.9052
3	314.76	1	65.414	985.85	28.257	3	317.65	1	0.94276	235.31	6.9052
			Vsp-He.2						Vsp- N2-2		
2	350	11.667	62.347	1095.7	28.488	2	350	11.667	0.89025	259.36	6.9603
3	329.08	1	68.388	1030.5	28.488	3	334.91	1	0.99407	248.15	6.9603
			Vsp-He-3						Vsp- N2-3		
2	375	1.25	62.347	1173.6	28.703	2	375	1.25	0.89025	277.99	7.0117
3	342.99	1	71.278	1073.8	28.703	3	351.84	1	10.444	260.76	7.0117
			Vsp-He-4						Vsp- N2-4		
2	400	1.33	62.347	1251.5	28.904	2	400	13.341	0.89025	296.65	7.0599
3	356.53	1	74.089	1116	28.904	3	368.49	1	10.939	273.17	7.0599
			Vsp-He-5						Vsp- N2-5		
2	450	1.5	62.347	1407.3	29.271	2	450	15.011	0.89025	334.14	7.1482
3	382.64	1	79.512	1197.3	29.271	3	401.01	1	11.906	297.46	7.1482
			Vsp-He-6						Vsp- N2-6		
2	500	16.666	62.347	1563.1	29.599	2	500	16.681	0.89025	371.92	7.2278
3	407.58	1	84.694	1275.1	29.599	3	432.71	1	12.847	321.21	7.2278
			Vsp-He-7						Vsp- N2-7		
2	550	18.333	62.347	1718.9	29.896	2	550	18.351	0.89025	410.1	7.3006
3	431.57	1	89.677	1349.8	29.896	3	463.79	1	13.771	344.59	7.3006
			Vsp-He-8						Vsp- N2-8		
2	600	19.999	62.347	1874.7	30.167	2	600	20.021	0.89025	448.75	7.3678
3	454.69	1	94.479	1421.9	30.167	3	494.35	1	14.678	367.7	7.3678
			Vsp-He-9						Vsp- N2-9		
2	650	21.666	62.347	2030.5	30.417	2	650	2.169	0.89025	487.93	7.4305
3	477.12	1	99.137	1491.7	30.417	3	524.53	1	15.575	390.67	7.4305

		Vsp-He-10						Vsp- N2-10			
2	700	23.332	62.347	2186.3	30.648	2	700	2.336	0.89025	527.69	7.4895
3	498.82	1	10.365	1559.4	30.648	3	554.46	1	16.464	413.6	7.4895

By processing the data shown in Table 4 according to the Vsp cycle shown in Fig.6 (b) and (c), the results shown in Table 5 are obtained, which give rise to the corresponding analysis on the thermodynamic behavior of each test. The use of two working heat fluids, helium and nitrogen, according to Table 5 allows us to observe:

1. The influence of each tested thermal working fluid on thermal efficiency.

2. A comparison between the two thermal working fluids to determine the advantages and disadvantages of each.

Table 5: Illustration of the results derived from the Vsp analysis of the data depicted in Table 4.

Test	1	2	3	4	5	6	7	8	9	10
T2-Vsp	325	350	375	400	450	500	550	600	650	700
T1-Vsp	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
CF(%)	7.69	14.29	20	25	33.33	40	45.45	50	53.85	57.14
					Helium					
qi12(kJ/kg)	77.86	155.86	233.76	311.66	467.46	623.26	779.06	934.86	1090.66	1246.46
wo23(kJ/kg)	31.85	65.20	99.80	135.50	210.00	288.00	369.10	452.80	538.80	626.90
qo31(kJ/kg)	46.01	90.66	133.96	176.16	257.46	335.26	409.96	482.06	551.86	619.56
η_th	40.91	41.83	42.69	43.48	44.92	46.21	47.38	48.44	49.40	50.29
					Nitrogen					
qi12(kJ/kg)	18.59	37.19	55.82	74.48	111.97	149.75	187.93	226.58	265.76	305.85
wo23(kJ/kg)	5.45	11.21	17.23	23.48	36.68	50.71	65.91	81.05	97.26	114.10
qo31(kJ/kg)	13.14	25.98	38.59	74.48	75.29	99.04	122.41	145.53	168.50	191.43
η_th	29.32	30.14	30.87	31.53	32.76	33.86	34.86	35.77	36.60	37.34

The Vsp cycle with helium exceeds the CF for temperatures below 670 K, while with nitrogen it exceeds the CF for temperatures below 450 K

The Vsp cycle with helium exceeds the CF at temperatures below 670 K, while with nitrogen it exceeds the CF at temperatures below 450 K.

The adiabatic expansion coefficient (or specific heat ratio, γ=Cp/Cv**)** for nitrogen gas (N_2) at room temperature is **1.4** and for helium is **1,67** [13]. According to the above previous data, there is a clear nonlinear relationship and influence between the adiabatic expansion coefficients and the thermal efficiency of the thermal working fluids.

Fig. 6 and Fig. 7 illustrate the behavior exhibited by the cycle Vsp operating with both, helium and nitrogen respectively. It can be observed that helium is much more efficient than nitrogen and consequently the cycle operated by helium exceeds the CF in a range of low temperatures much higher than that of nitrogen.

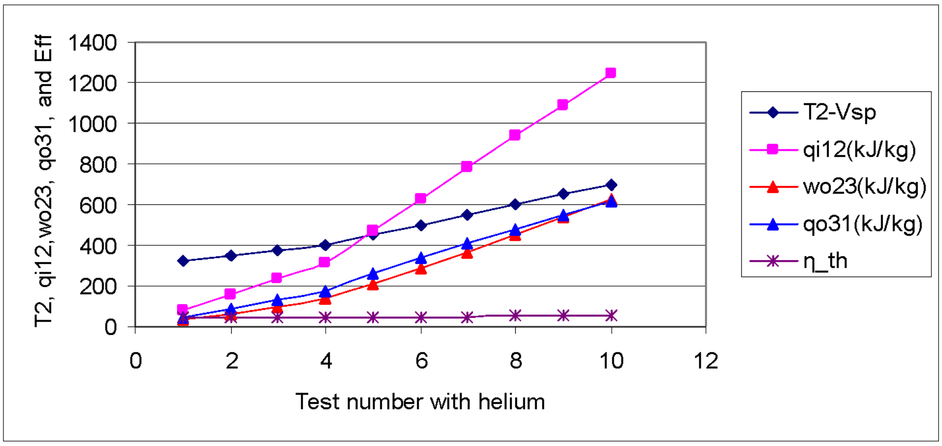

Figure 7. Illustration of the cycle Vsp parameters: added, extracted heat, work output and efficiency for **helium** as thermal working fluids in the Vsp cycle

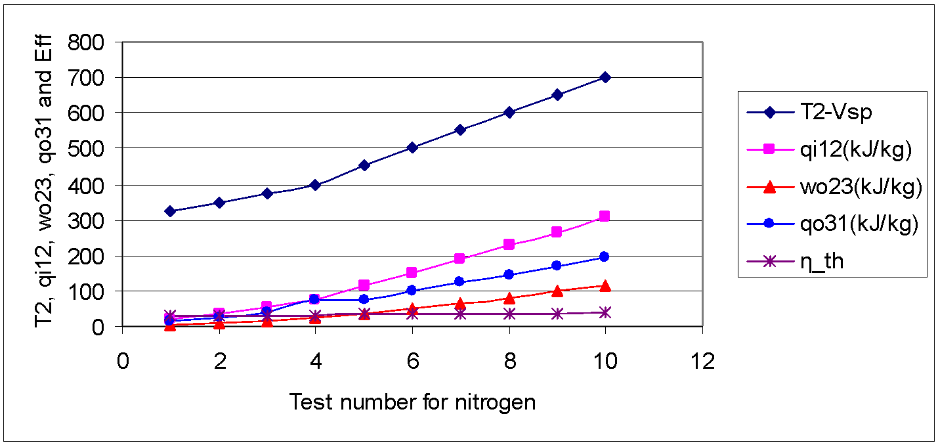

Figure 8. Illustration of the cycle Vsp parameters: added, extracted heat, work output and efficiency for **nitrogen** as thermal working fluids in the Vsp cycle

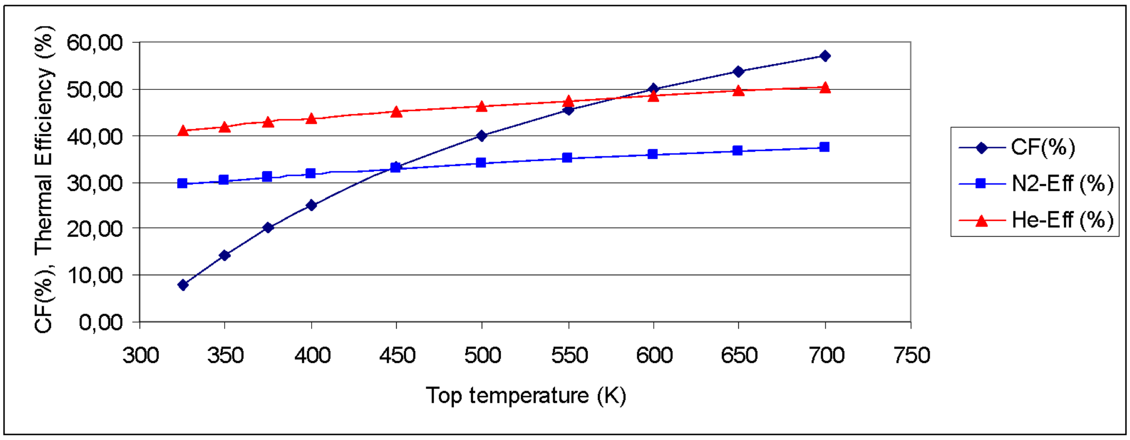

Figure 9. Illustration of the behavior of the thermal efficiency for helium and nitrogen as thermal working fluids in the Vsp cycle versus the CF

Figure 8 shows the behavior of the **thermal efficiency** of helium and nitrogen as thermal working fluids in the Vsp cycle versus the **CF**. It is observed that according to the Vsp thermal cycle, operating under closed thermal processes without state changes, using helium and nitrogen as working fluids, is aligned with both the first and second laws of thermodynamics.

2.9.3 Analysis of a closed process based on adiabatic expansion used in the Vsp cycle [16]

It can be seen that thermal cycles based on closed thermal processes doing useful work output by means of adiabatic expansion **exceed CF** under certain operating conditions in terms of their maximum and minimum operating temperatures.

Given the counterintuitive and surprising results related to the CF overshoot, it seems reasonable to reinforce the robustness and consistency of the previous study according to Eq. (22-24) by proceeding with the analysis of the FLT formulation subjected to the thermodynamic state constraints that occur in a closed adiabatic expansion process. This serves to support the rigor of the empirical study based on the energy balance, which in turn is grounded in the first law viewed from a generalist perspective.

However, demonstrating through the presented results that they significantly exceed the limits established by Carnot's theorem under operating conditions restricted to low operating temperatures clearly means that the Carnot cycle obeys Carnot's limitations in accordance with Carnot's theorem, but this is not applicable to other thermal cycles such as the Vsp cycle, meaning that CF is aligned with Carnot theorem for all Carnot engines including those that operates between two isothermal temperatures such ideal Stirling and Ericsson cycles.

Therefore, it can be concluded without a doubt that the limitations established by Carnot's theorem are rigorously true and irrefutable, but they are not applicable to other thermal cycles that operate through adiabatic expansion with closed processes without phase change such as the Vsp cycles represented in Fig .5

Summarizing, from everyday observation, for closed adiabatic expansion or compression upon which the FLT is based, it can be stated that:

1. If energy (heat and work) is added to a closed process, the process experiences an **increase** in internal energy.

2. When energy (heat and work) is removed from a closed process, the process experiences a **loss** of internal energy.

The following notation is applied to the energy balances for closed processes without state changes: E_i is the energy added to a process or thermodynamic transformation while E_o is the energy output from a process. Therefore, the formulation of the FLT for closed processes whish states that the changes in internal energy of closed a process is the difference between input and output energies. Let's return to the overall energy balance; therefore, the energy balance of the FLT is:

$$\Delta u = E_i - E_o$$

where

$$E_i = q_i + w_i$$
$$E_o = q_o + w_o$$

In general according to the FLT for closed processes without state changes an energy balance can be described as

$$\Delta u = (q_i + w_i) - (q_o + w_o) \tag{25}$$

In adiabatic closed processes $q_i = q_0 = 0$, which gives rise to

$$\Delta u = (w_i) - (w_o) \tag{26}$$

Considering that in the case of an expansion-based HWI $w_i = 0$, under such state conditional restrictions the FLT results as

$$\Delta u = -(w_o) \text{ or } w_o = -\Delta u \tag{27}$$

According to Eq. (27), this means that a negative change in internal energy is compensated by expansion work output. In other words, indicates us that the useful work output is due to a negative change in internal energy that means, a negative change in internal energy gives rise to useful work output.

2.9.4 Conclusions on CF behavior

1 Eq. (25-27) indicates that the useful work produced is due to a loss of internal energy. This means that the expansion work output is directly proportional to the change in internal energy. Using Eq. (22-24) in the

previous case study it is demonstrated empirically that CF ca be overcome without violating any fundamental principle. This means that the proof based on the FLT definition is perfectly consistent and agrees with the FLT.

2 The CF can be overcome in cycles affected by closed processes subjected to adiabatic expansion or adiabatic compression for low temperatures as demonstrated in the study carried out in section 2.10.1.

3 The range of low temperatures in which CF is violated depends on the characteristics of the thermal working fluid: the ratio of heat capacity (Cp) at constant pressure to heat capacity at constant volume CV which means the adiabatic expansion or contraction ratio is key to achieve high thermal efficiencies.

4 The CF, which results directly from Carnot's theorem, is rigorously applicable and irrefutable in ideal thermal cycles that perform useful work output by adiabatic expansion operating between two high and low isothermal temperatures such as Ideal Carnot, Ericsson and Stirling cycles.

In summary, the fact that the CF can be overcome in thermal cycles operating:

a) Solely through adiabatic expansion does not imply a violation of the second law of thermodynamics (SLT). Rather, it is irrefutable and useful for thermodynamic cycles operating between two constant temperature levels: high (H_T) and low (T_L), such as the Carnot, Eriksson, and Stirling cycles.

b) Through adiabatic expansion and contraction processes does not imply a violation of the SLT. Instead, the resulting net work comprises the expansion work due to heat addition plus the contraction work due to heat removal.

2.10 Kelvin–Planck and Clausius compliance disclaimer

On the basis of the statements of Kelvin-Planck and Clausius stated as:

Kelvin-Planck: It is impossible to convert 100% of the available heat into mechanical work output

Clausius: It is impossible to transfer heat from a colder body to a hotter body without the help of external work.

It follows that achieving a heat engine capable of operating without an external energy source in a cycle does not violate the second law in the Kelvin-Planck statements or in the Clausius statement for any individual power unit operated by a thermal cycle based on closed adiabatic contraction processes.

In other words, each and every one of the cascaded power units that make up the plant characterized by lacking external energy supply fully satisfy the statements of Kelvin-Planck and Clausius.

It is emphasized that, while the proposed architecture conforms to either the Kelvin-Planck or Clausius statements of the Second Law of Thermodynamics, the condition of self-sufficiency does not require an external heat source. According to the statements of Kelvin-Planck and Clausius, there is no reference to the prevailing need for an external heat source. This means that the existence of self-sufficient machines does not necessarily have to violate the second law of thermodynamics, if and only if strictly Kelvin-Planck and Clausius statements are taken into account.

In particular, the system does not operate by extracting heat from a single thermal reservoir and converting it entirely into work, nor does it induce net heat transfer from a colder body to a hotter one without external compensation. All work-producing stages are accompanied by corresponding entropy generation and compensating heat flows, and at no point is mechanical work obtained from heat alone without an associated entropy increase. Heat recovery and reinjection occur exclusively within the system boundaries and serve to reduce irreversible external heat rejection, not to abolish it. Consequently, the apparent performance gains arise from internal heat reutilization, exergy preservation, and entropy flow management across multiple interacting control volumes, rather than from any prohibited thermodynamic process. When evaluated as a closed system interacting with its surroundings, the overall operation remains fully compliant with both Kelvin–Planck and Clausius formulations of the Second Law.

2.10.1 Exceptions to the statements of Kelvin-Planck and Clausius:

In ideal isothermal heat-work conversion processes, two absolutely relevant exceptions affect the SLT, impacting both the Kelvin-Planck and Clausius statements:

1. **Impact on the Kelvin-Planck statement:** 100% conversion of heat into useful mechanical work.

2. **Impact on the Clausius statement:** Decrease in entropy during the production of useful work in a closed isothermal contraction process.

As shown in the T-s diagram in Fig.10 according to a VTVT cycle, the following facts occurs: The ideal isothermal conversion of heat to useful mechanical work in a closed isothermal heat-work conversion process, whether by isothermal expansion (process 2-3) or isothermal contraction (process 4-1), impacts the SLT in that:

1—Violates the Kelvin-Planck statement inevitably implies violation of the Clausius statement

2—The process of adding heat isothermically 9ideally gives rise to 100% thermal efficiency.

3— Throughout the isothermal contraction conversion process (4-1), entropy decreases proportionally to the heat extracted and, consequently, to the useful work output. Entropy decreases as useful work is obtained, which is counterintuitive.

With reference to the statement "It is not possible to convert 100% of the available heat into mechanical work" follows that in any ideal polytrophic transformation (including adiabatic and isobaric processes), the Kelvin-Planck statement is irrefutable. However, in an ideal isothermal transformation, all the heat absorbed during the transformation is converted entirely into useful work output, so in such special case Kelvin-Planck statement **cannot be fulfilled** as shown in Fig.10, since the added heat ideally will be converted 100% into mechanical work according to the model depicted in Fig.10 (a).

Therefore, according to processes 2-3 and 4-1, it follows that the following events occur when observing Figure 9(a):

$$q_{i23} = T_2 \Delta s_{23}$$

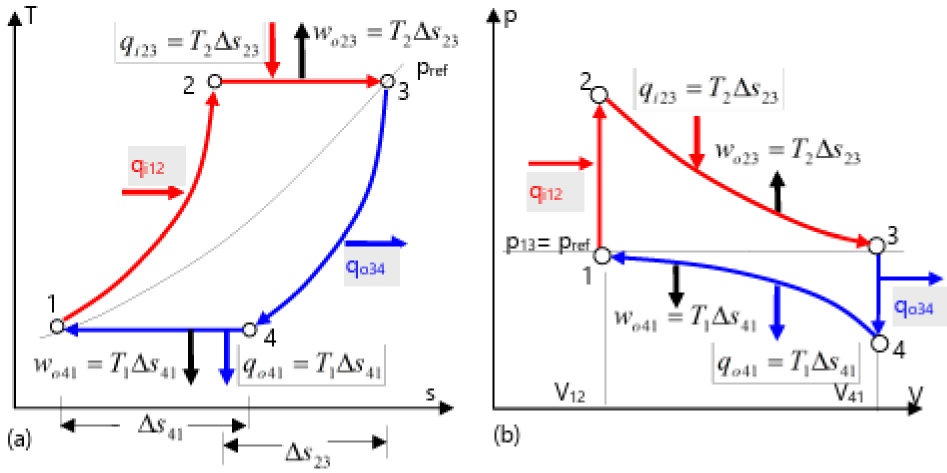

Figure 10. Illustration of the exception to the Kelvin-Planck statement using T-s and p-V diagrams for a DARA performing useful output work through isothermal expansion and contraction in a VTVT cycle.

Adding heat under an ideal closed isothermal process

$$q_{i23} = T_2 \Delta s = w_{o23}$$

Extracting heat under an ideal closed isothermal process

$$-q_{i41} = T_1(-\Delta s) = w_{o41}$$

where

$$\Delta s = \Delta s_{23} = |-\Delta s_{41}|$$

$w_{o41} < w_{o23}$ because $T_1 < T_2$

According to the ideal T-s and p-V diagrams are depicted in Fig.10 (a) and (b) for a DARA operating by means of isothermal expansion and isothermal contraction.

Summarizing the heat-work conversion based on the closed isothermal process 4-1 depicted in Fig.9(a)

(a) The adding heat process model is identical to the isothermal expansion work out, and

(b) The isothermal heat extracting process model is identical to the isothermal contraction work out.

In a VT-V cycle characterized by operating between two high and low isothermal temperatures, such as the one shown in Fig.10, which is realizable, it can be observed that in the execution of isothermal processes 2-3 and 4-1, all the heat transferred (to/from the cycle), both input and output, is converted 100% into useful work output, which is an exception to the generalized Kelvin-Planck statement. This fact justifies the inclusion of an exception to the SLT statement, despite it being rigorously irrefutable except in cases of obtaining useful work output by isothermal contraction.

3 Key design concepts that must meet the necessary conditions for achieving energy self-sufficiency

Disruptive innovation regarding self-sufficiency refers to the useful work output obtained during a contraction process that does not require the addition of thermal energy. Instead, it accompanies heat extraction, which can be recovered and regenerated. This alone nearly doubles thermal efficiency. Moreover, the recovered cooling heat is not only regenerated but reinserted into the system, further enhancing performance.

The key lies in:

(a) Isochorically increasing internal energy followed by delivering useful mechanical work output, and

(b) Systematically recovering the cooling heat rejected by each power unit (PU).

The fact of harvesting and reusing this cooling heat at every recovery stage (PU) is essential for self-sustaining operation.

In summary,

(a) The strategic arrangement of a cascade of PUs that perform both expansion and contraction work, together with efficient recovery and reutilization of heat rejected during cooling, constitutes the core approach to energetic self-sufficiency.

(b) The system inherently regenerates heat while recovering the cooling heat required generating the necessary vacuum. This cooling heat, which enables useful work through contraction, is recovered upstream and upgraded to a higher thermal level in each cascaded upstream power unit.

3.1 Essential conditions associated with design strategies for achieving energy self-sufficiency [3-16]

Recall that, given the review of concepts regarding the validity of the Carnot factor and useful heat-work interactions, such as the conversion of heat to vacuum-induced work created by cooling the TWF through heat extraction, carried out throughout this article, we are now in a position to establish a roadmap for implementing prototypes of energy-self-sufficient thermal engines.

The minimum conditions necessary to achieve energy self-sufficiency require two essential types of considerations: Thermodynamic and/or thermo-mechanic strategies and physical-structural resources.

A necessary set of conditions but not limited to the following includes:

1. Obtaining traction or pulling forces without energy cost, which consist of contraction forces originated by vacuum from cooling the TWF via cooling TWF via heat extraction

2. vacuum-induced contraction work through cooling the TWF via heat extraction

3. Recovery of the extracted heat for the cooling task mentioned in 2

4. Regeneration of the recovered heat to feed it back into the thermal cycle of the plant's first power unit.

3.2 Essential resources associated with the energy self-sufficiency [3-16], {21-26]

1. Power Unit structures enabled to operate under vacuum-induced contraction work

2. Contraction-based thermal cycles enabled to operate under vacuum-induced contraction work, which at least include the following types:

   VsVs cycles with continuous double-acting reciprocating actuators [2-7, 21-26]

   VsVs cycles with discontinuous-intermittent double-acting reciprocating actuators

   Continuous **sVsVs** cycles for rotary actuators (Gas turbines based on thermally-induced pressure pulses) [3-16]

3 Thermal working fluid characterized by a high heat capacity at constant pressure

4. Generalization of forced heat transfer by thermal convection for both heating and cooling the TWF.

5. Strict temperature, pressure and flow controls among other relevant variable parameters

3.3. A case study on Self-Sufficiency

The case study consists of determining the specific work of a self-sufficient thermoelectric plant composed of a cascade of power units characterized by their ability to do useful mechanical work by thermal contraction.

Assuming an available range of operating temperatures for the heat source Assuming an available range of operating temperatures for the heat source such that the number of PUs on the basis of a available heat range (T_H-T_L):

$$N_{PU} = \frac{\Delta T}{T_D} = \frac{T_H - T_L}{T_D} \quad (28)$$

Where the amount of specific work of each power unit is defined as

$$W_{PU} = \eta_{th} \cdot q_i \quad (29)$$

Then, the total amount of a cascaded (w_{casc}) set of PUs is

$$W_{casc} = \sum_{1}^{N_{PU}} W_{PU} = N_{PU} \cdot W_{PU} = N_{PU} \cdot \eta_{th} \cdot q \quad (30)$$

Therefore, the total net work (W_n)of a set of cascaded PUs (wcasc) after extracting an amount of heat from that total work to feed back into the first cascaded power unit is

$$W_n = W_{casc} - qi = N_{PU} \cdot \eta_{th} \cdot q_i - q_i = q_i \cdot (N_{PU} \cdot q_i - 1) \quad (31)$$

3.3.1 Implementation of an ideal case study

The proposed case study is based on equations (28-31) with a VsVs cycle operating with helium as the thermal working fluid (TWF). Its behavior is investigated over a temperature range of 800 to 350 K. The temperature drop between each power unit (PU) is 50 K, and the objective is to demonstrate its self-sufficiency as a function of the number of admissible PUs in cascade with data from [2], [12-13] and Vsp cycle described in section 2.6.5.

The operation mod is such that the heat input from a power converter (electrical power to heat) enters the first power unit (PU1), producing useful mechanical work through adiabatic expansion and contraction via a VsVs thermal cycle. The heat rejected in each power unit is transferred to the next power unit, producing useful mechanical work, and so on along the cascade of power units.

After the last power unit downstream in the cascade, the heat transfer fluid (in light-red color) is cooled and then passes through the upstream cascade of power units, recovering the cooling heat from each one, until it re-enters a power converter (electrical power to heat) or electro thermal heater acquiring the highest temperature to be added again to the first PU (PU1) of the cascade of PUs. On the other hand, the total mechanical work produced is converted to electrical power by means of a generator, from which the necessary amount of electrical energy is extracted to be converted back into heat input for the first power unit, thus closing the energy supply cycle and providing power to both the power converter and the operating facilities.

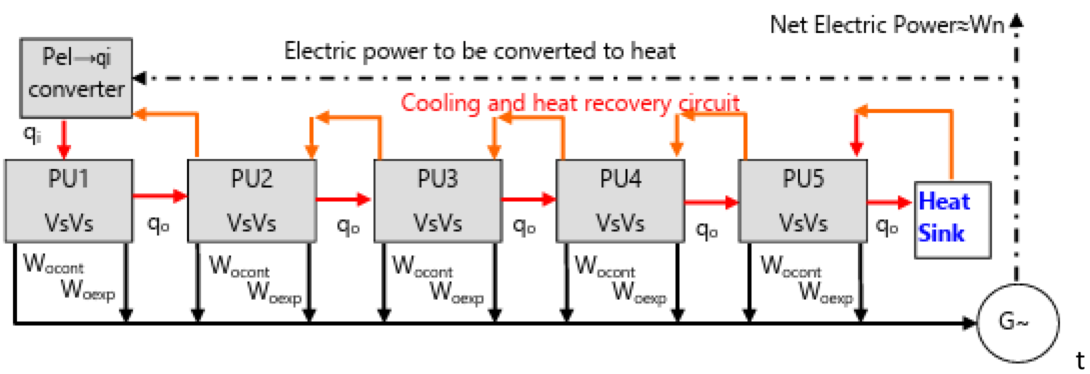

Figure 11. Illustration of a cascade of power units enabled to meet self-sustaining requirements. A fraction of the work extracted from the total cascaded work is used to power the first power unit in the chain.

The data corresponding to each PU is depicted in Table 6. Thermal efficiency 64%; Lowest temperature T_L, 300 K; Temperature drop TD between each PU, 50 K

Table 6: Illustration of the achieved data from processing Eqs. (28-31)

T_H(K)	N_PU	η_{th} (%)	q_{i_pu1}(kJ/kg)	W_{pu}(kJ/kg)	W_{casc} (kJ/kg)	Wn (kJ/kg)
800	9	64(%)	156	99.84	898.56	742.56
700	7	64(%)	156	99.84	698.88	542.88
600	5	64(%)	156	99.84	499.2	343.20
500	3	64(%)	156	99.84	299.52	143.52
450	2	64(%)	156	99.84	199.68	43.68
400	1	64(%)	156	99.84	99.84	-56.16

The data shown in Table 6 generate the curves represented in Figs 12 and 13, respectively. Fig. 12 shows the total cascade work (w_{casc}) and the net free work obtained (Wn) after extracting the feedback heat to power the first power unit (PU1). In the two right-hand columns of Table 6, it can be observed that the minimum number of PUs in the cascade to obtain useful output work is 2; likewise, the useful output work is proportional to the maximum temperature of the cascade. From this observation, it follows that by increasing the maximum temperature, a greater number of PUs is achieved, as well as greater useful output work. Therefore, to approach the optimum value, the limit of PUs would be subject to a compromise between the maximum technically feasible temperature and the installation and maintenance costs of the PU cascade.

Observing Fig. 12, as well as the last two columns on the right in Table 6, it is shown that the energy obtained in the form of useful mechanical work from the cascade of PUs and, finally, from the result of extracting the heat needed to power the first PU in the cascade (w_{casc} and Wn) is obtained from nothing in terms of energy balance. Although each PU operating with a VsVs cycle strictly obeys the SLT, the overall results **do not**. This highly controversial and counterintuitive concept effectively violates the SLT, affecting the first law and the definition of exergy.

Fig. 13 shows the number of cascaded PUs as a function of the chosen maximum temperature (T_H) of the cascade.

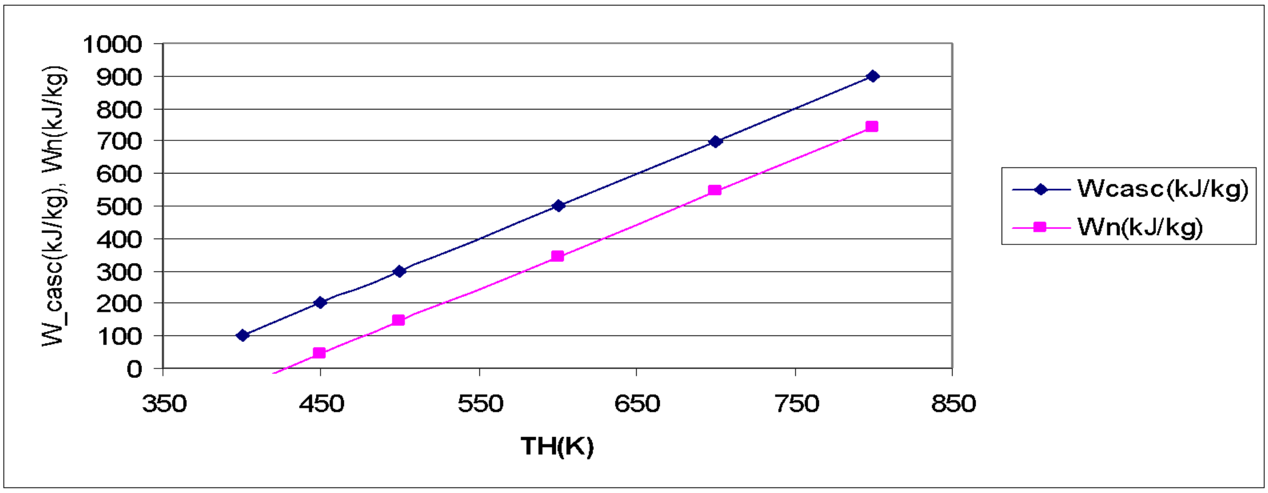

Figure 12. Illustration of the total cascade work (w_{casc}) and the net free work obtained (Wn) after extracting the feedback heat to power the first power unit (PU1) of the cascade.

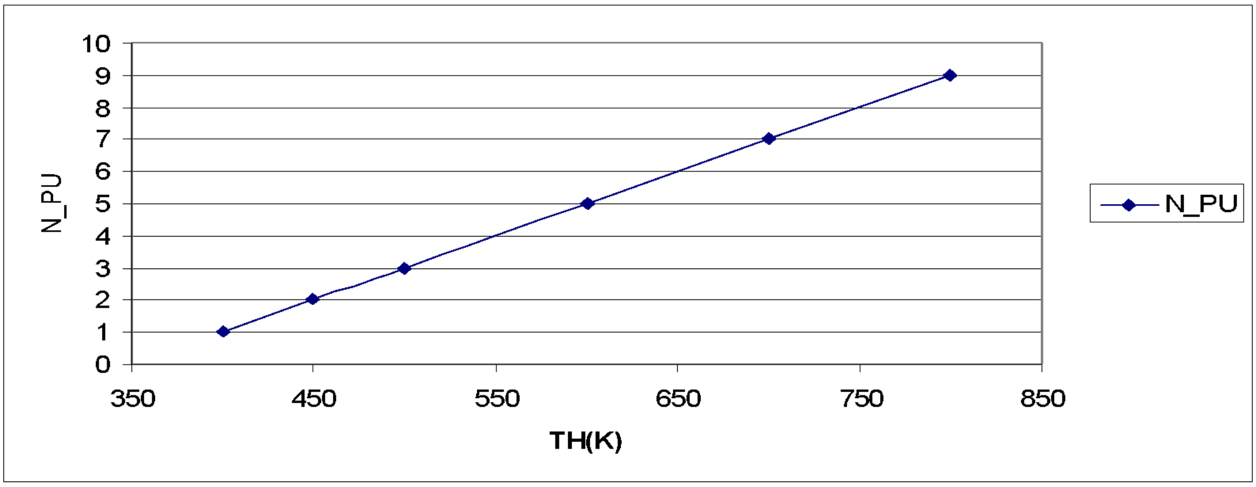

Figure 13. Illustration of the number of cascaded PUs as a function of the chosen maximum temperature ($T_{H)}$.

Note that each Power Unit exhibits efficiency far from 100%, in fact, 64%, although it exceeds the Carnot factor and individually obeys the second law of thermodynamics. However, the overall result violates the second law because it provides significantly more useful energy than it needs to operate.

To conclude, it is clearly observed in the curves that the self-sufficiency potential increases with the temperature range for a constant temperature drop, and that the number of power units required to cover that range increases proportionally. Therefore, the increased temperature range requires a proportional number of power units, which also implies a corresponding increase in design, implementation, and maintenance costs. From this reasoning, it follows that there is an optimal number of power units, which in turn requires an optimal temperature range.

3.3.2. A summary of the key concepts

The text outlines a design for achieving energy self-sufficiency in thermal engines through a novel approach that challenges traditional thermodynamics. The core concept involves a cascade of Power Units (PUs) that generate useful mechanical work not just from heat expansion, but also from **vacuum-induced contraction work**, which is created by cooling the thermal working fluid (TWF).

Crucially, the heat extracted during this cooling process is not wasted; it is systematically **recovered and regenerated** to be fed back into the system, theoretically boosting overall efficiency far beyond conventional limits.

The necessary conditions for this design are divided into two categories:

1 **Thermodynamic Strategies:** Generating contraction forces and work via vacuum-induced cooling, recovering the extracted heat, and regenerating it to power the first unit in the cascade.

2 **Physical-Structural Resources:** Using specialized power units (like double-acting reciprocating or rotary actuators), a TWF with high heat capacity (e.g., helium), and strict control of temperature, pressure, and flow.

A case study is presented where a cascade of PUs operates between 800 K and 350 K, with each unit having a 64% thermal efficiency. The data shows that the total work output from the cascade (Wcasc) and the net work after feeding energy back into the system (Wn) increases with the number of PUs and the temperature range.

However, the text makes a critical admission: while each individual unit obeys the second law of thermodynamics (with efficiency less than 100%), the overall cascaded system appears to produce **more useful energy than it consumes**—a result the author describes as "absolutely controversial and counterintuitive" and one that "effectively violates the second law of thermodynamics." The analysis concludes that while self-sufficiency potential increases with temperature, there is an optimal number of PUs and temperature range, as more units entail higher design and maintenance costs.

3.4. On the irrefutable existence of natural self-sufficiency: A critical analysis

In a quantum field habitat sustained by its quantum vacuum, could the zero-point energy (ZPE) of a hydrogen atom be interpreted as a natural form of energy self-sufficiency to sustain the dynamic activity of the quarks and its electron? Based on a large number of references cited in [27], it appears that this is the case in quantum field theory, or at least no strategy is known to refute it. The ZPE and quantum vacuum fluctuations can be interpreted as a natural, foundational form of energy self-sufficiency. It provides the perpetual, fluctuating background that sustains the dynamic activity of a hydrogen atom's constituents [27]. The zero-point energy and the stability of the hydrogen atom's constituents interact through several specific physical phenomena:

a) Continuous Ground-State Exchange: In stochastic electrodynamics (a branch of quantum physics), the ground state of a hydrogen atom is maintained by a continuous, dynamic balance. The electron continually radiates energy due to its acceleration, but it simultaneously absorbs an equal amount of energy from the surrounding zero-point background field. This prevents the electron from spiraling into the nucleus, making the atom's stability a sustained, self-sufficient interaction with the vacuum.

b) The Lamb Shift: Direct evidence of this interaction is the Lamb Shift, where the energy levels of a hydrogen atom are slightly altered due to the orbiting electron's interaction with zero-point vacuum fluctuations. Vacuum energy effectively "kicks" the electron, causing tiny shifts in its dynamic state, often incorrectly called its orbital state.

c) Quark and Gluon Dynamics (QCD Vacuum): The internal activity of the proton (the hydrogen nucleus) is governed by Quantum Chromodynamics. The majority of a proton's mass does not come from the rest mass of its constituent quarks, but from the immense kinetic and potential energy of the quarks and gluons interacting within the quantum chromodynamics (QCD) vacuum. This chaotic, self-generating energy is inherently tied to the quantum field habitat rather than requiring an external power source.

Because the system is at its lowest possible energy state (the ground state), this energy cannot be extracted or "tapped" to do external work without destroying the atom itself. However, intrinsically, the atom acts as a localized oscillator perfectly attuned to the vacuum field, sustaining its internal quark and electron dynamics indefinitely [27]. Given this evidence, if each electron is independently able to resist and overcome the resistances opposed by its neighboring atoms in a ZPE environment, then it exhibits the capacity to do the useful work necessary to avoid its collapse. That is energy self-sufficiency.

To interpret the electronic activity of a hydrogen atom's ground state as "natural energy self-sufficiency," we must analyze what the quantum vacuum actually sustains and what it doesn't. Let us consider here the analysis from the perspective of conventional physics:

3.4.1 The vacuum is not a fuel depot (The zero-point misconception)

The electron in a hydrogen atom does not "extract" energy from the quantum vacuum to maintain its orbit. If it did, it would violate the First Law of Thermodynamics (in fact, in this article, using thermal contraction to perform useful work through conventional vacuum-induced cooling by extracting heat from the working fluid violates the first law). **These are necessary conditions for achieving energy self-sufficiency**. Instead, the quantum vacuum provides the boundary condition for existence. The electron's ground state is not a dynamic orbit requiring constant replenishment; it is a stationary probability cloud (an eigenstate). It possesses no kinetic energy in the classical sense, but only a well-defined, time-independent energy eigenvalue (−13.6 eV).

3.4. 2 The Casimir-Polder Perspective (What the Vacuum Really Does)

In quantum electrodynamics (QED), the vacuum modifies atomic energy levels through virtual photon exchanges (Lamb shift) and zero-point fluctuations (which cause spontaneous emission). However, for a hydrogen atom in its ground state, spontaneous emission is forbidden, since there is no lower energy state to transition to. Vacuum fluctuations continuously perturb the electron, but the atom's wave function repolarizes instantaneously (within the Heisenberg uncertainty principle) to cancel these perturbations. It appear that the atom is not "burning" vacuum energy; it is shielding it.

3.4.3. Self-sufficiency as "topological stability"

If we interpret "self-sufficiency" from the perspective of complexity theory, rather than conventional thermodynamics, the atom more than fulfills this requirement. The atom is self-sufficient because:

a) It is observed on a daily basis,

b) It does not require an external input of work or electromagnetic excitations to maintain its charge distribution,

c) It is immune to radioactive collapse (unlike classical physics, which predicted that the electron would spiral into the nucleus in 10^{-11} seconds),

d) Its stability is guaranteed by quantized angular momentum obeying the Pauli Exclusion Principle, which are emergent properties of vacuum symmetry.

In this sense, the atom is an autopoietic system: it maintains its structural identity against entropic decay by being locked in a ground state with zero entropy production. This behavior is counterintuitive and incoherent with conventional physics theory

3.4.4. The drawback: It is not "free energy."

The drawback: For the atom to be "energetically self-sufficient" in a practical and extractable sense, it would have to perform work. It doesn't. If we try to extract its zero-point energy to power a micro machine, then we will break quantum coherence; the atom ionizes or emits photons through stimulated emission. We cannot extract its energy from the ground state without simultaneously destroying the condition that makes it self-sufficient.

3.4.5. The Cosmological Analogy

This interpretation perfectly aligns with Erwin Schrödinger's view in What Is Life?, where he argued that life feeds on "negative entropy." An atom in its ground state is an even purer case: it doesn't even need to feed on negative entropy; it exists as a time-independent solution to the Schrödinger equation. The vacuum provides the mathematical space for its existence, but the atom's energy is an intrinsic and conserved property of its charge-mass configuration, not a loan from the vacuum that must be repaid.

The final summary: It is a natural form of structural self-sufficiency, but not energetic self-sufficiency. It is self-sufficient like a Möbius strip: it requires no external maintenance to preserve its topology, but neither can it export that topology as work. The hydrogen atom is proof that stability does not require energy, and in that profound sense, it is the most elegant example of sustainable equilibrium in nature. However, this article demonstrates the violation of the first principle in special cases (those in which useful work is done by means of thermal contraction by cooling) and due to this counterintuitive result, the FLT must be reviewed and updated.

4. Analysis of Results

The results obtained are based on theoretical reasoning, simulated empirical experiments, and empirical studies to support a central and controversial claim: Is it possible to build a heat engine whose thermal efficiency exceeds the Carnot limit and that can achieve energy self-sufficiency? The analysis of these results is structured below:

4.1 Core Finding: Misalignment with the CF

The most significant result is the repeated claim that certain thermal cycles, specifically the **Vsp** (single-acting) and **VsVs** (double-acting) cycles operating with *closed processes without phase change*, can exceed the Carnot efficiency [1], [16-20].

4.1.1 Claim: The Carnot theorem, while irrefutable for Carnot, Ericsson, and Stirling cycles, is **not applicable** to some conventional cycles, including these new cycles (Vsp, VsVs).

4.1.2 Evidence Presented:

4.1.2.1 For the Vsp cycle (expansion only): Using the data from Table 4 and results in Table 5, it is calculated thermal efficiencies (η_{th}) for Helium and Nitrogen that are consistently higher than the CF for the same temperature range.

--*Example (Helium, Test 1):* CF = 7.69%, η_th = 40.91%.

--*Example (Nitrogen, Test 4):* CF = 25%, η_th = 31.53%.

4.1.2.2 For the VsVs cycle (expansion + contraction): The efficiency is even higher because it adds work from contraction (w_{o41}) to work from expansion (w_{o23}). The calculated η_{th} for the VsVs cycle in section 2.9 (e.g., 40.38%) is an order of magnitude greater than the CF for that small temperature difference (e.g., 4.24%).

4.1.3 Significance: This is the foundational result. If true, it overturns a cornerstone of classical thermodynamics established for nearly 200 years.

4.2. Mechanism for Exceeding Carnot Limit: The Role of "Contraction Work"

The article identified the specific mechanism that enables this performance improvement**: the production of useful work through thermal contraction**.

4.2.1 Result Demonstrated: A vacuum created by *cooling* the working fluid (heat extraction) generates a pulling (traction) force. This force can perform useful mechanical work (e.g., contracting a bellows or pulling a piston).

4.2.2 Counterintuitive Claim: This contraction work is performed without an **energetic** cost. The cooling process (heat extraction) is assumed and described as "cost-free" and the subsequent contraction is an "adiabatic-isentropic" process that **increases the fluid's internal energy *while* producing work**.

4.2.3 Analysis of the Contraction Process (Fig.3d-f and Table 2):

--Process 3-4 (Isochoric Cooling): Heat is extracted (q_{o34}). No work is done (piston blocked). Pressure and temperature drop, creating a vacuum.

--Process 4-1 (Adiabatic Contraction): Piston is unlocked. The vacuum causes the piston to move, producing output work (w_{o41}). Crucially, the model shows that during this contraction, **temperature, pressure, *and internal energy* (Δu_{41}) all increase.**

2.4 Resulting Efficiency Gain: For the VsVs cycle, the total work output is $w_o = w_{o23}$ (expansion) + w_{o41} (contraction). A conventional cycle only has w_{o23}. Therefore, the thermal efficiency $\eta_{th} = (w_{o23} + wo_{41}) / q_{i12})$ is always greater than the conventional $\eta_{th} = w_{o23} / q_{i12}$.

4.3. Summary of Experimental and Simulated Data Results

In the article it is provided numerical results from a test bench (Tables 1, 2, 4, 5) to support the claims shown in the table 7 shown below.

Table 7: Summary of the key data points from Tables 1, 2, 4, 5

Parameter	Value / Finding (Example)	Interpretation
Vsp Cycle (Helium)	For T2=325K, T1=300K: CF = 7.69% η_{th} = 40.91%	The cycle significantly exceeds the Carnot limit.
Vsp Cycle (Nitrogen)	For T2=400K, T1=300K: CF = 25% η_{th} = 31.53%	Nitrogen also exceeds the limit, but less dramatically than Helium.
VsVs Cycle	T range = 316-330K: CF = 4.24% η_{th} (expansion only) = 20.2% η_{th} (expansion + contraction) = 40.38%	Adding contraction work nearly doubles efficiency and massively exceeds Carnot.
Work Ratio (WR)	WR = w_{o41}/w_{o23} = 12.47/12.60 ≈0.99	Contraction work is almost equal to expansion work for the VsVs cycle
FLT Alignment	For Suction & Contraction processes, internal energy decreases while work is *added* (suction) or increases while work is *output* (contraction).	In the text, it has been assumed that these processes are "misaligned with conventional FLT," implying that the law needs to be revised and expanded to address these counterintuitive types of HWI.
SLT Compliance	In the text, I have assumed that all individual processes and cycles satisfy the Kelvin-Planck and Clausius statements.	This is used to argue that exceeding Carnot does not violate the Second Law, as the Carnot limit is not a universal law.

4.4 Key Comparative Results in the Selection of TWFs

The following comparison highlights that the heat capacity of a TWF is important because of its influence on the thermal efficiency in when dealing with heat-work conversion processes.

4.4.1 Helium vs. Nitrogen (Vsp Cycle, Fig.9): Helium (γ=1.67) achieves a higher thermal efficiency than Nitrogen (γ=1.4) at all temperature levels. Based on previous work [17] it is concluded that there is a "nonlinear relationship" between the adiabatic index (specific heat ratio) and the ability to exceed the CF.

4.4.2 Expansion-Only vs. Expansion + Contraction (Eq. 14-15**):** The analysis mathematically proves that $\eta_{th-VsVs} > \eta_{th-Vsp}$ because w_{o41} is a positive term. In the article text I have highlighted this as one of the key necessary conditions to self-sufficiency.

4.5. Implications for "Energy Self-Sufficiency"

The results are interpreted as providing the necessary conditions for a self-sufficient engine, conditions that conventional engines do not meet:

4.5.1 Necessary condition identified (not sufficient): The ability to generate useful work from contraction (pulling forces) via cooling.

4.5.2 Resource identified: Structural equipment for heat recovering and regenerating the heat extracted during the cooling process. Because the cooling heat is "cost-free" to extract, recovering it means the system can re-use energy that would otherwise be rejected. This is the proposed roadmap to self-sufficiency, where the only "external" energy is an initial start-up heat source.

4.6 Analysis of counterintuitive HWIs: suction and contraction

Throughout the study presented in this article, it is observed that the heat-work interactions (HWIs), specifically suction and contraction, are characterized by the presence of pulling forces and associated work due to the action of the thermal working fluid (TWF) when it is isochorically cooled or heated.

Furthermore, each HWI exhibits counterintuitive behaviors that should be highlighted due to their impact on the first law of thermodynamics:

Observed results about suction:

Work input adiabatically by pulling force while temperature with internal energy **decreases**. Intuitively, if work is added to a closed process, its temperature should **increase**. However, empirical analysis shows the opposite.

Observed results about contraction:

Work output adiabatically by pulling force while temperature with internal energy **increases**. Intuitively, if work output is obtained from a closed process, its temperature should **decrease**. However, rigorous empirical analysis shows the opposite.

In view of the empirical observations described, it seems reasonable to perform an analysis of the energy balance based on standard thermodynamics to rigorously justify such controversy.

4.6.1 Energy balance of adiabatic closed processes without state changes under standard thermodynamics

The following notation is applied to the energy balances of some processes misaligned with the FLT for closed processes without state changes considering: E_i energy added to a process or thermodynamic transformation: $E_i = q_i + w_i$ and E_o (energy output) from a process: $E_o = q_o + w_o$.

The FLT for closed processes sates that the changes in internal energy of a closed process is the difference between input and output energies. This can be modeled as

$$\Delta u = E_i - E_o \tag{32}$$

with,

$$E_i = q_i + w_i$$
$$E_o = q_o + w_o \tag{33}$$

Resulting in

$$\Delta u = (q_i + w_i) - (q_o + w_o) \tag{34}$$

In adiabatic processes $q_i = q_0 = 0$, which gives rise to

$$\Delta u = (w_i) - (w_o) \tag{35}$$

Where equation (31) indicates that the change in internal energy is equal to the difference between the input and output energy (in this case, adiabatic transformations).

Considering that in the case of an expansion-based HWI $w_i = 0$, under such state conditional restrictions the FLT results are:

$$\Delta u = 0 - (w_o) \text{ or } w_o = -\Delta u \tag{36}$$

In an adiabatic process, the loss of internal energy causes the generation of useful work. This indicates us that the useful work output is due to a negative change in internal energy. This equation derived from standard thermodynamics represents the first law of the thermodynamics (FLT) for closed adiabatic processes.

4.6.2 Comparison between the expansion, suction, and contraction behaviors of HWI

In what follows, the energy balance behavior of the adiabatic expansion process is compared with the adiabatic suction and contraction processes by means of the application of the FLT.

1 **Adiabatic expansion-based processes only:** For adiabatic expansion-based processes Eq. (36) yields

$$w_o = -\Delta u \tag{37}$$

This indicates us that the useful work output is due to a negative change in internal energy. These results are intuitive and perfectly aligned with FLT.

2 **Adiabatic suction processes:** For closed suction processes under pull forces the FLT results are

$$\Delta u = (w_i) - (0) \rightarrow w_i = \Delta u \tag{38}$$

This is interpreted as: the fact of adding energy in the form of work to the system contributes to increase the internal energy according to FLT.

However, the reality is that in suction processes, the fact of adding work to induce suction contributes to decreases the internal energy. The counterintuitive results are misaligned with FLT.

3 **Adiabatic contraction processes**: For closed contraction processes under pull forces the FLT results are

$$\Delta u = (0) - w_o \rightarrow -w_o = \Delta u \rightarrow w_o = -\Delta u \tag{39}$$

This is interpreted as: the fact of extracting useful work from the system contributes to decrease internal energy according to FLT.

However, the real observation indicates us that obtaining useful work by contraction increases the internal energy. Therefore, the counterintuitive results are misaligned with FLT.

4 **Impact on Exergy:** The fact that more useful work is obtained when operating by both adding and removing heat than when only heat is added results in a significant change in the net work output, which impacts the exergy or useful energy available due to both the addition and removal of heat. In other words, the concept of useful energy or exergy must be re-evaluated in cases where work is obtained by contraction due to heat removal, which is not accounted as energy entry.

4.6.3 Consequences of the heat-work interactions (HWI) based on suction and contraction on the FLT

The FLT states that:

Statement 1: if energy (heat and/or work) is added to a closed process, the internal energy increases by the same amount.

Statement 2: if energy (heat and/or work) is removed from a closed process, the internal energy decreases by the same amount.

In essence, this is the principle of conservation of energy. According to everyday experimental observations, this applies when the heat-work interaction consists of a closed adiabatic process of expansion or compression. However, it does not apply to closed adiabatic processes of **suction** or **contraction**, and therefore the first law must be revised to account for such counterintuitive cases. It is worthwhile to take the following controversial events seriously and to experimentally validate the facts using prototypes developed for commercial use, given that the patents cited in the article's references are free worldwide. Furthermore, the violation of the Carnot factor in special cases and the Kelvin-Planck and Clausius exceptions should be considered relevant enough to warrant reconsidering the revision, readjustment, or alignment of the fundamental laws of thermodynamics with observed facts.

Most relevant controversial facts:

In the case of **suction:** If energy (work) is added to a closed process, the internal energy **decreases** by the same amount, *instead of increase as stated by the FLT*

in the case of vacuum induced **contraction:** if energy (heat) is removed from a closed adiabatic process, the internal energy **increases** by the same amount, *instead of decrease as stated by the FLT.*

The conclusion derived from previous discussion and statements is that standard thermodynamics needs a revision to include the counterintuitive behavior observed with **suction** and **contraction** processes.

4.7 Core Argument for SLT Compliance

The central argument is that while the proposed cycles exhibit thermal efficiencies that exceed the Carnot Factor (CF), this does not constitute a violation of the Second Law of Thermodynamics.

Critical analysis based on the results of the entropy behavior of the closed-processes-based cycles provided in the article. A summary of the entropic analysis used to demonstrate that the second law of thermodynamics (SLT) is not violated by the proposed VsVs and Vsp cycles is shown bellow.

The reasoning is as follows:

The Carnot Limit is Not Universal: The author asserts that the Carnot limit (and its associated theorem) is **only** applicable to cycles operating between two isothermal reservoirs, such as the ideal Carnot, Ericsson, and Stirling cycles. The Vsp and VsVs cycles, which operate via closed processes without phase change (isochoric heating/cooling and adiabatic expansion/contraction), are not subject to this specific limit.

SLT Compliance is Achieved at the Process and Cycle Level: The analysis claims that every individual process and the cycle as a whole satisfy the fundamental statements of the Second Law:

Kelvin-Planck Statement: The system does not convert 100% of the available heat into work. Work output is accompanied by heat rejection and associated entropy increases elsewhere in the cycle and system.

Clausius Statement: The system does not transfer heat spontaneously from a colder body to a hotter body. The article notes that exceptions exist in ideal isothermal processes, which are not the primary focus of the self-sufficiency mechanism.

4.7.1 Entropic Analysis of the VsVs and Vsp Cycles

4.7.2 Core Argument for SLT Compliance

The central argument is that, although the proposed cycles exhibit thermal efficiencies exceeding the Carnot Factor (CF), this does not constitute a violation of the Second Law of Thermodynamics. To reinforce this point, let's examine the critical analysis based on the entropic behavior results of the closed-process cycles presented in the article: VsVs and Vsp. A summary of the entropic analysis used to demonstrate that the Second Law of Thermodynamics (SLT) is not violated in the proposed VsVs and Vsp cycles is shown below.

The Carnot Limit is Not Universal: According to the results about Carnot cycle studies I can assert that the Carnot limit (and its associated theorem) is **only** applicable to cycles operating between two isothermal reservoirs, such as the ideal Carnot, Ericsson, and Stirling cycles. The Vsp and VsVs cycles, which operate via closed processes without phase change (isochoric heating/cooling and adiabatic expansion/contraction), are not subject to this specific limit.

SLT Compliance is Achieved at the Process and Cycle Level: The analysis claims that every individual process and the cycle as a whole satisfy the fundamental statements of the Second Law:

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Clausius Statement: The system does not transfer heat spontaneously from a colder body to a hotter body. In the article can be noted that exceptions exist in ideal isothermal processes, which are not the primary focus of the self-sufficiency mechanism.

4.7.3 Entropic Analysis of the VsVs and Vsp Cycles

The entropic analysis focuses on demonstrating that entropy generation is properly accounted for and that the system does not create a thermodynamic impossibility.

a. Entropy Balance of the Vsp Cycle

Process 1-2 (Isochoric Heat Addition): Entropy increases as heat is added to the working fluid.

Process 2-3 (Adiabatic Expansion): Entropy remains constant (isentropic process), as shown in Table 4 of the article, where $s_2 = s_3$. The work output comes from a decrease in internal energy, which is aligned with the First Law.

Process 3-1 (Quasi-Isobaric Cooling): Entropy decreases as heat is rejected to the surroundings.

Overall Cycle: While the cycle exceeds the Carnot efficiency, the net entropy change over the complete cycle is zero. The entropy rejected to the cold reservoir accounts for the entropy that was generated and added during the heat input phase, satisfying the Second Law.

b. Entropy Balance of the VsVs Cycle

Process 1-2 (Isochoric Heating): Entropy increases in chamber A as heat is added ($s_2 > s_1$).

Process 2-3 (Adiabatic Expansion): Entropy remains constant (isentropic) in chamber A as it performs work ($s_2 = s_3$).

Process 3-4 (Isochoric Cooling): Entropy decreases in chamber B as heat is extracted ($s_3 > s_4$).

Process 4-1 (Adiabatic Contraction): Entropy remains constant (isentropic) in chamber B as it performs work ($s_4 = s_1$).

Simultaneous Operation: In the article it has been emphasized that the two chambers (A and B) operate simultaneously and are half a cycle out of phase. This is a key point: while the system as a whole performs extra work from contraction, the cooling and heat rejection phases are compensated by the heating and heat addition phases. The overall entropy generation of the complete, multi-chamber system is balanced by the heat rejection to the environment.

4.7.4 Conclusion on Entropic Analysis and SLT Compliance

Therefore, it can be concluded that the Second Law of Thermodynamics is **not violated** for the following reasons:

a No Net Entropy Decrease: There is no instance of the total entropy of the system and its surroundings decreasing. Entropy generation from heat transfer and irreversibilities in real processes is assumed to be present. In the ideal, reversible analysis provided, the entropy changes in the working fluid are balanced, and heat is ultimately rejected to a cold reservoir.

b Carnot Limit is a Cycle-Specific Constraint**:** By arguing that the Carnot limit is not a universal law for all thermal cycles, the primary point of conflict is removed. The Vsp and VsVs cycles are presented as a new class of cycles that operate under different principles, thereby "exceeding" a limit that was never intended to apply to them.

c Self-Sufficiency vs. Perpetual Motion: The article distinguishes between a self-sufficient machine and a perpetual motion machine. The proposed system still rejects heat to the environment, generates entropy, and requires a temperature gradient to operate. Its "self-sufficiency" comes from internal heat recovery and the exploitation of the previously overlooked "contraction work," not from the creation of energy or a violation of entropy increase. The article explicitly states that all work-producing stages are accompanied by corresponding entropy generation and compensating heat flows.

4.7.5 Summarizing the results of the case study on self-sufficiency (section 3.3)

From the study on meeting the conditions for achieving energy self-sufficiency, the following key concepts stand out:

1. Section 3.3.1 has shown that meeting the necessary conditions for achieving energy self-sufficiency involves violating fundamental laws of conventional thermodynamics.

2. While each processing unit (PU) operating with a VsVs cycle strictly obeys the Law of Thermodynamics (LT), the overall results do not. This highly controversial and counterintuitive concept effectively violates the SLT, affecting the first law and the definition of exergy.

3. Therefore, to approximate the optimal value, the PU limit would be subject to a compromise between the maximum technically feasible temperature and the installation and maintenance costs of the PU cascade.

5 Conclusions

The results presented challenge a fundamental pillar of classical thermodynamics: the universality and inviolability of the Carnot efficiency limit. Through theoretical reasoning, simulated data, and empirical results from Vsp and VsVs cycles, this study claims to have demonstrated thermal efficiencies that consistently exceed the CF for the same temperature range (e.g., 40.91% vs. 7.69% for helium).

The proposed mechanism for this transgression is the extraction of useful work from thermal contraction—a process described as "cost-free" cooling that generates a pulling force, producing additional work (wo41) without an energetic penalty. When contraction work is added to expansion work, the total thermal efficiency (η_{th}-VsVs) substantially exceeds both conventional cycles and the Carnot limit.

Crucially, the analysis reveals that key heat-work interactions—specifically suction and contraction—exhibit behavior misaligned with the First Law of Thermodynamics (FLT): work input during suction decreases internal energy, and work output during contraction increases internal energy. These contradictions lead to the central claim that the FLT, in its current form, does not apply to closed adiabatic processes of suction or contraction.

Therefore, if the empirical and simulated results are validated, the study concludes that standard thermodynamics requires a fundamental revision to accommodate these counterintuitive behaviors. Furthermore, the identification of contraction work and the ability to recover "cost-free" cooling heat provide the necessary conditions—though not yet sufficient—for achieving energy self-sufficiency, a feat impossible for conventional heat engines operating under classical Carnot constraints.

Disclaimer: This paper contains a very high number of self-citations (over 95%) because the author's ideas are completely new and unique. No other researchers have published work on topics like producing work from contraction at no energy cost, cascading power units, or recovering cooling heat to achieve self-sufficiency. Since there is no prior literature on these subjects, I had no choice but to cite his own previous work. The lack of citations from well-known authors does not affect the scientific value of this research, either positively or negatively.

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