DOI: https://doi.org/10.24297/jap.v23i.9792

Proposal for Prototyping Disruptive Self-Sufficient Power Engines: Harnessing "Pull" Forces

Ramon Ferreiro Garcia

Former, Prof. Emeritus at the University of A Coruña, Spain, https://www.udc.es

ramon.ferreiro@udc.es

Abstract

It is widely accepted that energy cannot be created from nothing, but must be transformed in accordance with the laws of conservation. Nonetheless, experimental evidence suggests that useful mechanical work can be generated not only by adding heat but also by extracting it. This process creates a vacuum that produces traction forces, which in turn can yield mechanical work—potentially paving the way for self-sufficient power engines. This article explores plausible technological pathways based on traction or pulling forces, which have been largely overlooked in conventional thermodynamic systems. These forces can be induced by cooling a thermal working fluid, generating vacuum without direct energy input. Achieving a truly self-sufficient heat engine would require rethinking or even challenging foundational principles of thermodynamics, including the conservation of energy, the first law of thermodynamics, Carnot's theorem, and the concept of exergy. In fact this proposal undergoes a feasible disruptive path toward Self-Sufficient Power Engines (SSPE). The best result among four cases studied consists of a self-sustaining power plant (SSPE) composed of a cascade of nine Power Units (PUs) that provide a self-sufficiency index of 250 with respect to a reference of 100 and a net electrical power of 597 (kJ/kg) per cycle.

Keywords: Cascaded power units, Cascaded heat recovery, Contraction-based work, Pulling forces, Self-sustaining power, Thermodynamic disruption and Vacuum traction,.

Nomenclature related to general VsVs cycles and SSPEs

Acronyms	**Description/Context**
Comp, comp.	Subscript of compression process: A form of compression (volume reduction) achieved by adding useful work to the system by means of a **push** force, resulting in increased pressure and internal energy.
Cont, cont.	Subscript of contraction process: A form of compression (volume reduction) previously achieved by cooling a TWF, which generates a **pull** force giving rise to output useful work.
CTF	Cooling Transfer Fluid (conventionally, thermal oil)
DARA	Double-acting reciprocating actuator
E_i	Energy input (heat and/or work)
EM	Electromagnetic
E_o	Energy output (heat and/or work)
EP	Electric Power
Exp, 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.
FCF	Forced convection fan (recirculation fan of the TWF)
FLT,	First law of thermodynamics
FP	Feed pump (feed compressor of the TWF)
Gen	Electric Power Generator: alternator or generator

H, L	Subscript of High, Low: I.e. T_L with L subscrit of T_{low}, T_H, with H subscript of T_{high}
HTF	Heating Transfer Fluid (conventionally, thermal oil)
Is_eff	Isentropic efficiency: (open processes). losses factor inherent to real gas exp/comp.
LF	Losses factor (include thermo-mechanical and thermo-hydraulic losses)
MUF	Mechanical utilization factor (%)
NEP	Net electric power (free electric power, self-sufficient electric power)
PP	Power Plant: a group of PUs coupled in cascade
PU	Power Unit driven by the thermal cycle sVsVs or VsVs cycle
qi_elect_PU1	Electric power as heat added to the first cascaded PU. qi_elect_PU1 = (u_2-u_1) of PU1
RF	Heat recovery factor (heat transfer losses including heat leaks)
RIT	Ratio of Isochoric low to high T: [T_L/T_H], [T_1/T_3] for sVsVs, and [T_1/T_2] for VsVs,
SEP	Self-Electric Power: SEP ≈ SSI (net mechanical power ≈ net electrical power)
SLT,	Second law of thermodynamics
sp	State point of any stationary point state of a thermal cycle
SSHS	Self-Sustaining Heat Supply
SSI	Self-Sustaining Index: means the net free energy as % : [$SSI = (\eta_{th} - 100)/100$]
SSPE	Self-sustaining power engines
SSPM	Self-Sustaining Power Machine, Self-Sufficient Power Machine
SSPM	Self-sustaining power machines
SSPP	Self-Sustaining Power Plant, Self-Sufficient Power Plant
Suct, 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.
T_{drop}	drop or jump in temperatures between each two power units [$T_{drop} = \cdot T_2(1 - RIT)$]
TNW	Total output net work: sum of the net mechanical work (w_n) produced by the PU cascade
TUF	Thermal utilization factor (%)
TWF	Thermal Working subjected to heat-work interactions carried out by actuators.
VsVs	Thermal cycle composed of the closed processes: isochoric V, adiabatic s.
Symbols/units	***description***
p(bar)	pressure
q_i(kJ/kg)	specific heat in to a cycle isochoric process
q_{i23} (kJ/kg)	Input heat to cycle isochoric process 2-3
q_o(kJ/kg)	specific heat out from a cycle isochoric process
q_{o41} (kJ/kg)	output heat from cycle isochoric process 4-1 in a VsVs cycle
q_{rec}	Recovered heat from cycle process 4-1 in a VsVs cycle
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
h(kJ/kg)	specific enthalpy
T(K)	temperature
T_H(K)	top cycle temperature
T_L(K)	bottoming cycle temperature
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_{iFP}(kJ/kg)	Work added to drive the feed pump responsible to transfer the TWF
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_{o23} due to previously added heat
$w_{ocont41}$ (kJ/kg)	Output contraction work w_{o41} due to previously extracted heat
w_n (kJ/kg)	Net useful work (w_{oexp} + w_{ocont}) = (w_{o23} + w_{o41})
wnT (kJ/kg)	Total net work (RBC work + Cascaded VsVs cycles works)
q_{rec}/PUi(kJ/kg	Heat recovered from every PU from cooling cycles processes
T_{q_rec}/PUi (K)	Temperature of the heat recovered from cooling cycles processes in every PU
η_{th} (%)	Cycle thermal efficiency (w_n/qi)

1 Introduction and Objectives

Empirical observations confirm that conventional heat-work interactions—whether adiabatic, isothermal, isobaric, or polytropic—are governed by thrust (push) and repulsion (pull) forces, and strictly adhere to the laws of thermodynamics. These include the First Law (energy conservation) and the Second Law (accounting for irreversibilities and dissipative forces). These principles, supported by everyday experience, have so far precluded the development of machines with 100% efficiency, let alone those capable of generating energy autonomously.

However, when examining baryonic matter from a broader perspective, intriguing phenomena emerge. For instance, a hydrogen atom maintains electrodynamic activity and resists collapse even near absolute zero, suggesting it operates like a self-sustaining engine. This behavior implies the existence of mechanisms capable of overcoming environmental resistance without any apparent external energy input. Such observations hint at thermodynamic possibilities beyond conventional expansion and compression forces.

Atomic interactions inherently involve both repulsive and attractive forces. This duality opens the door to exploring attraction-based mechanisms—particularly vacuum-induced traction—as a foundation for self-sufficient thermal engines. Accordingly, this work proposes a thermodynamic framework that leverages previously unconsidered traction, pulling or suction forces to enhance efficiency and enable self-sustaining operation.

Key Reflections Based on Common Sense and Observation

-- Atoms exhibit persistent dynamic activity even in a state of zero-point energy, resisting environmental dissipation since the Big Bang.

-- Cosmic dynamics continue indefinitely, suggesting a non-causal origin and an inherent capacity for eternal activity.

-- If energy is inherently dissipative yet remains extant, it must be replenished or regenerated through mechanisms not yet fully understood.

1.1 Background of the evolutionary path

The meaning and consequences of Carnot factor constraints have been discussed In References [1-2]. In essence, it has been shown that the constraints defined by the Carnot factor are aligned with thermal cycles in which a fraction of the expansion and compression processes are isothermal. Therefore, such constraints include the ideal Carnot, Erickson, and Stirling thermal cycles. Consequently, other disruptive cycles capable of performing useful mechanical work through tensile or tension forces obtained by cooling a working fluid by heat extraction [3-5] and [6-14] are not subject to the restrictions imposed by the Carnot factor; such a case is applicable to some scenarios considering self-sustaining power engine prototypes.

Therefore, references [3-5] present the state-of-the-art technologies that enable operation through both thermal expansion and contraction, characterized by thermal cycles composed of closed processes without state changes. Using closed processes avoids losses due to flow work, while avoiding state changes prevents losses from vaporization and condensation heats.

Recent contributions have led to disruptive advances in power plants composed of groups of power units coupled in cascade, operating through thermal cycles characterized by performing work due to the expansion and contraction of the thermal working fluid, as referenced in [6-13]. Expansion is achieved by adding heat, while contraction is achieved by extracting heat. Studies for designing and prototyping such power plants have been conducted using real gases as working fluids, with data obtained from E. W. Lemmon et al [14].

The focus of these advances is on improving the performance of SSPEs by employing disruptive heat regeneration techniques in the PUs, utilizing cascade heat recovery to achieve significantly higher efficiencies compared to conventional technologies. The prototyping tasks for the studied cases are covered by patents referenced in [15-19].

Based on a review of previously published references on SSPEs [15-19], it is easy to see that we are starting from incontrovertible facts, due to the empiricism they entail, and therefore irrefutable. These proven facts refer to the combination of thrust and traction forces that do not entail an energetic cost.

1.2 Background on Self-Sufficient Energy Systems

This study addresses four disruptive technological challenges essential for developing efficient power units (PUs) capable of operating via heat-work interactions driven by vacuum-induced thermal contraction:

a) **Closed-cycle operation**: Heat engine prototypes must support closed thermal cycles driven by isochoric heat transfer and adiabatic works processes.

b) **Heat recovery and reuse**: The systems must efficiently release and recover cooling heat upstream for reuse downstream, enhancing overall energy utilization.

c) **Advanced heat transfer techniques**: Forced convection methods must be optimized to enable rapid heat addition and extraction within each PU. Each PU consists of a pair of Double-Acting Reciprocating Actuators (DARAs) integrated with dedicated heat transfer systems.

d) **Upgrading efficiently upstream recovered heat** released during the vacuum creation process to be added to the first Power Unit downstream so that no external heat is required.

Additionally, the integration of two previously published conversion techniques [5–10] and patented prototypes [11–14] contributes to the development of power plants capable of operating without external heat sources.

The combination of these conversion techniques results in self-sufficiency, which in summary consists of achieving:

a) **Cooling-induced vacuum** that generates cost-free traction forces.

b) **Harnessing pulling forcers due to the consequences of (a)**

c) **Efficient recovery and reuse of upwelling heat**, avoiding the use of external heat..

Therefore, the disruptive innovation of this contribution consists of selecting a constant temperature drop or jump between each of the cascaded PUs that make up the PU cascade. If the temperature jump is sufficiently small, PUs with similar capacities are obtained, which favors both the design and operation of the machine by minimizing costs.

2. On viable thermodynamic actuator technologies

The generic thermomechanical actuator consists of a converter of thermal energy into mechanical energy. It is characterized by constituting the link or nexus between thermal and mechanical energy and vice versa. Depending on the causality-based operating mode, it can respond to changes in force, which entails work with changes in thermal energy, as well as respond to changes in thermal energy with changes in forces that entail mechanical work.

2.1 Relevance and main differences between pushing and pulling forces in HWIs

In nature, two forces can be observed on a daily basis that is unique in their consequences. The effects of the forces of repulsion and attraction are radically different:

Repulsion (thrust forces characterized by their impact on generating a tendency toward separation or relaxation from the focus of action).

Attraction (traction forces characterized by their impact on generating a tendency toward absorption or approaching the focus of action).

In the thermodynamics of heat-work interactions (HWI), these concepts are known as:

Thrust (Push) Forces:

--Nature and Direction: Thrust is a reaction force that acts perpendicular (normal) to a surface, typically pushing against or compressing a system.

--Typical Processes: In thermodynamic systems, thrust forces are responsible for compression (input work) and expansion (output work). Compression decreases volume and increases pressure and temperature; expansion increases volume and decreases pressure and temperature.

--Energy Effect: Input thrust work (compression) increases the internal energy of the system, while output thrust work (expansion) decreases it.

--Conformity to Thermodynamics: These interactions align with the FLT, where energy is conserved and boundary work is well-defined.

Traction (Pull) Forces:

--Nature and Direction: Traction refers to a pulling force, perpendicular (normal) to a surface, typically pulling or expanding a system1 along the axis of movement, such as the inverse of contracting a system.

--Typical Processes: In heat-work interactions, traction forces are responsible for suction (input work) and contraction (output work). Suction increases volume and decreases pressure and temperature; contraction decreases volume and increases pressure and temperature.

--Energy Effect: Input traction work (suction) decreases the internal energy of the system, while output traction work (contraction) increases it.

--Conformity to Thermodynamics: These processes can display effects on internal energy that are opposite to those of thrust forces and may not always conform straightforwardly to the traditional FLT energy balance.

The relevance and main differences between pushing and pulling forces in HWIs are summarized in Table 1. It's worth highlighting the consequences of using traction forces. Thanks to the correct use of these previously unconsidered or simply underestimated forces, the implementation of self-supporting heat engines is possible.

Table 1: Summary of some differences between **push** and **pull** forces

Feature	*Thrust (**Push**) Forces*	*Traction (**Pull**) Forces*
Direction	Along axis motion axis	Along the axis of motion, reversed
Typical Processes	Compression, Expansion	Suction, Contraction
Input Work Effect	Increases internal energy	Decreases internal energy
Output Work Effect	Decreases internal energy	**Increases internal energy**
FLT Alignment	Directly conforms	May require special consideration

In summary, according to the data shown in Table 1, thrust (**push**) forces are associated with pushing (compression/expansion) and its abilities to be aligned with classical thermodynamic work, while traction (**pull**) forces involve pulling (suction/contraction) and can produce **inverse effects** on internal energy, sometimes challenging the standard energy balance framework. This counter-intuitive result contributes to disruptive changes regarding to energy unprecedented management strategies.

2.2 The Single Acting Reciprocating Actuator (SARA)

One of the most widely used actuators, valued for its efficiency and robustness, is the Single Acting Reciprocating Actuator (**SARA**). Fig. 1 illustrates the simplified scheme of a generic SARA, such as self-sustaining heat engines. Let us examine this system from a thermodynamic perspective.

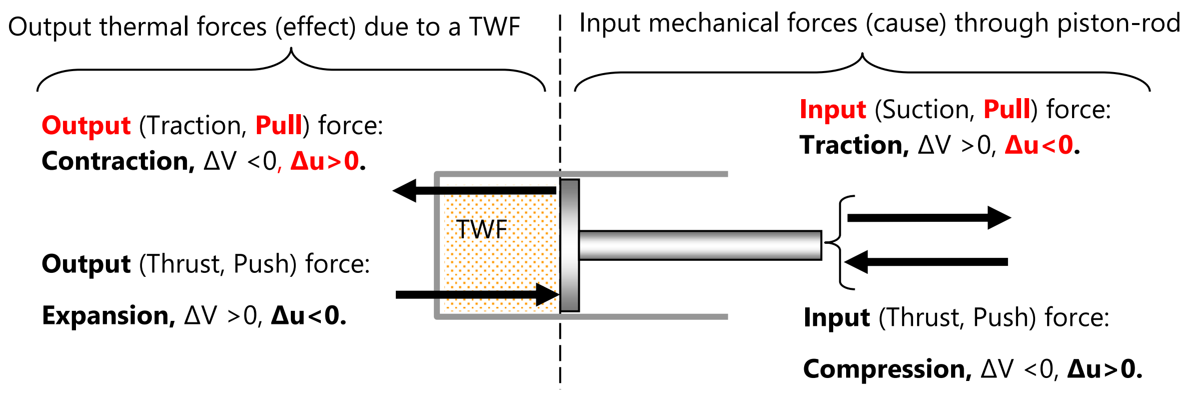

Figure 1: Illustration of the thermo mechanical nomenclature involved in HWIs carried out in a SARAs. Red text indicate parameters of HWIs misaligned with FLT

This thermo-mechanical device is responsible for transforming or converting heat into work and vice versa. Its simplicity makes it highly relevant, as it enables complex thermodynamic transformations that underpin energy conversion systems.

The formulation of balances is governed by the principles of causality, in such a mode that input elements cause sufficient effect on output to maintain equilibrium of forces and momentum conservation.

Experimentally, it has been observed that input actions (causes) are responsible for both variations in output and internal variations (effects). In thermodynamic energy balances of closed systems, the input variables

–energy and input work– are responsible (cause) for the changes in internal energy and output energy (effects) –heat and output work–.

The energy balance in terms of heat-work interactions (**HWIs**) for any closed system, according to the **FLT** can be described as follows:

Generic closed energy system balance:

$$E_i - E_o = \Delta u \quad (1)$$

where:

Input energy is defined as: $E_i = q_i + w_i$ (2)

Output energy is defined as: $E_o = q_o + w_o$ (3)

Adiabatic closed HWIs

For adiabatic transformations, there is no heat transfer in any direction, so:

$$q_i = q_o = 0 \quad (4)$$

Consequently, according to the FLT, as deduced from equations (1-4) the energy balance is simplifies to:

$$E_i - E_o = w_i - w_o = \Delta u \quad (5)$$

which yields

$$w_i - w_o = \Delta u \quad (6)$$

where heat transfer has been excluded from the energy balances.

However, this generic adiabatic energy balance shown in equation (6) is not always feasible (not realizable) as verified through experimental validation through SARA–based cylinders, so it needs to be split into two realizable options, representing two closed adiabatic HWIs, where adiabatic energy balances including thrust or **push** forces are consistent with the FLT and adiabatic energy balances including traction or **pull** forces are not consistent with the FLT.

FLT-based **consistence** for closed adiabatic energy balance:

$$w_i = \Delta u \quad (7)$$

$$w_o = -\Delta u \quad (8)$$

Specifically, in the Eq. (7) and (8) the input and output forces aligned with the FLT are adiabatic **compression** and **expansion**, respectively:

$$w_{icomp} = \Delta u \quad (9)$$

$$w_{o\exp} = -\Delta u \quad (10)$$

FLT-based **inconsistence** for closed adiabatic energy balance:

Specifically, in the Eq. (7) and (8) the input and output forces misaligned with the FLT are adiabatic **suction** and **contraction**, respectively:

$$w_{isuct} = -\Delta u \quad (11)$$

$$w_{ocont} = \Delta u \quad (12)$$

Summarizing, HWIs that give rise to Eq. (9) and (10) are aligned with he FLT and therefore supports energy balances enabled to sustain the energy conservation principles without dissipative forces in closed isolated systems. However, as illustrated with Fig. 1, the suction and contraction forces (pull forces), which are responsible for suction and contraction works, respectively, exhibit **reversed behavior**:

The results obtained by equations (11) and (12) are not aligned with the energy balance that obeys FLT, Eq. (7) and (8). However, such misalignment is a key factor to achieving useful work without adding heat and, consequently, a disruptive path toward self-sufficient energy machines. As a result of these controversies, the following section analyzes these apparent inconsistencies.

2.2.1 On the limitations of HWIs carried out by a SARA

Regarding the limitations of heat-work interactions carried out by a single-acting linear actuator, it should be noted that it can only perform a movement task that necessarily involves exclusively input or output mechanical work. Therefore, in a SARA-based cylinder the solution given by Eq. (6) cannot be executed as an HWI. Input or output works undergoes motion and displacement. However, the piston-rode cannot do both movements simultaneously. This is due to the fact that single-acting actuators can only operate (act) in an optionally exclusive manner with one of the displacement motion options. This is because there are only two alternative modes of operation for the actuator via the piston-rod (forward or backward), up or down, left or right, increasing or decreasing volume, etc. This concept is illustrated with Fig. 1. It ca be observed that cannot perform more than one motion option. It cannot simultaneously perform two tasks simultaneously, that means compress and expand a process simultaneously. If an adiabatic conversion process is carried out under these conditions, it turns out that only two variables are involved (work and internal energy) since there is no heat transfer. As a consequence, the adiabatic energy balance model based on the FLT only allows one input term as input work (w_i can be w_{icomp} or w_{isuct}) and one output term as output work (w_o can be w_{oexp} or w_{ocont}).

Therefore, on the basis of observed facts let's try to link it to the FLT. Input/output thrust forces (e.g., responsible for compression/expansion works) are essential because they represent boundary work ($W=\int P\,dV$) in closed systems. The FLT ($\Delta U=Q+W$) explicitly accounts for such work, ensuring energy conservation. Therefore, "boundary work" refers to the work done when a system's boundary moves, typically by expanding or compressing a gas or fluid. In short, it is assumed as the energy transfer that occurs when a system's boundary displaces, like during the expansion or compression of a gas.

Thermal working fluid (TWF) is characterized by its ability to convert useful mechanical work into thermal energy, as well as convert thermal energy into useful mechanical work. These energy exchanges involve forces capable of performing work, such as the thrust forces of the TWF on a piston (output expansion work) or absorbing mechanical work from a piston to compress the TWF (input compression work). These forces (expansion and compression, both **thrust** or **push** forces) irrefutably demonstrate the ability to influence the internal energy of a closed system, such that input work contributes to an increase in internal energy $\boldsymbol{\Delta u > 0}$, while output work contributes to a decrease in internal energy $\boldsymbol{\Delta u < 0}$. The energy balance obeys the laws of conservation and is therefore the fundamental basis of the first law of thermodynamics.

However, it has been experimentally demonstrated that there are other forces that behave inversely to expansion and compression. Those are the forces **traction** or **pull** responsible of **suction and contraction** useful mechanical works. Suction force and work input (**w_{isuct}**) causes a decrease in internal energy, while contraction force and work out (**w_{ocont}**) increases it. These forces and associated works due to suction and contraction produce the opposite effect on internal energy, that is: **w_{isuct}** decreases internal energy $\boldsymbol{\Delta u < 0}$**,** while **$w_{ocont}$** increment internal energy $\boldsymbol{\Delta u > 0}$**.** As consequence, the energy balance associated with them does not conform to the first principle and, for this reason, requires special consideration.

2.3 On the realizability of HWIs carried out by a SARA

To satisfy the conditions of realizability by means of a heat-work converter or vice versa of the SARA type, a heat-work interaction is required in which only one work type (input work or output work) participates, as shown in Fig. 2. Thus, Fig. 2 illustrates the realizable HWIs that could be executed by a SARA. Therefore, Fig. 2 (a) and (b) depicts a generic energy balance aligned with FLT, where input energy E_i can be composed by input heat q_i, and input works like w_{icomp} and w_{isuct} in the same way, output energy E_o includes output heat, and output works such as w_{oexp} and w_{ocont}. According to the comments previously stated, the SARA-based energy converter is not capable of performing the tasks of simultaneous conversion of input and output heats in addition to the aforementioned mechanical input and output works. Therefore, the block diagrams in Fig. 2 (c), (e), (g) and (i) show the realizable balances for polytropic HWI transformations, while the block diagrams (d), (f), (h) and (J) show the balances for adiabatic HWI transformations, in which there is no heat transfer.

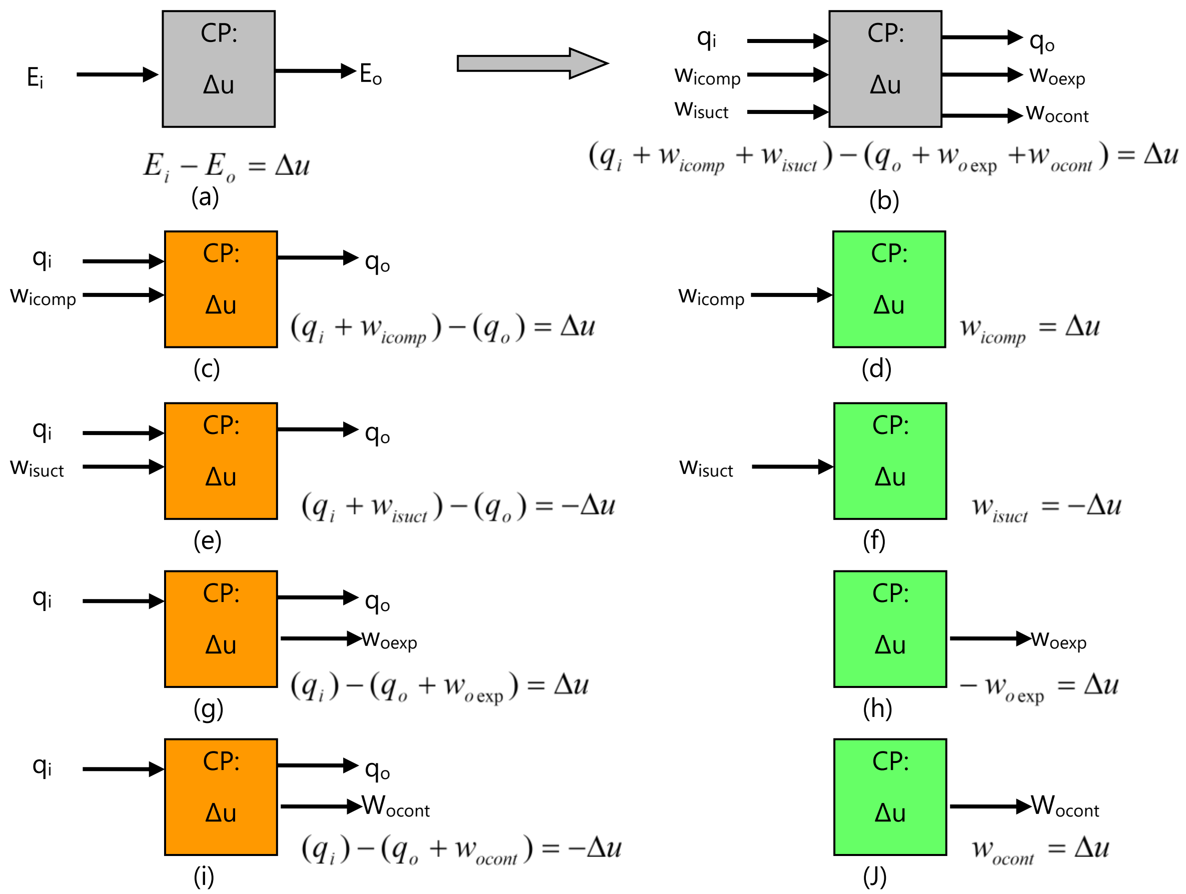

Figure 2: Physically realizable HWIs by a SARA

The adiabatic transformations corresponding to the block diagrams (f) and (J) are not aligned with the FLT in accordance with the balances of equations (11) and (12) respectively. Among the HWIs misaligned with the FLT, the one represented by the block diagram in Fig. 2(J) stands out in a relevant way, based on the conversion of internal energy to useful mechanical work by contraction of the TWF. That is, it stands out for converting internal energy into useful mechanical work without heat input, and is based on a closed adiabatic process by which the increase in internal energy of the TWF entails the contribution of useful mechanical work. This surprising observation represents a flagrant violation of the laws of conservation of energy and, consequently, a violation of the FLT.

However, it represents the principle by which the design and development of prototypes of self-sufficient heat engines is possible, that is, capable of overcoming the irreversibilities inherent in all real systems, which are subject to dissipative variables and also exceed the energy used for their operation.

2.4 Benefits of the contraction-based HWIs

The benefits of thermal contraction-based HWI lie in the fact that it facilitates the generation of useful mechanical work through:

- Cooling the TWF: responsible for a vacuum generation capable of doing useful work by contraction

- Utilization of the TWF's cooling heat: useful recoverable high-grade heat capable of doing useful work.

This means that adding a quantity of heat to a thermal cycle enabled to operate with thermal contraction-based HWIs obtained by cooling the TWF delivers more useful work than the thermal energy required.

This is because the commented strategies generate mechanical work through three means:

- Useful work due to heat addition,

- Useful work due to zero-cost cooling, and

- Useful work due to utilization of the cooling heat at zero cost.

Such an unprecedented disruptive innovation poses a major challenge to the fundamental laws of thermodynamics.

2.5 Validation of adiabatic HWIs involving Push forces and alignment with FLT

The adiabatic HWIs are carried out without any transfer of heat in any direction. Thus only input/output mechanical work can be interchanged with internal energy.

2.5.1 Test 1: Energy transfer in a CP-based adiabatic HWI with Push forces

The push forces associated with works are expansion work, due to the pressure of the TWF exerted on the piston-road, and compression work exerted by the piston-rod on the TWF.

Core Principles:

Energy addition (compression work $W_{in} > 0$) increases internal energy ($\Delta U>0$), temperature increases.

Energy removal (expansion work $W_{out}<0$) decreases internal energy ($\Delta U<0$), temperature decreases.

Test: Work Transfer and Internal Energy in a CP influenced by **push** or thrust forces

Core Principles based on FLT statement: Aligned

Energy addition to a CP based on **push work or compression** increases its internal energy.

Energy removal from a CP based on **releasing heat and push** work or expansion decreases its internal energy.

2.5.2 Experimental Verification

These principles are supported by the following rigorously proven and experimentally validated statements:

Statement 1 – Energy Addition (Isochoric Process):

If a quantity of energy (E_i), composed of heat (q_i) and/or mechanical work via compression (W_i), is applied to a fixed mass of gas (thermal working fluid) in a closed, constant-volume process, the result is:

An increase in internal energy ($\Delta U > 0$).

A corresponding rise in temperature ($\Delta T > 0$) and pressure ($\Delta P > 0$).

Statement 2 – Energy Removal (Adiabatic Expansion):

If the same thermal working fluid (now at high temperature and pressure) undergoes a closed, adiabatic expansion process, the result is:

--A decrease in internal energy (**$\Delta U < 0$**).

--A corresponding drop in temperature ($\Delta T < 0$) and pressure ($\Delta P < 0$).

--The release of useful mechanical expansion work (**W_{oexp}**).

Summarizing, the above statements are irrefutably validated by thermodynamic laws (FLT) and experimental evidence, confirming the direct relationship between energy transfer and internal energy in CPs driven by **push** or thrust forces

2.6 Validation of adiabatic HWIs involving Pull forces and alignment with FLT

This section illustrates how the misalignment of HWIs involving **pull** forces exerted by mechanical forces through the piston-rod (suction forces) with FLT as well as thermal-based **pull** forces exerted by the TWF on the piston-rode (contraction), gives rise to a conflict with the FLT alignment. However such misalignment due to contraction is responsible for creating the necessary conditions to achieve Self-Sustaining thermal engines.

2.6.1 Test 2: Energy transfer in a CP-based adiabatic HWI with Pull forces

The pull forces associated with works are contraction work W_{ocont}, due to the pressure (vacuum) of the TWF exerted on the piston-road, and suction work w_{isuct} exerted by the piston-rod on the TWF generating a vacuum.

Core Principles:

Energy addition (suction work $W_{isuct} > 0$) decreases internal energy ($\Delta U<0$), temperature decreases.

Energy removal (contraction work $W_{ocont} >0$) increases internal energy ($\Delta U>0$), temperature increases.

Test: Work Transfer and Internal Energy in a CP influenced by **pull** or traction forces

Core Principles based on FLT statement: Misaligned

Energy addition to a CP based on **pull work or suction** (**$W_{isuct} > 0$)**decreases its internal energy (**$\Delta U <0$**).

Energy removal from a CP based on **releasing heat and pull** work (**$W_{ocont}>0$**) or contraction increases its internal energy (**$\Delta U>0$**).

2.6.2 Experimental Verification

These principles are supported by the following rigorously proven and experimentally validated statements:

Statement 1 – Energy Addition (Adiabatic pull work addition process):

If a quantity of energy (E_i), composed of mechanical work via suction (**W_{isuct}**) , is applied to a fixed mass of gas (TWF) in a closed adiabatic process, the result is:

A decrease in internal energy (**$\Delta U < 0$**).

A corresponding decrease in temperature (**$\Delta T < 0$**) and pressure (**$\Delta P < 0$**).

Statement 2 – Energy Removal (Adiabatic Contraction process):

If the same thermal working fluid (now at low temperature and pressure) undergoes a closed, adiabatic contraction process, the result is:

--An increase in internal energy (**$\Delta U > 0$**).

--A corresponding Increase in temperature (**$\Delta T > 0$**) and pressure (**$\Delta P > 0$**).

--The release of useful mechanical work (**W_{ocont}**).

Summarizing, the above statements (1 and 2) are misaligned with the FLT based on experimental evidence, confirming the controversial relationship between energy transfer and internal energy in CP affected by Suction or Traction **(Pull)** forces.

2.7 Interpretation of experimental results

In Table 2 it is shown the key interactions between heat and work that have led to the development of self-sufficient power engines. Therefore, Table 2 illustrates the closed adiabatic HWIs carried out by a SARA, showing the HWIs misaligned with FLT. It is convenient to take into account and highlight that the interactions that are truly valid for developing self-sufficient heat engines are only the adiabatic expansion (push force) aligned with the FLT and the adiabatic thermal contraction (pull force) misaligned with the FLT.

Table 2: Observed experimental effects on a SARA (qualitative results) with closed adiabatic processes

Initial process state	Cause	Effects on works		Effect on V,T,p,	Effect on u	Complies FLT
Low p, low T.	Push in		w_{icomp}	-ΔV, ΔT, Δp, +Δs	Δu	Aligned
middle p, middle T.	Pull in		w_{isuct}	ΔV,-ΔT,-Δp,-Δs	-Δu	**Misaligned**
High p, high T		Push out	w_{oexp}	ΔV,-ΔT,-Δp,-Δs	-Δu	Aligned
Low p, low T		Pull out	w_{ocont}	-ΔV, ΔT, Δp, s const	Δu	**Misaligned**

Figs. 3 and 4 depict the test rig consisting of a SARA performing key HWIs –expansion, compression, and suction, contraction–: While Fig. 3(a) depicts aligned expansion HWIs, Fig. 3(b) depicts aligned compression. Fig. 4(a) depicts misaligned suction HWIs, while Fig. 4(b) depicts misaligned contraction.

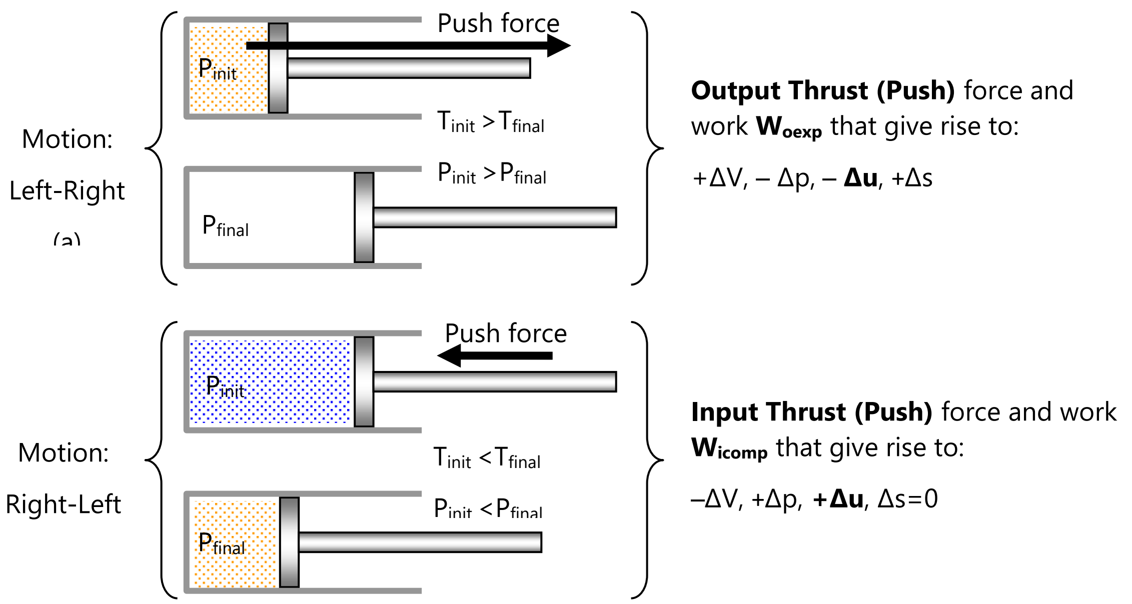

Figure 3: illustration of heat-work interactions (HWI) aligned with the FLT. (a): Expansion HWI. (b): compression HWI.

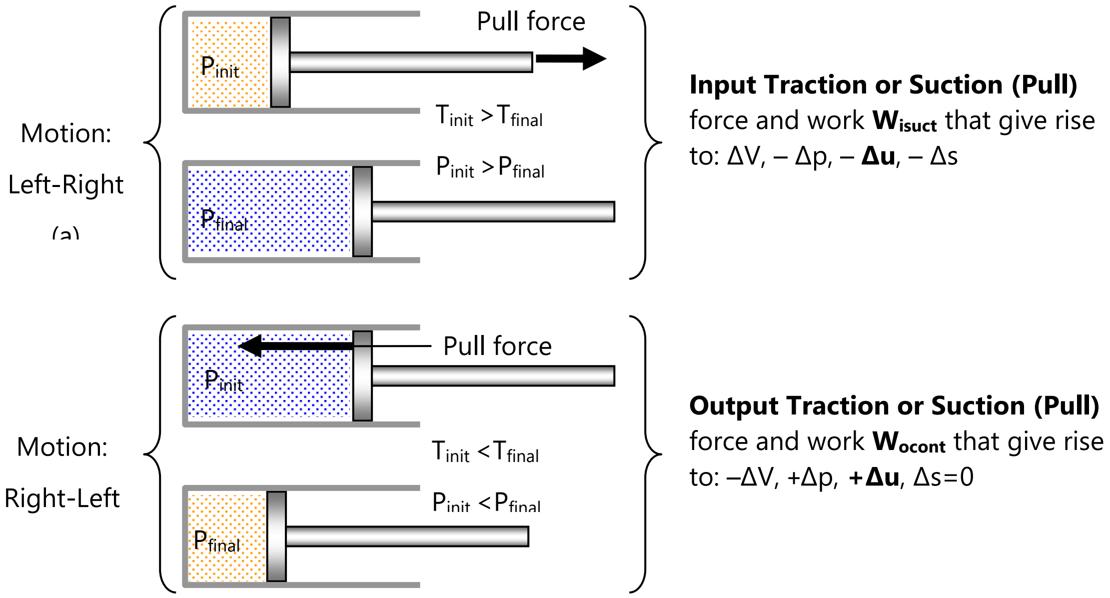

Figure 4: illustration of HWIs misaligned with the FLT. (a): suction HWI. (b): contraction HWI.

2.8 Main conclusions about SARA behavior

1 Heat-work interactions in closed systems can be classified by the type of mechanical force involved:

--Thrust or **Push** forces (compression and expansion)

--Traction or **Pull** forces (suction and contraction)

2 Thrust/Push forces (compression/expansion):

--Compression (input work) increases the internal energy, pressure, and temperature of the system.

--Expansion (output work) decreases the internal energy, pressure, and temperature.

--These processes conform to the First Law of Thermodynamics (FLT), where energy is conserved and boundary work is accounted for.

3 Traction/**Pull** forces (suction/**contraction**):

--Suction (input work) decreases internal energy, pressure, and temperature.

--Contraction (output work) increases internal energy, pressure, and temperature.

--These processes appear to have an inverse effect on internal energy compared to push forces and do not conform straightforwardly to the FLT as traditionally formulated.

4 The standard energy balance (FLT) applies well to push/thrust (compression/expansion) processes, but may require modification or special consideration to account for the effects of pull/traction (suction/contraction) forces.

2.9 Double-Acting Reciprocating Actuator (DARA)

The reciprocating double-acting actuators enable the simultaneous application of Hybrid Work Interactions (HWIs) through both **push** and **pull** forces. These forces are utilized additively or complementarily, with the output forces from each actuator chamber **–A** and **B–** acting concurrently in a single, exclusive direction (e.g., forward-backward, outward-inward, left-right, or up-down strokes).

To extract heat from a system and convert it into useful mechanical work, a sufficiently high heat capacity must be available. If this condition is met, heat can be converted into mechanical work through two distinct interactions:

Direct Conversion: Heat is transformed into work via expansion –a **push** force aligned with FLT– of the TWF, achieved by introducing heat.

Indirect Conversion: Heat is converted to useful mechanical work via contraction of the TWF –generates a **pull** force **misaligned** with FLT–, achieved by extracting useful-grade rejected heat through cooling.

While such a force combination is not conventionally feasible, assuming cost-free heat extraction reveals clear efficiency advantages.

On the DARA-based operation modes: Fig. 5 illustrates the operating principle of a DARA (Double-Acting Reciprocating Actuator) driven by a VsVs thermal cycle. The operating mode is as follows:

In Figure 5(a)**,** it is shown that a VsVs thermal cycle is executed in each chamber of the double-acting actuator cylinder. The cycles in both chambers operate **180 degrees out of phase**, meaning that when heat is added to one chamber, heat is simultaneously extracted from the complementary chamber, and vice versa.

The DARA simultaneously generates two useful forces—**a pushing force and a pulling force**—one in each chamber of the double-acting actuator cylinder. When a pushing force is generated in one chamber, a pulling force is generated in the complementary chamber, and vice versa

Outward motion under VsVs cycle:

Assuming that p_1 and p_3 are equal, which is the reference pressure (p_{ref}), let's explain the operation mode:

When heat is added to the cylinder chamber **A,** the temperature and pressure increase. The temperature changes from T_1 to T_2, while the pressure changes from p_1 to p_2. As a result, a pushing force is exerted on the piston, attempting to move the piston rod outward.

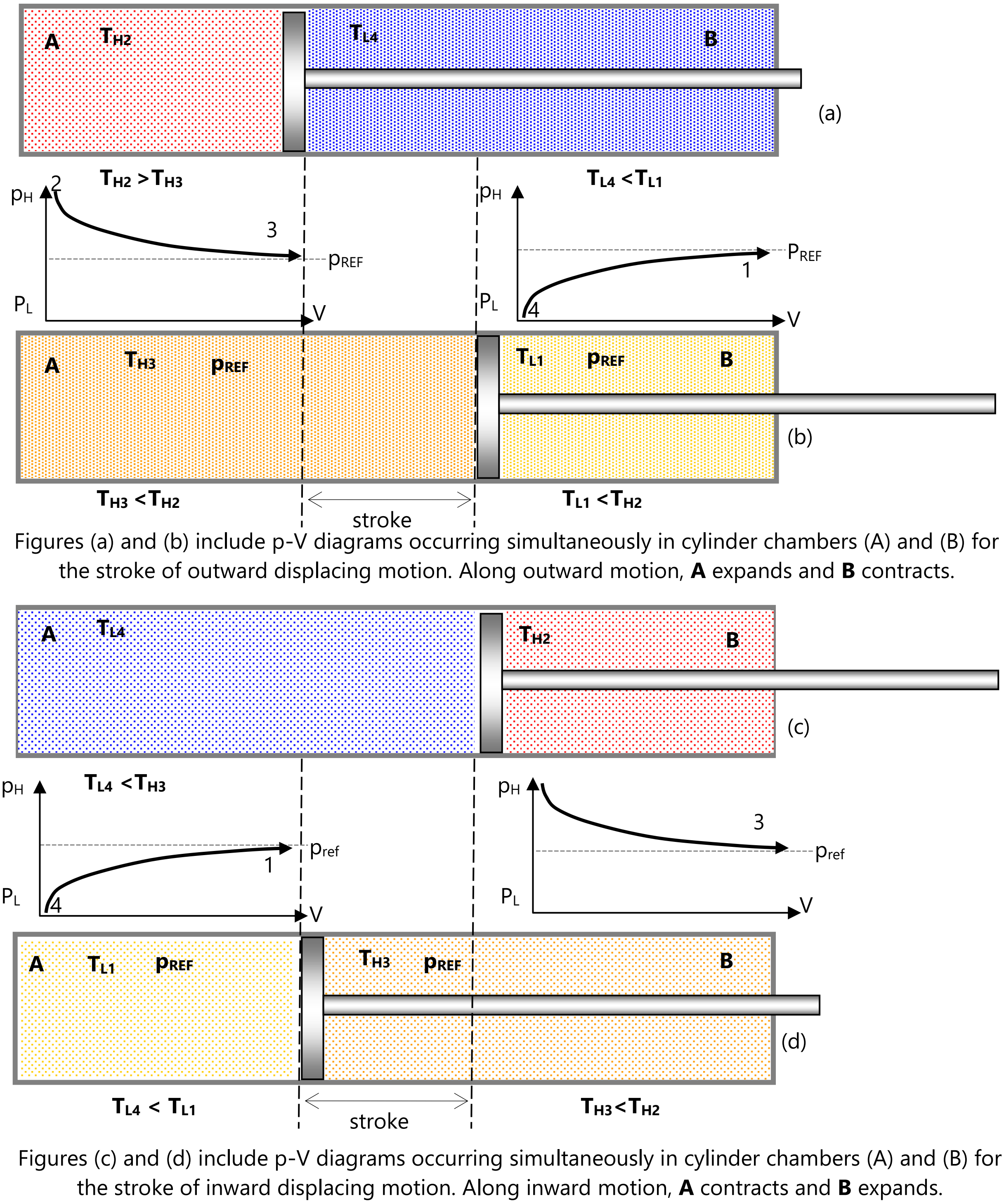

Figure 5: Illustration of the operating principle of a DARA –double-acting reciprocating cylinder– driven by a VsVs thermal cycle carried out in both cylinder chambers A and B. Two simultaneous VsVs cycles are executed: one for each cylinder chamber.

When heat is removed from the cylinder chamber **B,** the temperature and pressure decreases. The temperature changes from T_3 to T_4, while the pressure changes from $p_1 = p_{ref}$ to p_4. As a result, a pulling force is exerted on the piston, attempting to move the piston rod outward.

Therefore, the net force on the piston rod is the sum of the pushing and pulling forces.

As consequence of an expansion process into cylinder chamber **A** and a contraction process into cylinder chamber **B**, a complete stroke outwards has been performed, so that piston rod position is located at the position depicted in Fig. 5(b) due to the useful work performed by expansion in chamber **A** and contraction in chamber **B**.

It is worth noting that the function of one DARA type actuator can be performed by two SARA type actuators.

Inward motion under VsVs cycle:

Assuming that the thermodynamic state in chamber A is identical to that exhibited by chamber B in Fig. 5(a) and that the thermodynamic state in chamber B is identical to that exhibited by chamber A in Fig. 5(a), the process of returning the piston to its initial cycle position is carried out. Along the returning stroke the same amount of useful work is performed Likewise, the same amount of heat has been used.

2.9.1 Basic Principle of a double-acting reciprocating thermal cylinder —DARA—

According with Fig. 5, a DARA converts thermal energy into mechanical work via reciprocating (back-and-forth) piston motion by means of two thermo-mechanic procedures:

-- Expansion of a heated TWF.

-- Contraction of a cooled TWF

Unlike single-acting cylinders, it uses pressure differentials on **both sides** of the piston to perform work in both directions. The main consequence is that along every stroke achieve two forms of additive works: expansion work w_{oexp} and contraction work w_{ocont} .

The Key Components include:

Piston & Cylinder: Sealed piston Responsible for isolate both cylinder chambers moves linearly inside a cylinder.

Hot & Cold Sources: Simultaneous application of heat and cold alternately to the TWF contained in both cylinder chambers on either side of the piston.

Valve system: Controls heat flow by forced thermal convection to the TWF on the sides of the piston.

Work-to-useful-energy conversion system: A mechanism responsible for transferring useful mechanical work, in the form of displacement work, through the piston rod to an energy converter (i.e., electrical energy, whether hydraulic or mechanical).

Fig. 6(a) shows a simplified scheme of a Single DARA-based PU under continuous motion. The prototype scheme obeys to the patents with priority numbers **P201700181** and **P201700667**, characterized by a VsVs continuous motion cycle without regenerative system. The Single DARA must be equipped with volumetric clearances outside the cylinder chambers A and B, so that the TWF add heat to 2 volumetric reservoirs (one per cylinder chamber) and extract heat from 2 volumetric reservoirs (one per cylinder chamber). It is characterized by released heat recovery and heat reused facilities, so that no individual heat regeneration is necessary.

Fig. 6(b), shows a simplified scheme of a Double DARA-based PU composed by two discontinuous motion PUs operating alternatively and intermittently. The prototype scheme obeys to the patent with priority number **P202200035** and **P202400002**, characterized by 2 simultaneous VsVs operating under discontinuous and intermittent motion with released heat recovery and heat reused facilities.

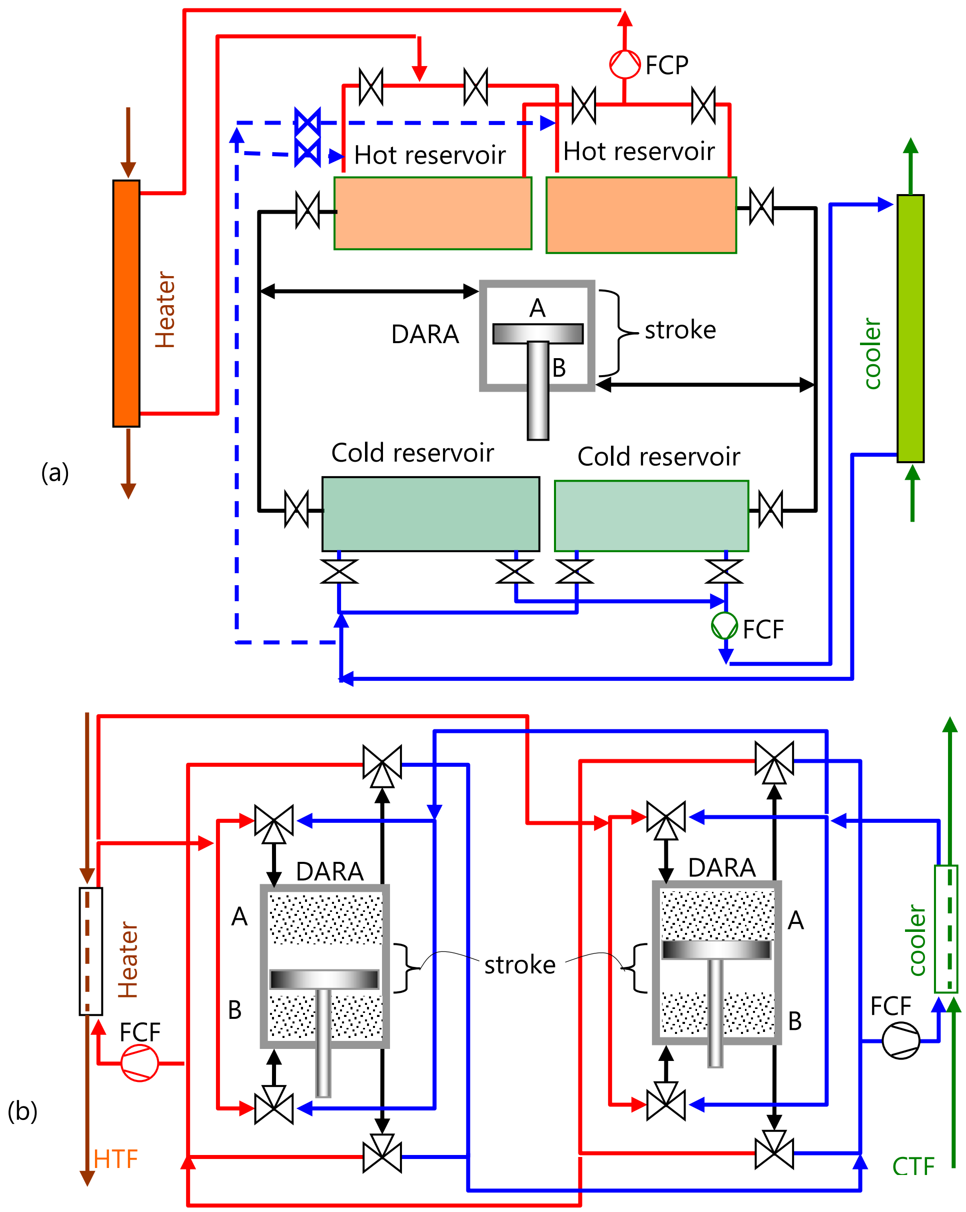

Figure 6: Illustration of two available SSPE schemes, depicting the basic structural configurations. (a): According to patent with priority numbers P201700667. (b): According to patent with priority numbers P202200035.

In order to simplify the structural schemes represented in Fig. 6 (a) and Fig. 6(b) it can be by illustrated by means of symbolic schemes. Thus, Fig. 7 illustrates the energy (heat-work) flow diagram of a double VTVT thermal cycle. This system performs work using as HTF commercial thermal oil through closed isothermal expansion and contraction while simultaneously transferring heat via closed isochoric heat addition and extraction. The process operates under an alternating and intermittent timing control to meet heating and cooling demands efficiently. The heat transfer fluid: HTF and CTF responsible for heating and cooling demands is the same; in general, when operating within a range of conventional temperatures industrial thermal oil could be used. For special cases of cryogenic temperatures, nitrogen, helium and even hydrogen would be useful.

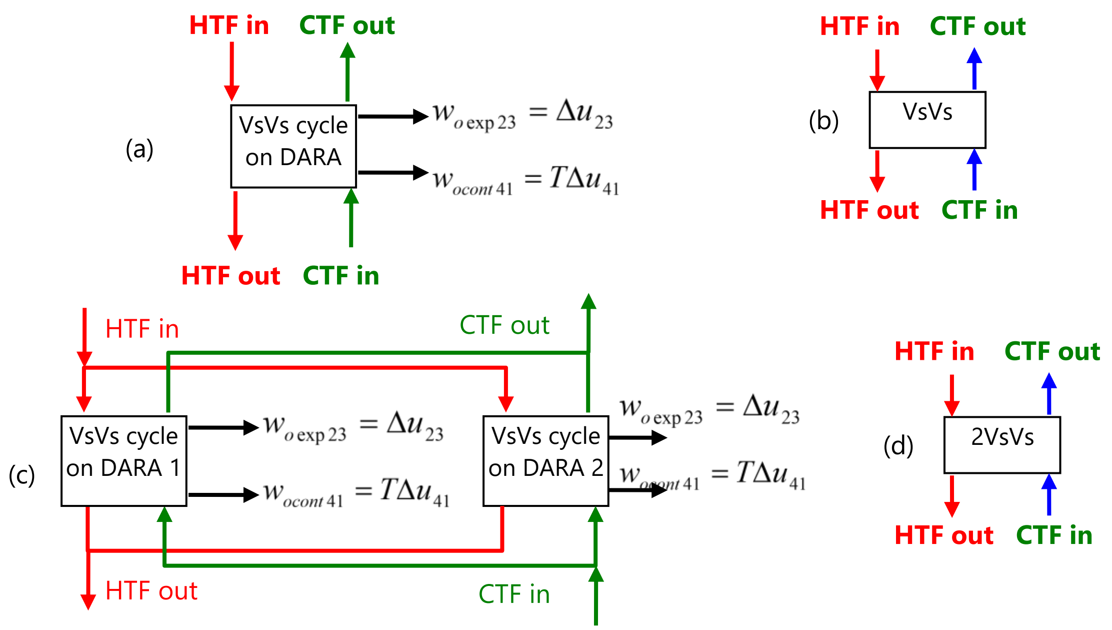

Figure 7: illustration of two types of PUs: continuous motion VsVs cycle is shown in Figs (a) and (b) which is implemented by means of a single DARA, and discontinuous motion VsVs cycle shown in Figs. (c) and (d), which is implemented by means of two DARAs. In both cases it is depicted the heating and cooling transfer piping depicting the input/output energy (heating and cooing heat transfer) flow diagrams.

Regarding to **heat transfer circuits**, the diagram depicts the circuits responsible for adding and extracting heat to/from both intermittent VsVs cycles executed in parallel. Each VsVs cycle remains stationary during the heat transfer which includes simultaneous addition and extraction processes assisted by forced convection transfer ensuring effective and precise thermal transfer. With regard to **discontinuous operation and PU Structure**, the execution of each discontinuous VsVs cycle necessitates a discontinuous-type PU structure. Consequently, a continuous motion PU requires two VsVs cycles operating alternately and intermittently. This configuration allows for seamless operation while maximizing energy efficiency and thermal management.

Each cycle of a PU formed by two discontinuous-intermittent DARAs requires two piston strokes (one forward and one reverse).

In each stroke, two mechanical output work processes are performed simultaneously (expansion work and contraction work).

-- Forward stroke: expansion work at A and contraction work at B.

-- Return stroke: expansion work at B and contraction work at A.

It can be deduced that to complete a VsVs thermal cycle of a PU formed by two discontinuous-intermittent PUs, four expansion work processes and four contraction work processes are produced.

2.9.2 The Physical Cycle of a DARA

Forward Stroke:

High-pressure TWF (heated gas) contained into the **rear side** of the piston, is expanding and pushing it forward.

Simultaneously, the front side at lower pressure and temperature (vacuum) contracts the TWF, pulling the piston while increasing temperature and pressure.

Backward or Return Stroke:

Heated gas is now admitted to the **front side**, forcing the piston backward.

The **rear side** vents gas to the cold sink.

The cycle repeats, driven by thermal expansion/contraction.

Table 3: Observed experimental effects on a DARA (qualitative results) with closed adiabatic processes

Initial process state	Cause	Effects on w_o		Effects on V,T,p,s	u	FLT alignment
High p, high T, $p>p_{ref}$	Heat in q_i	Push out	w_{oexp}	ΔV,-ΔT,-Δp,-Δs	— Δu	Aligned
Low p, low T, P p_{ref}	Heat out, q_o	Pull out	w_{ocont}	-ΔV, ΔT, Δp, Δs=0	Δu	**Misaligned**

According with the observed experimental effects on a DARA, (as illustrated in Table 3) operating with closed adiabatic processes on a thermal cycle VsVs, the consequences of the observed misalignment with FLT of pull forces obtained by contraction of a TWF giving rise to a pull output useful work means an extraordinary and disruptive consequence responsible for giving rise to the self-sustaining power machines.

This ability to produce useful mechanical work without adding heat changes the paradigm of energy conversion, paving the way for new heat engine architectures that will likely enable much greater efficiency and even self-sufficiency for heat engines. The disruptive result not only violates the laws of conservation of energy, but also gives rise to a new law of energy creation under controlled conditions.

In summary, heat expands gas on one piston side, pushing it; cooled gas contracts on the opposite side, pulling it back. Valves switch the heated/cooled TWF flow direction cyclically, creating cyclically discontinuous reciprocating-base pulse motion.

2.9.3 First consequence of the misalignment of contraction work with the FLT due to output pulls forces

Energy balances modelling conservation laws are rigorously irrefutable in mechanical interactions of isolated systems, even with dissipative variable interactions. However, as shown in Table 2, the output pulling forces responsible for the output pulling work, which includes heat-work interactions, alter the energy balance so that it is not aligned with the energy balances involving heat-work-based energy interactions that include only thrust or expansion forces.

In order to test the Carnot factor consistence in the energy balances including pulling forces that give rise to output contraction work, let's consider an analysis of the thermal efficiency definition:

The net output work $\mathbf{w_{o1}}$ in a conventional thermal cycle is:

$$\mathbf{w_{o1}} = w_{oexp} - w_{icomp} \tag{13}$$

The net output work $\mathbf{w_{o2}}$, per DARA stroke operating on a thermal cycle including contraction work is:

$$\mathbf{w_{o2}} = w_{oexp} + w_{ocont} \tag{14}$$

Assuming that $\mathbf{w_{o1} < w_{o2}}$ the thermal efficiencies due to the works done in Eqs. (13) and (14) are:

$$\eta_{th1} = \frac{w_{o1}}{qi}, \ \eta_{th2} = \frac{w_{o2}}{qi} \tag{15}$$

Thus, Eqs. (13), (14) and (15) suggest us that

$$\eta_{th1} < \eta_{th2} \text{ since } \frac{w_{o1}}{qi} < \frac{w_{o2}}{qi} \tag{16}$$

Furthermore, equation (16) confirms that the thermal efficiency of a thermal cycle that includes contraction work is absolutely independent of conventional thermal cycles that are characterized by operating without contraction work. Since this conclusion is not aligned with the Carnot factor then it is deduces that it does not meet Carnot theorem.

2.10 The thermodynamics of the VsVs thermal cycle

The controversial thermodynamics inherent to the V-s/V-s (isochoric-isentropic_adiabatic / isochoric-isentropic_adiabatic) cycle (VsVs) is especially interesting because it exhibits closed adiabatic processes dominated by traction or pulling forces that involve output thermal contraction-based useful work, which leads to misalignment and inconsistency with the FLT. The singularity due to adiabatic contraction processes is particularly relevant because, as a result of a recoverable heat extraction process, useful work output is generated by thermal contraction while the internal energy of the TWF increases. This is a real observed fact inconceivable to the human mind according to the conventional fundamental laws of thermodynamics.

The following subsection briefly describes the concepts associated with the thermal expansion and contraction processes responsible for the pushing and pulling forces, respectively, of the VsVs cycle. It also shows the inconsistency of the work of contraction with the FLT, highlighting the need to consider the energy balances associated with pulling forces.

2.10.1 The influence of useful contraction work on the VsVs cycle performance

As mentioned above, traction (puling) forces are essential for achieving useful mechanical work without adding external heat to a cycle. It has been shown that generating a vacuum relative to a reference pressure by cooling a TWF can be used to produce useful mechanical work by contracting a confined TWF.

The condition for completing a thermal cycle requires that the internal conditions at the beginning and end of the cycle be equal.

Observing the Fig. 8 we can note that the representation of the VsVs thermal cycle using a T-s diagram, where temperature (T) is shown on the ordinate axis and entropy (s) on the abscissa axis, means that temperature changes in each process of the cycle are observed on the ordinate axis, while entropy changes are observed on the abscissa axis. Every change in temperature indicates a change in internal energy, with a linear relationship proportional to the specific heat at constant volume.

2.10.2 The internal energy balance of a VsVs cycle

This study is based on the assumption that

-- Initial and final conditions of each thermal cycle are identical by nature.

-- Total input-output energy involved in a thermal cycle is constant

This gives raise to the fact that two-dimensional coordinate system of the T-s diagram is key to identifying the dynamics of the closed processes carried out by the VsVs cycle based on the evolution of temperatures during the cycle.

This statement about the equality of initial and final conditions means that the variation in temperature, pressure, volume, and entropy between the start and end of the cycle are zero. Therefore, if the conditions mentioned above are not met, then the set of thermodynamic transformations is not a thermal cycle.

Regardless of the causes that give rise to the identity of the initial and final conditions of the cycle, it naturally has to occur that all the energy that enters a cycle has to satisfy the identity of the output energy, since within the cycle nothing remains in accordance with the conditions of equality between the beginning and end of the cycle. These assumptions are essential to satisfying the thermal cycle conditions. Consequently, the differences between the values of the initial and final cycle variables are zero.

Since in all possible thermodynamic transformations between heat and work less useful work is obtained than heat used, both expansion work based on the addition of heat and contraction work by heat extraction, it is impossible to obtain machines that satisfy the conditions of the SSPEs. Since in all possible thermodynamic transformations between heat and work, less useful work is obtained than heat used, both expansion work based on heat addition and contraction work by heat extraction, it is impossible to create machines that satisfy the conditions of SSPEs.

Such machines are only possible by combining several key elements, among which are the interaction between thermal cycles, equipped with the ability to perform useful mechanical work through both expansion and contraction. This is characterized by producing useful mechanical work without the need for heat addition, but rather heat extraction, which can be efficiently recovered and reused.

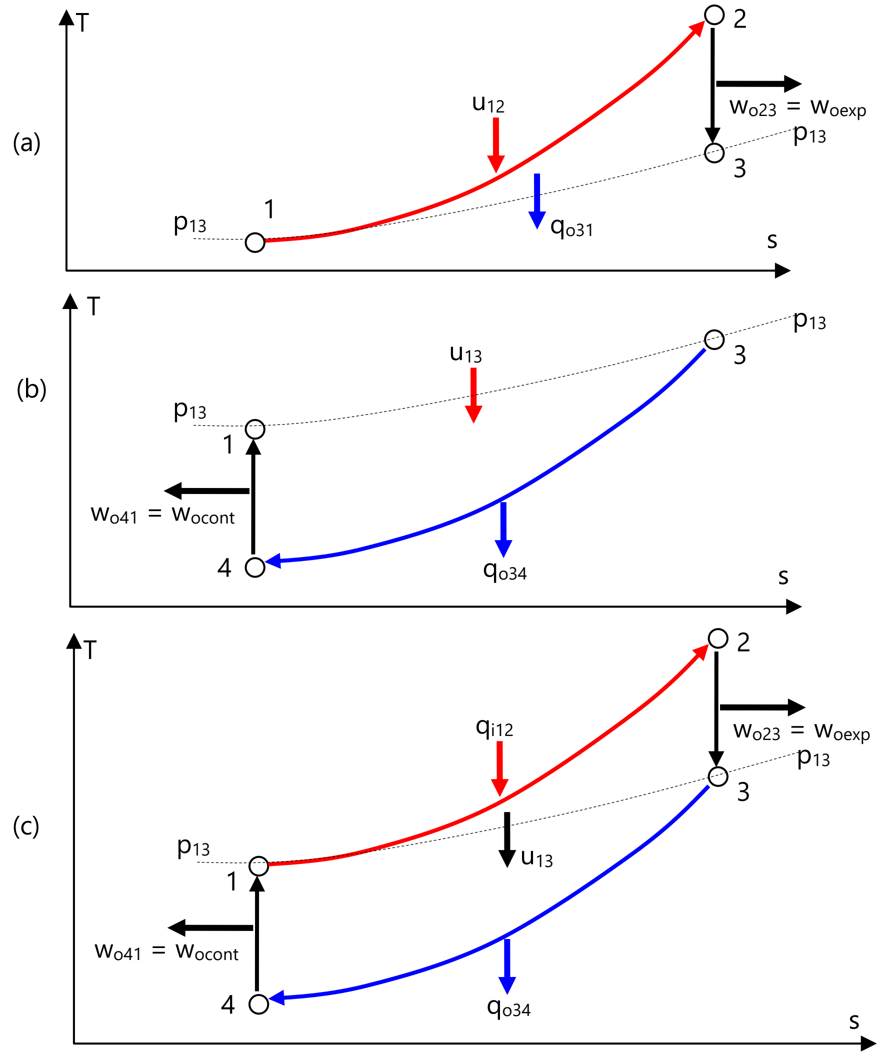

Figure 8: Illustration of the T-s diagram of a VsVs cycle and the usefulness of the T-s coordinates.

In Fig. 8, the decomposition of the VsVs cycle into two parts covers the two modes of production of useful mechanical work by a DARA type actuator, as shown in Fig. 8. Therefore Fig. 8(a) shows the fragment of the VsVs cycle associated with expansion work, while the fragment of the VsVs cycle associated with contraction work is depicted in Fig. 8(b, giving rise to the VsVs cycle shown in Fig. 8(c).

Let´s define the notation assigned to the cycle processes temperature differences in Eq. (17):

$$\Delta T_{12} = T_1 - T_2;\ \Delta T_{23} = T_2 - T_3;\ \Delta T_{34} = T_3 - T_4; \Delta T_{14} = T_1 - T_4 \qquad (17)$$

From Eq. (1) follows that

$$\Delta T_{14} + \Delta T_{12} = \Delta T_{23} + \Delta T_{34} \qquad (18)$$

which is aligned with the balance of the internal energy of closed processes-based cycle in which Δu =0.

Thus, Eq. (18) according to the T-s diagram of Fig. 8 may be written as

$$\Delta T_{14} + \Delta T_{12} - \Delta T_{23} - \Delta T_{34} = 0 \tag{19}$$

Based on Eq. (19) and the fact of the inherent relationship of dependence between temperatures and internal energies, we have that:

$$\Delta u_{14} + \Delta u_{12} - \Delta u_{23} - \Delta u_{34} = 0, or$$

$$(w_{ocont} + q_{i12}) - (w_{o\exp} + q_{o34}) = 0 \rightarrow \frac{w_{ocont} + q_{i12}}{w_{o\exp} + q_{o34}} = 1 \tag{20}$$

which in summary means that Δu=0 in any closed processes-based thermal cycle.

2.10.3 Thermodynamic considerations

Let us consider the changes in internal variables that occur in the closed processes of the VsVs cycle to identify the consequences derived from equations (1-4) and the T-s diagram represented in figure (zz) due to the heat-work interactions that occur throughout the cycle. Closed processes of the VsVs thermal cycle that cause changes in internal energy:

1-2 Isochoric heat addition process (ΔT, Δu, Δp, Δs)

2-3 Adiabatic-isentropic expansion process (–ΔT, –Δu, –Δp, Δs = 0, thrust=push forces, Δw)

3-4 Isochoric heat removal process (–ΔT, –Δu, –Δp, –Δs)

4-1 Adiabatic-isentropic contraction process (ΔT, Δu, Δp, Δs = 0, pulling forces, Δw)

By observing the behaviour of process 4-1, it is observed that the increase in temperature, which leads to an increase in internal energy with an increase in pressure, results in work output due to contraction of the TWF. This phenomenon, as indicated previously, is misaligned with the energy balances governed by the first law of thermodynamics. By observing the behaviour of process 4-1, we see that the increase in temperature, which leads to an increase in internal energy with an increase in pressure, results in work output due to contraction of the TWF. This phenomenon, as previously indicated, is misaligned with the energy balances governed by the first law of thermodynamics (FLT). What most draws our attention is that this thermodynamic transformation results in a net output of useful work without the need for thermal energy input.

2.10.4 Conventional thermodynamic analysis

The following analysis is referred to the notation used in Fig. 8. Therefore the works definition is as follows:

$$w_{o\exp} = w_{o23} = \Delta u_{23} = Cv(T_2 - T_3) \tag{21}$$

$$w_{ocont} = w_{o41} = \Delta u_{41} = Cv(T_1 - T_4) \tag{22}$$

The energy balance for the defined works is as follows:

Energy balance of expansion work

$$\Delta u_{12} = \Delta u_{23} + \Delta u_{13} \tag{23}$$

Energy balance of contraction work

$$\Delta u_{34} = \Delta u_{14} + \Delta u_{13} \tag{24}$$

Elimination of variable Δu_{13} from Eq. (7-8)

$$\Delta u_{13} = \Delta u_{12} - \Delta u_{23} \tag{25}$$

Introducing (23) into (24) yields

$$\Delta u_{34} = \Delta u_{14} + \Delta u_{12} - \Delta u_{23} \tag{26}$$

Rearranging (26) by 7(23) transposition yields

$$\Delta u_{34} + \Delta u_{23} = \Delta u_{14} + \Delta u_{12} \quad (27)$$

From Eq. (27) it is possible to obtain the energy balance in terms of input/output heat and output works. Thus, from (27) follows that

$$q_{o34} + w_{o23} = w_{o14} + q_{i12} \rightarrow \; q_{i12} - q_{o34} = w_{o23} - w_{o14} \quad (28)$$

However, in conventional energy balances of thermal cycles the following occurs

$$q_i - q_o = w_o \text{ instead of } q_{i12} - q_{o34} = w_{o23} - w_{o14} \quad (29)$$

In fact, in the cycle VsVs the total output useful work due to expansion and contraction is

$$w_n = w_{o23} + w_{o14} = w_{o\exp} + w_{ocont} \quad (30)$$

which is not in any way aligned with the energy balance given by Eq. (29)

Equation (29) provides no useful results beyond blatantly showing the inconsistency of the result of such an energy balance when compared with energy balances of conventional cycles based on the performance of useful mechanical work by expansion. This is because the added input heat q_{i12} is converted to output useful mechanical work by expansion of the TWF while the extracted output heat q_{o34} is converted to useful mechanical work output by contraction of the TWF. These results are depicted with Eq. (30) and are not aligned with FLT.

2.11 Cycle transformations for a VsVs discontinuous motion prototype

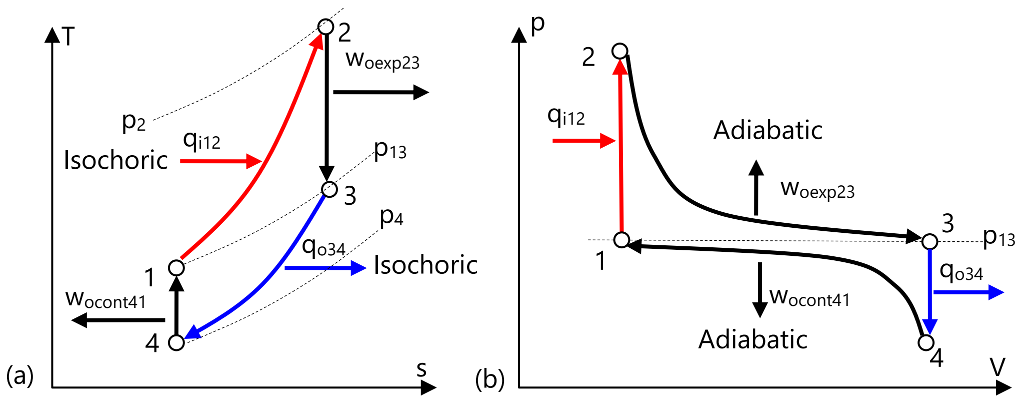

Figure 9: Illustration of the single VsVs closed processes-based thermal cycle. (a) depicts the T-s diagram, while (b) depicts the p-V diagram

Regarding the information provided in Table 2 and Figure. 2 (a), (b), and Figure 9 the thermodynamic transformations between each pair of cycle state points performed on the left side of the discontinuous RDAC are summarized below:

Process (1)-(2) corresponds to a closed isochoric heat addition process in which the TWF is heated according to the heat transfer model:

$$q_{i12} = \Delta u_{12} = u_2 - u_1 = Cv \cdot (T_2 - T_1) \quad (31)$$

Process (2)-(3) corresponds to a closed adiabatic expansion process (cylinder chamber volume increases doing work). Thus, the thermal energy in the form of internal energy is converted into mechanical work, provided that the piston can move freely to permit the expansion work.

$$w_{o23} = w_{o\exp} = u_2 - u_3 = Cv \cdot (T_2 - T_3) \quad (32)$$

Process (3)-(4) corresponds to a closed isochoric heat extraction process in which the working fluid is cooled without any work being done because of the constant volume process:

$$q_{o34} = \Delta u_{34} = u_3 - u_4 = Cv \cdot (T_3 - T_4) \tag{33}$$

Process (4)-(1) corresponds to a closed adiabatic contraction-based compression process. Thus, the thermal energy in the form of internal energy is converted into mechanical work by contraction (cylinder chamber volume decreases doing work), provided that the piston can move freely to permit the contraction work:

$$| w_{o41} | = | w_{ocont} | = | u_4 - u_1 | = Cv \cdot | (T_4 - T_1) | = Cv \cdot | (T_1 - T_4) | \tag{34}$$

The table 4 also depicts the useful work, constant parameters and heat transfer direction associated with each transformation according to Equations (35-37).

The heat-work interaction tasks performed in chambers A and B of the cylinder to complete a cycle consist of heating, cooling, or work by expansion or contraction.

As shown in Table 4, during the stationary time interval, heat is added to chamber A, while heat is extracted from chamber B. Simultaneously, while this cylinder remains stationary, the complementary cylinder performs work in both chambers: expansion in one and contraction in the other.

Table 4: Illustration of the cycle transformations carried out in the discontinuous VsVs cycle showing the thermodynamic functions carried out simultaneously into both DARA chambers (A) and (B).

VsVs Cycle performed in cylinder chamber A				VsVs Cycle performed in cylinder chamber B			
sp	useful work	constant	heat in/out	sp	useful work	constant	heat in/out
1-2	motionless	V	$q_{i12} = \Delta u_{12}$	3′-4′	motionless	V	$q_{o34} = \Delta u_{34}$
2-3	$w_{o23} = \Delta u_{23}$	s		4′-1′	$w_{o41} = \Delta u_{41}$	s	
3-4	motionless	V	$q_{o34} = \Delta u_{34}$	1′-2′	motionless	V	$q_{i12} = \Delta u_{12}$
4-1	$w_{o41} = \Delta u_{41}$	s		2′-3′	$w_{o23} = \Delta u_{23}$	s	

Figure 10 depicts the energy flow-chart associated with the transformations carried out along the thermal cycle VsVs. It is observed that no feed pump is required, so that the cycle processes (useful work obtained, heat added and heat extracted) are carried out under thermodynamic closed systems.

In Fig. 10(a) it is depicted the energy flow diagram (heat and work) composed bay cascaded PUs operating with the VsVs thermal cycle. The output useful work is converted into electric power (EP) which is scheduled to upgrade the recovered heat to be returned again to the first PU pf the cascaded SSPE. In Fig. 10(b) it is depicted a detailed diagram of the conversion phases necessary to convert work to EP, followed by a conversion step to achieve high-grade heat and free EP. This heat flow structure will be used to implement a SSPEs composed by cascaded PUs portaging optionally with discontinuous or continuous VsVs cycles.

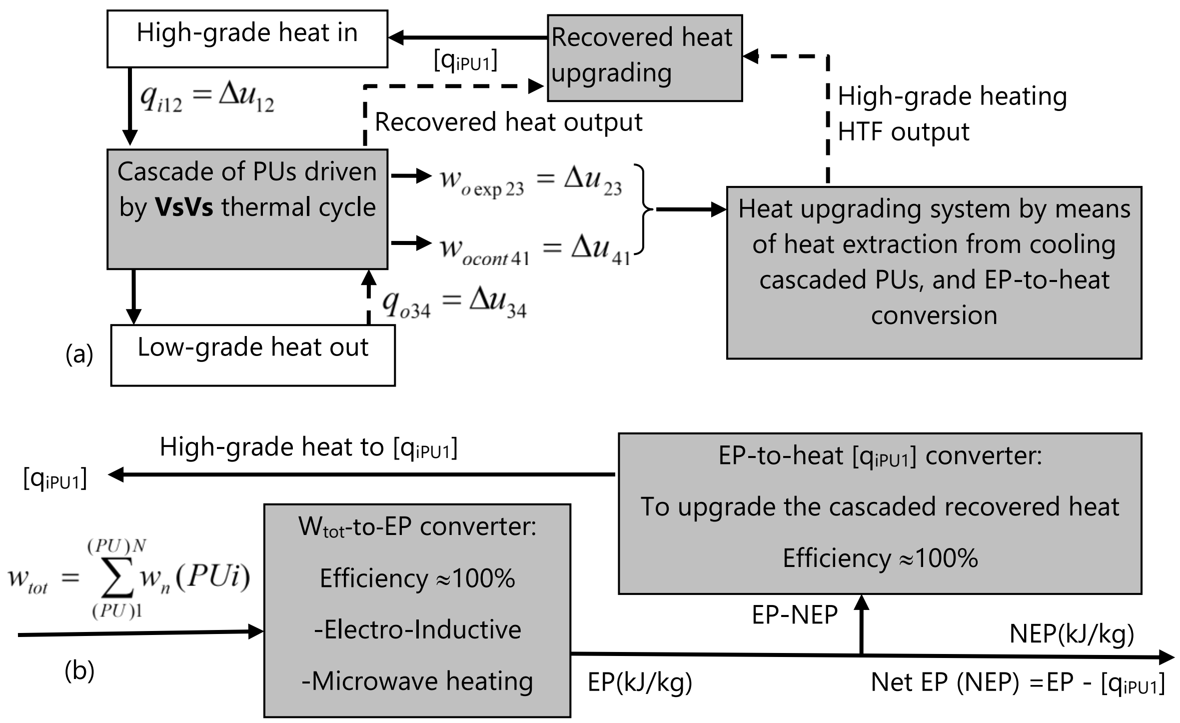

Figure 10: Illustration of the implemented heat-work scheduling algorithm.

2.11.1 Cycle analysis of a VsVs discontinuous motion prototype

The cycle analysis is based on the first law. Thus, the energy transfer flows include the following energy balances derived from the previous section:

Added input heat

$$q_i = q_{i12} = u_2 - u_1 = Cv \cdot (T_2 - T_1) \tag{35}$$

Extracted output heat

$$q_o = q_{o34} = u_3 - u_4 = Cv \cdot (T_3 - T_4) \tag{36}$$

Net useful output work

$$\begin{aligned} w_o &= w_{o\exp} + |\, w_{ocont} \,| = Cv \cdot (T_2 - T_3) + Cv \cdot |\,(T_4 - T_1)\,| \\ &= (u_2 - u_3) + |\,(u_4 - u_1)\,| \end{aligned} \tag{37}$$

Therefore, the thermal efficiency is given by the ratio of the net mechanical work to the added input heat, yielding

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o23} + |\, w_{o41} \,|}{u_2 - u_1} = \frac{\Delta u_{23} + \Delta u_{41}}{\Delta u_{21}} = \frac{(u_2 - u_3) + |\,(u_4 - u_1)\,|}{u_2 - u_1} \tag{38}$$

However, since an important fraction of the useful work is carried out by a vacuum or thermal contraction, it is interesting to consider the proportions of useful work obtained by thermal contraction due to cooling concerning those obtained by thermal expansion.

2.12 Influence of cycle temperature ratios of each PU on the SSPE performance

Every PU proposed to implement a SSPE completes a VsVs cycle by executing two simultaneous VsVs-type cycles. Both thermal cycles are executed in such a way that when one of the thermal cycles is doing useful mechanical work due to expansion and contraction simultaneously, the complementary thermal cycle is in the phase of heat addition and extraction simultaneously. Therefore, to continue the study of the SSPE, it is necessary to know the characteristics of each PU, which depend on the thermodynamic characteristics of the considered thermal cycle. Thus, in order to know the behavior of the VsVs cycles with respect to the Ratio of Isochoric Temperatures (RIT) is considered: RIT = T_1/T_2

The optional value of RIT is chosen fulfilling a criterion such that they provide an acceptable performance of each cascaded PU. Thus, the search is based on the definition of the relationship of temperatures in a similar application range to that expected for operating in the desired SSPE when PUs are coupled in cascade downstream.

2.12.1 Definition of the RIT for discontinuous-motion cycle VsVs

From equations (32) and (34) we have

$$w_{o\exp 23} = Cv \cdot (T_2 - T_3) \quad (39)$$

$$w_{ocont41} = Cv \cdot (T_1 - T_4) \quad (40)$$

From (39) and (40) it is achieved the isochoric temperatures as

$$T_2 = \frac{w_{o\exp 23} + Cv \cdot T_3}{Cv} \quad (41)$$

$$T_1 = \frac{w_{ocont41} + Cv \cdot T5_4}{Cv} \quad (42)$$

Thus, the ratio of the isochoric temperatures *RIT* is

$$RIT = \frac{T_1}{T_2} = \frac{w_{ocont41} + Cv \cdot T_4}{w_{o\exp 23} + Cv \cdot T_3} \quad (43)$$

Unlike the designs presented in previous publications related to the concept of "Self-Sustaining Power Engines" (SSPE) referenced in [6-13] based on prototyping patents referenced in [15-19], in which a constant isochoric temperature ratio (RIT) was used (cascade of PUs with an RIT of equal value), this design proposes an operation criterion in which the duties of each PU in the cascade are equal. This criterion requires that the RIT values be different for all the power units in the cascade. With this criterion, equal volumes are obtained for the structure of each PU in the cascade that makes up the SSPE.

In the design of successive prototypes, a design criterion based on modules or power units characterized by dimensional equality in both the structural and energy capacities will be used, resulting in equal power, pressure, and volume. To achieve this characteristic, the temperature differences in each power unit must be equal.

Therefore given a constant value for the temperature difference (T_{drop}) between each power units so that

$$= T_{drop} \cdot (T_2 - T_1) \quad (44)$$

then, the corresponding ratio of isochoric temperatures $RIT = \frac{T_1}{T_2}$ can be related with T_{drop} as

$$T_1 = \cdot T_2 \cdot RIT \quad (45)$$

Thus, from (44) follows that

$$T_{drop} = \cdot T_2 - T_2 \cdot RIT = T_2(1 - RIT) \quad (46)$$

By eliminating T_2 from the previous Eqs. (45-46), the RIT as function of T_1 and T_{ref} yields

$$RIT = \frac{T_1}{T_{drop} + T_1} \qquad (47)$$

From Eq. (47) it is deduced that since the value of T_1 changes the constant value T_{drop} in each cascaded PU, then follows that for every cascaded PU a different RIT value must exist. However, the advantages of a variable RIT assuming a constant T_{drop}, means simplifying the structural design as well as its cost and performance. A key factor consists in designing prototypes equipped with PU cascades that operate with VsVs cycles with constant, low T_{drop} (temperature differences), which requires a high and variable RIT value as function of the T_{drop}.

3. Prototyping Design Strategy

Unlike the designs presented in previous publications related to the concept of Self-Sustaining Power Engines (SSPE) referenced in [15-19], in which a constant RIT was used (cascade of PUs with a RIT of equal value), this design proposes an operation criterion in which the duties of each PU in the cascade are equal. This criterion requires that the RIT values be different for all the power units in the cascade. With this criterion, equal volumes are obtained for the structure of each PU in the cascade that makes up the SSPE. To achieve the same volume at the same pressure, resulting in a similar amount of mechanical work per PU in the cascade, precise temperature control is required across each power unit (PU). This involves choosing a uniform temperature drop across each power unit PU between every two cascaded power units. At the same time, a sufficiently high RIT value is required to realize the thermal efficiency potential of each PU. This entails choosing an appropriately low, uniform temperature drop for each PU without sacrificing a constant T_{drop} value. A constant T_{drop} value between cascaded PUs significantly simplifies SSPE design tasks and reduces design, implementation, operating and maintenance costs.

The prototyping design process is essentially derived from patents based on the strategy of coupling groups of PUs in cascade, so that most of the added heat can be efficiently recovered and regenerated to be returned feeding the first PU in the set of cascaded PUs downstream. The corresponding patent is identified by its application number: P202400002 and publication number: ES 3 031 584 A1

3.1 Assumed criteria to carry out the prototyping design tasks

With respect to this topic, as mentioned in previous papers, the design criteria obey to the previous studies along this work as well as previous results from references [15-19]. Therefore, the key innovative concepts proposed for improving mechanical work achieved by thermal expansion and contraction efficiency in the SSPEs systems are summarized by four disruptive and strategic key points:

1- Doing useful work by utilizing thermal contraction by cooling a TWF:

-- The SSPE design leverages the thermal **contraction** of the TWF, in addition to **expansion**, to generate efficiently useful mechanical work.

-- Performing work through contraction is a critical mechanism that enables the SSPE to achieve remarkably high efficiencies and self-sufficiency on the basis of a proper selection of the Tdrop and/or proper RIT values. This achievement is mainly due to the proper choice of T_{dif} or RIT by which almost as much work can be obtained by thermal contraction based on cost-free heat extraction as by expansion due to heat addition, which entails costs inherent to the addition of heat.

-- This contrasts with traditional power cycles that rely solely on expansion to produce work, apart from the fact that there is no possibility of using the concept of T_{drop} or proper RIT, so that the plant structure based on cascaded PUs doesn't work at all. The main reason is that the heat rejected by the expansion becomes a low-grade heat, so that its recovery is inefficient.

2- Closed processes-based thermal cycles with expansion and contraction, without state changes (no condensing or vaporizing processes):

-- The SSPE employs specialized thermal cycles, such as VsVs cycles that operate through closed processes of both heat addition and heat extraction to perform closed processes-based thermal expansion and contraction. Closed processes are characterized by the lack of typical losses due to flow and isentropic work, which results in an increase in the efficiency of the heat-useful work conversion processes.

-- This allows the system to extract useful work from both the expansion and contraction of the working fluid. This feature leads to the need for a selection of the optimal constant T_{dif} or corresponding RIT value to efficiently exploit the assistance due to the performance of work by thermal contraction.

3 Disruptive strategies on efficient heat recovery and reuse tasks:

-- The SSPE consisting of a group of cascaded PUs coupled in cascade recovers the heat resulting from the cooling process that drives the thermal contraction. The value of this heat represents almost half of the heat manipulated in heat-work conversion processes. This is why it is so important since it is obtained at no cost.

-- This recovered heat will be then reintegrated to power the first PU in the cascaded system, enabling the "heat superposition" or heat upgrading strategy on the basis of electric power to heat conversion which undergoes near 100% efficiency.

-- This heat management approach allows the SSPE to generate more useful work than the initial heat input, exceeding 100% thermal efficiency, which in conventional thermodynamics is not possible, since violates the first law (FLT).

4- Working Fluid Selection:

-- The choice of TWF exerts a strong influence on the mechanical dimensions of each PU structure.

-- The heat capacity ratio also known as the adiabatic index play an important roll in the thermal efficiency.

-- The choice of TWF, such as helium versus air, has a major impact on the thermal contraction and expansion efficiencies and overall performance of the SSPE.

-- Helium's superior thermodynamic properties allow it to extract significantly more useful work from the expansion and contraction processes compared to air.

3.2 Prototyping design task considerations

A SSPE must be characterized by its ability to operate indefinitely without an external energy input [15-19]. This essential characteristic must overcome the irreversibilities inherent in any real machine, which may approach over 27%. This means it must surpass the limitations of second-kind perpetual motion machines, whose operation involves a combination of mechanical and thermal transformations that are inherently affected by dissipative forces. These include irreversibilities due to mechanical losses, primarily from friction and sound energy, as well as thermal losses, including isentropic losses due to flow work caused by thermal fluid friction, heat leaks, and heat transfer losses (due to conduction, convection, and radiation).

In summary, the **essential key factors** to achieve an SSPE require performing useful mechanical work by:

--1 Isothermal expansion of a TWF due to a previous iheat addition task under a closed isochoric process.

--2 Isothermal contraction of a TWF due to a previous heat extraction task under a closed isochoric cooling process.

--3 Work produced by the heat efficiently recovered from the counter-flow heat transfer cooling of the working fluid in the contraction processes of each upstream PU.

--4 Ability to upgrade the recovered heat in order to increment the thermal potential energy to be efficiently reused by feeding the first downstream PU

3.2.1 Key strategies

However, among the essential key factors mentioned, some key strategies must be satisfied such as:

1. A unified heat carrier circuit for cascaded Power Units (PUs) responsible for both adding and recovering heat efficiently.

2. An optimal value of the Tdrop or corresponding RIT (Ratio of Initial isochoric Temperature to Final isochoric Temperature, T_1/T_2 to enhance the thermal efficiency of each individual PU while taking into account considering the relevance of implementing the SSPE with the minimum number of PUs while keeping the maximum SSI value.

3. The importance of supplying heat to the top PU in the cascade coupling structure, which is carried out using one of the available heat transfer techniques based on heat recovered overlay using the thermal energy superposition potential technique, which involves adding heat to the recovered working fluid by increasing the temperature of the recovered cooling fluid. This capability is due to the unique disruptive properties exhibited by electric-based heaters, by means of resistance-based, or magnetic induction-based or radiation-based such as microwaves heating techniques.

4. In this heat management strategy the HTF recirculation circuit used to feed thermal cycles of the VsVs type whose thermal cycle diagram is depicted in Figs. 11 and 12. These cycles are characterized by their ability to provide useful mechanical work through thermal expansion, thermal contraction, and recovered heat from the cooling system of each upstream PU.

3.3 Structure of the heat management circuit

Heat is added and extracted to/from the TWF by recalculating a HTF by heat exchangers by means of forced convection fans (FCF) as depicted in Fig. 6(a) and Fig.6(b).

As mentioned in the above point 4, the management circuit is responsible supplying and extracting heat for provide useful mechanical work through thermal expansion, thermal contraction, and recovered heat from the cooling system of each upstream PU. With reference to Fig. 11 and Fig. 12, the dashed red line indicates the heating flow diagram, while the dashed blue line indicates the cooling flow diagram. The heat adding system performs the useful work output by expansion of a TWF, while the cooling system performs both tasks:

- Generating a vacuum that provides useful work through thermal contraction.

- Improving the cooling heat output in each cascade power unit to efficiently recover and reuse it as heating heat.

HTF can operate as either a heating or cooling thermal fluid. When the HTF circulates downstream, transferring heat to the cascade PUs, it behaves as a heat-add thermal fluid, while when the HTF circulates upstream, recovering heat from the cascade PUs, it behaves as a cooling or heat-extracting thermal fluid.

4. Prototyping case studies on SSPEs

This section is dedicated to the design of SSPEs through four cases in which the aim is to obtain useful design data for the implementation of viable prototypes, as well as to discard those that are not applicable.

The proposed cases consider four T_{drop} values (temperature difference between cascaded PUs) that entail a given number of PUs. Therefore, the objective is to investigate what T_{drop} is necessary for the number of PUs and the respective self-sustainability index (SSI) value to be adequate and/or satisfactory.

Considering that both prototype models shown in Fig. 6 (a) and Fig. 6(b) driven respectively by a single continuous VsVs cycle depicted in Fig 11(a) and (b) and a double discontinuous VsVs cycle depicted in Fig. (12) are equal from a thermodynamic perspective; the case studies are focused on the single continuous VsVs cycle model. This may result in lower self-sustaining index results than a model driven by a discontinuous double VcVc cycle because the former inherently requires a TWF feed pump, which absorbs some power.

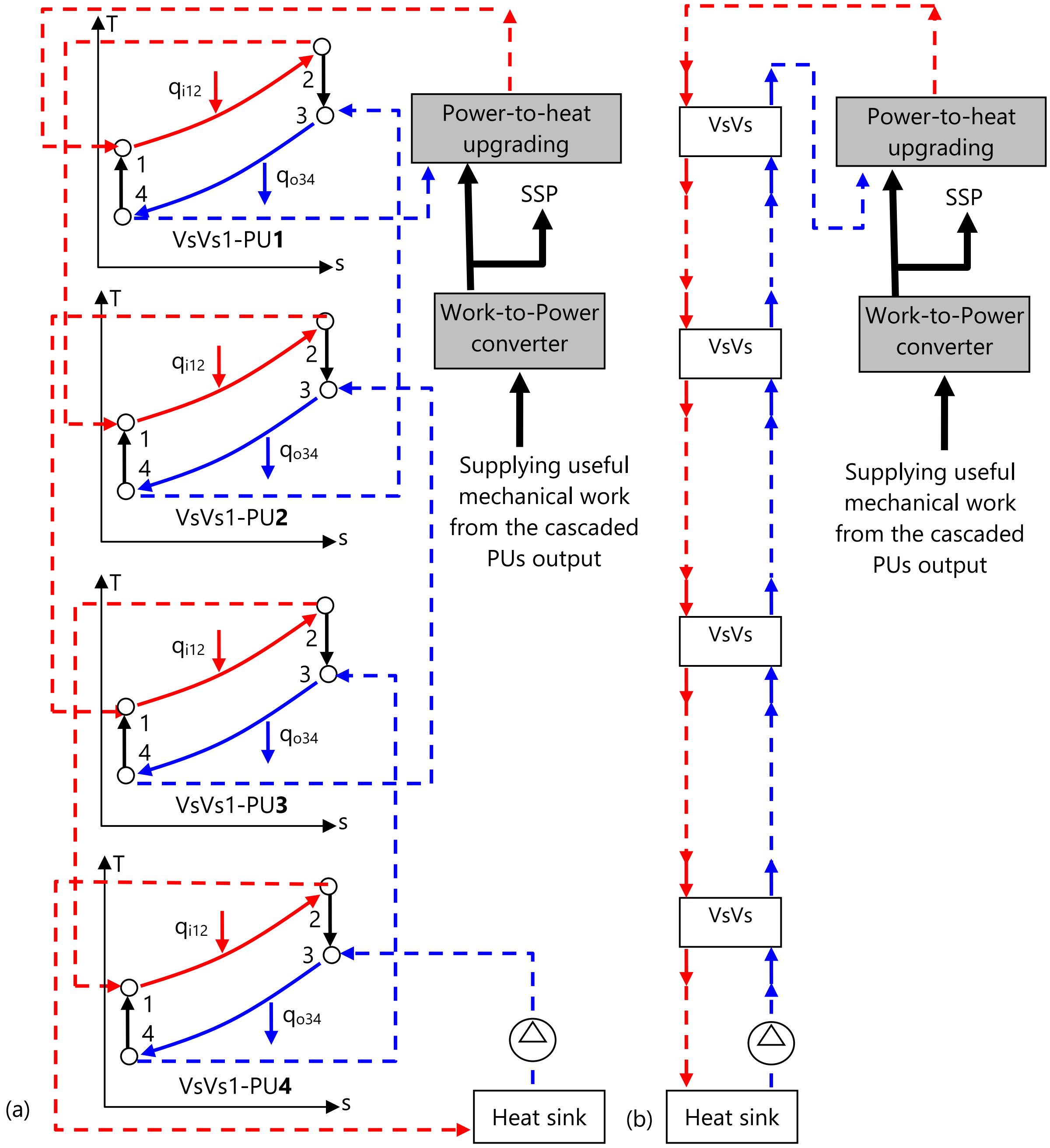

Figure 11: Illustration of the HTF (heating-cooling circuit) recirculation scheme for a SSPE consisting of a set of 4 Single PUs in a cascade-based continuous-motion VsVs cycle. While the detailed heat recirculation circuit through the VsVs cycle is shown in (a), the symbolic representation is shown in (b).

Therefore, Fig. 11 represents the HTF recirculation scheme for a SSPE consisting of a set of four individual PUs coupled in a cascade-based **continuous** motion VsVs cycle, where a detailed heat recirculation circuit through the VsVs cycle is shown in (a), while the symbolic representation is shown in (b).

In Fig. 12 it is depicted the HTF recirculation scheme for a SSPE consisting of a set of four double PUs coupled in a cascade-based **discontinuous** motion VsVs cycle.

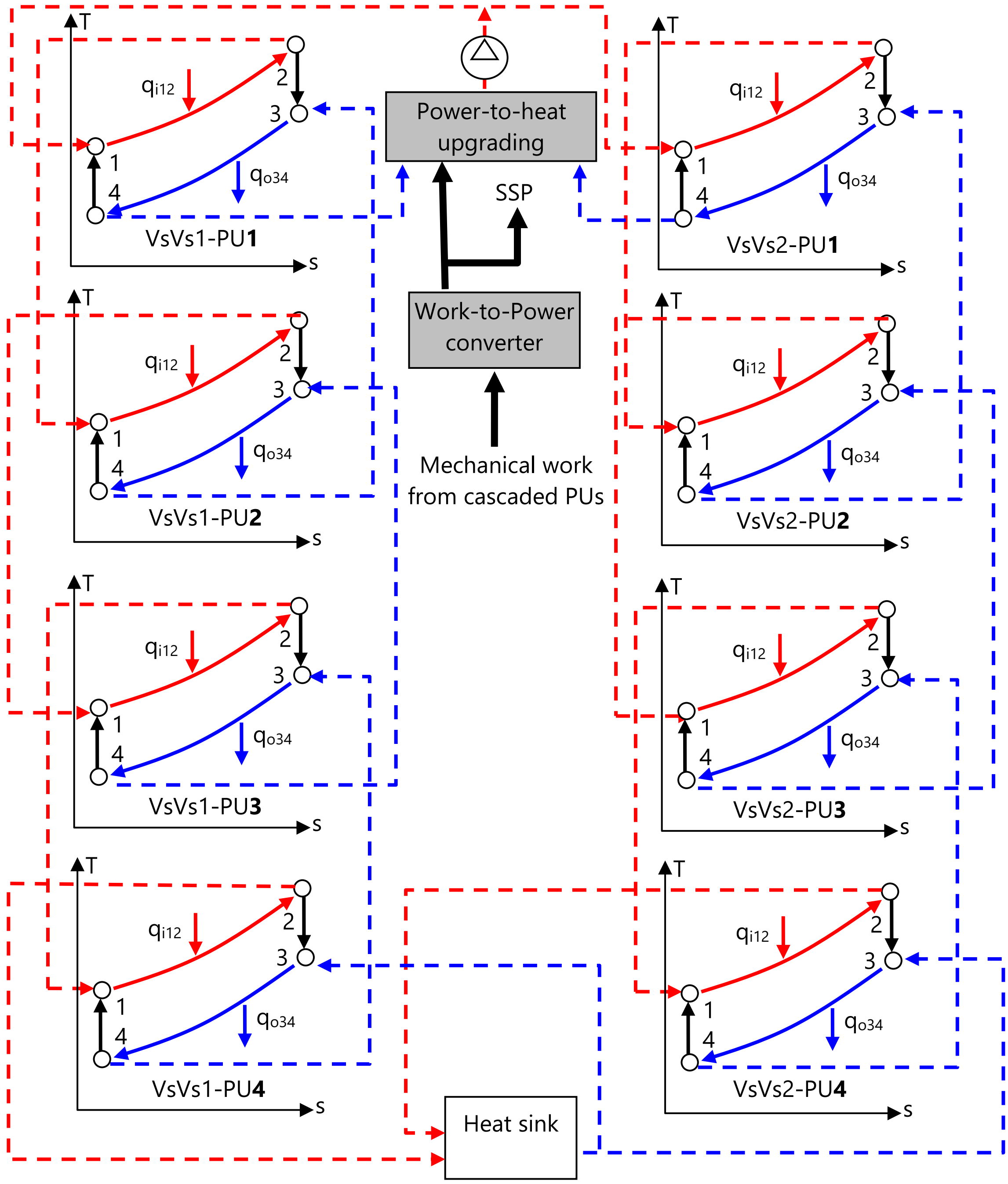

Figure 12: Illustration of the HTF (heating-cooling circuit) recirculation scheme for a SSPE consisting of a set of 4 Double PUs in a cascade-based discontinuous-motion VsVs cycles.

4.1 Studying the SSPEs prototype driven by a VsVs cycle for several constant values of the T_{drop} for several case studies.

In order to prototyping PPs based on SSPEs, helium has been selected as TWF for the four case studies. The thermodynamic data of the TWF is retrieved from [14]. Therefore, the case study proposed in Table 4 operates with a T_{drop} between cascaded PUs of 125 K. The case study proposed in Table 6 operates with a T_{drop} between cascaded PUs of 100 K. The case study proposed in Table 8 operates with a T_{drop} between cascaded PUs of 75 K. The case study proposed in Table 10 operates with a T_{drop} between cascaded PUs of 50 K. Tables 4, 6, 8 and 10 depict the thermodynamic data according with the VsVs cycle. The Tables 5, 7, 9, and 11 depicts the results of the analysis of the data depic6tedem in tables 4, 6, 8 and 10 respectively.

Table 4: Thermodynamic data of the VsVs cycle for T_{drop} = 125 K. Table data corresponds to the real gas Helium as TWF. Values are taken from NIST database [14].

PU1-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	675.00	20	0.70368	2109.30	25.997
2	800.00	23.7010	0.70368	2499.00	26.527
3	747.50	20	0.77892	2335.20	26.527
4	630.40	16.8690	0.77892	1970.20	25.997
qi_elect_PU1					**528.80**
PU2-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	550.00	20	0.57395	1719.80	24.934
2	675.00	24.5410	0.57395	2109.60	25.573
3	622.03	20	0.64870	1944.20	25.573
4	506.60	16.2910	0.64870	1584.30	24.934
PU3He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	425.00	20	0.4442	1330.20	23.595
2	550.00	25.8780	0.4442	1720.10	24.399
3	496.15	20	0.5181	1551.90	24.399
4	383.50	15.4610	0.5181	1200.60	23.595

Table 5: Results of a SSPE prototype designed for a T_{drop} = 125 using the data from Table 4

PUi	**1**	**2**	**3**	**Total:3 PU**
LF= MUF	0.85	0.85	0.85	
RF=TUF	0.8	0.8	0.8	
T2	800.00	675.00	550.00	
T4	506.6	383.5	383.50	
qi_elect_PU1				**528.80**
qi_12/PU	389.70	389.80	389.90	528.80
qo_34	365.00	359.90	351.30	
qo34_rec	365.00	359.90	351.30	1076.20
Tm_qrecov	688.95	564.32	439.83	
Wn	205.97	204.61	202.50	**TNW = 613.09**
η_th	52.85	52.49	51.94	
RW*100	84.92	81.92	77.05	
RIT*100	84.4	81.5	77.3	
Eff%				**115.94**
SSI				**15.94**

T_{drop} (K)	**125**
NEP(Net Electric Power) = Wn-qielect_PU1	**223.39**

Table 6: Thermodynamic data of the VsVs cycle for T_{drop} = 100 K. Table data corresponds to the real gas Helium as TWF using data from NIST database.

PU1-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	700.00	20	0.72962	2187.20	26.186
2	800.00	22.8550	0.72962	2499.00	26.602
3	758.38	20	0.79021	2369.10	26.602
4	663.6	17.5000	0.79021	2073.30	26.186
qi_elect_PU1					**425.70**
PU2-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	600.00	20	0.62584	1875.60	25.386
2	700.00	23.3300	0.62584	2187.40	25.866
3	658.14	20	0.68618	2056.80	25.866
4	564.30	17.1500	0.68618	1764.20	25.386
PU3He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	500.00	20	0.5221	1563.90	24.439
2	600.00	23.9940	0.5221	1875.80	25.008
3	557.89	20	0.5821	1744.40	25.008
4	464.80	16.6660	0.5821	1454.10	24.439
PU4-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	400.00	20	0.41830	1252.20	23.281
	500.00	24.9940	0.41830	1564.20	23.977
3	457.42	20	0.47788	1431.20	23.977
4	366.00	16.0060	0.47788	1146.10	23.281

Table 7: Results of a SSPE prototype designed for a T_{drop} = 100 using the data from Table 6

PU	**1**	**2**	**3**	**4**	**Total:4 PU**
LF=MUF	0.85	0.85	0.85	0.85	
RF=TUF	0.8	0.8	0.8	0.8	
T2	800.00	700.00	600.00	500.00	
T4	564.3	464.8	464.80	366.00	
qi_elect_PU1					**425.70**
qi_12/PU	311.80	311.80	311.90	312.00	425.70
qo_34	295.80	292.60	290.30	285.10	

qo34_rec	295.80	292.60	290.30	285.10	1163.80
Tm_qrecov	710.99	611.22	511.35	411.71	
Wn	165.78	164.56	164.02	162.59	**TNW = 656.95**
η_th	53.17	52.78	52.59	52.11	
RW*100	87.68	85.30	83.56	79.77	
RIT*100	87.5	85.7	83.3	80.0	
Eff%					154.32
SSI					54.32
T_{drop} (K)					**100**
NEP(Net ElectricPower) = Wn-qielect_PU1					**345.15**

Table 8: Thermodynamic data of the VsVs cycle for T_{drop} = 75 K. Table data corresponds to the real gas Helium as TWF using data from NIST database

PU1-He	T(K)	p(bar)	V(m³/kg)	u(kJ/kg)	s(kJ/kg.K)
1	725.00	20	0.75557	2265.10	26.368
2	800.00	22.0670	0.75557	2499.00	26.675
3	769.11	20	0.80136	2402.60	26.675
4	697	18.1260	0.80136	2177.80	26.368
qi_elect_PU1					**321.20**
PU2-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	650.00	20	0.67773	2031.40	25.801
2	725.00	22.3060	0.67773	2265.30	26.142
3	694.08	20	0.72347	2168.80	26.142
4	622.00	17.9250	0.72347	1944.00	25.801
PU3He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	575.00	20	0.5999	1797.70	25.165
2	650.00	22.6060	0.5999	2031.50	25.547
3	618.92	20	0.6455	1934.60	25.547
4	547.30	17.6870	0.6455	1711.20	25.165
PU4-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	500.00	20	0.52206	1563.90	24.439
	575.00	22.9970	0.52206	1797.80	24.875
3	543.78	20	0.56750	1700.40	24.875
4	473.00	17.3990	0.56750	1479.70	24.439
PU5-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	425.00	20	0.44424	1330.20	23.595

	500.00	23.5250	0.44424	1564.10	24.102
3	468.56	20	0.48944	1466.00	24.102
4	398.20	16.99900	0.48944	1246.50	23.595
PU6-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	350.00	20	0.36642	1096.40	22.587
	425.00	24.2800	0.36642	1330.30	23.193
3	393.31	20	0.41136	1231.40	23.193
4	324.00	16.47800	0.41136	1015.20	22.587

Table 9: Results of a SSPE prototype designed for a T_{drop} = 75 using the data from Table 8

PU	**1**	**2**	**3**	**4**	**5**	**6**	**Total:6 PU**
LF=MUF	0.85	0.85	0.85	0.85	0.85	0.85	
RF=TUF	0.8	0.8	0.8	0.8	0.8	0.8	
T2	800.00	725.00	650.00	575.00	500.00	425.00	
T4	622	547.3	547.30	473.00	398.20	324.00	
qi_elect_PU1							**321.20**
qi_12/PU	233.90	233.90	233.80	233.90	233.90	233.90	321.20
qo_34	224.80	224.80	223.40	220.70	219.50	216.20	
qo34_rec	224.80	224.80	223.40	220.70	219.50	216.20	1329.40
Tm_qrecov	733.06	658.04	583.11	508.39	433.38	358.66	
Wn	124.92	125.05	124.71	123.49	123.62	122.47	**TNW** = 744
η_th	53.41	53.46	53.34	52.80	52.85	52.36	
RW*100	90.56	90.57	89.27	86.45	85.32	82.10	
RIT*100	90.6	89.7	88.5	87.0	85.00	82.35	
Eff%							231.71
SSI							131.71
T_{drop} (K)							**75**
NEP(Net ElectricPower) = Wn-qielect_PU1							**510.36**

Table 10: Thermodynamic data of the VsVs cycle for Tdrop = 50 K. Table data corresponds to the real gas Helium as TWF using data from NIST database.

PU1-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	750.00	20	0.78152	2343.00	26.544
2	800.00	21.3320	0.78152	2498.90	26.746
3	779.70	20	0.81235	2435.60	26.746
4	731	18.7510	0.81235	2283.80	26.544

qi_elect_PU1					215.10
PU2-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	700.00	20	0.72962	2187.20	26.186
2	750.00	21.4280	0.72962	2343.10	26.401
3	729.58	20	0.76032	2279.40	26.401
4	680.70	18.6610	0.76032	2127.00	26.186
PU3He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	650.00	20	0.6777	2031.40	25.801
2	700.00	21.5370	0.6777	2187.30	26.032
3	679.53	20	0.7084	2123.40	26.032
4	630.70	18.5630	0.7084	1971.20	25.801
PU4-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	600.00	20	0.62584	1875.60	25.386
	650.00	21.6650	0.62584	2031.50	25.635
3	629.50	20	0.65646	1967.50	25.635
4	581.00	18.4600	0.65646	1816.30	25.386
PU5-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	550.00	20	0.57395	1719.80	24.934
	600.00	21.8170	0.57395	1875.70	25.205
3	579.47	20	0.60453	1811.60	25.205
4	531.00	18.32900	0.60453	1660.50	24.934
PU6-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	500.00	20	0.52206	1563.90	24.439
	550.00	21.9980	0.52206	1719.90	24.736
3	529.42	20	0.55259	1655.60	24.736
4	481.00	18.17200	0.55259	1504.60	24.439
PU7-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	450.00	20	0.47018	1408.10	23.892
	500.00	22.2200	0.47018	1564.00	24.221
3	479.43	20	0.50072	1499.80	24.221
4	431.40	17.99800	0.50072	1350.00	23.892
PU8-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	400.00	20	0.41830	1252.20	23.281
	450.00	22.4970	0.41830	1408.20	23.648
3	429.33	20	0.44874	1343.70	23.648

4	381.70	17.78300	0.44874	1195.10	23.281
PU9-He	**T(K)**	**p(bar)**	**V(m³/kg)**	**u(kJ/kg)**	**s(kJ/kg.K)**
1	350.00	20	0.36642	1096.40	22.587
	400.00	22.8540	0.36642	1252.40	23.004
3	379.26	20	0.39678	1187.60	23.004
4	331.80	17.49900	0.39678	1039.50	22.587

Table 11: Results of a SSPE prototype designed for a T_{drop} = 50 using the data from Table 10

PU	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total:9 PU**
LF=MUF	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	
RF=TUF	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
T2	800.00	750.00	700.00	650.00	600.00	550.00	500.00	450.00	400.00	
T4	680.7	630.7	630.70	581.00	531.00	481.00	431.40	381.70	331.80	
qielect_PU1										**215.10**
qi_12/PU	155.90	155.90	155.90	155.90	155.90	156.00	155.90	156.00	156.00	215.10
qo_34	151.80	152.40	152.20	151.20	151.10	151.00	149.80	148.60	148.10	
qo34_rec	151.80	152.40	152.20	151.20	151.10	151.00	149.80	148.60	148.10	1356.20
Tm_qrecov	755.35	705.14	655.12	605.25	555.24	505.21	455.42	405.52	355.53	
Wn	83.30	84.25	84.39	83.84	83.91	84.05	83.16	82.69	83.30	**TNW = 752.90**
η_th	53.43	54.04	54.13	53.78	53.82	53.88	53.34	53.01	53.05	
RW*100	93.52	94.51	94.21	92.66	92.51	92.22	90.50	88.53	87.81	
RIT*100	93.8	93.3	92.9	92.3	91.67	90.91	90.00	88.89	87.50	
Eff%										350.02
SSI										250.02
T_{drop} (K)										**50**
NEP(Net Electric Power) = Wn-qielect_PU1										**597.00**

Table 12: Summary of prototypes main results

T_{drop} (K)	125	100	75	50
N. PUs	3	4	6	9
SSI	15.94	54.32	131.71	250.02
q_ielect_PU1 (kJ/kg)	528.80	425.70	321.20	215.10
TNW	613.09	656.95	744.26	752.90
NEP (kJ/kg)	223.39	345.15	510.36	597.00

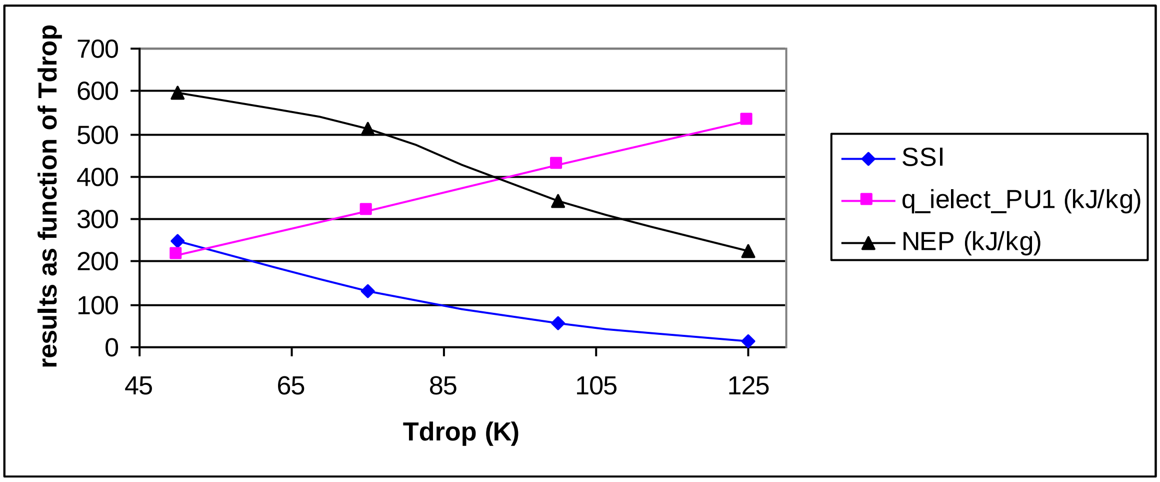

Figure 13: Illustration of the summary of the main results of the prototypes studied retrieved from Table 11.

As depicted in Fig. 13, the value chosen for the temperature drop (T_{drop}) between cascaded PUs within the operating temperature range influences the prototype structure with the following effects:

a The number of PUs in the cascade **decreases** as the value of T_{drop} increases.

b The Self-Sufficiency Index (SSI) **decreases** as the value of T_{drop} increases.

c The amount of heat required to power the first PU in the cascade **increases** as the value of T_{drop} increases.

d The net electrical energy (NPE) **decreases** as the value of T_{drop} increases.

As can be seen in Table sss, the difference between the net mechanical work (TNW) produced by the cascade of power units (SSPE) and the net electrical energy (NEP) in each cycle is used to power the primary power unit downstream of the cascade in the form of heat. This difference is also observed to be aligned with the constant T_{drop} value assigned to each power unit in the cascade.

According to the results shown in Table 12 and illustrated in Fig. 13, the smaller the temperature drop between each PU in the cascade, the smaller the difference between the heating and cooling heats of each VsVs cycle. Ideally, this temperature difference should be zero, meaning that the heating and cooling heats would be equal. However, this condition requires a very high number of PUs, making the design infeasible. We estimate that a temperature drop (T_{drop}) of 50 K is an acceptable value to implement a prototype with 9 PUs. It maintains the structural symmetry of the SSPE while providing a high NEP.

5 Analysis of Results

The analysis of results considers the key findings derived from the proposed case studies. This analysis highlights the article's innovative approach while underscoring the need for empirical evidence to support its revolutionary claims through the implementation of prototypes validated through experimental testing.

5.1 Theoretical Foundation

a **Disruptive Thermodynamics**: The paper challenges conventional thermodynamics by proposing that **"pull" (traction) forces**—generated by cooling-induced vacuum—can produce useful mechanical work without direct energy input. This contradicts the First Law of Thermodynamics (FLT) but is argued to be experimentally observable.

b **Self-Sufficiency Mechanism**:

The proposed **Self-Sufficient Power Engines (SSPEs)** combine:

Expansion work (push forces, FLT-aligned).

Contraction work (pull forces, FLT-misaligned, enabled by cooling).

Heat recovery (reusing extracted heat to sustain the cycle).

5.2 Prototype Performance

The study evaluates SSPE prototypes with cascaded Power Units (PUs) using helium as the Thermal Working Fluid (TWF). Key metrics:

Self-Sustaining Index (SSI): Measures net free energy as a percentage.

Net Electric Power (NEP): Self-sufficient output after powering the first PU.

Temperature Drop (T_{drop}): The temperature difference between cascaded PUs.

Table 13: Summary of prototypes main results readapted from Table 12

Case Study	T_{drop} (K)	No. of PUs	SSI (%)	NEP (kJ/kg)	TNW (kJ/kg)	TNW-NEP
1	125	3	15.94	223.39	613.09	389.7
2	100	4	54.32	345.15	656.95	311.8
3	75	6	131.71	510.36	744.26	234.24
4	50	9	250.02	597.00	752.90	155.9

Table 13 represents the same aspects considered in Table 12. The duplication of tables 13 and 12 is due to the need to avoid confusion in the interpretation of table 12. The aim is to promote understanding by changing the order of parameters in table 13. The differences between TNW and NEP represent the amount of energy used in the thermo mechanical management of the plant considered.

It is observed that the lower the number of PUs in the plant, the greater the amount of energy required to maintain self-sustainment. This means that the value of the (TNW—NEP) difference varies inversely with the SSI index and therefore with the value of the net energy NEP.

5.3 Critical Observations

Trade-off Between T_{drop} and Efficiency:

Higher T_{drop} (e.g., 125 K): Fewer PUs, lower SSI, and lower NEP.

Lower T_{drop} (e.g., 50 K): More PUs, higher SSI, and higher NEP (approaching self-sufficiency).

Thermal Efficiency: Ranges from **52% to 54%**, exceeding Carnot limits due to contraction work.

Heat Recovery: Up to **1356.20 kJ/kg** of heat is reused in the 50 K case, reducing external energy needs.

5.4 Validation & Challenges

Experimental Validation: The paper references patents (e.g., P202400002) and prior work but lacks empirical data from physical prototypes. As consequence, rigorous experimental validation should be performed by means of the proposed prototype.

Thermodynamic Controversy:

FLT Violation: Contraction work increases internal energy while producing output work, defying classical energy conservation.

Second Law Implications: The SSPE's efficiency claims challenge Carnot's theorem, requiring further scrutiny.

5.5 Practical Implications

Feasibility: A **Tdrop of 50 K with 9 PUs** suggested as optimal for prototyping, balancing complexity and performance.

Applications: Potential for **off-grid power systems**, space exploration (e.g., Mars/Moon missions), and industrial energy recovery.

6 General Conclusions

It is essential to emphasize that the conclusions depend on experimental validation to reconcile them with classical thermodynamics and at the same time open new energy frontiers that support disruptive changes with systematic assumptions. Therefore, this proposal explores the development of **Self-Sufficient Power Engines (SSPEs)** by harnessing **"pull" forces** generated through **cooling-induced vacuum**, a concept that challenges conventional thermodynamic principles. The study demonstrates that mechanical work can be produced not only by heat addition (expansion) but also by **heat extraction (contraction)**, enabling energy generation without direct input—potentially leading to self-sustaining power systems.

Key Findings & Innovations:

1 Disruptive Thermodynamics:

Traditional heat engines rely on **push forces** (expansion), but SSPEs leverage **pull forces** (contraction via cooling), violating classical energy conservation (First Law of Thermodynamics) in controlled conditions.

Adiabatic contraction increases internal energy while producing work, contradicting standard energy balances but enabling higher efficiencies.

2 Prototype Performance:

A **cascade of nine Power Units (PUs)** achieved a **Self-Sufficiency Index (SSI) of 250%** (net output exceeds input by 2.5×) and **597 kJ/kg net electrical power per cycle**.

Smaller temperature drops (**Tdrop = 50 K**) between cascaded PUs improve efficiency but require more units.

3 Heat Recovery & Efficiency:

Upgrading waste heat from cooling processes allows reuse, reducing external energy needs.

Thermal efficiency (52–54%) exceeds Carnot limits due to dual work extraction (expansion + contraction).

4 Validation Challenges:

Experimental evidence supports traction forces, but completely challenging the FLT requires further empirical testing before being "de facto" refuted.

Patents and simulations validate feasibility, but real-world prototypes must address irreversibilities although some irreversibilities have been assumed in the case studies.

5. Implications & Future Work:

Energy Independence: SSPEs could enable off-grid power, space missions, or industrial applications without any type of fuel.

6. Scientific Debate: Challenges to thermodynamic laws necessitate peer-reviewed experimental verification.

Optimization: Future work should refine **T_{drop} values**, **PU cascading strategies**, and available cost effective **materials** for practical deployment.

7. Final Takeaway:

This research presents a **paradigm shift** in energy conversion, proposing **self-sustaining engines** via pull forces and cascaded heat recovery. While theoretical and patented, physical prototypes must confirm viability, potentially revolutionizing power generation if proven scalable.

References

1. Ramon Ferreiro Gracia, Jose Carbia Carril, Manuel Romero Gómez and Javier Romero Gómez. Energy and entropy analysis of closed adiabatic expansion based trilateral cycles. Energy Conversion and Management 119 (2016) 49–59. http://dx.doi.org/10.1016/j.enconman.2016.04.031.

2. Ramon Ferreiro Garcia. Reply to: Comment on ''Energy and entropy analysis of closed adiabatic expansion based trilateral cycles" by Garcia et al. Energy Conversion and Management 119 (2016) 49–59. Energy Conversion and Management 123 (2016) 646–648. http://dx.doi.org/10.1016/j.enconman.2016.06.05.

3. Ramon Ferreiro Garcia, Jose Carbia Carril. Combined Cycle Consisting of Closed Processes Based Cycle Powered by A Reversible Heat Pump that Exceed Carnot Factor. Journal of Advances in Physics, Volume 15, (2018), Pages: 6078-6100. ISSN: 2347-3487. DOI: https://doi.org/10.24297/jap.v15i0.8034.

4. Ramon Ferreiro Garcia. Study of the disruptive design of a thermal power plant implemented by several power units coupled in cascade. Energy Technol. 2023, 2300362 (1-17). Published by Wiley-VCH GmbH. DOI: https://doi.org/10.1002/ente.202300362.

5. Ramón Ferreiro Garcia. Efficient disruptive power plant-based heat engines doing work by means of strictly isothermal closed processes. Journal of Advances in Physics Vol 22 (2024), p 30.53, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9587. DOI: https://doi.org/10.24297/jap.v15i0.9587.

6. Ramón Ferreiro Garcia. Design study of a disruptive self-powered power plant prototype. Journal of Advances in Physics Vol 22 (2024), p 62.92, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9596. DOI: https://doi.org/10.24297/jap.v22i.9596.

7. Ramón Ferreiro Garcia. Prototyping a Disruptive Self-Sustaining Power Plant enabled to overcome Perpetual Motion Machines. Journal of Advances in Physics Vol. 22 (2024), p 141.178, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/963. DOI: https://doi.org/10.24297/jap.v22i.9633.

8. Ramón Ferreiro Garcia. Prototyping Self-Sustaining Power Machines with Cascaded Power Units Composed by Pulse Gas Turbines. Journal of Advances in Physics Vol. 22 (2024), p 141.178, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9648. DOI: https://doi.org/10.24297/jap.v22i.9648

9. Ramón Ferreiro Garcia. Prototyping disruptive self-sufficiency power machines composed by cascaded power units based on thermo-hydraulic actuators. Journal of Advances in Physics Vol 22 (2024), p 141.178, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9662. DOI: https://doi.org/10.24297/jap.v22i.9662.

10. Ramón Ferreiro Garcia. How to violate the first law of thermodynamics with an ASE of Papain and Newcomen before it was stated by Clausius. JOURNAL OF ADVANCES IN PHYSICS, 23, 9–27. (2025) https://doi.org/10.24297/jap.v23i.9706

11. Ramon Ferreiro Garcia. Power Plants and Cycles: Advances and trends. Book (2020): ISBN: 9789390431595; DOI:10.9734/bpi/mono/978-93-90431-59-5. https://www.researchgate.net/publication/347635047_Power_Plants_and_Cycles_Advances_and_Trends

12. Ramon Ferreiro Garcia. Preliminary design task for prototyping Self-Sustaining Power Machines on Mars using local resources. Journal of Advances in Physics,23, 83-115. (2025) https://doi.org/10.24297/jap.v23i.9737

13. Ramon Ferreiro Garcia. Prototyping Studies for Self-Sufficient Power Machines with local resources from the Moon. Journal of Advances in Physics, 23, 116-146 (2025) https://doi.org/10.24297/jap.v23i.9747

14 E. W. Lemmon, M. L. Huber, M. O. McLinden, NIST Reference Fluid Thermodynamic And Transport Properties - REFPROP Version 8.0, User's Guide, NIST, Boulder, CO. 2007.

15. Patente: Máquina térmica alternativa regenerativa de doble efecto, de procesos cerrados y abiertos y su procedimiento de operación. "Regenerative double-effect heat engine, with closed and open processes and its operating procedure". Ramon Ferreiro Garcia, Jose Carbia Carril. University of A Coruna. Número de solicitud: P201700181. Accessed at:

https://consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=qzBIO1KHmr9+xjw8ggw8YH5X.ConsultasC1.

16. Patent: Planta térmica con máquina de doble efecto, acumuladores térmicos, convección forzada y alimentación térmica reforzada con un ciclo Brayton inverso y procedimiento de operación. Thermal power plant with double-effect machine, thermal accumulators, forced convection and reinforced thermal supply with a reverse Brayton cycle and operating procedure. Ramon Ferreiro Garcia, Jose Carbia Carril. application number P201700667 and publication number 2 696 950 B2. Accessed at: https://consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=MDkG1OIa9BfQrxSiImwxtYIC.ConsultasC2.

17. Patent: Procedimiento de operación de una máquina alternativa de doble efecto con adición y extracción de calor y convección forzada. Operating procedure of a double-acting reciprocating machine with heat addition and extraction and forced convection and operating procedure. Jose Carbia Carril, Ramon Ferreiro Garcia, application number P201700718 and publication number 2 704 449 B2. Accessed at: https://consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=-wHy58sbfVYQutIYN8s0+JKK.ConsultasC1.

18. Patent: Planta termoeléctrica multiestructural policíclica y procedimientos de operación. "Polycyclic multi-structure thermal power plant and operating procedures". Ramon Ferreiro Garcia, Application number: P202200035 and publication number 2 956 342 B2. Accessed at: https://consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=-wHy58sbfVYQutIYN8s0+JKK.ConsultasC1. https://www.researchgate.net/publication/347635047_Power_Plants_and_Cycles_Advances_and_Trends

19. Patente: Sistema de transferencia de calor para calentar y enfriar módulos de potencia acoplados en cascada de plantas termoeléctricas y procedimiento de operación. ": Heat transfer system for heating and cooling cascade-coupled power modules of thermoelectric plants and operating procedure". Ramon Ferreiro Garcia. Application number: P202400002. Accessed at: https://consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=qzBIO1KHmr9+xjw8ggw8YH5X.ConsultasC1.