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Improving the design of self-sustaining power plant prototypes through profit optimization

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Abstract:

This study investigates disruptive technological pathways for the optimal design of self-sustaining thermal power systems. It focuses on unconventional "vacuum-induced pulling forces," a phenomenon largely overlooked by traditional thermodynamics, where cooling a thermal working fluid (TWF) generates a vacuum and produces mechanical work without direct thermal energy input. This mechanism challenges foundational principles, including the First Law of Thermodynamics (FLT), energy conservation, Carnot's theorem, and exergy concept definitions.

The research aims to refine the design methodology for Self-Sustaining Power Plants (SSPPs) by optimizing the constant temperature drop (ΔT) between cascaded Power Units (PUs). This strategy facilitates the use of identical PUs, minimizing the number of units required while maximizing life-cycle benefits. A constant ΔT is critical for ensuring consistent useful work output under a constant heat input. The primary objective is to determine the optimal number of cascaded PUs that maximizes the system's self-sufficiency index and overall performance.

Design results indicate that the optimal SSPP configuration, achieving a peak self-sufficiency index, utilizes 8 to 9 cascaded PUs for a ΔT between 40–50 K. This approach simplifies mechanical structure and reduces design, implementation, and operational costs, offering a feasible and disruptive pathway toward truly autonomous energy systems.

Keywords: Self-Sustaining Power, Cascaded Power Units, Constant Temperature Drop, Vacuum-Induced Pulling Forces, Optimal Design, Thermodynamic Disruption.

Nomenclature related to general VsVs cycles and SSPPs

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)
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 subscript 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)
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
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
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.
TUF	Thermal utilization factor (%)
TWF	Thermal Working fluid (a gas with high adiabatic expansion coefficient like helium, argon..)
VsVs	Cycle with the sequential processes: Isochoric **V**, adiabatic **s**, Isochoric **V**, adiabatic **s**: [**VsVs**]

Nomenclature related to the optimization process

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,
T_{drop}=T_D	drop or jump in temperatures between each two power units [$T_{drop} = \cdot T_2(1 - RIT)$]
T_R	Range of temperatures between TH and TL. $T_R = T_H - T_L$
NPU	Number of PUs associated with the cascaded PUs of a SSPP; $NPUs \approx \frac{T_H - T_L}{T_D} = \frac{T_R}{T_D}$
TNW	Total net work delivered by the cascaded PUs; TNW ; $T_R \cdot 2 \cdot \eta_{th} \cdot Cv$
η_{th} (%)	conversion efficiency from heat added to output useful work: $\eta_{th} = w_o / q_i$
η_{EL} (%)	conversion efficiency from work to electric power
EP(kJ/kg)	Total output Electric Power: $EP \approx TNW \cdot \eta_{EL} \approx T_R \cdot 2 \cdot Cv \cdot \eta_{th} \cdot \eta_{EL}$
NEP	Net Electric Power (difference between EP and the heat added to the first cascaded PU yields): $NEP \approx 2 \cdot Cv \cdot T_D \cdot (NPU \cdot \eta_{th} \cdot \eta_{EL} - 1)$
EIC	Expenses index coefficient (this coefficient is used to align the expenses and revenues sub-functions when EIC = 1.
RIC	Revenues index coefficient: RIC=1 if EIC is adjusted accordingly
F_{exp}	Expenses sub- function; $F_{\exp} = EIC \cdot NPU$
F_{rev}	Revenues sub-function $F_{rev} = RIC \cdot NEP$

F_{prof}	profit function (optimization function); $F_{prof} = F_{rev} - F_{exp} = RIC \cdot NEP - EIC \cdot NPU$	
Symbols/units	***description***	
p(bar)	pressure	
q_i(kJ/kg)	specific heat in to a cycle process	
q_{i23} (kJ/kg)	Input heat to cycle process 2-3	
q_o(kJ/kg)	specific heat out from a cycle process	
q_{o41} (kJ/kg)	output heat from cycle 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_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 ($w_{oexp} + w_{ocont}$) = ($w_{o23} + w_{o41}$) in an VsVs thermal cycle	
q_{rec}/PUi(kJ/kg	Heat recovered from every PU from cooling cycles processes	
η_{th} (%)	Cycle thermal efficiency (w_n/qi)	

1 Introduction

The pursuit of self-sustaining power plants (SSPPs) represents a paradigm shift in energy conversion. This research enhances SSPP design methodology by optimizing a benefit function to determine the ideal constant temperature drop (ΔT) and number of cascaded Power Units (PUs). This enables implementation with identical PUs, minimizing complexity while maximizing life-cycle benefits

A key requirement for efficient SSPPs is maintaining a constant and optimal ΔT between each cascaded PU. This ensures a consistent useful work output from each unit under a constant heat input. The core challenge is to develop an optimization function that determines the optimal number of PUs within a defined operational temperature range (TR), maximizing system self-sufficiency and performance.

Power Units (PUs) are the fundamental components of any SSPP, implemented as either Single-Acting (SARA) or Double-Acting (DARAs) Reciprocating Actuators. These actuators harness nature's fundamental forces—repulsion and attraction—to perform work:

SARA: Utilizes repulsion (push) and attraction (pull) forces sequentially.

DARA: Utilizes repulsion and attraction forces simultaneously, effectively doubling the total force per stroke.

Both types enable useful mechanical work through two distinct mechanisms:

a) Push Forces: Generated by positive pressure from heating a TWF.

b) Pull Forces: Generated by negative pressure (vacuum) from cooling a TWF.

Although their causes are independent, push and pull forces produce equivalent effects in terms of energy potential, momentum, and mechanical work, playing a crucial role in the proposed disruptive energy transformations.

1.1. Background and Previous Innovations

Prior innovations [1-5, 6-14, 15, and 16-20] have laid the groundwork for SSPPs by introducing key concepts that challenge traditional thermodynamic models:

Vacuum-Based Work Generation: Mechanical work is produced through vacuum-induced contraction of a TWF upon cooling, eliminating the need for phase changes.

Advanced Thermodynamic Cycles: Utilization of unconventional cycles (e.g., VTVT, sVsVs, VsVs) that leverage vacuum-induced pulling forces to enhance conversion efficiency.

Cascaded Power Units: Sequential coupling of PUs allows for heat recovery from upstream units to be reused downstream, achieving high thermal efficiency (up to 59.8% for air, 66.7% for helium) and heat utilization factors exceeding 85%.

Heat Superposition and Regeneration: Techniques to upgrade and regenerate recovered heat, further improving thermal performance.

Pulse-Based Gas Turbines: Configurations using these as core components, optimized for self-sufficiency when cascaded.

Diverse Working Fluids: Experimentation with gases like air, argon, and helium to tailor system performance.

Forced Convection Heat Transfer: Enhances cycle control and efficiency during heat addition and extraction.

Modular and Scalable Design: The cascaded architecture supports adaptability to various energy needs.

Self-Sustaining Potential: These systems aim to produce more mechanical work than the heat input, challenging conventional thermodynamic boundaries.

While promising, these claims necessitate rigorous experimental validation. This underscores the critical need for prototype implementation, which is encouraged by the open availability of the underlying patents for global manufacturing.

1.2 Thermal Energy and Work: A Conceptual Overview

The disruptive advance toward self-sufficient heat engines hinges on overcoming several milestones [14]:

a) A Thermal Working Fluid (TWF) with a high adiabatic expansion coefficient.

b) The ability to perform mechanical work via pulling forces generated by cooling the TWF.

c) The efficient recovery and conversion of cooling heat into useful work.

d) The use of cascaded PUs operating with an optimal, constant temperature drop (ΔT) to maximize benefits.

e) Central to this concept is the exploitation of vacuum-induced pulling forces. Its importance stems from two key attributes:

1) Vacuum generation through cooling is potentially feasible without direct energy cost.

2) It can produce useful mechanical work comparable to that obtained by heating.

These conditions are foundational to SSPPs. Both push (from heating) and pull (from cooling) forces can be harnessed additively through efficient heat transfer.

Fundamentals of a SARA Actuator

Fig. 1 illustrates a Single-Acting Reciprocating Actuator (SARA) operating with a single VsVs-type cycle. Its operation requires:

a) A TWF confined within the cylinder chamber.

b) Equipment to add heat to the TWF (heating).

c) Equipment to extract heat from the TWF (cooling).

d) Valves system control equipment to drive a Vsvs cycle

The operating cycle consists of four closed processes:

a) Isochoric Heat Addition (1-2): Piston locked. Heating the TWF increases temperature, pressure, and entropy.

b) Adiabatic-isentropic Expansion (2-3): Piston unlocked. The high-pressure TWF expands, doing useful work via push forces, decreasing temperature and pressure at constant entropy.

c) Isochoric Heat Extraction (3-4): Piston locked. Cooling the TWF decreases temperature, pressure, and entropy.

d) Adiabatic-isentropic Contraction (4-1): Piston unlocked. The vacuum pulls the piston inward, doing useful work via pull forces, increasing temperature and pressure at constant entropy.

A critical observation from process (4-1) is that useful work is performed simultaneously with an **increase** in the internal energy of the TWF—a phenomenon that appears to contradict the First Law of Thermodynamics (FLT), which states that **work done by a closed system, should decrease its internal energy.**

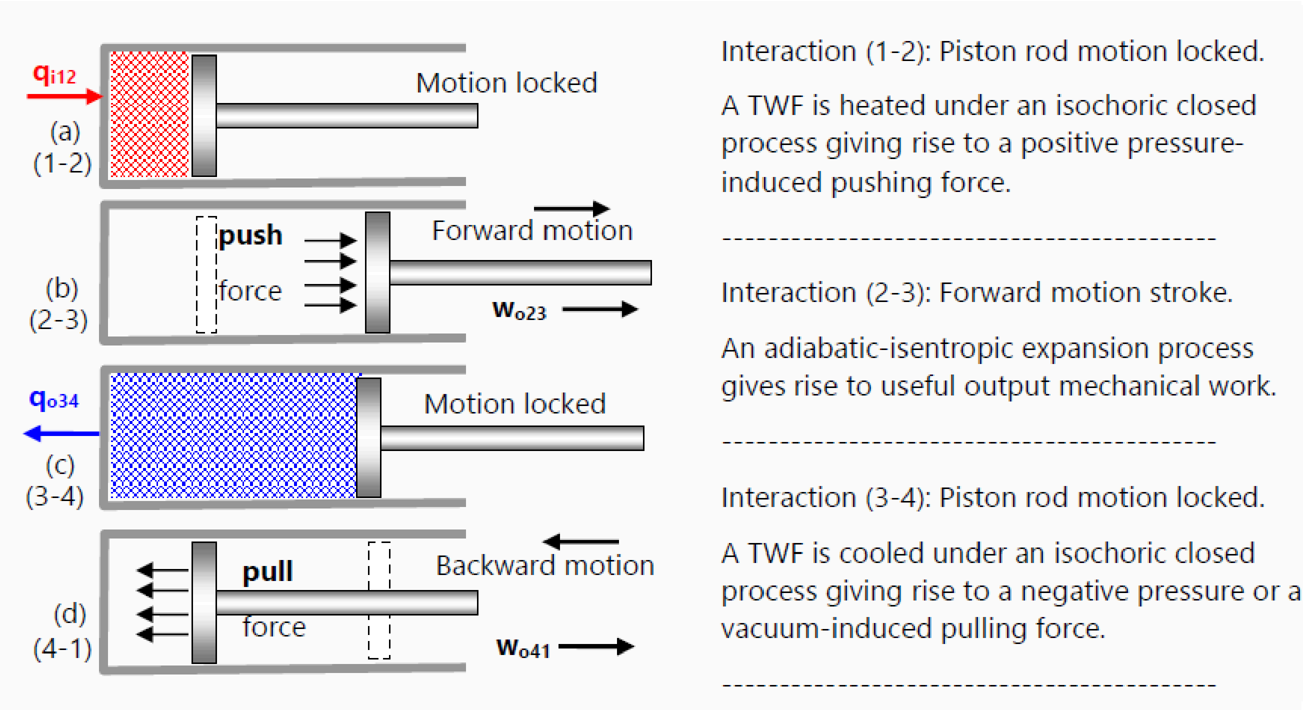

Figure 1: Illustration of the operation mode of a SARA driven by a thermal cycle of the type VsVs operating with closed system-based processes, composed of four thermal interaction processes: isochoric heat addition, adiabatic expansion by push forces, isochoric heat extraction, and adiabatic contraction by pulling forces. It should be noted that the work of contraction under pulling forces is achieved through heat extraction, i.e., through cooling, which does not entail any energy costs.

A sequence of closed processes carried out into a SARA is depicted in Table 1. The tasks carried out between every change of state points are illustrated. The effects of adding and extracting heat are depicted, the consequences on internal energy, forces, causes of doing work and work done is presented.

Table 1: Illustration of a sequence of closed processes carried out into the cylinder chamber of a SARA obeying a sequence of closed processes VsVs

State Points	Closed Process	Internal energy	Forces	Cause of work	Work out
1-2	Isochoric heat addition	Δu_{12} increases			$+\Delta u_{12}$
2-3	Adiabatic expansion	Δu_{23} decreases	Push	heating induced expansion	$W_{o23}=\Delta u_{23}= Cv.(T_2-T_3)$
3-4	Isochoric heat extraction	Δu_{34} decreases			$-\Delta u_{34}$
4-1	Adiabatic contraction	Δu_{41} **increases**	**pull**	cooling induced contraction	$Wo_{41}=\Delta u_{41}= Cv.(T_1-T_4)$

The resulting useful mechanical work as response to changes in internal energy induced by changes of temperatures of the TWF is highlighted. Observing the adiabatic process carried out between state points 4-1 follows that a useful pulling force is produced while at same time internal energy increases. This phenomenon is not aligned with FLT. It should be noted that the mechanical work done by the piston through vacuum-induced pulling forces is due exclusively to the extraction of heat and therefore has no energy cost because no heat addition has been necessary.

1.3. Relevance of Forces in Heat-Work Interactions

All fundamental forces in nature manifest as **push** (repulsion) or **pull** (attraction). The capacity to perform mechanical work arises from a potential difference in an intensive physical property (e.g., thermal, electrical, gravitational among others). Conversely, a potential difference in an intensive physical property (e.g., thermal, electrical, gravitational) exhibits the ability to perform mechanical work.

Therefore, in thermal systems:

a) **Push Forces:** are produced by a positive thermal potential (increased pressure from heating).

b) **Pull Forces:** are produced by a negative thermal potential (vacuum from cooling).

Consequently, mechanical work is the fundamental link converting one form of energy potential to another. Therefore, adding or extracting heat from a TWF creates a thermal potential (internal energy change) that can be converted into push/pull forces and mechanical work.

1.4. Thermodynamic Modeling: A Challenge to Conventional Theory

The thermodynamic analysis reveals a fundamental inconsistency.

Heating-Induced Work (Aligned with the FLT):

In a cycle driven by push forces (e.g., processes 1-2-3), the energy balance holds:

`Net Work Output = Net Heat Input`

This aligns perfectly with the FLT.

Cooling-Induced Work (Misaligned with the FLT):

In a cycle incorporating pull forces (e.g., processes 3-4-1), the energy balance is violated. For the adiabatic contraction (4-1):

Observed Fact: Useful work (`$W_{out}$`) is performed by the system *and* the internal energy (`$\Delta U$`) increases.

Conventional FLT Expectation: `$\Delta U = Q - W_{out}$`. For an adiabatic process (`$Q=0$`), this simplifies to `$\Delta U = -W_{out}$`, meaning work output must result in a decrease of internal energy.

The observed reality leads to:

`$W_{out} > 0$` and `$\Delta U > 0$`, resulting in `$W_{out} + \Delta U > 0$`

This is inconsistent with the FLT, which would require this sum to be zero for an adiabatic process. This suggests that work derived from cooling-induced vacuum pulling forces represents an energy source not accounted for in traditional models

1.5. Performance of a DARA and the VsVs Cycle

A Double-Acting Reciprocating Actuator (DARA) performs two simultaneous VsVs thermal cycles in its two chambers, 180 degrees out of phase. The VsVs cycle sequence is: Isochoric (V) heat addition, adiabatic (s) expansion, Isochoric (V) heat extraction, adiabatic (s) contraction.

The net work output per stroke is the sum of the work from both chambers. Because the contraction work in one chamber is driven by cooling (with ostensibly no energy cost), the total net work output of the DARA, when analyzed with standard FLT, appears to be greater than the net heat input.

Conclusion of Controversy

While individual PUs may appear to comply with energy conservation in isolation, the integrated SSPP system—particularly when cascaded PUs leverage vacuum-induced pulling forces—demonstrates a net energy gain. This indicates that heat-work interactions involving pull forces (cooling-induced contraction) are not fully described by the First Law of Thermodynamics. The core issue is that useful work can be obtained from a process that simultaneously increases the system's internal energy, a direct challenge to the principle of energy conservation and consequently the FLT. However, everyday observation confirms and reinforces such assertions, and they are therefore irrefutable.

2 Description and thermodynamic analysis of a thermal cycle composed of closed processes (VsVs)

The SARA actuator is capable of supporting various thermal cycles. This section is dedicated to the implementation of a thermal cycle that is inherently symmetrical in terms of the closed processes carried out: VsVs, which means a sequence of closed processes named as isochoric (V), adiabatic (s), isochoric (V), and adiabatic (S) types. The closed processes or transformations named above based on heat-work interaction with a thermal working fluid (TWF) consist respectively of isochoric heat addition, adiabatic expansion, isochoric heat removal and adiabatic contraction.

The symmetry attributed to the proposed VsVs cycle results in the ability to achieve PUs characterized by providing equal output powers while operating at different temperatures. This feature allows the implementation of a cascade of PUs capable of operating at different temperatures and providing similar power outputs.

The proposed plant structure based on a PU cascade is essential to achieving SSPPs, since heat recovery upstream in the cascade is one of the fundamental pillars to achieve more useful work than the external heat demand.

Since a DARA is characterized by its ability to support the same properties as a SARA in terms of thermodynamic symmetries, the analysis on SARA is assumed for DARA.

2.1 thermodynamic modeling

In Table 2 it is illustrated the effects of heat transfer to obtain forces and useful mechanical work. The thermodynamic model of the heat-work interactions carried out long the cycle VsVs is depicted in Fig. 2, by means of T-s and p-V diagrams.

The sequence of closed processes carried out into SARA due to adding and removing heat is illustrated in Table 2. This sequence of processes can be observed also in the T-s and p-V diagrams depicted in Fig. 2.

The thermodynamic aspects considering the effects of heating and cooling a TWF evolving into a SARA are described in Table 2.

It should be noted that the remaining available heat expelled by the half-cycle (1-2, 2-3, 3-1) shown in Fig. 2 (a) and (b) corresponding to the complete VsVs cycle, is used as useful heat supplied to the half-cycle (1-3, 3-4, 4-1) shown in Fig. 2 (d) and (e) corresponding to the complete VsVs cycle.

Also note that the remaining available heat u_{13} is not input/output heat transferred, but rather heat used in the VsVs cycle. This heat is needed to balance the heat-work balances in both half-cycles (1-2, 2-3, 3-1) with (2-3, 3-4, 4-1) of the complete VsVs cycle.

Table 2: Illustration of a sequence of closed processes carried out by a SARA depicted in Fig. 2.

State Points	Closed Process types	Internal energy	Process models
Positive pressure-force conversion by means of push forces achieved by pressure induced heating			
1-2	Isochoric heating	increases	$+\Delta u_{12}= Cv.(T_2-T_1)$
2-3	Adiabatic expansion	decreases	$\Delta u_{23}= Cv.(T_2-T_3)$
3-1	Isobaric cooling	decreases	$-\Delta u= Cv.(T_3-T_1)$
Negative pressure-force conversion by means of pull forces achieved by vacuum induced cooling			
1-3	Isobaric heating	increases	$\Delta u_{13} =Cv.(T_3-T_1)$
3-4	Isochoric cooling	decreases	$\Delta u_{34}= Cv.(T_3-T_4)$
4-1	Adiabatic contraction	increase	Contraction work out

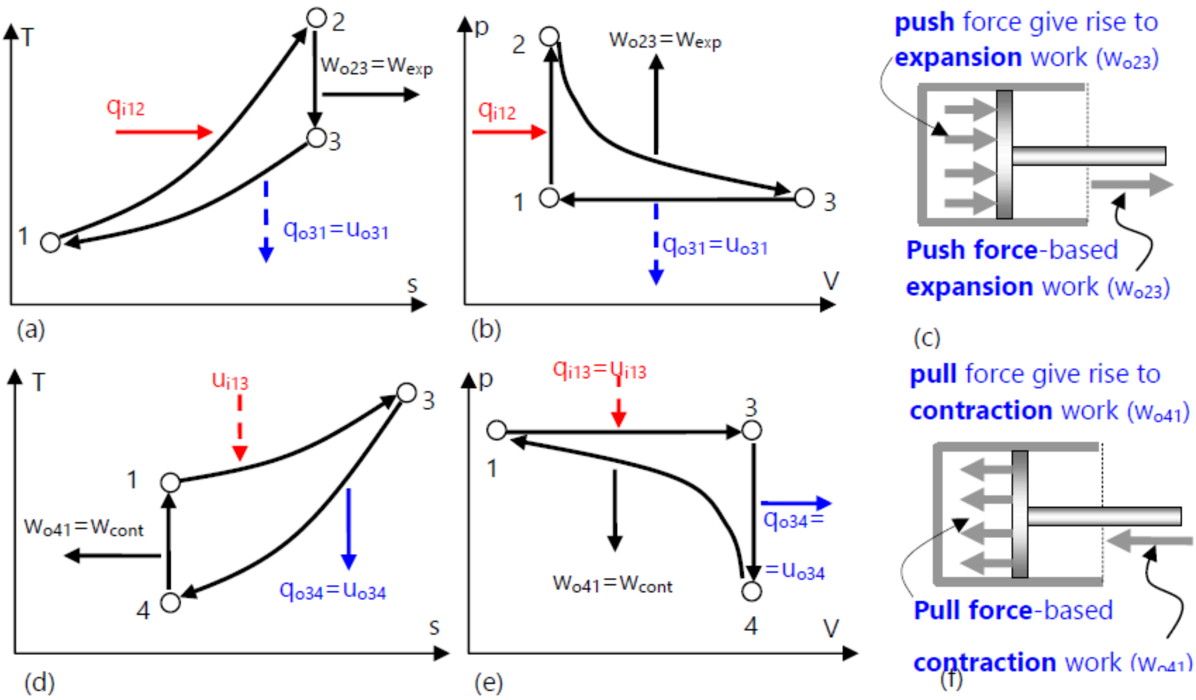

Figure 2: Illustration of the T-s and p-V diagrams of closed processes-based thermal cycles driven by heat transfer which give rise to expansion-based work by means of heat-induced positive pressure as shown in Fig. 2 (a), (b) and (c), and cycles driven by heat transfer which give rise to contraction-based work by means of cold-induced negative pressure (vacuum) as shown in Fig. 2 (d), (e) and (f).

2.1.1 Hating-induced mechanical work

Using temperature change as energy potential via **positive** pressure-force conversion by **push** forces:

There are several techniques for transferring heat to the TWF and achieving a temperature increase that leads to an increase in pressure and, consequently, an increase in the thrust force essential for performing expansion work.

Energy balance aligned with FLT:

In all heat-work interactions carried out in a cycle conducted by push forces the change of energy is zero, (aligned with the conservation of energy principle). Therefore considering the T-s and P-v diagrams depicted in Fig. 1 (a) and (b), the general balances are fulfilled

$$\sum E = 0 \rightarrow Ei - Eo = 0 \rightarrow Ei = Eo \quad (1)$$

Positive pressure-force conversion by means of push forces:

$$Ei = Eo \rightarrow q_{i12} = w_{o23} + q_{o31} \quad (2)$$

Assuming closed processes flows that

$$\Delta u_{12} = \Delta u_{23} + \Delta u_{31} \quad (3)$$

2.1. 2 Cooling induced mechanical work

Using temperature change as energy potential via **negative** pressure-force conversion by **pull** forces:

Observed facts according to the Fig. 1 (d), € and (f), suggest us that in heat-work interactions carried out in a cycle conducted by pull forces the change of energy is different of zero. (Impossibility of fulfilling the Energy Conservation principle)

Energy balance misaligned with FLT:

Considering the T-s and P-v diagrams depicted in Fig. 1 (d) and (e), the general balances are fulfilled

$$Ei = Eo \rightarrow u_{13} + u_{14} = u_{34} \quad (4)$$

However, while the heat balance associated with first law of the thermodynamics (FLT) strictly complies with conventional thermodynamic balances, the reality regarding useful mechanical work presents a marked discrepancy with the FLT, since in reality useful work is performed simultaneously with the increase in internal energy. This blatant controversy is illustrated as follows:

$$u_{13} + w_{o14} = u_{34} \rightarrow Ei \neq Eo \quad (5)$$

Comparing Eq. (5) with (4) it is observed that while in (4) the temperature or internal energy increases during process 4-1 giving rise to thermal contraction, in Eq. (5) it is seen that useful mechanical work is performed while internal energy increases. This phenomenon can be observed in the T-s and p-V diagrams depicted in Fig. 1 (d) and (e) along the closed isentropic process (4-1)

That is, the internal energy increases while at the same time, useful mechanical work is obtained due to a previous cooling-induced vacuum which give rise to useful pulling forces. Therefore, the input-output energy balance is

$$u_{i13} = w_{o14} + u_{34} \rightarrow Ei \neq Eo \text{ ; or } u_{13} = u_{14} + u_{34} \rightarrow Ei \neq Eo \quad (6)$$

which is absolutely inconsistent with the FLT.

Given a closed adiabatic heat-work interaction from which useful mechanical work can be obtained,

$$w_{o\,cont} = w_{o14} = u_{i14} = Cv(T_1 - T_4) \text{ ,} \quad (7)$$

while simultaneously increasing the internal energy as

$$\Delta u_{14} = Cv(T_1 - T_4) \quad (8)$$

of the process (4-1), this has never been considered in conventional thermodynamic theory, except in recent references [1-5].

The dramatic consequences are:

Obtaining useful mechanical work from a process and simultaneously increasing its internal energy under a closed adiabatic-isentropic process violates the FLT and, consequently, the foundation of energy conservation.

2.2 Useful Mechanical Work by a DARA due to Heating and Cooling a TWF

In a DARA (Double Acting-Reciprocating Actuator), ideal heat input and output occur under closed isochoric processes, while the mechanical work—both expansion and contraction—is performed under closed adiabatic-isentropic conditions [6–14], [16–20]. These thermodynamic processes are illustrated in Fig. 3(a) and 3(b) using temperature-entropy (T–s) and pressure-volume (p–V) diagrams.

The complete cycle follows a sequence of four distinct stages:

1-2 Isochoric (constant volume) heat addition,

2-3 Adiabatic (isentropic) expansion,

3-4 Isochoric heat removal,

4-1 Adiabatic contraction.

This sequence defines what is referred to as the **VsVs thermal cycle**.

The net mechanical work output, denoted as w_n, results from both the expansion and contraction phases. Notably, the contraction work —generated by cooling the thermodynamic working fluid (TWF)— does not require heat input. As a result, the total work produced (from both expansion and contraction) does not align with the First Law of Thermodynamics (FLT), as expressed in Equation (5).

This discrepancy arises because the energy balance based on the FLT fails to account for the mechanical work generated during cooling. Specifically, the contraction phase produces useful work through traction or pulling forces, which have not been traditionally considered in standard thermodynamic analyses.

The **net work output (w·)**—representing the total useful work—is generated by two complementary mechanisms:

a) Thrust (push) forces **produced by heating the TWF in** Cylinder Chamber A **(Figure 3c).**

b) Traction (pull) forces **resulting from cooling the TWF in** Cylinder Chamber B **(Figure 3c).**

The total (net) work obtained per stroke is the sum of the works carried out simultaneously between state points 2-3 into cylinder chamber A (CCA) and between state points 4-1 into cylinder chamber B (CCB).

That is, net work during outward stroke: include work done by CCA +CCB

$$w_n = w_{o\exp}\ in\ CCA + w_{ocont}\ in\ CCB = (u_3 - u_2) + (u_1 - u_4) \tag{9}$$

net work during inward stroke: include work done by CCA +CCB

$$w_n = w_{ocont}\ in\ CCA + w_{o\exp}\ in\ CCB = (u_1 - u_4) + (u_3 - u_2) \tag{10}$$

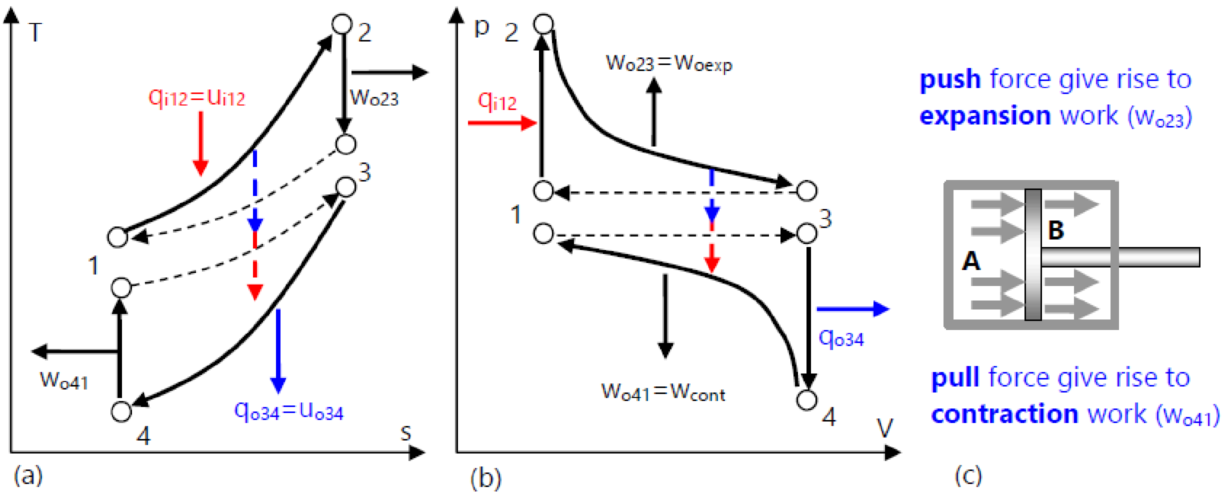

Figure 3: Visualization of the T–s and p–V diagrams representing a closed thermodynamic cycle driven by heat transfer. The cycle generates expansion work through heat-induced positive pressure and contraction work through cold-induced negative pressure (vacuum), illustrating the interplay between thermal energy and mechanical output. The transformations caried out into both cylinder chambers are described in Table 3.

The cycle illustrated in **Fig. 3** corresponds to a DARA system capable of executing two simultaneous VsVs cycles, offset by 180 degrees. This configuration enables continuous operation through alternating phases in each cylinder chamber.

The sequence of closed thermodynamic processes occurring concurrently in both chambers is detailed in **Fig. 3**, using **T–s** and **p–V** diagrams, and summarized in **Table 3**.

Table 3: Illustration of the thermal cycle VsVs driving a DARA according to Fig. 3.

SP	Closed Process		SP	Closed Process	
VsVs cycle into CCA			**VsVs cycle into CCB**		
1-2	Isochoric heating	$q_{i12} = u_2 - u_1$	3-4	Isochoric cooling	$q_{o34} = u_3 - u_4$
2-3	Adiabatic expansion	$w_{oexp} = u_3 - u_2$	4-1	Adiabatic contraction	$w_{ocont} = u_1 - u_4$
3-4	Isochoric cooling	$q_{o34} = u_3 - u_4$	1-2	Isochoric heating	$q_{i12} = u_2 - u_1$
4-1	Adiabatic contraction	$w_{ocont} = u_1 - u_4$	2-3	Adiabatic expansion	$w_{oexp} = u_3 - u_2$

3. Thermo-Mechanical Prototype Design Based on Symmetry in Functional Relationships

One of the most relevant tasks related to SSPPs design concerns SSPPs thermodynamic optimization. Optimization significantly influences the plant structure, making it an essential task to increase the potential for self-sufficiency as well as the global benefits along its life-cycle.

This article presents a highly ambitious and controversial study that proposes a paradigm shift in thermodynamics and energy conversion.

In the new paradigm, the concept of energy self-sufficiency is considered a disruptive finding, which is absolutely prohibited by the first law of thermodynamics. However, it is supported by rigorous prior empirical studies as well as by the irrefutable, experimentally proven observation of vacuum-induced traction forces achieved by cooling a TWF without significant energy costs in terms of heat balance [1-5], [6-14] and [16-20].

A foundational principle of self-sustaining heat engines lies in the generation of traction forces through the removal of heat or the cooling of a Thermal Working Fluid (TWF). This process creates a vacuum, which in turn gives rise to **Vacuum-Induced Pulling Forces (VPF)** and as consequence useful output mechanical work**.** Figures 2 and 3 illustrate how heat transfer can be harnessed to generate mechanical forces and perform useful work. The thermodynamic interactions between heat and work throughout the VsVs cycle are represented in the T–s and p–V diagrams shown in these figures.

The sequence of closed thermodynamic processes occurring within the SARA system—driven by the addition and removal of heat—is detailed in **Table 2**. This sequence is also reflected in the T–s and p–V diagrams in **Figure 2**.

Table 2 further outlines the thermodynamic behavior of the TWF as it undergoes heating and cooling within the SARA system. Notably, the residual heat expelled during the half-cycle 1–2–3–1 (depicted in Figures 2a and 2b) of the complete VsVs cycle is repurposed as useful input heat for the subsequent half-cycle 1–3–4–1 (shown in Figures 2d and 2e).

It is important to emphasize that the remaining available heat, denoted as $\mathbf{u_{13}}$, is not external heat input or output. Instead, it is internally utilized within the VsVs cycle to maintain thermal balance between the two half-cycles: (1–2–3–1) and (2–3–4–1).

Unlike conventional heat engines, which rely on expansion forces to perform mechanical work, the traction or pulling forces in this system can generate useful work **without requiring additional thermal energy input**. This represents a transformative advantage, enabling the development of a new class of self-sustaining heat engines. Such systems have the potential to radically shift the energy paradigm—extending beyond terrestrial applications to a **global and even cosmic scale**. In this context, survival and energy independence are no longer reliant on solar or stellar sources, offering the possibility of healthier and more sustainable habitats.

The symmetry of functional relationships in thermo-mechanical prototype design is governed by the distribution of heat—both input and output—during the heating and cooling phases of the TWF in VsVs thermal cycles. A cascade configuration of power units is proposed, where each unit delivers equal power output at different temperature levels. This is achieved by ensuring that the heat supplied to each unit results in a consistent temperature drop in the TWF.

Crucially, the **constant temperature drop ($\mathbf{T_{drop} = T_D}$)** across each unit is adopted as a key design criterion to optimize the prototyping process for self-sustainability. The concept of a constant $\mathbf{T_D}$ is elaborated in reference [14].

3.1 General structural design methodology

The **dimensional design methodology of a thermos-mechanical machine** involves a structured approach to ensure that the machine performs accurately under thermal and mechanical loads.

Machine sizing to supply the demand for machine production must be carried out through scalability based on case studies. However, a breakdown of the main steps typically involved and focused on best practices includes the following generic key points:

a **Material Selection, Geometry, and Design Principles**

This is the foundation of thermos-mechanical design:

Low coefficient of thermal expansion (CTE) materials (e.g., Zerodur, Silicon Carbide, Invar) are chosen to minimize thermal expansion.

Geometry optimization ensures structural integrity and thermal stability.

Design principles like kinematic design or elastically averaged design help manage constraints and improve repeatability.

b **Thermal Conditioning**

This step addresses how to manage heat within the system:

Passive methods: Insulation, minimizing heat sources near critical components, using materials with high thermal diffusivity.

Active methods: Countercurrent-based forced convection heat transfer, temperature-controlled fluids, and advanced control systems.

c **Software Compensation**

When physical design can't eliminate all thermal effects:

Error mapping and **metrology frames** are used to correct for thermal distortions.

Control algorithms adjust for thermal drift and mechanical inaccuracies in real-time.

d **Structural Design and Stiffness Requirements**

The machine's structure must be:

Stiff enough to resist deformation under load.

Damped adequately to reduce vibrations and improve dynamic response

Structurally designed, if necessary, with load paths and triangulation to enhance rigidity.

e **Predictive Modeling and Thermal Measurements**

Though sometimes treated separately, these are crucial:

Modeling helps simulate thermal behavior before physical prototyping.

Measurements validate the model and guide refinements.

f **Integration of Components**

Mechanical components must be:

Independent functionality between integrated components to avoid interference.

Preloaded to eliminate slack and improve precision.

Symmetrically designed to reduce complexity and improve manufacturability

3.2 Thermodynamic-based design tasks

Vacuum-induced pulling forces (**VPF**s) generate contraction forces that enable useful mechanical work without the need for additional thermal energy input. These forces are produced by cooling a thermal working fluid (TWF), representing a disruptive approach that advances the feasibility of Self-Sustaining Power Engines (SSPEs).

To support the design of a prototype based on a constant temperature drop (T_D) between each cascaded Power Unit (PU), it is essential to establish a relationship between the T_D, the number of required Power Units (**NPU**s), and the net electrical power (**NEP**) generated per kilogram of TWF per cycle.

Assuming the T_D between each cascaded PU is sufficiently small, the heat input and output at each PU become approximately equal. This condition enables parametric, dimensional, and structural symmetry across the PUs, significantly simplifying both the design and implementation of the prototype.

3.2.1 Consequences of constant T_D on the prototyping modeling tasks

In an ideal setting, since the resulting output mechanical works exhibit approximately a similar value and are a direct function of the heat transferred both at the input and output of each thermal cycle, the obtained mechanical works done by expansion and contraction are also approximately similar.

Therefore, starting from the hypothesis based on a small T_D with respect to range of temperatures —T_R = TH-TL— for an ideal system, follows that in a thermal VsVs cycle heat-work interactions obey approximately the functional relations described in next section.

3.3 Thermal similarity relations with a small T_D

Symmetric VsVs cycles exhibit certain likelihood between thermodynamic functional relationships. In other works cycles exhibit some similarity between thermodynamic transformations based on closed symmetric processes when a small temperature drop occurs in the cycle as a consequence of a heat-work conversion taking place.

3.3.1 Similarities of input/output HWIs in the VsVs cycle with constant low T_D and constant reference pressure (p_{13})

According to the notation proposed by means of the illustration in Fig.1 follows that

$$q_{i12} \approx q_{o34} \rightarrow u_{i12} \approx u_{o34} \tag{11}$$

Based on thermal efficiency definitions for any given thermal working fluid follows that due to the fact that $q_{i12} \approx q_{o34}$, then

$$\eta_{th} = w_{o23} / q_{i12}\,;\, \eta_{th} = w_{o41} / q_{i34}\,.$$

Thus, the useful mechanical works as function of input/output transferred heats are:

$$w_{o23} = \eta_{th} \cdot q_{i12}\,;\, w_{o41} = \eta_{th} \cdot q_{i34} \tag{12}$$

The symmetries established based on a constant temperature drop between each PU allows us to establish the following rule regarding thermal efficiencies:

For a unique TWF, the thermal efficiency of each PU is equal to each other, and is also equal to the thermal efficiency of the plant.

From Eq. (12) follows that

$$IF\ q_{i12} \approx q_{o34}\ THEN\ w_{o23} \approx w_{o41} \rightarrow w_{o\exp} \approx w_{o\,cont} \tag{13}$$

From Eq. (3) follows that

$$[\Delta u_{23} \approx \Delta u_{14}] \equiv [w_{o23} \approx w_{o14}] \tag{14}$$

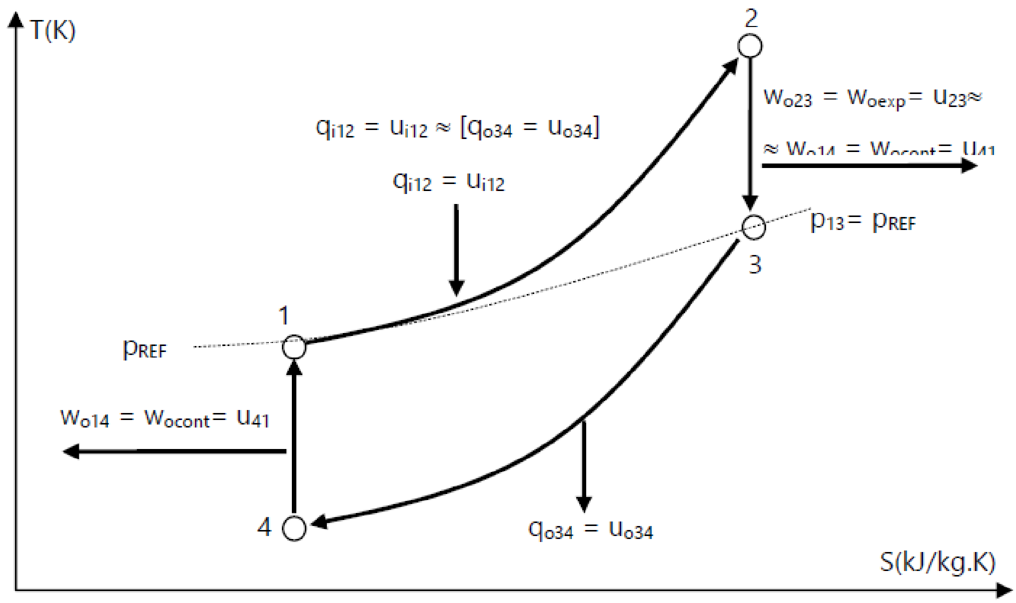

Figure 4: Illustration of the used notation and similarity relations (thermodynamic symmetries) between thermodynamic parameters in VsVs thermal cycles

In Fig. 5 it is illustrated a block diagram of the SSPP structure. Blocks are linked by means of energy flows (heat, useful mechanical work and electric power). Block (A) represents the cascade of PUs that makes up the SSPP. Block (B) corresponds to the power generation equipment from the useful mechanical work supplied by block (A), and block (C) comprises the system responsible for converting a required fraction of the generated electrical power into high-grade heat to feed the first PU in the downstream cascade of PUs that make up the SSPP. The number of cascaded PUs depicted by block (A) depends on the constant value assigned to the temperature drop between cascaded PUs (T_D). An optimization procedure will find the number of PUs to achieve maximum benefits along its life-cycle.

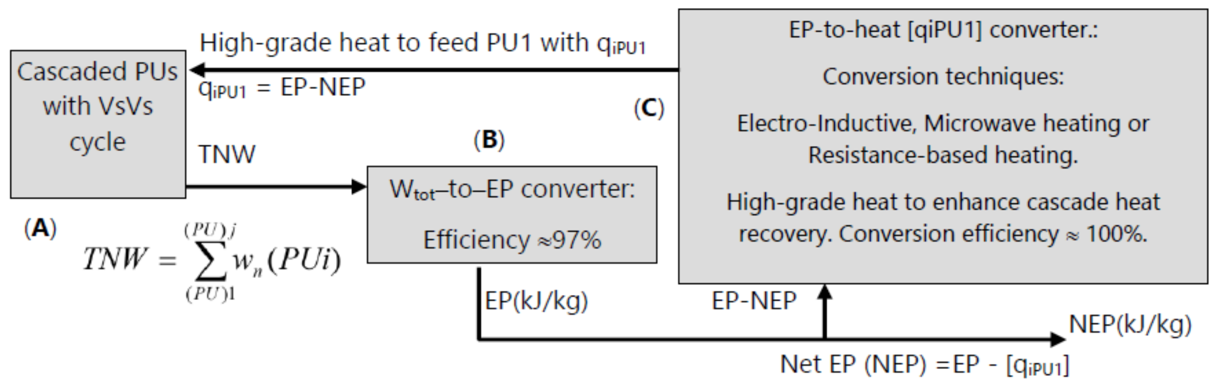

Figure 5: Block diagram illustrating the heat, work, and electrical power flows implemented in the proposed SSPP.

3.4 Functional symmetric relations based on similarities of thermodynamic transformation models

To describe thermal symmetries, let's take into account the fact that the net work done by any PU during each cycle is the sum of the expansion and contraction works, resulting in:

$$w_n = w_{o23} + w_{o41} = \eta_{th} \cdot u_{12} + \eta_{th} \cdot u_{34} = 2 \cdot \eta_{th} \cdot u_{12} = 2 \cdot \eta_{th} \cdot u_{34} = 2 \cdot w_{o23} = 2 \cdot w_{o41} \tag{15}$$

From Eq. (15) follows that

$$w_n = w_{o23} + w_{o41} = w_{o\exp} + w_{ocont} = 2 \cdot w_{o23} = 2 \cdot w_{o41}$$
$$\rightarrow 2 \cdot \eta_{th} \cdot \Delta u_{o23} = 2 \cdot \eta_{th} \cdot \Delta u_{o14} = 2 \cdot Cv \cdot T_D \tag{16}$$

In agreement with Eq. (16), the heat added to the first cascaded PU is

$$q_{iPU1} = w_n / \eta_{th} = (w_{o23} + w_{o41}) / \eta_{th} = (w_{o\exp} + w_{ocont}) / \eta_{th} \cdot = 2 \cdot Cv \cdot T_D \cdot \tag{17}$$

Assuming that T_D is a constant value, from Eq. (17) follows that

$$q_{iPU1} = w_n / \eta_{th} = 2 \cdot Cv \cdot T_D = q_{iPU2} = \cdots q_{iPUj} .$$

Therefore, the direct consequence is the equality of PU works, so that, $w_{n1} = \eta_{th} \cdot q_{iPU1}, w_{n2} = \eta_{th} \cdot q_{iPU2}, w_{n3} = \eta_{th} \cdot q_{iPU3},$ and so on.

Therefore, $w_{n1} = w_{n2} = \cdots \cdot w_{nj}$.

The temperature range within which a SSPP-type thermoelectric plant operates is defined as $T_R = T_H - T_L$.

Consequently, the total work per cycle of the SSPP plant is the sum of the partial workloads corresponding to the PUs that comprise it.

3.4.1 Functional relationships derived from Eq. (11-17) exhibiting symmetries:

The number of cascaded PUs (NPUs) into the range of operating temperatures [T_H-T_L = T_R] is given as

$$NPUs \approx \frac{T_H - T_L}{T_D} = \frac{T_R}{T_D} \tag{18}$$

The total net work (**TNW**) delivered by the cascaded PUs is a constant which depends only on the range of operating temperatures (T_R) of a cascaded group of PUs:

$$TNW \approx (NPU)\cdot 2\cdot \eta_{th}\cdot Cv\cdot T_D \approx$$
$$\approx (\frac{T_H - T_L}{T_D})\cdot 2\cdot \eta_{th}\cdot Cv\cdot T_D = \frac{T_R}{T_D}\cdot 2\cdot \eta_{th}\cdot Cv\cdot T_D$$
$$= T_R\cdot 2\cdot \eta_{th}\cdot Cv \tag{19}$$

Assuming η_{EL} (%) conversion efficiency from work to electric power, the Electric Power **(EP)** is given as:

$$EP \approx TNW\cdot \eta_{EL} \approx T_R\cdot 2\cdot Cv\cdot \eta_{th}\cdot \eta_{EL} \tag{20}$$

Assuming Net Electric Power (**NEP)** as the difference between EP and the heat added to the first cascaded PU yields:

$$NEP \approx EP - q_{iPU1} \approx T_R\cdot 2\cdot Cv\cdot \eta_{th}\cdot \eta_{EL} - q_{iPU1} =$$
$$= T_R\cdot 2\cdot Cv\cdot \eta_{th}\cdot \eta_{EL} - 2\cdot Cv\cdot T_D =$$
$$= 2\cdot Cv\cdot (T_R\cdot \eta_{th}\cdot \eta_{EL} - T_D) \tag{21}$$

To achieve a functional relationship including NPU and T_D as parameters, let's include NPU into Eq. (21) by substituting T_R by NPU from Eq. (18):

$$NEP \approx EP - q_{iPU1} = 2\cdot Cv\cdot (NPU\cdot T_D\cdot \eta_{th}\cdot \eta_{EL} - T_D) =$$
$$= 2\cdot Cv\cdot T_D\cdot (NPU\cdot \eta_{th}\cdot \eta_{EL} - 1) \tag{22}$$

The obtained functions shown in Table 4 are the basis for the optimization problem-solving task. The synthesis of functional relations associated with thermal models' symmetries assumed for heat-work interactions derived from the consequences of a constant T_D between cascaded PUs are depicted in Table 4.

Table 4: Key functions involved in the proposed prototyping modeling tasks from Eq. (18-22)

Number of cascaded PUs	**NPU**	Eq. (18)	$NPU \approx (T_H - T_L)/T_D = T_R/T_D$
Total net work of the SSPP	**TNW**	Eq. (19)	$TNW \approx 2\cdot Cv\cdot T_R\cdot \eta_{th}$
Electric Power of the SSPP	**EP**	Eq. (20)	$EP \approx TNW\cdot \eta_{EL} \approx 2\cdot Cv\cdot T_R\cdot \eta_{th}\cdot \eta_{EL}$
Net Electric Power of the SSPP	**NEP**	Eq. (21)	$NEP \approx 2\cdot Cv\cdot T_D\cdot (NPU\cdot \eta_{th}\cdot \eta_{EL} - 1)$

It is observed that according to the curve, a nonlinear relationship function has been achieved, that is, there is a non-linear relationship function as depicted in Fig. 6.

Design results are based on the key functions depicted in Table 5. By processing these functions accordingly, an optimal SSPP configuration corresponding to a self-sufficiency index peak, is achieved, which occurs with 8 to 9 cascaded PUs. This design strategy, based on an optimal constant T_D, simplifies the mechanical structure and reduces costs associated with design, implementation, and operation.

Figure 6 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.

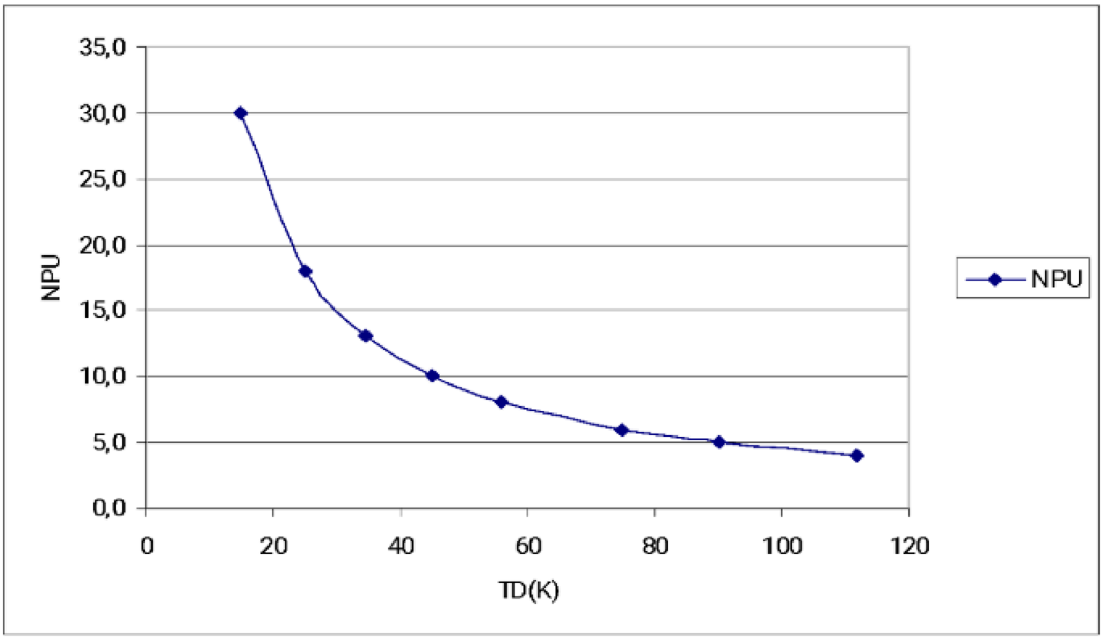

Figure 6: illustration of the function NPU —the number of cascaded PUs— as function of the constant value T_D

In Fig. 6 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 of the cascaded SSPE. In Fig. 6 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 SSPMs composed by cascaded PUs portaging optionally with discontinuous or continuous VsVs cycles.

Fig. 7 indicates that the NEP is a proportional function of the T_D. in concordance with Eq. (12)

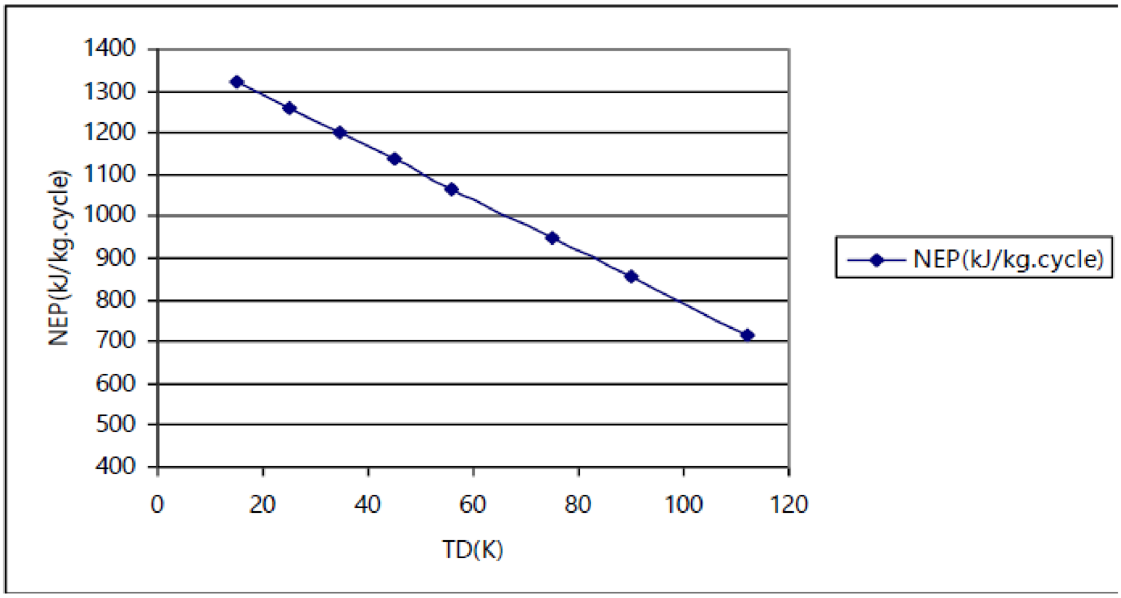

Figure 7: illustration of the function NEP —the net electric power— as function of the constant value T_D

4 Optimization procedures through a case study

The goal is to find the appropriate constant temperature difference T_D, between each cascaded PU to maximize benefits over the SSPP life cycle. The optimal T_D value involves keeping the number of cascaded (PUs as small as possible based on the results of the optimization procedure. Therefore, Fig. 5 represents the HTF recirculation scheme for a SSPP 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 Fig 9- 5 it is also illustrated the concept of NPU which depends on the temperature drop as well as the range of useful high-low temperatures.

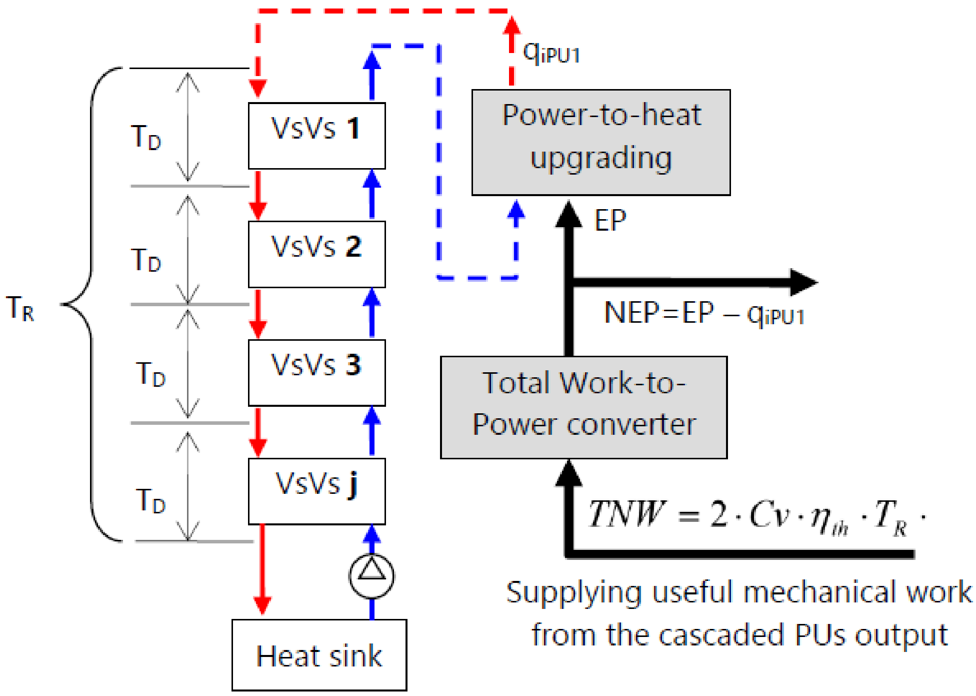

Figure 8: Illustration of the HTF (heating-cooling circuit) recirculation scheme for a SSPP consisting of a set of 4 single PUs in a cascade-based continuous-motion VsVs cycle, where a temperature drop between each PU is highlighted. Prototypes structures are depicted in patent references [16-20].

4.1 Modeling a Profit-Based Optimization Function

An optimization function—also known as an objective or cost function—is designed to quantify a specific criterion within a system. This criterion is either **maximized** (e.g., profit or benefit) or **minimized** (e.g., cost or loss) through the use of an algorithm that identifies the optimal solution.

Objective: The primary goal is to determine the set of input values that **maximize the profit** or **benefit** defined by the optimization function.

Input Variables: The optimization algorithm systematically adjusts and evaluates input variables to identify the combination that yields the **highest possible benefit**. These variables represent controllable factors within the system that influence the outcome of the optimization process.

In this case the optimization function is composed by:

Expenses index coefficient (**EIC**),

expenses sub-function (**F_{exp}**),

revenues sub-function (**F_{rev}**), and

profit function (**F_{prof}**), where **(RIC)** is a revenues index coefficient:

$$F_{\exp} = EIC \cdot NPU \tag{23}$$

$$F_{rev} = RIC \cdot NEP \tag{24}$$

$$F_{prof} = F_{rev} - F_{\exp} = RIC \cdot NEP - EIC \cdot NPU \tag{25}$$

Therefore, assuming the parameters depicted in Table 5 it is obtained the results depicted in the five right hand columns of Table 6 and some of them graphically represented in Fig. 9, since Fig. 6 illustrates the response to the data entry depicted in Table 5.

The optimization procedure consists of a well-known systematic methodology that maximizes a functional benefit relationship between T_D and NPU throughout its life cycle. To determine the function to be optimized, a method based on the study of a generic case of a self-sufficient thermoelectric plant is used. Therefore, as shown in Table 5, the working fluid (helium in the case study) is used as the starting fluid, with a constant-volume specific heat capacity, Cv, of 3.12 (kJ/kg-K) with data for helium from [15]. It operates in a closed-process VsVs cycle with a thermal efficiency η_{th} of 0.52 and a mechanical work-to-electrical power conversion efficiency of 0.97. The operating temperature range T_R of the PUs cascade with TH = 800 K and TL = 350 K is $T_R = T_H - T_L = 450$ K.

The benefit function model obeys to the SSPP structure depicted in Fig. 8, and the handled parameters are depicted in Tables 5-6. Likewise, the relational functions that give rise to the benefit function to be maximized are found in Table 6.

Table 5: Data used for achieving the results of the key functions involved in the proposed prototyping modeling tasks for SSPPs of different number of cascaded PUs

Cv(kJ/kg-K)	Ef_th(%)	Ef_el(%)	T_H(K)	T_L(K)	T_R(K)	T_D(K)
3.12	0.52	0.97	800	350	450	112
3.12	0.52	0.97	800	350	450	90
3.12	0.52	0.97	800	350	450	75
3.12	0.52	0.97	800	350	450	56
3.12	0.52	0.97	800	350	450	45
3.12	0.52	0.97	800	350	450	34.5
3.12	0.52	0.97	800	350	450	25
3.12	0.52	0.97	800	350	450	15

Table 6: Results of the key functions involved in the proposed prototyping modeling tasks for SSPPs.

NPUs	TNW (kJ/kg-cycle)	EP (kJ/kg-cycle)	NEP (kJ/kg-cycle)	EIC	expenses	RIC	revenues	profit
4.0	1460.16	1416	717	30	121	1	717	597
5.0	1460.16	1416	855	30	150	1	855	705
6.0	1460.16	1416	948	30	180	1	948	768
8.0	1460.16	1416	1067	30	241	1	1067	826
10.0	1460.16	1416	1136	30	300	1	1136	836
13.0	1460.16	1416	1201	30	391	1	1201	810
18.0	1460.16	1416	1260	30	540	1	1260	720
30.0	1460.16	1416	1323	30	900	1	1323	423

In Table 6, it is shown that the number of PUs (NPU) depends on the value of T_D (constant value of the temperature drop) between each PU. These results are only valid for helium as thermal working fluid (TWF).

The first four left hand columns of Table 6 are obtained from the relational functions described in Table 5 as the key functions involved in the proposed prototyping modeling tasks. The four right-hand columns of Table 6 belong to the benefit function model responsible for achieving optimal results.

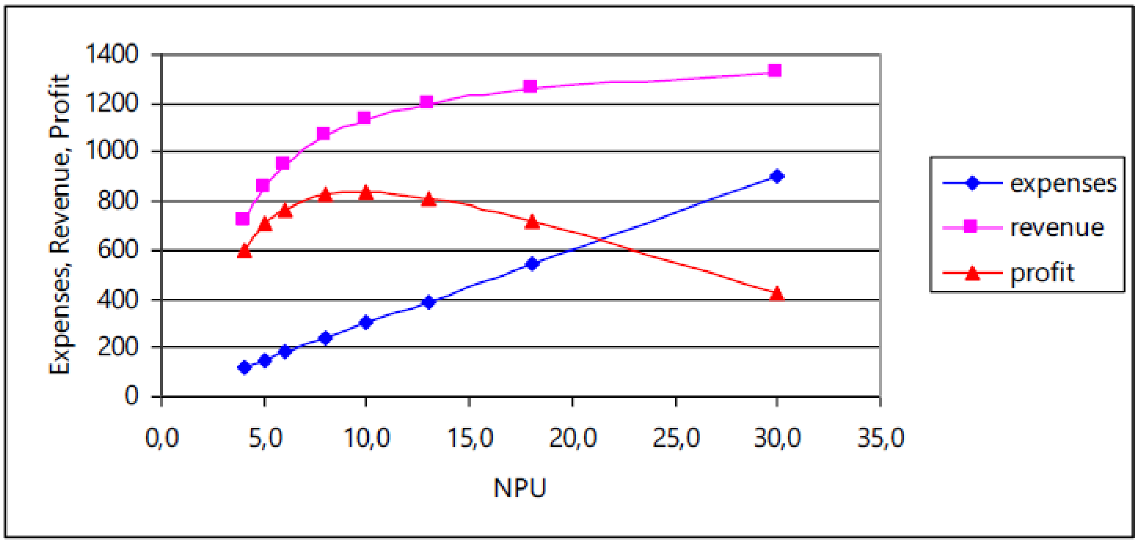

Figure 9: Illustration of the functions involved in the SSPP prototype design optimization process for helium as TWF [15]

Fig. 9 shows that the maximum profit —net benefits— occurs when the number of PUs approaches a value between 8 and 9 PUs, which corresponds to a constant TD that ranges from 40 to 50 K.

5 Analyses and Critical Discussion of Results

This article presents a highly ambitious and controversial study that proposes a paradigm shift in thermodynamics and energy conversion. The core claim is the feasibility of a Self-Sustaining Power Plant (SSPP) that generates more useful work than its external heat input, ostensibly violating the First Law of Thermodynamics (FLT). The analysis below breaks down the methodology, results, and the profound implications of these claims.

5.1. Analysis of the Core Proposition and Thermodynamic Challenge

The foundation of this research rests on the exploitation of "vacuum-induced pulling forces." The authors argue that cooling a Thermal Working Fluid (TWF) in a closed, adiabatic process (e.g., process 4-1 in the VsVs cycle) can generate a vacuum that performs useful mechanical work while simultaneously increasing the internal energy of the fluid.

(a) The Alleged FLT Violation: The authors correctly identify that this phenomenon is irreconcilable with the conventional FLT for a closed system ($\Delta U = Q - W$). For an adiabatic process ($Q=0$), if the system does work ($W > 0$), its internal energy ***must decrease*** ($\Delta U < 0$). Their claimed observation of $W > 0$ and $\Delta U > 0$ leads them to conclude that $W + \Delta U > 0$, which conventionally would represent a net creation of energy.

(b) Proposed Mechanism: The work from the "pull" force during contraction is treated as having "no energy cost" because it is initiated by cooling (heat extraction), not heating. When this "free work" is added to the work from the traditional "push" force of expansion, the total net work output appears to exceed the net heat input.

This is the central, disruptive claim that underpins the entire concept of the SSPP. Without this mechanism, the system would be bound by conventional efficiency limits (Carnot, etc.).

5.2. Analysis of the Proposed System Design and Methodology

To harness this controversial effect, a sophisticated system design has been proposed:

Cascaded Identical Power Units (PUs):

The plant is composed of multiple, identical PUs arranged in a cascade. Each PU operates the same VsVs cycle but at a progressively lower temperature.

Constant Temperature Drop (ΔT or T_{**D**}):

A critical design parameter is maintaining a constant temperature difference between each successive PU. This ensures symmetry, simplifies manufacturing, and is key to the optimization process.

Heat Recovery:

(a) The "waste heat" from the cooling process of an upstream PU is used as the "input heat" for the next downstream PU. This cascading heat recovery is essential for achieving high overall thermal utilization and is a legitimate strategy used in conventional multi-stage systems (like cascaded Rankine cycles).

(b) The methodology transitions from a theoretical thermodynamic challenge to a practical engineering optimization problem. The goal is to find the optimal number of PUs (N_{PU}) and corresponding ΔT that maximizes a profit function over the plant's lifecycle.

5.3. Analysis of the Optimization Results and Key Findings

The optimization model, while simplified, yields clear and specific results:

Optimal Configuration:

The analysis identifies that for a temperature range of 800 K to 350 K (T_R = 450 K) using Helium as the TWF, the optimal number of cascaded PUs is between 8 and 9. This corresponds to a constant ΔT of 40-50 K between units.

Trade-off Driven Result:

This optimum arises from a fundamental trade-off:

(a) More PUs (Smaller ΔT): Lead to higher Net Electric Power (NEP) because more heat is recovered and converted through the cascade (increasing revenue).

(b) Fewer PUs (Larger ΔT): Lead to lower capital and maintenance costs (reducing expenses).

The profit function peaks where the marginal gain in revenue from adding another PU is balanced by the marginal increase in cost.

Graphical Evidence:

Figure 9 clearly shows the profit curve reaching a maximum at N ≈ 9-10, confirming the results in Table 6, where the profit peaks at 836 for N≤10 and begins to decline thereafter.

The design outcome is significant: an optimal, modular configuration that minimizes complexity and cost while purportedly maximizing energy output and self-sufficiency.

5.4. Critical Discussion and Assessment of Validity

This is where the study faces its most significant scrutiny. The discussion must be bifurcated into the internal consistency of the engineering model and the fundamental validity of its physical premises.

5.4.1) **Internally, the engineering approach is sound:**

(a) The use of cascade systems with heat regeneration is a well-established method to improve efficiency.

(b) The optimization procedure, which balances performance gains against economic costs, is standard practice in plant design.

(c) The pursuit of modular, identical components is a rational design goal for reducing cost and complexity.

5.4.2) **However, the foundation of the entire concept is scientifically highly problematic:**

(a) **The First Law Challenge**

The claimed violation of the FLT is extraordinary and requires extraordinary evidence. The analysis provided is theoretical and based on a specific interpretation of the VsVs cycle. There is no conventional thermodynamic analysis that argues that the energy for the work obtained by "traction" during contraction (4-1) is possible while the internal energy of the TWF is increased. However, both empirically and experimentally, it is observed in everyday life. This irrefutable fact is peer-reviewed and published in [4].

(c) **Lack of Experimental Validation?**

An extensive experimental validation has been conducted through a series of proof-of-concept tests, as documented in references [2–3]. These tests involve cooling a thermodynamic working fluid (TWF) confined within a chamber of a single-acting reciprocating cylinder with its motion initially blocked, by creating a vacuum. Upon releasing the piston, it begins to move, performing useful mechanical work on the surrounding environment. During this process, the fluid contracts, leading to an increase in its internal energy and pressure. In essence, the system generates useful work while simultaneously increasing both pressure and internal energy, until force equilibrium is reached between the external load and the environment.

6. Overall Conclusion and Interpretation

The article explores the thermodynamic optimization of self-sustaining power plants, a topic of interest in prototyping and conceptual design. While the concept is intriguing, it remains a highly controversial thought experiment.

(a) **Considering an Engineering Design case study**:

The research work effectively demonstrates a structured methodology for optimizing a complex, cascaded thermal system. The identification of an optimal temperature differential (ΔT) and the ideal number of modules represents a meaningful contribution to the conceptual design of such systems—*provided* the underlying thermodynamic cycle is valid.

(b) **Considering a Scientific Claim**:

Although the article does not offer conclusive evidence supporting the fundamental premise of circumventing the First Law of Thermodynamics, its claims are based on a theoretical-empirical model that challenges one of the most rigorously established principles in science. Consequently, and in light of the experimental evidence cited in references [2–4], the concept demands validation through a commercially available demonstration prototype. Based on the previously cited empirical studies, the probability of success of the mentioned contributions is high. However, it is clear that exhaustive design and optimization studies are required before implementing such a prototype: such commendable studies have been previously conducted and published; this is the main justification for the article. In essence, the article proposes a disruptive and potentially revolutionary idea, but it does so on a basis that the scientific community at large would almost universally reject without solid, experimental, and independently verified evidence. Consequently, despite successfully passing irrefutable proofs of concept regarding obtaining useful work by cooling-induced contraction in double-acting reciprocating actuators, only a commercial prototype could resolve these doubts.

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