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Prototyping Self-Sustaining Power Machines with Cascaded Power Units Composed by Pulse Gas Turbines

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Abstract;

This research work aims at designing a prototype of a disruptive Self-Sustaining Power Machine (SSPM) composed of cascaded power units (PUs). Each PU consists of a Pulse Gas Turbine (PGT). The prototyping design task involves a singular thermal cycle (sVsVs) associated to each PU, characterized by doing work by: of a Thermal Working Fluid (TWF) due to previous heat addition, contraction of a TWF previously cooled by heat extraction and, upgrading recovered heat by increasing thermal potential by heat superposition techniques, and efficiexpansion ent use of the heat recovered from each upstream PU to feed the first PU downstream.

The fact of achieving useful mechanical work with the above-mentioned procedures by adding only heat to produce expansion work, undergoes an excess of useful mechanical work greater than the amount of added heat, which gives rise to a SSPM enabled to defy Perpetual Motion Machines (PMM) of second kind.

In the proposed configuration, the heat released from each PU due to the cooling of the TWF is efficiently recovered and reused in the first PU in the cascade. Results have been verified through two case studies carried out on a SSPM simulated prototype, being conducted using air and helium as real gases.

According to the results, the SSPM composed by a group of cascaded PUs, each exhibiting an average efficiency of less than 35% with air as TWF, can approach a SSI of 22% while the SSPM composed by a group of cascaded PUs, each exhibiting an average efficiency of less than 57% with helium as TWF, can approach a SSI of 84 %. Consequently, the results achieved from the case studies of the SSPM indicate that it is possible to overcome second kind PMMs.

Keywords: cascade coupling, contraction work, expansion work, heat recovery, pulse gas turbines, vacuum work.

Nomenclature

Acronyms	*description*
CF	Carnot Factor
Cont.	contraction
CTF	Cooling Transfer Fluid (conventionally, thermal il)
EM	electromagnetic
EP	Electric Power
Exp.	expansion
FCF	Forced convection fan (recirculation fan of the TWF)
FP	Feed pump (feed compressor of the TWF)
HTF	Heating Transfer Fluid (conventionally, thermal il)
Is_eff	Isentropic efficiency (open processes)
LF	Losses factor
ORC	Organic Rankine Cycle
PMM	Perpetual Motion Machine
PMM	Perpetual Motion Machine
PP	Power Plant: a group of PUs coupled in cascade
PP	Feed pump
PU	Power Unit operating with the thermal cycle sVsVs
RF	Herat recovery factor

RIT	Ratio of Isochoric low to high temperatures [T_L/T_H], [T_1/T_3]
SSI	Self-Sustaining Index, which is equivalent to the net free energy as % : [$SSI = (\eta_{th} - 100)/100$]
SEP	Self-Electric Power: SEP ≈ SSI (net mechanical power ≈ net electrical power)
SKPMM	Second kind Perpetual Motion Machine
sp	State point of any stationary point state of a thermal cycle
SPPP	Self-Powered Power Plant
SSPM	Self-Sustaining Power Machine
SSPP	Self-Sustaining Power Plant
sVsVs	Cycle with the sequential processes: [isentropic-adiabatic (s), Isochoric (V),]
TWF	Thermal Working Fluid
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
q_{rec}	Recovered heat from cycle process 4-1
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 in
w_{iFP}(kJ/kg)	Work added to drive the feed pump of 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 ($w_{oexp} + w_{ocont}$) = ($w_{o23} + w_{o41}$)
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
TF (%)	Heat transfer losses due t heat recovery effectiveness
LF (%)	Losses factor (thermal and mechanical irreversibilities)

η_{th} (%) Cycle thermal efficiency [w_n/qi]

1 Introduction

This research work combines two aspects inherent to the heat-to-work conversion techniques, despite being well known, that have never been considered for the design and development of technically disruptive and highly efficient power units necessary to form self-powered power plants (SPPP). Such concepts consist of the well-known vacuum used in conventional rotary and reciprocating steam engines, which includes Rankine and ORCs. In this work a disruptive cycle strictly composed by closed heat transfer processes to give both expansion and contraction or a vacuum, while doing useful work by open transformations is resented.

It is has been experimentally observed that when steam is cooled inside a Rankine cycle condenser, entropy decreases even at a constant temperature. Due to the generated vacuum, a significant amount of work is produced in addition to the work obtained by steam expansion. This makes it possible to obtain useful mechanical work when even when entropy decreases.

The idea that vacuums or contraction pressure (any pressure lower than atmospheric pressure or lower than the initial or reference pressure of a contraction-based thermal cycle) can be used to perform useful mechanical work in heat engines is an ancient concept. Practical vacuum systems are available for carrying out useful mechanical work using vacuums obtained by cooling a TWF in several ways. For instance, some vacuum systems undergo a change of state via the condensation of the TWF (from steam to liquid water), which can be carried out in both open and closed processes.

Considering the fact that useful work by contraction is obtained when entropy is quasi-constant in the cases of adiabatic contraction, is evident by observation, and this transformation doesn't violate the second law of thermodynamics. Nevertheless, it is the key to achieving a thermal machine that uses a vacuum to carry out useful mechanical work via the thermal contraction of the TWF. If strictly adiabatic expansion and contraction are added to this technique, highly disruptive and efficient thermal machines are achieved.

Recently, Gerald Müller (2013) [1] presented an innovative concept concerning low-temperature-based atmospheric steam engines. The author extended the theory of the atmospheric steam engine operating under a vacuum (contraction) achieved by heat extraction to show that operation is possible at temperatures between 60 °C and 100 °C, although efficiency is further reduced as the temperature increases.

Similarly, Gerald Müller and George Parker (2015) [2] conducted a series of experiments to assess this theory by including a forced expansion stroke. Recently, the atmospheric steam engine (which implies that useful work is due to the presence of a vacuum) was re-evaluated. According to the authors, the theoretical efficiency of the ideal engine can be increased from 6.5% to 20%.

R. Ferreiro et al. [3-7 presented state-of-the-art technologies for thermal cycles that allow operation with closed processes of both thermal expansion and contraction.

Some interesting topics that has been taken into account deals with three disruptive technological challenges that must be overcome to implement efficient power units (PUs) capable of being operated by means of thermal contraction based on a vacuum under closed processes-based adiabatic-isentropic transformations, due to R. Ferreiro et al. [7-9] as well as optionally contraction based on strictly isothermal closed processes. The first challenge is that a thermal machine must be able to operate with the aforementioned thermal cycle (i.e., it must be capable of operating through thermal contraction). The second challenge is that the thermal cycles of a thermal machine must be able to operate with strictly isothermal processes of both thermal expansion and contraction. The third technological challenge is that a thermal machine must be able to develop highly effective forced thermal convection heat transfer media at the transfer rate required by the nominal power of each PU, where every PU is composed of a pair of RDACs equipped with associated heat transfer equipment.

Mentioned contributions were recently followed by advances on power plants composed bi groups of power unites coupled in cascade where, R. Ferreiro et al. [10-13], in which regenerative expansion-contraction-based cycles Power Plants have been researched.

The present study is focused on improving the efficiency of Power Plants in which instead of using heat regeneration in the PUs, cascade heat recovery is used, thereby achieving absolutely disruptive efficiencies compared to conventional technologies.

2. Background on SPPP technologies

A self-powered power plant (SPPP) comprises a novel power plant architecture based on a perpetual motion machine (PMM) of second-kind, designed to generate more power than it consumes. However, the focus of the study is not on the SKPMM itself but a SPPP.

According to Emmy Noether's theorem, "every continuous symmetry of the action of a physical system with conservative forces has a corresponding conservation law". However from this theorem it is derived the following statement: *If the energy of a physical system is conserved, then this system is closed and isolated*. This means that in a non isolated system where successive transformations based on heat-work interactions are resent undergoing dissipative variables, then energy is not conserved due to the inherent irreversibilities. This is the case of all real systems.

Based on Noether's theorem, real perpetual motion machines of the first and third kinds, which purport to produce free energy, are impossible due to the constraints imposed by the second law of thermodynamics due to its inherent irreversibilities. That is, real perpetual motion machines of the first and third kinds exhibit dissipative forces, making them impossible. This does not apply to real machines for which dissipative forces are inherent.

The energy conversion processes in PMMs of first and third kind are purely mechanical, such as the conversion of kinetic to potential energy or vice versa, which only involve conservative forces. However, real machines of the second kind experience inherent losses due to irreversibilities or non-conservative variables (thermo-mechanical losses due to the conversion of a fraction of kinetic energy into heat from non-conservative forces such as friction, and isentropic losses), in accordance with the second law. The case of SPPPs, as presented in this research work, while adhering to the second law, is distinctly different as they employ a strategy to compensate for and overcome the inherent losses caused by non-conservative or dissipative forces using an innovative and disruptive heat recovery strategy. Through empirical development, it will be demonstrated that a SPPP overcomes the losses inherent to non-conservative forces, including all types of irreversibilities but also generates more free energy than is necessary to operate at nominal load. This essential characteristic defines a true SSPM.

This unprecedented machine consists of a cascaded array of power units (PUs), each designed to defy the limitations imposed by the Carnot factor while still adhering to the principles of the second law of thermodynamics. The SSPM is composed of a series of cascaded PUs, where each PU does not necessarily possess the characteristics of a PMM of second kind —that is, the capacity to surpass or indeed reach 100% of the externally added power. This implies that a group of PUs, each exhibiting a thermal efficiency of less than 100%, can collectively achieve a type of power engine whose efficiency exceeds 100%, without violating the first or second laws of thermodynamics.

This peculiar behaviour is attributed to the fact that each PU is capable of performing useful mechanical work through the vacuum created by thermal contraction during heat extraction. The heat removed from the cooling system is effectively reclaimed through a strategy based on the cascaded coupling of PUs, where the recovered heat is reintroduced to the first PU in the SSPM sequence. Consequently, a series of PUs connected in cascade, each with an efficiency of less than 65%, can result in an SPPP that produces more energy than it consumes, thereby exhibiting an efficiency greater than 100%. This is possible because nearly half of the work produced by each cascaded power unit is obtained at no cost (free-cost energy) due to the work done by contraction due to previous cooling. Moreover, this is further enhanced by the efficient cascaded heat recovery strategy consisting of an additive mode of potential energy superposition, where the magnitude is temperature. Therefore, in this study, the concept of 'energy' is assumed to be an intrinsic property of nature, characterized by the difference of potential between two points of a trajectory within a physical field magnitude. The trajectory of the magnitude under consideration can be described by a continuous, differentiable function. Among such physical magnitudes are, but not limited to, temperature, electrical potential, pressure difference, electric field potential, magnetic field potential, and gravitational field potential. One of the consequences of the second principle of thermodynamics is the 'principle of minimum energy,' which states that physical systems tend to evolve toward lower energy states due to the tendency toward thermodynamic equilibrium. Thus, in a local context, if the energetic system is in equilibrium, its energy is at a minimum—zero useful energy. As a consequence, the only known method to achieve a potential difference—energy—is by adding external energy, such as work or heat, among other available energetic magnitudes.

2.1 Brief description of the PGT structure and its operating modes

The PUs corresponding to the prototype proposed to implement of the SPPP are based on the PGT patented with application number P202000032 and publication number ES2851381. The PGT scheme is illustrated in Figure 1a. Four main sub-systems compose the PGT structure: A supply heat system, an extraction heat system, a PGT and a feeding pump system. According to Figure 1(a), an expansion-contraction heat scheduling scheme equipped with two heating and cooling reservoirs operating under alternative and intermittent sequence is depicted. In Figure 1(b), it is depicted a symbolic scheme to represent every power unite of each self-powered power plant

The prototype of a PGT depicted in Figure 1(a) consists of one or more closed-circuit gas turbines enabled to be installed in power plants which are coupled through a common shaft to all the rotating machines of the system. Each of the PGTs operate intermittently based on barothermal pulses, which consist of positive pressure pulses associated with the temperature achieved by heat addition with isochoric heating and/or pressure pulses associated with the temperature achieved by heat extraction with isochoric cooling of the gaseous TWF carried out within reservoirs intended for this purpose.

Mentioned barothermal pulses are applied to the gas turbine in two ways:

Positive barothermal pulses (pressure higher than an equilibrium or reference pressure) applied from high-pressure reservoirs, and

Negative barothermal pulses (pressure lower than the equilibrium or reference pressure) applied from low-pressure reservoirs.

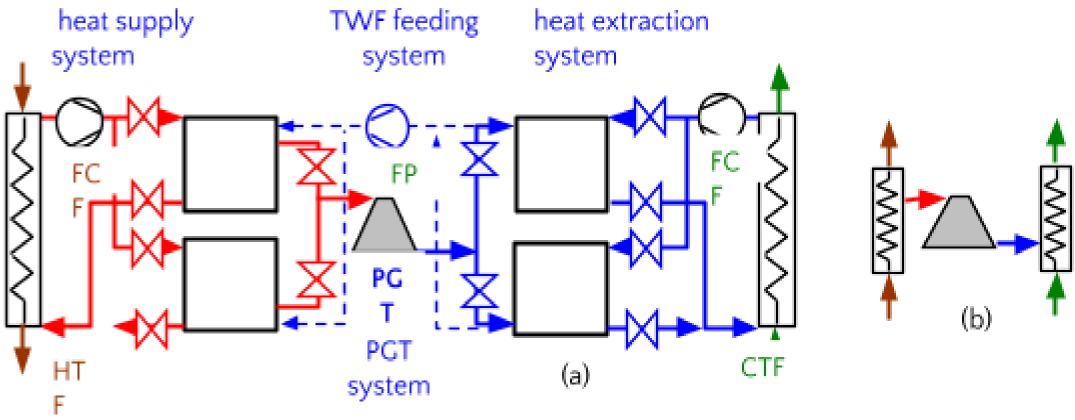


Figure 1: Illustration of the PGT based on the patent application number P202000032 and publication number ES2851381, [15]. Figure 1(a) depicts the main subsystems including the heat supply system, the heat extraction system, the TWF feeding system and the PGT machine. Figure 1 (b) depicts illustrates the symbol used to represent the main subsystems depicted in Figure 1(a).

To facilitate and simplify the brief description of the operation modes of a PGT-based PU with a sVsVs type thermal cycler, we have Figure 2.

Thus, Figures 2(a) and 2(b) show:

isochoric heat addition process in reservoir A

isochoric heat extraction process in reservoir B

Figures 2(c) and 2(d) show:

isochoric heat addition process in reservoir C

isochoric heat extraction process in reservoir D

Figures 2(e) and 2(f) show:

p-V diagrams of the sVsVs cycle carried out in reservoirs A-B and C-D sequentially to complete each operating cycle of the PU considered.

Figures 2g and 2h show the pressure-time diagrams for both reservoirs illustrating the net pressure as the difference between the pressures of reservoirs A-B in the case of the first sVsVs cycle and between the pressures of reservoirs C-D in the case of the second sVsVs cycle.

The concatenation of the sVsVs cycles corresponding to the p-V diagrams shown in Figures 2g and 2h is illustrated by Figure 3, showing the pressure pulses as a function of time in each PGT cycle, which is composed by two sVsVs thermal cycles.

The reason for having at least two reservoirs to accumulate the heated TWF at constant volume at the heat source and cooled in the heat sink area is that it allows generating high-pressure and temperature pulses intermittently at the gas turbine's inlet operating with barothermal pulses intermittently and sequentially. Similarly, the reason for having at least two reservoirs to accumulate the cooled TWF at constant volume in the heat sink area is that it allows generating low-pressure and temperature pulses, which produce negative pressure pulses intermittently in the evacuation zone of the gas turbine with thermal pulses, which are applied intermittently and sequentially, in synchrony with the positive barothermal pulses.

In one of the possible design options of the gas turbine operating with barothermal pulses, for each high-pressure barothermal pulse applied at the gas turbine's inlet operating with barothermal pulses, a negative pressure pulse is applied in the evacuation zone of the gas turbine operating with barothermal pulses synchronized with the high pressure.

Figure 2 (b) and 2(d) illustrates the sVsVs thermal cycle by means of T-s diagrams, highlighting the active heating and cooling processes. Such processes are also represented in Table 1. According to the thermodynamic functions executed sequentially, there are two heat transfer processes: isochoric heat addition and isochoric heat extraction. While the processes of heat addition undergo temperature and pressure increasing, which gives rise expansion work, the processes of heat extraction undergo temperature and pressure decreasing which gives rise contraction work. In next section further information dealing with cycle analysis will be provided.

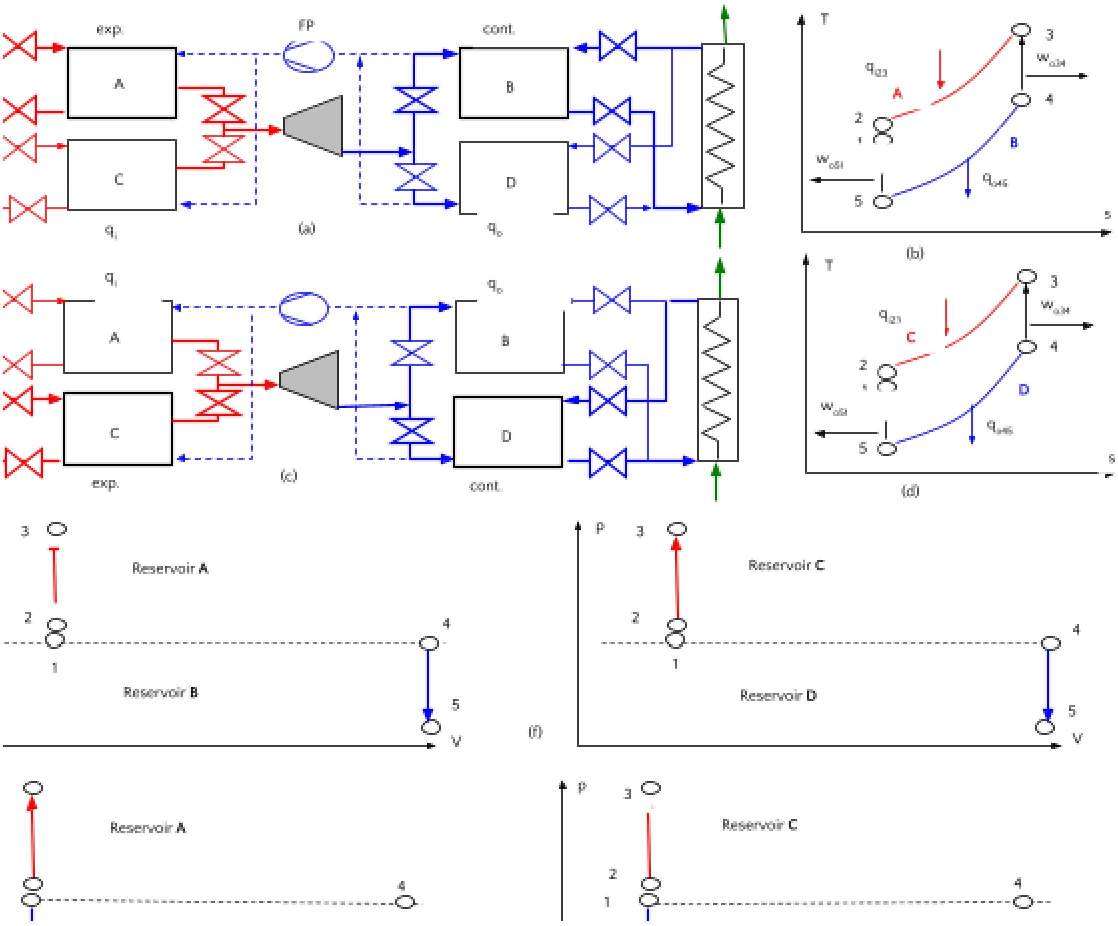


Figure 2: PU scheme to illustrate the operating modes

With the application of both positive and negative pressure pulses simultaneously in the high and low-pressure zones of the gas turbine operating with barothermal pulses, a significant pressure difference is achieved between the inlet and outlet of the gas turbine operating with barothermal pulses, generating at the beginning of each barothermal pulse a significantly high torque, which attenuates as the TWF expands within the gas turbine with thermal pulses. In another of the possible design options of the gas turbine operating with barothermal pulses, for each high-pressure barothermal pulse applied at the gas turbine's inlet operating with barothermal pulses, a negative pressure pulse is not applied in the evacuation zone of the gas turbine operating with barothermal pulses, but the heat extraction process towards the sink is carried out under the reference pressure and temperature. With the application of pulses of positive pressures only in the high-pressure zone of the gas turbine operating with barothermal pulses, only the pressure difference between the inlet and outlet of the gas turbine operating with barothermal pulses subjected to the equilibrium pressure with which it evacuates to the heat sink is achieved. Therefore, in this case, the effect of each barothermal pulse results in a torque smaller than in the case of the option of positive and negative barothermal pulses simultaneously. The TWF subjected to high temperature and its corresponding pressure within each high-pressure reservoir, once released in pulse form, expands adiabatically within the gas turbine operating with barothermal pulses (where the adiabatic expansion process approximates a quasi-isothermal expansion process because the heat accumulated in the metal of each isochoric heating reservoir as well as in its respective associated heat exchanger, transfer heat to the TWF during the theoretically adiabatic expansion process, and similarly, each isochoric cooling reservoir as well as its respective associated heat exchanger or cooler, transfer heat from the thermal fluid of heat extraction during the theoretically adiabatic expansion process), generating useful mechanical work that can be converted to eclectic energy via mechanical energy.

Table1 sVsVs thermal cycle execution sequence

sp	Process task	Sequential sVsVs cycle processes	Thermal-model
1-2	Feed pump work in	Open adiabatic-isentropic	$w_{i12} = \Delta h_{12}$
2-3	Heating the TWF	Closed isochoric heat addition	$q_{i23} = \Delta u_{23}$
3-4	Expansion work out	Open adiabatic-isentropic expansion	$w_{o\exp 34} = \Delta h_{34}$
4-5	Cooling the TWF	Closed isochoric heat extraction	$q_{o45} = \Delta u_{45}$
5-1	Contraction work out	Open adiabatic-isentropic contraction	$w_{ocont51} = \Delta h_{51}$

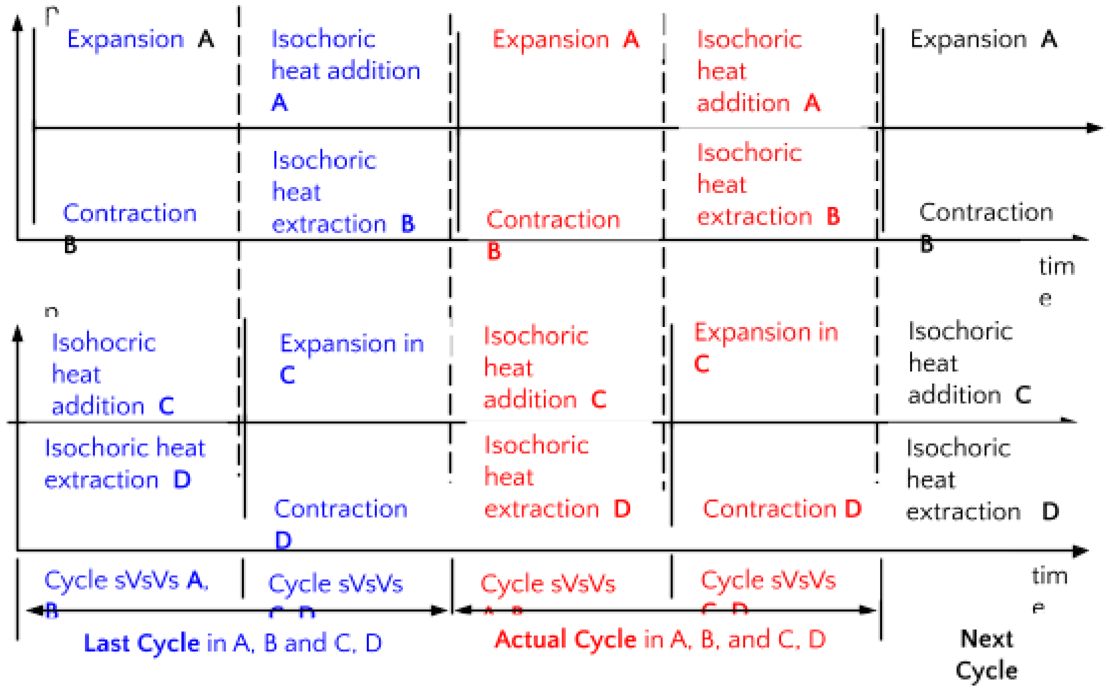


Figure 3: Pressure-time diagrams of the thermal cycle sVsVs and cycle timing synchronization

Generally, when one of the thermal fluid reservoirs subjected to high pressure by having been heated at constant volume is applied to the gas turbine operating with barothermal pulses, it expands; after expanding, which leads to a decrease in pressure to the level of the reference intermediate pressure, such a reservoir is isolated from the gas turbine operating with barothermal pulses, thus the next heating reservoir with TWF at high temperature and corresponding pressure comes into operation, so that when one of the isochoric heating reservoirs is in the expansion process, the other reservoirs are in the isochoric heating phase. Similarly, generally, when one of the low-pressure working fluid reservoirs, after contracting by having been cooled at constant volume, communicates with the evacuation zone of the gas turbine operating with barothermal pulses, which leads to an increase in pressure from the minimum pressure reached by isochoric cooling to the level of the reference intermediate pressure, then it is isolated from the gas turbine with thermal pulses, giving way for the next reservoir of TWF at low temperature and corresponding pressure to come into operation, so that when one of the isochoric cooling reservoirs is in the working state, its complementary isochoric cooling reservoir is in the is in he isochoric cooling state.

The significant differences of the presented technology based on the proposed PGT technology, compared to Rankine cycles, ORCs, and Brayton cycles are summarized in the following points:

- There are no phase changes of the TWF (such as helium, dry nitrogen, dry air, among other TWFs, which means that the heats of vaporization and condensation are not present.
- The tasks of adding and extracting heat to/from the cycle are carried out at constant volume. This is possible by alternately operating with two or more heating and cooling isochoric reservoirs, which operate under forced convection heat transfer.
- No conventional feed pumps are required because there are no phase changes. Instead, a low-pressure TWF feed compressor is used, where the low-pressure compression is due to the fact that during the time the working fluid is being pumped from a low-temperature fluid reservoir to a high-temperature fluid reservoir, it exhibits suction and discharge pressures very close to each other.
- Cooling turbine blades is not required in any case.
- An installation based on a cascade coupling structure of a group of PGTs with respect to the heat transfer fluid (HTF) temperature mechanically coupled on the same rotating shaft contributes to an effective waste heat recovery system based on the following facts:

1 Effective recovering and use of low-grade heat exhausted from the connected upstream turbines.

2 The thermal efficiency of a PGT cycle is independent of the range between high and low temperatures since it does not obey Carnot constraints. Contrary to Carnot, indeed, efficiency is higher for low-temperature ranges (T_H-T_L) which implies high temperature ratios (T_L/T_H). This characteristic also contributes to the increase of the residual heat utilization factor.

Given that the efficiency of each individual PGT is significantly higher than in conventional Rankine cycles-based steam turbines, associated to the fact that the heat utilization factor is also greater, the overall efficiency is significantly increased

3 PGT-based sVsVs cycle: development and analysis

Let's begin by identifying the acronym corresponding to the name of the thermal cycle studied, the sVsVs cycle e to operate a PGT. Thus, the acronyms that identify the thermal cycle denote the thermodynamic transformation carried out between each two state points of the thermal cycle. If s means the constant entropy and V means the specific constant volume of the thermal fluid, then sVsVs means a sequence of processes equivalent to isentropic, isochoric, isentropic, isochoric, isentropic.

3.1 PGT-based sVsVs cycle processes

The transformations associated with each state point of the cycle composed by 1-2 open isentropic, 2-3 closed isochoric, 3-4 open isentropic, 4-5 closed isochoric and 5-1 open isentropic processes (sVsVs), carried out in the PGT are illustrated with Table 1 and described as follows:

Process 1-2:

Correspond to an open adiabatic-isentropic compression process driven by a feed pump –gas compressor–. This process consists of an open process since it involves mass transfer. The amount of work added to the feed gas compressor under an adiabatic-isentropic process is described as:

$$w_{i12} = w_{iFP} = \Delta h_{12} = h_2 - h_1 = Cp \cdot (T_2 - T_1) \tag{1}$$

Process 2-3:

Correspond to a closed isochoric heat addition process in which the working fluid is heated.

$$q_{i23} = \Delta u_{23} = u_3 - u_2 = Cv \cdot (T_3 - T_2) \tag{2}$$

Process 3-4:

Correspond to an open adiabatic expansion process in the PGT which undergoes mass transfer while volume increases. Thus the thermal energy in the form of enthalpy is converted into mechanical work, provided that the PGT rotates freely doing expansion work.

$$w_{o34} = w_{o\exp 34} = h_3 - h_4 = \Delta h_{34} = Cp \cdot (T_3 - T_4) \tag{3}$$

Process 4-5:

Correspond to a closed isochoric heat addition process in which the working fluid is heated without work done because of the constant volume process

$$q_{o45} = \Delta u_{45} = u_4 - u_5 = Cv \cdot (T_4 - T_5) \tag{4}$$

Process 5-1:

Correspond to open adiabatic contraction-based compression process. Thus the thermal energy in the form of enthalpy is converted into mechanical work by contraction (TWF volume decreases in the cold PGT reservoir), provided that the PGT can move freely to permit the contraction-based compression work.

$$|w_{o51}| = |w_{ocont51}| = |h_5 - h_1| = Cp \cdot |(T_5 - T_1)| = Cp(T_1 - T_5) \tag{5}$$

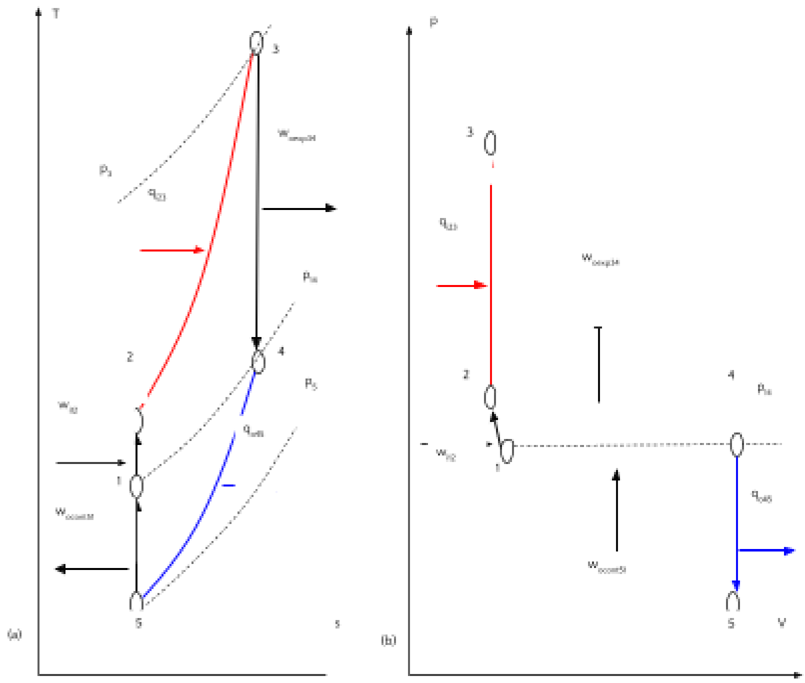


Figure 4: Single PGT-sVsVs hybrid (closed & open processes) thermal cycle. (a): T-s diagram. (b): p-V diagram

The sVsVs thermal cycle is hybrid due to be composed by closed and open processes. While heat transfer is carried out by adding and extracting heat by means of isochoric closed processes, the rest of processes involving work undergo mass transfer. Consequently, the open process-based heat-work interactions are modeled by using enthalpies. This concept is illustrated in the Figure 5, where heat transfer and mass transfer are symbolically separated.

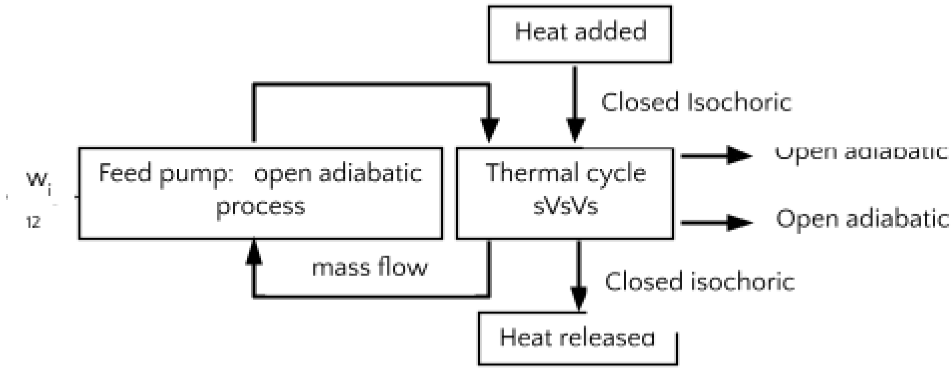


Figure 5: sVsVs thermal cycle energy (heat-work) flow diagram doing work by open adiabatic expansion and contraction while transferring heat by closed isochoric heat addition and heat extraction during.

3.2 sVsVs analysis

The analysis of the 4CP VsVs is based on the first law, so that the energy transfer flows include the following energy balances derived from the previous section:

Input heat:

heat added at closed isochoric heat transfer process

$$q_{i23} = \Delta u_{32} = Cv \cdot (T_3 - T_2) \tag{6}$$

Output heat

heat extracted at closed isochoric heat transfer process

$$q_{o45} = \Delta u_{45} = Cv \cdot (T_4 - T_5) \tag{7}$$

Input work

The input work in the sVsVs cycle is due to the pumping effort of the feed compressor. In order to simplify the analysis without loss of generality, the amount of work done on the feed compressor to transfer the working fluid from the cold reservoir to the hot reservoir is

$$w_{i12} = \Delta h_{21} = h_2 - h_1 = Cp \cdot (T_2 - T_1) \tag{8}$$

where the required work used to drive the forced convection circulation fans (one per heat exchanger) is neglected in this analysis.

Output work

The work done by expansion along the process 2-3 due to the isochoric heat added is

$$w_{o34} = w_{o\exp 34} = \Delta h_{34} = Cp \cdot (T_3 - T_4) \tag{9}$$

The work done by contraction along the process 5-1 due to the isochoric heat extracted is

$$w_{o51} = w_{ocont51} = \Delta h_{51} = Cp \cdot (T_1 - T_5) \tag{10}$$

Net useful work

$$w_n = w_{o\exp 34} + | w_{ocont51} | - \Delta h_{12} = \Delta h_{34} + \Delta h_{51} - \Delta h_{12} \tag{11}$$

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

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o34} + | w_{o51} | - \Delta h_{12}}{\Delta u_{32}} = \frac{\Delta h_{34} + \Delta h_{51} - \Delta h_{12}}{Cv \cdot (T_2 - T_1)} = \tag{12}$$

3.3 Performance results of the PGT-sVsVs cycle

Every PU completes a PGT cycle by executing two sequential sVsVs thermal cycles. Both thermal cycles are executed in such a way that when one of the thermal cycles sVsVs is carrying out mechanical work of expansion and contraction simultaneously, the complementary thermal cycle is in the phase of heat addition and extraction simultaneously.

To continue the study of the SSPM, it is necessary to know the characteristics of each power unit (PU), which depend on the properties of the thermal cycle used. So, in order to know the behavior of the PGT-sVsVs thermal cycle with respect to the isochoric temperature relationship *RIT* = T_1/T_3 such that they provide an acceptable performance of each PU, the study is based on the definition of the relationship of temperatures in a similar application range to that expected for operating in the SSPM coupled in cascade downstream.

From equations (9) and (10) we have

$$w_{o\exp 34} = Cp \cdot (T_3 - T_4) \tag{13}$$

$$w_{ocont51} = Cp \cdot (T_1 - T_5) \tag{14}$$

From (13) and (14) it is achieved the isochoric temperatures as

$$T_3 = \frac{w_{o\exp 34} + Cp \cdot T_4}{Cp} \tag{15}$$

$$T_1 = \frac{w_{ocont51} + Cp \cdot T5_5}{Cp} \tag{16}$$

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

$$RIT = \frac{T_1}{T_3} = \frac{w_{ocont51} + Cp \cdot T_5}{w_{o\exp 34} + Cp \cdot T_4} \tag{17}$$

To observe the relevance of selecting an appropriate RIT value under efficiency criteria apart from other operating parameters such as cycle reference pressure and maximum pressures, the following case study on the PGT-sVsVs cycle is carried out.

3.4 Validation of the PGT-sVsVs cycle based on case studies

The cases depicted in Table 3 consists of the study of 5 thermal cycles of the type PGT-sVsVs, where top temperature T3 is fixed in 800 K and the temperature T1 is fixed in a value such that assuming the value of RIT as T1/T3, then, T1 = RIT(PUi).T3 . Thus, the selected RIT for each case considered is 0.9, 0.85, 0.8, 0.7 and 0.6 respectively. By processing the data of Table 2 according to the thermodynamic model of the proposed thermal cycle described along equations (6-18), a useful set of data is obtained as results of the analysis, as function of the RIT for each case which is depicted in Table 3. The mentioned results include the high and low temperatures, the specific flows of input heat and output heat, as well as useful mechanical work, and with the aim of comparison purposes the thermal efficiency and Carnot factor is also depicted.

Table 2 Computation data for helium as working fluid, sowing the results of the PUs operating with a PGT-sVsVs thermal cycle corresponding to the T-s diagram depicted in Figure 5. Real TWF data used belongs to the database provided by Lemmon E. W., et all, (2007), [29].

sp	T(K)	p(bar)	v(m³/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg. K)
			PU 1; RIT*100 = 90			
1	720.00	2.00	4.9661	2248.60	3745.10	3745.10
2	729.49	2.10	4.8700	2278.20	3799.88	3794.40
3	800.00	2.40	4.8700	2497.90	4160.60	4160.60
4	761.09	2.00	5.2493	2376.70	3978.62	3958.40
5	695.00	1.74	5.2493	2170.70	3615.10	3615.10
			PU 2; RIT*100 = 85			

1	680.00	2.00	4.6904	2124.00	3537.30	3537.30
2	688.94	2.10	4.5994	2151.90	3588.97	3583.80
3	800.00	2.60	4.5994	2498.00	4160.70	4160.70
4	743.84	2.00	5.1304	2322.90	3898.08	3868.90
5	640.00	1.58	5.1304	1999.40	3329.50	3329.50
			PU 3; RIT*100 = 80			
1	640.00	2.00	4.4146	1999.40	3329.60	3329.60
2	648.39	2.10	4.3289	2025.50	3378.04	3373.20
3	800.00	2.83	4.3289	2498.00	4160.70	4160.70
4	726.01	2.00	5.0075	2267.40	3814.74	3776.30
5	589.00	1.43	5.0075	1840.40	3064.60	3064.60
			PU 4; RIT*100 = 70			
1	560.00	2.00	3.8632	1750.10	2914.20	2914.20
2	567.39	2.10	3.7885	1773.10	2956.87	2952.60
3	800.00	3.38	3.7885	2498.00	4160.90	4160.90
4	688.30	2.00	4.7476	2149.90	3638.45	3580.40
5	488.00	1.12	4.7476	1525.70	2540.00	2540.00
			PU 5; RIT*100 = 60			
1	480.00	2.00	3.3118	1500.80	2498.70	2498.70
2	479.98	2.10	3.3116	1500.70	2498.59	2498.60
3	800.00	4.01	3.3116	2498.00	4161.10	4161.10
4	652.17	2.00	4.4985	2037.30	3469.63	3392.80
5	391.00	0.79	4.4985	1223.40	2036.20	2036.20

In the PGT-sVsvS cycle design task it is of paramount importance the selection of an acceptable value of the RIT. This is necessary to implement a SPPP composed of several PUs coupled in cascade, which are all the more useful the higher their thermal efficiency.

The SPPM (Self-Powered Power Plant) consists of multiple Power Units (PUs) arranged in a cascade downstream based on the Heat Transfer Fluid (HTF) temperature. The cascade spans a temperature range from the maximum supply temperature feeding the first PU to the minimum operating temperature of the last PU. If the RIT (Ratio of Isochoric Temperature) of each PU is low, it implies a wide temperature range for each PU. However, this leads to less PUs fitting in the cascade. To address this, selecting a sufficiently high RIT value ensures more PUs can be cascaded. In other words, the number of PUs that can be cascaded depends on the operating temperature range. Figure 3 shows that lower RIT values result in a broader temperature range (T1 to T3) for each PU. When this range is high, less PUs fit in the cascade. To maximize the number of PUs, opt for higher RIT values, reducing the temperature range for each PU and allowing more PUs in the cascade. As consequence, the acceptable value for the selected RIT is 0.85

Table 3 Performance results of the PGT-sVsVs cycle applied on the five case studies with the data depicted in the Table 2.

	PU1	PU2	PU3	PU4	PU5
T_3 (K)	800.00	800.00	800.00	800.00	800.00
T_1 (K)	720.00	680.00	640.00	560.00	480.00
RIT*100	90	85	80	70	60
q_i (kJ/kg)	360.72	571.73	782.66	1204.03	1662.51

q_o (kJ/kg)	363.52	568.58	750.14	1098.45	1433.43
w_o (kJ/kg)	230.51	385.06	523.90	805.90	1107.86
$\eta_{\eta T}$)%(	57.51	57.25	53.55	46.85	39.98
CF(%)	13.13	20.00	26.38	39.00	51.13

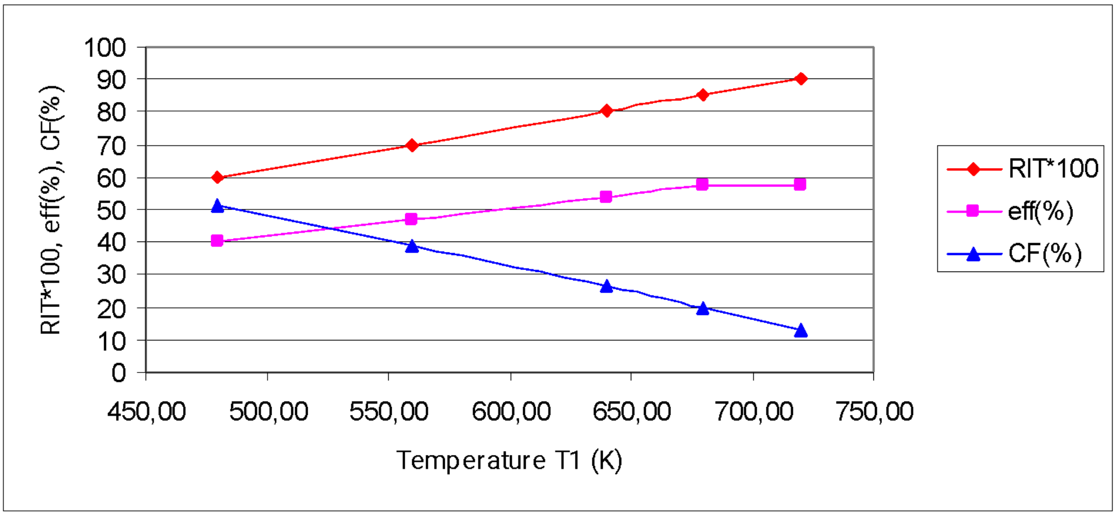


Figure 6: The effect of the RIT on the thermal efficiency and comparison with Carnot factor with data from Table 3.

In Figure 6 can be observed that an acceptable value for the RIT approaches the value of 85. As shown in Table 3, while the thermal efficiencies vary between 57.5 % and 40 %, as function of the RIT that changes from 90 to 60, the Carnot factor ranges from 13.1 % to 51 %. These results are in agreement with the maximum thermal efficiency inherent to the Carnot, Erikson and Stirling thermal cycles in which work is only due to the difference between added and rejected heat, while in the studied thermal cycle work is done by two types of heat-work interaction modes: (added heat and extracting heat).

3.5 Summary of the PGT-based PUs operating with the sVsVs thermal cycle

The key innovative concepts proposed for improving thermal contraction efficiency in the SSPMs systems are summarized by three disruptive and strategic considerations:

1. Utilizing thermal contraction to generate useful work:

- The SSPM design leverages the thermal contraction of the working fluid, in addition to expansion, to generate useful mechanical work.
- Performing work through contraction is a critical mechanism that enables the SSPM to achieve remarkably high efficiencies and self-sufficiency.
- This contrasts with traditional power cycles that rely solely on expansion to produce work.

2. Hybrid (closed/open processes-based thermal cycles with expansion and contraction:

- The SSPM employs specialized thermal cycles, such as the sVsVs cycle, that operates under a hybrid mode: through closed processes of both heat addition and heat extraction to perform open processes-based thermal expansion and contraction.
- This allows the system to extract useful work from both the expansion and contraction of the working fluid.

3. Disruptive strategy on efficient heat recovery and reuse tasks:

- The SSPM composed by a group of cascaded PUs composed by a group of PGTs coupled in cascade recovers the heat expelled during the cooling process that drives the thermal contraction.
- This recovered heat will be then reintegrated to power the first PU in the cascaded system, enabling the "heat superposition" strategy.

- This heat management approach allows the SSPM to generate more useful work than the initial heat input, exceeding 100% thermal efficiency.

4. Working Fluid Selection:

- The choice of working fluid, such as helium versus air, has a major impact on the thermal contraction efficiency and overall performance of the SSPM.
- Helium's superior thermodynamic properties allow it to extract significantly more useful work from the contraction process compared to air.

4 The structure of a SSPM based on PGTs

The SSPMs previously described in references [12-13] consist of double-acting reciprocating machines characterized by implementation difficulties regarding the coupling of movements and the uniform distribution of output forces towards a common eclectic generator.

In this prototype, it is intended to eliminate such drawbacks by simplifying the installation by means of a common mechanical coupling consisting of a shaft comprising all the PGT-based PUs and an electric generator.

4.1 Design task considerations

A SSPM must be characterized by their ability to do work indefinitely without an external energy input [11-13]. Required characteristic must overcome the irreversibilities inherent to any real machine. This means that it must overcome perpetual motion machines of the second kind, whose operation mode consists of a combination of mechanical and thermal transformations, are inherently affected by dissipative forces. These include irreversibilities due to mechanical losses primarily from friction, sound energy, as well as thermal losses including isentropic losses due to flow work caused by the thermal fluid friction, heat leaks, and heat transfer losses (due to conduction, convection, and radiation).

Since the efficiency of every single PU is less than 25% for air and less than 55% for helium as working fluids some Key factors for the efficiency enhancements in the SSPM structure must be developed and implemented. Therefore, the development and implementation of power characterized by generating more power than they consume for operation, are absolutely disruptive in terms of thermal energy utilization. They fundamentally consist of a set of PUs connected in cascade, each equipped with special thermal energy management capabilities. This results in a SSPM. To achieve such a disruptive effect, a series of key constructive and operational factors must be met:

In summary, the essential key factors to achieve a SSPM require to do useful mechanical work by**:**

1 expansion of a TWF due to previous heat addition

2 contraction of a TWF, due to previous heat extraction by cooling and

3 work produced by the heat efficiently recovered from the cooling of the working fluid in the contraction processes of each upstream PU.

However, these mentioned essential factors must be accompanied by the following key strategies:

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

2 A reduced Ratio of Isochoric Temperatures (RIT) to enhance the efficiency of each individual PU.

3 The task of supplying heat to the top PU in the cascade coupling structure is carried out using one of the available heat transfer techniques based on heat overlay using the thermal energy superposition potential technique which consists in adding heat by increasing temperature.

4.2 Description of the proposed SSPM structure

In Figure 7 it is depicted a cascade coupling scheme of a SPPP equipped wit a group of PUs coupled in ascade. In this figure it can be observed the HTF circuit in brown color along the heating section of pipe and in color green the cooling section of pipe conducting the same fluid operating as CTF. The same HTF is used for both, the heat adding section of heating piping and the heat recovering section of the cooling piping.

Apart from the power units equipped with their heat supply and extraction exchangers, the first power unit is equipped with a heat management system. This system consists of three fundamental components:

1 Heat exchanger (Self-feed heater) responsible for increasing the temperature of the heat transfer fluid to supply heat to the cascaded downward power units,

2 Electrical energy accumulation system (Star-up EP supply) to provide electrical energy to the heat exchanger described in 1 during the start-up phase.

3 Electrical networks (Start-up EP supply) from which electrical energy is supplied to the external network as well as to the first power unit of the installation described.

Likewise, it also needs a thermal sink responsible for cooling the HTF to the ambient temperature or minimum temperature to which the TWF of the first upstream PU has to be cooled. Located immediately after the upstream thermal sink, is a HTF recirculation pump. The first function performed by the HTF when driven by the pump is to cool the cascade of upstream PUs, recovering the cooling heat to transfer it to the first PU that operates at the highest temperature in the installation. One of the fundamental keys to achieving enhanced efficiency is based on the fact that the greater the amount of heat recovered, the lower the amount of heat that needs to be supplied to the first PU.

All isolated real thermal cycles must comply with the first and second laws of thermodynamics and therefore adhere to Noether's main theorem. However, the cascade coupling strategy of thermal cycles, which individually comply with the first and second laws, can surpass the limits set by these fundamental principles and generate more energy than they consume, thus functioning indefinitely.

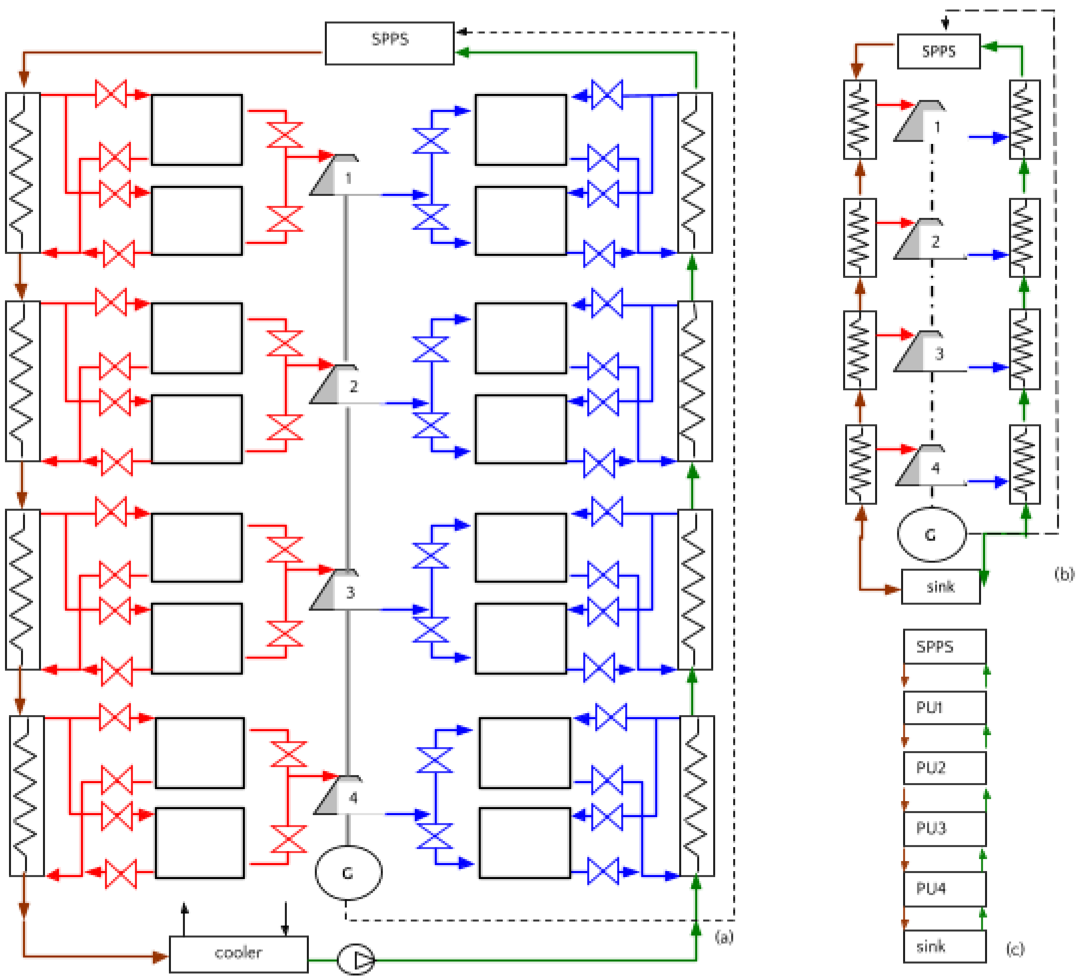


Figure 7: Illustration of a SSPM composed by means of several PUs coupled in cascade, each composed by a pair of single PGT-sVsVs thermal cycles. The design is based on the patent with application number P202000032 and publication number ES2851381. Figure 7 (a) depicts the general scheme showing the circuits responsible for heat addition (red), and heat extraction (blue), the heat supply exchanger, the heat sink exchanger and the group of PGTs mechanically coupled by means of a shaft including the power generator indicated with **G**. Figure 7 (b) depicts the SSPM symbol by a simplified scheme of the Figure 7 (a). Figure 7 (c) depicts the SSPM symbol to include in the results of the case studies.

To achieve this, they must satisfy three currently feasible conditions:

1 A cascade heat recovery strategy (without heat regeneration).

In this installation, it happens that the strategy of dispensing with the auxiliary circuits necessary to implement a regeneration system in each individual PU, entails a significant reduction in thermo-mechanical equipment, which contributes to a significant reduction in costs associated with the design, installation and maintenance tasks.

The conversion of nearly 100% of work into heat -electrical energy to heat- using one of the three available techniques referenced in (4) which are characterized by transferring heat by superposition of heat potential such as:

a) Heating based on electric resistance, or

b) Microwave-based heating, or

c) Magnetic induction-based heating.

2 Additionally, another alternative technique is available to convert work into heat 100 % efficient: It consists of a dissipative magnitude such as resistance to movement in both liquid and gaseous fluids (drag) and mechanical friction (friction).

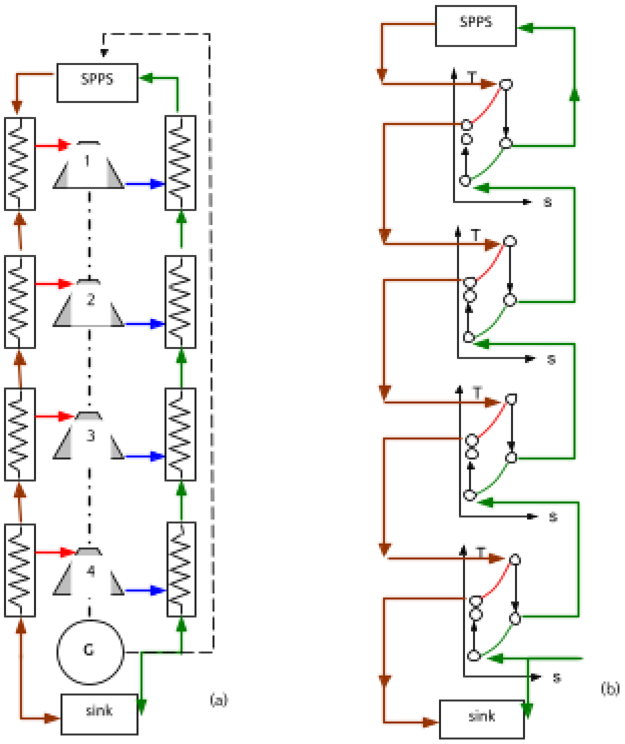


Figure 8: Flowchart of the closed circuit responsible for heat energy supply (brown) and heat energy recovery (green) of a SSPM. It consists of a closed circuit responsible for heat transfer addition in cascade downstream and heat transfer recovery in cascade upstream. While in Figure 8(a) it is shown the schematic heat transfer piping structure, the Figure 8 (b) depicts the heat flowchart through the T-s thermal cycle sVsVs associated with its corresponding PU.

A heat scheduling strategy is proposed that utilizes the cooling heat from each preceding PU upward to supply heat to the first PU by means of the power supply. Consequently, the heat supplied to the next PU downward is divided into two energy fractions: one that is directly converted into work and the complementary fraction of heat that is used to power the next downward PU. Based on the heat power supply strategy to the first PU, the breakthrough disruptive characteristic lies in the fact that the SSPM is capable of achieving a thermal efficiency greater than 100% of the heat added to the first PU of an SPPP composed of a series of cascaded PUs, all while adhering to the constraints imposed by the first and second laws of thermodynamics. In other words, the sum of the individual works of each PU within the SPPP exceeds the heat supplied to the first PU of the SSPM. This excess of work obtained is due to the class of thermal contraction, which is free of energy costs, with the condition that there is a coast-free cooling system.

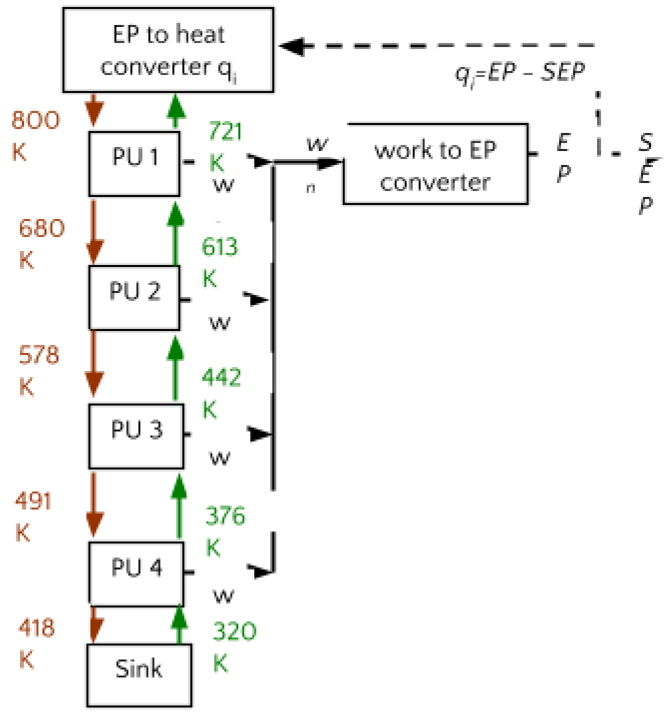
This revolutionary result is attained by capitalizing on the heat recovered from each upstream PU to be reused in powering the first PU; in essence, bolstering the heat input through the heat discharged in each successively coupled PU. The end result is that, with the strategy of scheduling the recovered heat, more useful work is produced than the heat required powering the first PU of the thermoelectric power plant.

This heat management strategy has been illustrated by means of the Figures 7 and 8. Figure 8 illustrates the HTF recirculation circuit used to feed thermal cycles of the sVsVs type. 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.

4. 3 Case studies: Implementation an SSPM with PUs-based PGTs operating with sVsVs thermal cycle

The basic scheme of a generic self-sustained thermal power plant equipped with the fundamental means to provide downstream heat to each PU coupled in cascade, as well as recover the cooling heat of each PU to be conducted upstream and feed back to the first PU (PU0) of the cascade, is represented in Figure 10. The useful mechanical work produced by each PU is converted to electrical power, being managed in such a way that a fraction of the electrical power is returned to the heat addition system to the PU0, while the remaining electrical power is sent to the network.

The fraction of electrical power sent to the PU0 is previously converted to heat by one of the available means: heating system based on electrical resistances, electro-inductive heating system or microwave heating system. Likewise, an alternative direct mechanical means of work-heat conversion through friction in a liquid could be used. The number of PUs in the plant is a function of two parameters: Temperature range available between the power source and the sink and the chosen value of the ratio (T_1/T_2), denoted as RIT for each PU.



IF $w_n > q_i$ *THEN* $EP > q_i \longrightarrow$ SEP > 0 and SSI > 0

Figure 9: Schematic structure of a SPPP as the paradigm of a self sustaining power machine (SSPM) showing the inlet temperatures of every PU downstream with a RIT = 0.85, as well as the temperatures of the recovered heat of PUs upstream. Acronyms used are: EP, electrical power; SEP, self electrical power; EP-SEP, amount of heat to feed PU0.

According to the plant structure depicted in Figure 9, energy balance is carried out according to the following model:

The total mechanical work is defined as,

$$w_n = \sum_{j=1,n} w_j \tag{18}$$

where the required amount of heat to feed the first PU of the cascade structure, is given as

$$q_{i(PU1)} = EP - SEP \tag{19}$$

Thus, the condition to achieve a feasible SSPM is written as,

$$IF\ w_n\ > q_{i(PU1)}\ THEN\ SEP > 0 \tag{20}$$

This means that output electric power (EP) is greater than the added heat energy q_i, so that there exist a free-cost useful energy available, that is, SEP. Such condition is represented as

$$IF\ w_n\ > q_{i(PU1)}\ THEN\ EP > q_{i(PU1)} \tag{21}$$

So, starting from this notable difference in behaviour in terms of thermal efficiency between PUs that operate through expansion and contraction (case of the VsVs thermal cycle), it is about analyzing both cases and draw the pertinent conclusions. The structure of the analysis obeys the scheme shown in Figure 10 using equations (18-21) to compare the final results of each SSPM.

Energy management in each SSPM is carried out in accordance with the flow diagram of energy manipulated in heat-work-electrical energy interactions shown in Figure 10, such that the heat addition options can be electrical or mechanical: Among the electrical options we have heating techniques by electrical resistance, magnetic induction or microwave, while among the mechanical options we have friction in liquid fluids and drag in gaseous fluids, which is not considered in this work.

Finally, the self-sustained index (SSI) is used to establish the quality criterion of the net free energy delivered by the SSPM in terms of the amount in percentage of nominal design power of energy obtained at free cost:

$$SSI(\%) = \frac{\eta_{th} - 100}{100} \tag{22}$$

According Equation (22), if the global thermal efficiency satisfies the condition ($\eta_{th} < 100$) then, SSI is negative, indicating the amount of heat demanded from an external heat source to keep the engine active, which is a verification of the impossibility of a real perpetual motion machine of second kind.

4.4 Available heat scheduling scheme and adopted heating strategies

In the Figure 10 it is illustrated the task of adding heat to the first PU of the cascaded set of PUs. It is sown that the system enabled to adding heat the de first PU of the cascaded PUs, only can be implemented by means of devices capable for exhibiting heat superposition capacities. Well known techniques to transfer heat energy by superposition potential include the option based in adding heat by means of electric power, which includes- heat conversion techniques among them are optionally:

Electric-resistance-based heating,

Micro-waves-based heating or

Magnetic induction-based heating.

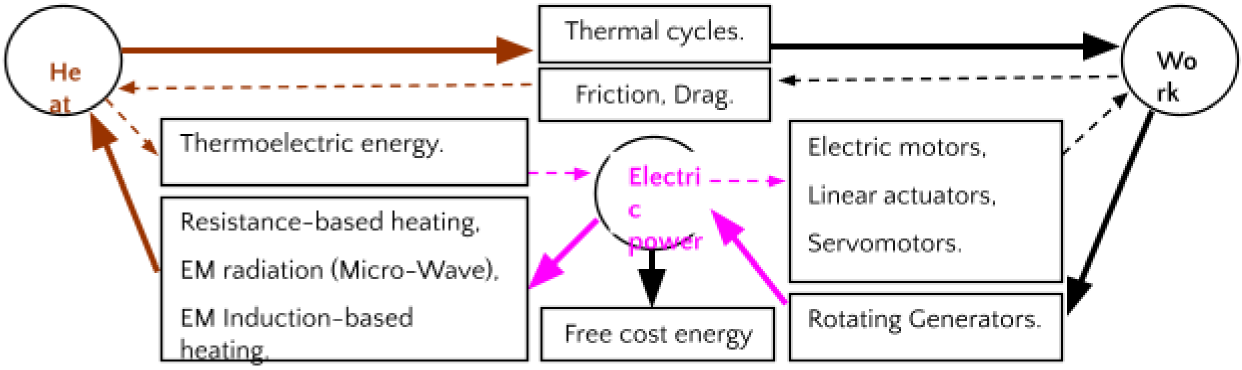


Figure 10: Energy flow interactions in energy conversion tasks carried out in a SSPM.

4.5 Case study: SSPM based on cascaded PUs equipped with the sVsVs cycle for air and helium as working fluids

The study to be carried out on the SSPM with PUs implemented under PGTs is denoted as sVsVs. It studies a variety of thermal cycles characterized by closed and open processes that perform mechanical work both through the expansion and contraction of the TWF. This cycle is not traditional, being characterized by violating the energy balance (heat and work) associated with the heat-work interactions, according to the conventional energy balance with regard to the first law [11-13]. This means that considering the net useful work as

$$w_n = w_{o\exp 34} + |\, w_{ocont51} \,| - \Delta h_{12} = \Delta h_{34} + \Delta h_{51} - \Delta h_{12} \quad , \tag{23}$$

follows that in agreement with references [10-13] the energy balance in (23) gives rise to the inequality

$$q_i - q_o \neq [w_n = w_{o\exp 34} + |\, w_{ocont51} \,| - \Delta h_{12} = \Delta h_{34} + \Delta h_{51} - \Delta h_{12}] \tag{24}$$

This is absolutely normal in all thermal cycles enabled to perform useful mechanical work by contraction.

The VsVs thermal cycle shown in Figure 4 (a) and (b) exhibit thermal contraction and therefore performs useful mechanical work by expanding and contracting the TWF. In this study, both individual and collective thermal efficiency is tested, that is, when it constitutes a thermal power plant formed by a group of sVsVs thermal cycles coupled in cascade in such a way that the cascade coupling structure composed by PUs ends when the heat exhausted by the last downstream cycle at its lowest temperature reaches a working temperature incapable to produce useful work. Likewise, the heat rejected by cooling each sVsVs thermal cycle is recovered upstream so that it can be reused through feedback to the first cycle of the cascade.

Table 4 sVsVs cycle data for air and helium as working fluids with RIT = 0.85

sp	T(K)	p(bar)	V(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg-K)	T(K)	p(bar)	V(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg-K)
			PU1-Air						**PU1-He**			
1	680.00	2.00	0.648	623.02	818.47	44.153	680.00	2.00	4.690	2124.00	3537.30	29.966
2	686.01	2.10	0.633	627.72	826.52	44.153	688.94	2.10	4.599	2151.90	3588.97	29.966
3	800.00	2.62	0.633	718.73	948.71	45.380	800.00	2.60	4.599	2498.00	4160.70	30.432
4	761.81	2.00	0.726	687.91	915.25	45.380	743.84	2.00	5.130	2322.90	3898.08	30.432
5	652.00	1.57	0.726	601.20	788.58	44.153	640.00	1.58	5.130	1999.40	3329.50	29.966
			PU2-Air						**PU2-He**			
1	629.00	2.00	0.600	583.37	764.17	43.323	629.00	2.00	4.338	1965.10	3272.50	29.561
2	634.63	2.10	0.585	587.71	771.62	43.323	637.25	2.10	4.254	1990.80	3320.17	29.561
3	740.00	2.62	0.585	670.42	883.17	44.528	740.00	2.60	4.254	2311.00	3849.10	30.027
4	704.20	2.00	0.671	642.04	852.19	44.528	688.04	2.00	4.745	2149.10	3606.10	30.027
5	603.00	1.57	0.671	563.43	736.72	43.323	592.00	1.58	4.745	1849.80	3080.20	29.561
			PU3-Air						**PU3-He**			
1	581.83	2.00	0.555	547.25	714.48	42.501	581.83	2.00	4.013	1818.10	3027.50	29.156

2	587.04	2.10	0.542	PU8551.20	721.31	42.501	589.44	2.10	3.935	1841.80	3071.50	29.156
3	684.50	2.62	0.542	626.51	823.30	43.687	684.50	2.60	3.935	2138.10	3560.90	29.622
4	650.98	2.00	0.621	600.38	794.65	43.687	636.42	2.00	4.389	1988.20	3335.99	29.622
5	557.50	1.57	0.621	528.85	689.06	42.501	548.00	1.58	4.389	1712.70	2851.70	29.156
			PU4-Air							**PU4-He**		
1	538.19	2.00	0.513	514.27	668.95	41.688	538.19	2.00	3.712	1682.10	2800.90	28.751
2	543.07	2.10	0.501	517.93	675.29	41.688	545.22	2.10	3.640	1704.00	2841.46	28.751
3	633.16	2.62	0.501	586.54	768.57	42.857	633.16	2.60	3.640	1978.10	3294.30	29.217
4	601.86	2.00	0.574	562.53	742.13	42.857	588.67	2.00	4.060	1839.40	3086.13	29.217
5	515.00	1.56	0.574	496.95	644.94	41.688	506.90	1.58	4.060	1584.60	2638.30	28.751
			PU5-Air							**PU5 -He**		
1	497.82	2.00	0.474	484.12	627.19	40.882	497.82	2.00	3.434	1556.30	2591.30	28.347
2	502.40	2.10	0.463	487.51	633.09	40.882	504.41	2.10	3.368	1576.90	2629.30	28.347
3	585.68	2.62	0.463	550.13	718.51	42.035	585.68	2.60	3.368	1830.10	3047.70	28.813
4	556.43	2.00	0.530	528.00	694.05	42.035	544.61	2.00	3.757	1702.10	2855.55	28.813
5	477.00	1.57	0.530	468.73	605.80	40.882	469.00	1.58	3.757	1466.50	2441.50	28.347
			PU6-Air							**PU6-He**		
1	460.49	2.00	0.439	456.51	588.84	40.081	460.49	2.00	3.177	1440.00	2397.40	27.942
2	464.74	2.10	0.429	459.63	594.28	40.081	466.56	2.10	3.115	1459.00	2432.51	27.942
3	541.75	2.62	0.429	516.89	672.63	41.221	541.75	2.60	3.115	1693.30	2819.60	28.408
4	514.46	2.00	0.490	496.51	650.02	41.221	503.75	2.00	3.475	1574.80	2641.85	28.408
5	441.00	1.57	0.490	442.24	568.94	40.081	434.00	1.58	3.475	1357.50	2259.70	27.942
			PU7-Air							**PU7-Air**		
1	425.95	2.00	0.406	431.17	553.55	39.284	425.95	2.00	2.939	1332.40	2218.10	27.537
2	429.89	2.10	0.396	434.03	558.56	39.284	431.56	2.10	2.882	1349.90	2250.43	27.537
3	501.12	2.62	0.396	486.51	630.56	40.414	501.12	2.60	2.882	1566.70	2608.60	28.003
4	475.70	2.00	0.453	467.73	609.66	40.414	465.95	2.00	3.215	1457.00	2444.08	28.003
5	408.00	1.57	0.453	418.12	535.33	39.284	401.00	1.58	3.215	1254.60	2088.30	27.537
			PU8-Air							**PU8- He**		
1	394.00	2.00	0.375	407.87	521.05	38.491	394.00	2.00	2.719	1232.80	2052.10	27.132
2	397.66	2.10	0.366	410.52	525.69	38.491	399.18	2.10	2.666	1249.00	2082.10	27.132
3	463.53	2.62	0.366	458.68	591.91	39.611	463.53	2.60	2.666	1449.50	2413.40	27.598
4	439.81	2.00	0.419	441.32	572.54	39.611	431.00	2.00	2.974	1348.10	2261.21	27.598
5	377.00	1.57	0.419	395.59	503.87	38.491	371.00	1.58	2.974	1161.10	1932.60	27.132
			PU9-Air							**PU9-He**		
1	364.45	2.00	0.347	386.43	491.09	37.701	364.45	2.00	2.515	1140.70	1898.70	26.727
2	367.86	2.10	0.339	388.89	495.40	37.701	369.23	2.10	2.466	1155.70	1926.37	26.727
3	428.77	2.62	0.339	433.15	556.37	38.815	428.77	2.60	2.466	1341.20	2232.90	27.193
4	406.76	2.00	0.387	417.16	538.49	38.815	398.66	2.00	2.751	1247.40	2091.96	27.193
5	349.00	1.57	0.387	375.32	475.53	37.701	343.00	1.58	2.751	1073.90	1787.10	26.727
			PU10-Air							**PU10-He**		
1	337.12	2.00	0.321	366.66	463.44	36.912	337.12	2.00	2.326	1055.60	1756.70	26.322
2	340.27	2.10	0.313	368.93	467.40	36.912	341.53	2.10	2.281	1069.30	1782.26	26.322
3	396.61	2.62	0.313	409.69	523.63	38.021	396.61	2.60	2.281	1241.00	2065.90	26.788
4	376.16	2.00	0.358	394.91	507.09	38.021	368.75	2.00	2.545	989.75	1935.49	26.788
5	322.70	1.57	0.358	356.33	448.95	36.912	317.00	1.58	2.545	992.87	1652.10	26.322

The resulting thermal plants are shown in Figures 11, in which Figure 11 (a) operates with air as the TWF, while Figure 11 (b) operates with helium as the TWF. In this study, the results of both thermal work fluids are compared, where it is observed that air is still valid to produce more mechanical work than the heat demanded to function as a self-sustained plant, providing a valid SSI value with a RIT of 0.85. Similarly, when operating with helium, significantly higher results are obtained in terms of the SSI value for a RIT of 0.85.

The data resulting from processing the VsVs cycle states for air and helium at each PU are shown in Table 4 using real gas values obtained from the NIST database [14].

Table 5 Results of case studies with the data from Table 4 for the irreversible SSPM composed of ten cascaded PUs operating with air as a working fluid under the sVsVs cycle obeying to the scheme depicted in Figure 11(a)

SSPM Air	1	2	3	4	5	6	7	8	9	10	Total
Is_eff	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85	0,85	
LF	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	
RF	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	
RIT*100	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	
T3	800.00	740.00	684.50	633.16	585.68	541.75	501.12	463.53	428.77	396.61	
T1	680.00	629.00	581.83	538.19	497.82	464.74	425.95	394.00	364.45	337.12	
qi_23/PU	122.19	111.55	102.00	93.28	85.42	78.35	72.00	66.22	60.97	56.23	**848.21**
qo_34	126.67	115.47	105.59	97.19	88.25	81.08	74.33	68.67	62.96	58.14	878.36
q_rec	126.67	115.47	105.59	97.19	88.25	81.08	74.33	68.67	62.96	58.14	**562.15**
T_rec_mean	720.91	666.60	616.40	570.02	527.13	487.47	450.83	416.91	385.61	356.64	
wn/PU	50.30	46.37	42.99	40.13	36.33	33.72	31.03	29.03	26.49	24.63	**350,36**
η_{th} /PU	34.99	35.33	35.83	36.56	36.15	36.58	36.63	37.27	36.94	37.24	35,28
η_{th}–plant					η_{th}–plant = (wn/PU) /(qi_23/PU - q_rec)						**122,48**
SSI					$SSI = (\eta_{th} - 100)/100$						**22,48**

Table 6: Results of case studies with the data from Table 4 for the irreversible SSPM composed of ten cascaded PUs operating wit helium as a working fluid under the sVsVs cycle obeying to the scheme depicted in Figure 11(b)

SSPM He	1	2	3	4	5	6	7	8	9	10	Total
Is_eff	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
LF	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	
RF	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	
RIT*100	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	
T3	800.00	740.00	684.50	633.16	585.68	541.75	501.12	463.53	428.77	396.61	
T1	680.00	629.00	581.83	538.19	497.82	466.56	425.95	394.00	364.45	337.12	
qi_23/PU	571.73	528.93	489.40	452.84	418.40	387.09	358.17	331.30	306.53	283.64	**4128.04**
qo_34	568.58	525.90	484.29	447.83	414.05	382.15	355.78	328.61	304.86	283.39	4095.44
q_rec	568.58	525.90	484.29	447.83	414.05	382.15	355.78	328.61	304.86	283.39	**2621.08**
T_rec_mean	711.92	658.52	609.12	563.43	521.22	482.12	445.95	412.50	381.56	352.93	
wn/PU	385.06	356.49	328.13	303.82	279.47	257.79	240.92	222.24	206.80	192.61	**2773.32**
η_{th} /PU	57.25	57.29	56.99	57.03	56.78	56.61	57.18	57.02	57.34	57.72	57.12
η_{th}–plant					η_{th} –plant = (wn/PU) /(qi_23/PU - q_rec)						**184.03**
SSI					$SSI = (\eta_{th} - 100)/100$						**84.03**

In Figure 11, the cascaded structure of the seven Power Units (PUs) in each SSPM is depicted. The SSPM shown in Figure 11(a) operates with **air** as the working fluid, while the SSPM depicted in Figure 11(b) uses **helium** as the working fluid.

Table 4 presents data resulting from the sVsVs thermal cycle analysis for both air and helium as working fluids. The structure of Tables 5 and 6 aligns with the first column, where LF/PUi, RF/PUi, RIT*100/PUi, T_3/PUi [K], T_2/PUi [K] represent input variables. Additionally, the output variables—q_{i12}/PUi [kJ/kg], q_{o34}/PUi [kJ/kg], q_{rec}/PUi [kJ/kg], T_{q_rec}/PUi [K], w_n/PUi [kJ/kg], η_{th}/PUi [%], η_{th}/plant [%], and SSI %/plant—are assumed as results.

These results in Tables 5 and 6 allow us to assess the validity of the proposed input data based on the output results that best align with the expected performance of the implemented prototype. The energy balance, ans consequent analysis is based on the first law and described by Equations (6)–(12), has been considered in this study.

The case study results, obtained from the data in Table 4, pertain to an irreversible SSPM composed of seven cascaded PUs operating with air and helium as working fluids under sVsVs cycles. These results focus on the SSPM's performance, particularly the SSI (Self-Sufficiency Index), as a function of the RIT (Recovered Input Temperature) considered being 0.85. The assumptions include a heat recovery factor (RF) of 0.85 and a losses factor (LF) of 0.9.

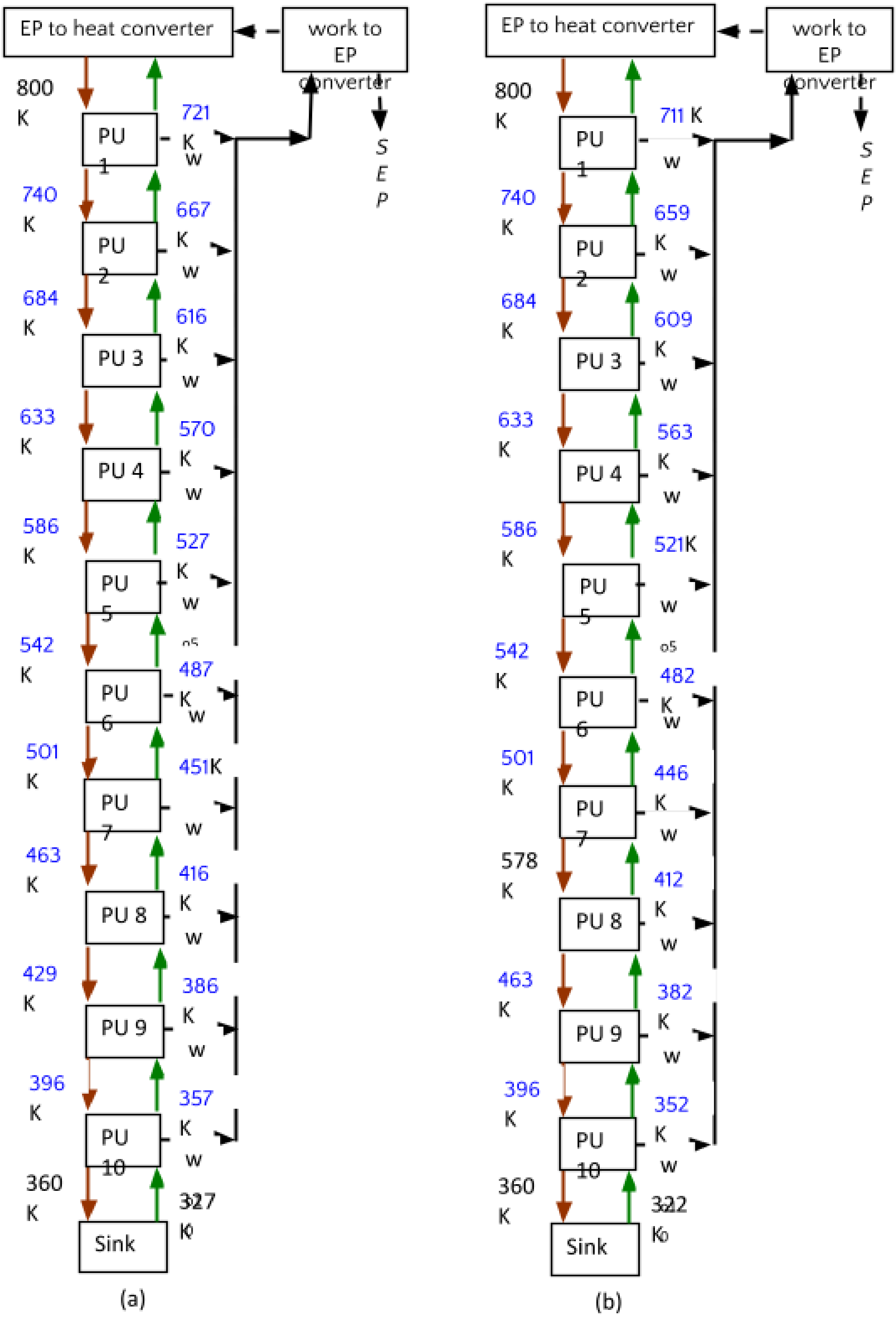


Figure 11: Case studies based on a sVsVs cycle: (a) SSPM operating with air as working fluid. (b) SSPM operating with helium as working fluid

5 Analysis of results and discussion

It is noteworthy that the thermal efficiencies among the sVsVs cycles remain nearly constant as the peak temperatures decrease, even when the thermal fluids are considered as real gases. This constancy is attributed to the temperature ratios (RIT = T_1/T_3) within each cycle adhering to the preselected value for the RIT, which is optionally chosen to be constant; in these case studies, the value is 0.85. In summary the thermal efficiencies are not influenced by the peak temperatures but rather by the temperature ratios. Thus, even with thermal fluids treated as real gases, the efficiencies remain almost constant.

Table 7 Global data resulting from tables 5 and 6 derived from case studies -air and helium respectively-.

Main results	sVsVs cycle (case study shown in tables 5 and 6)	
Number of PUs	10	10
Thermal fluid	Air	Helium
q_{i23}/plant [kJ/kg]	**848.2**	**4128**
w_n/plant [kJ/kg]	**350.4**	**2773**
q_rec/plant [kJ/kg]	**562.1**	**2621**
η_{th}/plant [%]	**122.5**	**184**
SSI [%]/plant	**22.5**	**84**

Table 7 presents the comprehensive results for the two TWFs —air and helium— as real gases. Therefore, the most significant aspect of the global results for the thermal power plant utilizing sVsVs cycles, as shown in Table 7, is the SSI, which is defined previously. For a thermal power plant equipped with 10 PUs and using air as the TWF, the SSI value is **22.5**, corresponding to an efficiency of **122.5%**. In contrast, a thermal power plant with 10 PUs using helium as the TWF yields an SSI value of **84.0** equating to an efficiency of **184.0%**.

Consequently, based on the case studies object of the researched topic carried out in this section, which are focused on the fact that each PU, whose thermal cycle produces useful mechanical work through the thermal contraction of the TWF for sVsVs thermal cycles operating with helium, nearly increase four times the useful work output compared to air as TWF. Thus, the TWF is relevant to achieve the highest value of SSIs

As a result, a series of thermal cycles functioning through contraction can potentially increase significantly the total useful work output in comparison to the same plant structure o0erating with a non convenient TWF.

Furthermore, if we consider the added benefit of recuperating the heat expended for cooling—which is responsible for the thermal contraction in each PU—and if this recovered heat is reintegrated into the power supply, it becomes apparent that the system can generate more useful work than the heat input required to power the first PU in the cascaded structure of PUs. Thus recovery effectiveness ia relevant to achieve the highest SSI

The overall results obtained with respect to the overall thermal efficiency shown in Tables 5 and 6 appear to represent a flagrant violation of the principle of energy conservation. However, all the Power Units (PUs) used in the implementation of the proposed power plants in both cases studied exhibit thermal efficiencies with values notably lower than 100% of the ideally possible efficiency.

Given the current scenario, how is it possible that with a group of PUs coupled in cascade, whose individual thermal efficiencies are much less than 100%, a global amount of useful work greater than the amount of heat required to power the single PU that needs external heat to ensure the operation of the power plant without additional heat requirements? According to the average values of the thermal efficiency corresponding to the individual PUs that forms a SSPM observed in Tables 5 and 6, we have:

sVsVs cycle with air:	efficiency, **35%**	SSI	**22.5**
sVsVs cycle with helium:	efficiency **57%**	SSI	**84**

From the above data, the following facts are deduced:

The efficiency of the SSPM system changes significantly depending on the working fluid used:

- With air as the working fluid, the overall thermal efficiency of the SSPM composed of 10 cascaded PUs operating under the sVsVs cycle is about 35% and the Self-Sufficiency Index (SSI) is 22.5.
- In contrast, with helium as the working fluid, the overall thermal efficiency increases to 57% and the SSFI rises to 84.

This means the SSPM using helium has nearly double the efficiency and self-sufficiency compared to using air. The key reasons are:

1. The thermal efficiencies of the individual PUs operating with helium are higher, ranging from 45-55%, compared to only 20-25% with air.
2. Helium has superior thermodynamic properties that allow it to extract more work from the heat addition and cooling processes in each PU.

In summary, the choice of working fluid has a major impact on the overall performance of the SSPM. Helium provides significantly better results than air, demonstrating the importance of fluid selection in maximizing the efficiency of this novel power generation concept.

The heat superposition capacity has a significant influence on the Self-Sufficiency Index (SFI) of the SSPM system:

Key Findings:

- The ability to efficiently recover and reuse the heat expelled from the cooling of each upstream PU is a crucial factor in achieving a high SFI.
- By recovering this heat and reintroducing it to power the first PU in the cascaded SSPM, the system can generate more useful work than the heat input required for the first PU.
- This "heat superposition" strategy allows the SSPM to achieve thermal efficiencies greater than 100%, which would normally violate the laws of thermodynamics.
- When using air as the working fluid, the SSPM with 10 cascaded PUs has an SFI of 22.5%.
- In contrast, using helium as the working fluid increases the SFI to 84%.

The key reasons are:

1. Helium has superior thermodynamic properties that allow it to extract more work from the heat addition and cooling processes in each PU.
2. The recovered heat from the cooling of each upstream PU can be more effectively reused to power the first PU when using helium, leading to a higher SFI.
3. The heat superposition strategy, where the recovered heat is reintegrated into the power supply, is a critical enabler for achieving SFI values greater than 100%.

In summary, the heat superposition capacity, enabled by the efficient recovery and reuse of cooling heat, is a crucial factor that allows the SSPM to achieve remarkably high SFI values, especially when using the superior working fluid of helium. This heat management strategy is a key innovation that sets the SSPM apart from traditional power generation systems.

The key relationship between thermal contraction and useful work output in the SSPM system is:

- Performing useful mechanical work through the thermal contraction of the working fluid, in addition to expansion, is critical for achieving high Self-Sufficiency Index (SFI) values.
- When the working fluid (TWF) undergoes thermal contraction in each PU, it generates significant additional useful work compared to expansion alone.
- For example, using helium as the TWF, the useful work output of the SSPM with 10 cascaded PUs operating under the sVsVs cycle increases nearly 4 times compared to using air, due to the superior contraction work.
- The ability to recover the heat expelled during the cooling process that drives the contraction, and reintegrate it to power the first PU, allows the system to generate more useful work than the initial heat input.
- This "heat superposition" strategy, enabled by the thermal contraction, is a key innovation that allows the SSPM to achieve thermal efficiencies greater than 100% and SFI values up to 184% with helium.

In summary, the thermal contraction of the working fluid is a crucial mechanism that enables the SSPM to extract significantly more useful work compared to traditional power cycles that rely only on expansion. Coupled with the efficient recovery and reuse of the contraction heat, it is a defining feature that allows the SSPM to achieve its remarkably high performance

It has been observed that the global efficiencies of the SSPM equipped with PUs operating with air as working fluid is about 33% less than the SSPM equipped with PUs operating with helium as working fluid. Therefore, the achievement of overall thermal efficiencies that exceed the ideally possible 100% limit value is not exclusively due to the upstream cascade heat recovery strategy but also to the contraction-based work. While the heat recovered in conventional power engines –without contraction work- consists mainly in low-grade heat, so that the opportunities to be efficiently reused as complement to the main power has been lost, as seen previously in this work, it is observed that the heat recovered has been upgraded by increasing its temperature or heat potential so that heat can be transferred to be efficiently reused. Such method concerns to infrared-based electric heating technique by resistance-based heating or by induction-based heating or by microwave radiation-based heating.

5. Conclusions

The article, "Self-Sustaining Power Machines composed of disruptive cascaded pulse gas turbines", presents a methodology to implement a SSPM that defies conventional laws of thermodynamics. As commented in the previous section, the selection of an appropriate Ratio of Isochoric Temperature is crucial for the design of the PGT-sVsVs cycle in an SSPM composed of multiple cascaded PUs. A higher RIT value allows more PUs to be cascaded, as it results in a narrower temperature range for each PU. This is important to maximize the thermal efficiency of the overall SSPM. The thermal efficiencies of the sVsVs cycles remain nearly constant as the peak temperatures decrease, even when the working fluids (air and helium) are treated as real gases. This is attributed to the temperature ratios (RIT) within each cycle adhering to the preselected constant value of 0.85.The case study results presented in Tables 5 and 6 demonstrate the performance of an irreversible SSPM composed of 10 cascaded PUs operating with air and helium under the sVsVs cycle, with a focus on the Self-Sufficiency Index (SSI) as a function of the RIT value of 0.85.

In summary, the key innovations consist of the utilization of thermal contraction to generate work, the specialized thermal cycles that leverage expansion and contraction, the efficient recovery and reuse of contraction heat, and the strategic selection of working fluids - all of which contribute to the SSPM's remarkable improvements in thermal efficiency and self-sufficiency.

To achieve such a level of improvements, some disruptive contributions have been carried out that gave rise to the following controversies with respect to the conventional statements:

Exergy concept, First law (the energy balance of thermal cycles with contraction-based work needs revision and), the energy balance of any SSPP, and Second law, needs a deep revision

As consequence, based on the method and clarity of the rigorous reasoning presented throughout the article, we are convinced that the contributions made are responsible for the controversy raised. This leads us to take precautions regarding the confidence we place in the results that lack experimental validation.

Although the concept of a thermoelectric plant capable of operating at efficiencies greater than 100% is intriguing, it blatantly contradicts the current understanding of the laws of thermodynamics. Therefore, since the article explores some theoretical and/or hypothetical concepts that have not yet been demonstrated in practice, a greater effort must be done to remove any doubt about the evidence about the achieved results. We are therefore willing to cooperate with any researcher who wishes to carry out a prototyping project, subject to a contract for the transfer of the copyright that we currently hold.

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