DOI: https://doi.org/10.24297/jap.v22i.9679

Self-sufficient power plant prototype composed by cascaded disruptive power units doing work by isothermal contraction and expansion

Ramon Ferreiro Garcia (independent author)

Former, Prof. Emeritus at the University of A Coruna, Spain

https://www.udc.es. ramon.ferreiro@udc.es

Abstract;

This research work aims at the design and development of a disruptive prototype for a Self-sufficient power plant (SSPP) prototype composed by cascaded disruptive power units (PUs) doing work by isothermal contraction-expansion processes. The innovative design integrates thermo-hydraulic actuators enabled to drive hydraulic pumps connected to a hydraulic motor-generator. The prototype's cascaded PUs operates on a double closed processes-based isochoric-isothermal-isochoric-isothermal (VTVT) thermal cycle, enabled to do useful work by contraction and expansion of a thermal working fluid (TWF), which is notable for its high specific work output and high thermal efficiency. This is due to a disruptive cascaded heat recovering technique associated to a heat upgrading strategy.

Among the most relevant Key Features are its self-sufficient operation modes that challenge traditional limitations of second-kind perpetual motion machines (PMMs)

The expected capabilities on the basis of the consistency of empirical analysis are summarized as:

- Design based on the optimal number of cascaded power units,

- Efficient generation of useful mechanical work through expansion and contraction of the TWF,

- High specific useful work (kJ/kg of TWF), such as helium,

- Low ratio of actuator volume and weight to specific work.

Preliminary tentative validation:

The prototype design model was validated through case studies using air and helium as real TWFs. Empirical results demonstrate the SSPP's exceptional performance under certain conditional restrictions.

- The optimal SSPP completed with nine cascaded PUs each operating on a double-VTVT cycle per PU.

- Helium: RIT value of 0.9 and 9 PUs coupled in cascade to give an SSI of 156.72and a SSEP yield of 922.23 kJ/kg.cy.

- Air: RIT value of 0.9 and 9 PUs coupled in a shell to give an SSI of 27.41 and a SSEP production of 37.67 kJ/kg.cy.

These findings highlight the prototype's potential to significantly advance energy production efficiency and self-sufficiency in power generation systems.

Keywords: cascade coupling, cascade heat recovery, contraction work, thermal potential conversion, thermal potential upgrading, vacuum work.

Nomenclature related to thermo-hydraulic converters

Acronyms	***description***
ETWFR	External Thermal Working Fluid Reservoirs
HyM	Hydraulic rotary-motor-generator
RHyP	Reciprocating Hydraulic Pump
ITWFR	Internal Thermal Working Fluid Reservoirs
THyA	Thermo-Hydraulic Actuator
RDAA	Reciprocating double-acting actuator (thermo-mechanic, thermo-hydraulic)
RDAC	Reciprocating double-acting cylinder (thermo-mechanic cylinder)
RDAHyR	Reciprocating double-acting hydraulic reservoirs
RDAHyC	Reciprocating double-acting hydraulic cylinders

RDAHyP	Reciprocating double-acting hydraulic pump

Nomenclature related to general SSPPs

Acronyms	***description***
CF	Carnot Factor
cont.	contraction
CTF	Cooling Transfer Fluid (conventionally, thermal oil)
EM	electromagnetic
EP	Electric Power
exp.	expansion
FCF	Forced convection fan (recirculation fan of the TWF)
FP	Feed pump (feed compressor of the TWF)
Gen	Electric Power Generator
HTF	Heating Transfer Fluid (conventionally, thermal il)
Is_eff	Isentropic efficiency (open processes)
LF	Losses factor (include thermo-mechanical and thermo-hydraulic losses)
ORC	Organic Rankine Cycle
PMM	Perpetual Motion Machine
PP	Power Plant: a group of PUs coupled in cascade
PU	Power Unit operating with the thermal cycle VTVT
q_feed	Difference between recovered heat and required heat to sustain the first cascaded PU
RF	Heat recovery factor (includes heat transfer losses and leaks)
RIT	Ratio of Isochoric low to high temperatures [T_L/T_H], or [T_1/T_2] applied on VTVT cycles
SSI	Self-Sustaining Index, equivalent to the net free energy as % : [$SSI = (\eta_{th} - 100)/100$]
SSHS	Self-Sustaining Heat Supply
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, Self-Sufficient Power Machine
SSPP	Self-Sustaining Power Plant, Self- Sufficient Power Plant
SSEP/cycle	Self-Sustaining Electric Power (kJ/kg.cy)
TWF	Thermal Working Fluid
VTVT	Cycle with the sequential processes: [isochoric (V), isothermal (T), V, T]
VsVs	Cycle with the sequential processes: [isochoric (V), isentropic-adiabatic (s), V, s]
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 TWF feed pump
w_o(kJ/kg)	specific work out
w_{oexp} (kJ/kg)	Output expansion work due to previously added heat for VTVT and VsVs cycles
w_{ocont} (kJ/kg)	Output contraction work due to previously extracted heat for VTVT and VsVs cycles
w_{oexp23} (kJ/kg)	Output expansion work w_{o23} due to added heat for VTVT and VsVs cycles
$w_{ocont41}$ (kJ/kg)	Output contraction work w_{o41} due to extracted heat for VTVT and VsVs cycles
w_n (kJ/kg)	Net useful work (w_{oexp} + w_{ocont}) = (w_{o23} + w_{o41})
W_n/cycle	(kJ/kg.cy),
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 to heat recovery effectiveness
LF (%)	Losses factor (thermal and mechanical irreversibilities)
η_{th} (%)	Cycle thermal efficiency [w_n/qi] = ([w_{oexp}/q_i] + [w_{ocont}/q_o])/ q_i
η_{th_exp} (%)	Expansion work-based cycle thermal efficiency [w_{oexp}/q_i]
η_{th_cont} (%)	Contraction work-based cycle thermal efficiency [w_{ocont}/q_o]

1 Introduction

The research work deals with the design methodology applied on the disruptive prototyping design tasks for validating by means of experimental verification of Self-Sufficient Power Plants (SSPP) composed of cascaded power units (PUs) driven by VTVT thermal cycles. Therefore, starting from the general objective of establishing the design methodology for prototyping a self-sufficient thermoelectric power plant (characterized by not needing the assistance of any type of fuel or external energy source), two aspects inherent to the techniques of converting heat into work are essentially combined, which despite being known for more than a century, have not been taken into consideration for the design and development of efficient and technically disruptive PUs, which are necessary to implement a self-Sufficient Power Machine (SSPP), or SSPP, which is the final objective of the proposed work.

Among the aspects considered, the following stand out:

-- useful mechanical work due to vacuum and atmospheric back-pressure used in both alternative steam engines that obey the developments of Savery [1], Newcomen [2] and Watt [3], as well as conventional rotary steam engines (high-pressure steam turbines), which include the Rankine steam and organic Rankine thermal cycles. In all of them, a vacuum is used to increment the thermal efficiency.

-- useful mechanical work due to thermal contraction, characterized by a pressure lower than the reference pressure. The reference pressure is usually higher than the atmospheric pressure. When the reference pressure is equal to atmospheric pressure, the contraction pressure consists of a vacuum.

Regarding vacuum, it is convenient to highlight that, based on experimental observations when a thermal fluid contained in a closed space is cooled due to heat extraction, its temperature and pressure decrease, creating a vacuum, as well as its entropy. If the space is allowed to change its volume by means of a displacement of a piston and its rod, then it can produce useful mechanical work while the entropy decreases. That is, entropy can decrease while doing useful work. Such a concept has never been taken into account in conventional thermodynamic studies.

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 Thermal Working Fluid (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.

Based on vacuum-based operating techniques, it has been possible to implement several reciprocating steam engines enabled to operate at atmospheric pressure characterized by thermal cycles composed of open processes undergoing state changes. These machines operated firstly at atmospheric pressure undergoing a vacuum to perform contraction-based useful work, using Reciprocating Double-Acting Actuators (RDAA) including cylinders.

This advance was initially due to Savery, Newcomen and Watt [1-3]. Recently, Gerald Müller [4] 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 [5] 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%. Also, in reference [6], it was developed a thermo dynamical model of an atmospheric steam engine, yielding acceptable results. From these technologies, high-pressure and supercritical temperature steam engines were developed in Rankine cycles using the advantages of vacuum until today.

In references [7-11] the state of the art of thermal cycle technologies that allow operation with both thermal expansion and contraction, characterized by thermal cycles composed of closed processes without state changes, was presented. The fact of using closed processes has the advantage of avoiding losses due to flow work, while avoiding state changes entails avoiding losses of vaporization and condensation heats.

These machines can also operate at atmospheric pressure by being subjected to a vacuum to perform useful work based on contraction. This is possible by using double-acting reciprocating actuators, both those based on Reciprocating Double-Acting Cylinders (RDAC) and on reciprocating thermo-hydraulic systems.

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, as described in [12-13] 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 disruptive advances on power plants composed by groups of power units coupled in cascade and conducted by thermal cycles characterized by doing work due to expansion and contraction of the thermal working fluid according to references [14-18], in which expansion has been achieved by adding heat and contraction has been achieved by extracting heat. The studies for designing and prototyping such power plants have been carried out considering real gases as working fluids. The data on the studied thermal real working fluids to be applied on the studied cases is achieved from E. W. Lemmon et al [19].

The present study is focused on improving the performance of SSPPs through increasing the Self-sufficiency index SSI which instead of using heat regeneration in the PUs, cascade heat recovery is used, thereby achieving absolutely disruptive efficiencies compared to conventional technologies. The studied cases regarding to the prototyping tasks belong to patents referenced in [20-22].

Thus, based on the references [14-18], the design of a physical prototype configuration of SSPPs enabled to widely exceed the nominal design powers is proposed, making use of the patents [20-22]. Therefore, the prototype proposed to demonstrate the capabilities characterised by overcoming 100% efficiency include a group of power units driven by closed processes-based thermal cycles of the type VTVT. This means that a discontinuous motion VTVT thermal cycle is responsible for driving the thermo-mechanical-hydraulic or thermo-hydraulic actuators inherent to each power unit.
Summarizing, the proposed physical prototype configuration of SSPPs aims to exceed nominal design powers significantly. It incorporates a group of PUs driven by closed processes-based thermal cycles of the VTVT type, utilizing thermo-mechanical-hydraulic or thermo-hydraulic actuators in each PU. This improved design methodology and prototype configuration offer a path towards highly efficient SSPPs enabled to revolutionize power generation technology [14]-[22]. Therefore, in line with expectations of the results, potential applications derived from this and previous studies will be considered as prototyping priorities including but not limited to:

1) Booster power supply for launching of satellites, rockets space shuttles, raising the (satellite rockets or space shuttles) to the height at which it has to orbit (low orbit height of about up to 50-70 Km for the first propulsion phase) without any type of fuel,

2) Low orbit self-propulsion aircrafts, propelled by self-powered engines based on heated air Self-Sustaining turbo-reactors,

3) Static aircrafts propelled by in-situ self-powered engines based on heated air-based turbo-reactors,

4) In-situ thermos-electric power plants,

5) Ships propulsion engines,

6) Submarine propulsion,

7) Railway traction,

8) Large trucks traction,

9) Free electricity supply for on-site industrial applications,

10) District heating/cooling

11) Self-powered extra planetary cosmic habitats

12) Self-powered autonomous cosmic habitats

13) Power supply including areas of this planet with few renewal energy resources.

14) Fight against desertification:

(a) to balance the atmospheric carbon dioxide and combat areas of agro-food deficit in-situ through massive irrigation systems to obtain water by condensation of local atmospheric air.

(b) to expand sustainable native plantations in desert areas.

(c) to harmonize the ecological system on the planet

15) H_2, NH_3 production via on-site SSPPs production

16) Megawatt-type power supply could be implemented to feed plasma-based propulsion of cosmic vehicles.

2. Structure of PUs composed by RDAA driven by a VTVT thermal cycle

The task of prototyping a self-sustaining power machine using cascaded Power Units (PUs) depends on the characteristics of each PU, which can be implemented under two main structural types of reciprocating double-acting actuators (RDAAs). These types relate to the volumetric reservoirs of thermal working fluid (TWF), which can be installed inside each reciprocating double-acting cylinder (RDAC), as illustrated in Fig. 1 (a).

The design criterion for the RDAA regarding the location of the volumetric reservoirs of TWF is influenced by the type of displacement movement of the piston. To achieve effective heat transfer through FTC when the actuator is at rest, the TWF reservoirs should be installed internally within the RDAC, as shown in Fig. 1 (a). This indicates that the location of the TWF reservoirs determines the mode of movement of the reciprocating actuator (continuous or discontinuous). Therefore, to achieve continuous movement with reservoirs of TWF located inside the RDAC, as illustrated in Fig. 1 (a), two RDACs must operate in a discontinuous and intermittent manner. This configuration ensures that when one RDAC is at rest, the other is in motion, and vice versa.

2.1 Structure of PUs composed by discontinuous-motion RDACs equipped with ITWFR

The task of prototyping a self-sustaining power machine by means of cascaded power units composed of RDAA based on discontinuous motion-based actuators are characterized by doing work by expansion and contraction. These types relate to the volumetric reservoirs of TWF, which is necessarily installed inside each RDAA: That means inside each RDAC or inside each RDAHyR as illustrated in Fig. 1 (a) and (b) respectively. Mentioned prototyping options obey the disruptive technology patented under the application number P202200035.

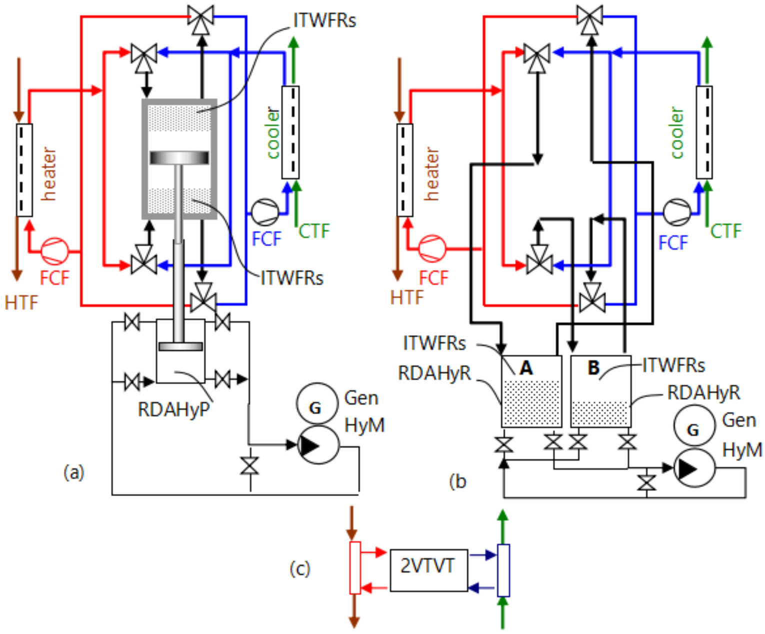

Figure 1: Schematic structure of a discontinuous-motion RDAA equipped with ITWFRs. (a), Discontinuous RDAC coupled to a RDAHP enabled to drive a rotary hydraulic motor-generator. Patent P202200035, [22]. (b), Discontinuous RDAHyRs to drive a rotary hydraulic motor-generator. (c), symbol to represent each PU operating with a cycle VTVT of the type shown in 2(a) and 2(b). (d), simplified symbol of (c).

As depicted in Fig. 1(a), a single discontinuous motion RDAC with ITWFRs is equipped with heat transfer accessories including heat addition and heat extraction equipment. In addition, the discontinuous RDAC is coupled to a reciprocating double-acting hydraulic pump enabled to drive a rotary hydraulic motor-generator coupled to a generator. In Fig. 1 (b) it is depicted the scheme of a discontinuous-motion RDAHyR equipped with the necessary hydraulic flow control valves enabled to drive a rotary hydraulic motor-generator coupled to a generator. When ETWFRs are installed instead of ITWFRs like in this case, then the RDAC associated will correspond to a continuous motion RDAC according to references [20-21].

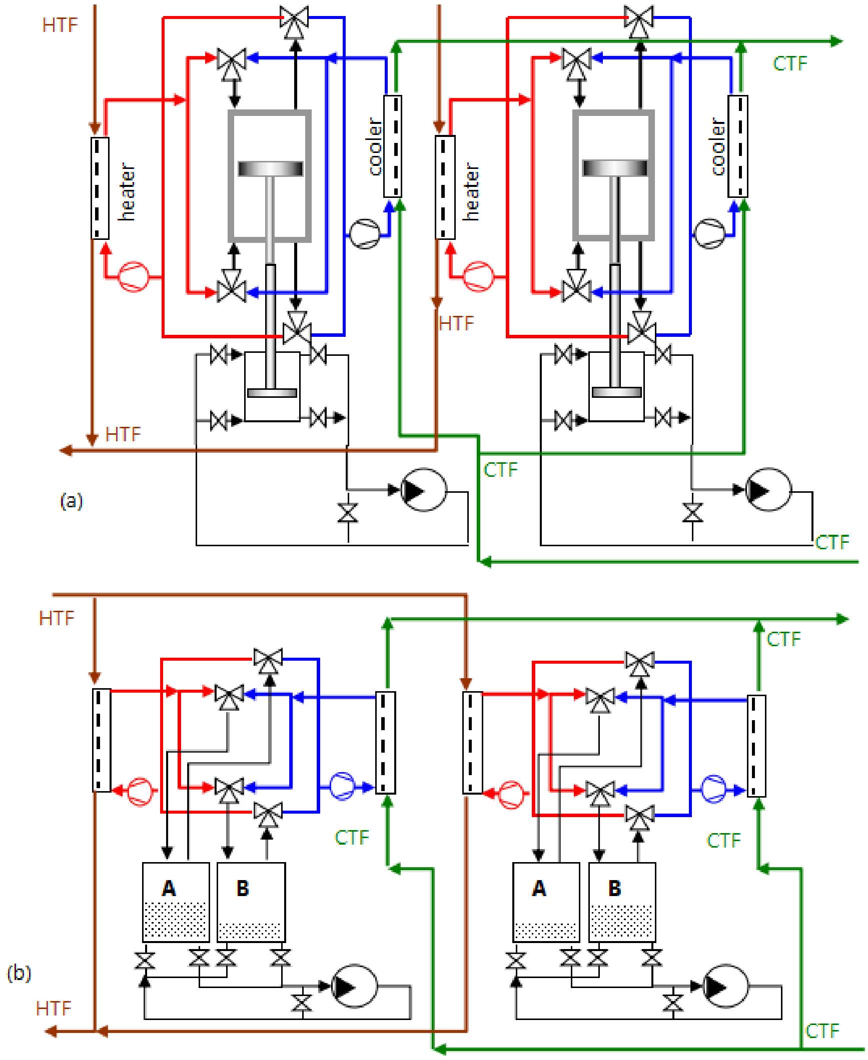

Figure 2: Continuous-motion PU composed of two discontinuous-motions actuators, each equipped with heat supply and heat recovery piping systems, according to patent P202200035, [22]. (a), Discontinuous RDAC coupled to a RDAHP enabled to drive a rotary hydraulic motor-generator. Patent: P202200035, [22]. (b), Discontinuous RDAHyRs to drive a rotary hydraulic motor-generator.

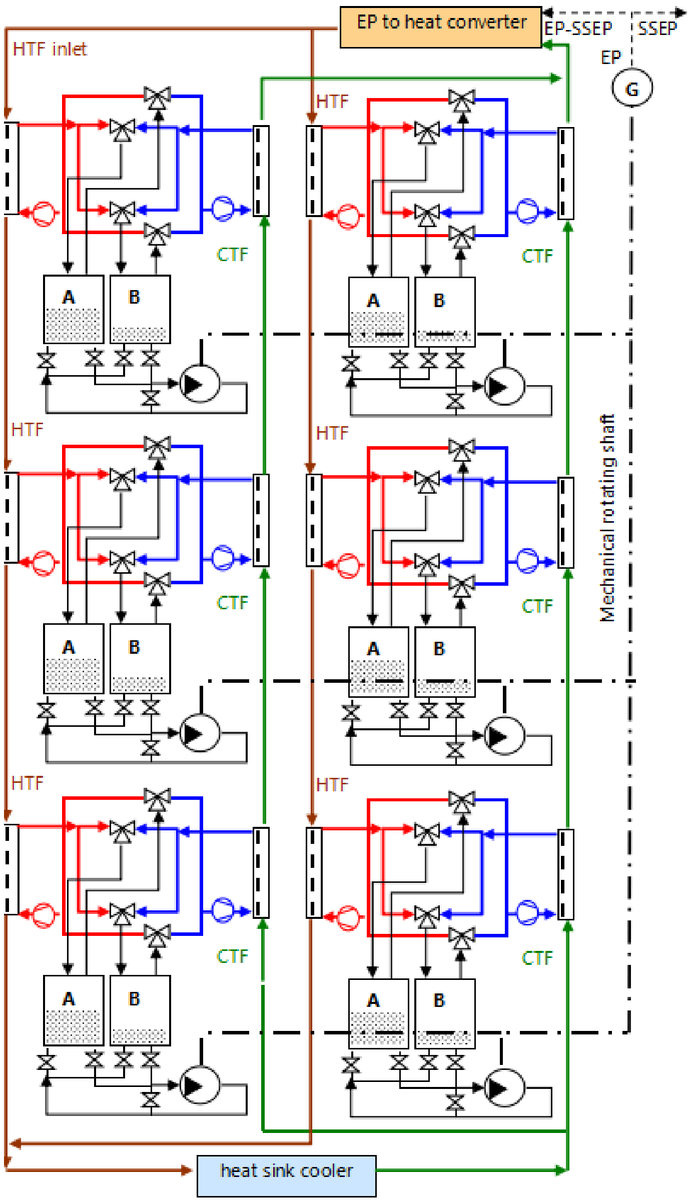

Figure 3: Representation of the SSPP structure composed by three cascaded continuous PUs, each implemented by discontinuous RDAHyRs to drive rotary hydraulic motors coupled to a generator. Power units structure are described in patent application number: P202200035, [22].

The continuous-motion PUs composed of two discontinuous-motions actuator is depicted in Fig. 2. Therefore, Fig. 2(a) shows the discontinuous-motion RDAC coupled to a RDAHyP to drive a rotary hydraulic motor-generator coupled to a generator, and Fig. 2(b) shows the discontinuous RDAHyRs to drive a rotary hydraulic motor coupled to a generator.

Each PU, characterized by having volumetric ITWFR (**A** and **B**) of the TWF inside the RDAA, exhibits the characteristic of disabling the TWF feed pump. In turn, this characteristic necessarily requires intervals of dynamic inactivity of the actuator to allow heat transfer to the TWF. Then, the time elapsed during the simultaneous processes of isochoric addition and extraction of heat to/from the TWF inside the RDAA, requires that it remain stationary (without performing either expansion or contraction work) to favor heat transfer in both the heat addition and extraction processes. To compensate and eliminate the RDAA inactivity time interval, and achieve continuous movement, it is proposed to duplicate each RDAA in such a way that when one of them acts performing expansion or contraction work [10-11], its complementary RDAA remains stationary transferring heat and vice versa.

In Fig. 3 can be observed that each continuous PU is composed by a pair of discontinuous PUs. Each discontinuous PU drives a hydraulic motor enabled to transfer mechanical power to a generator by means of a common mechanical rotating shaft. This means that all hydraulic motors are connected by a rotating mechanical shaft that transfers mechanical energy to a generator, or the generator is driven by a common mechanical shaft.

3 Brief description of the thermal cycle VTVT applied on discontinuous motion-based PUs

The prototypes depicted Figs 1 and 2 must operate with the same thermal cycle VTVT described previously in [14] and [15], which are adapted to each of the two prototyped models, independently of the structures adopted in Figs. 1 and 2. The differences between them concern only to the mechanic-hydraulic structures. Such structures were discussed in detail in references [19], [22].

The name of the cycle VTVT obeys to the first character of the thermodynamic transformations involved in each thermal cycle. The following nomenclature depicted in the above list is used along the studied thermal cycles considered in the paper:

Cycle transformations	**Process type**	**Acronym**
Isentropic-adiabatic	Constant entropy (no heat transfer)	s
Isochoric	**Constant volume**	**V**
Isothermal	**Constant temperature**	**T**
Isobaric	Constant pressure	p

Thus, the cycle depicted in above list operates with only two thermodynamic transformations: adiabatic-isentropic (s) and isothermal (T). Since these processes must be performed to obtaining expansion and contraction works, a complete cycle requires the following closed processes: **V**, **T**, **V** and **T**, so that it is named along the paper as **VTVT.**

3.1 Cycle transformations of a VTVT for a discontinuous motion prototype

Regarding the information provided in Fig. 4(a) and (b), the thermodynamic transformations between each pair of state points of the cycle carried out on any chamber of the discontinuous RDAA are summarized as follows:

Observing Fig. 4 with respect to thermodynamic transformations, follows that:

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

$$q_{i12} = \Delta u_{12} = u_2 - u_1 = Cv \cdot (T_2 - T_1) \quad (1)$$

Process (2)-(3) corresponds to a closed isothermal heat transfer (heating) associated to closed isothermal expansion process (cylinder chamber volume increases due to the piston displacement doing expansion.-based work, while pressure decreases at the initial reference value). Thus, the thermal energy transferred is converted into mechanical work by changing only entropy and pressure while internal energy remains constant, provided that the piston or other corresponding device can move freely to permit doing work during expansion of the TWF.

Therefore, the heat added is

$$q_{i23} = T_2 \Delta s_{23} = T_2 (s_3 - s_2) \quad (2)$$

The corresponding work done due to expansion of the TWF is

$$w_{o23} = w_{o\exp} = T_2 \Delta s_{23} = T_2 (s_3 - s_2) \quad (3)$$

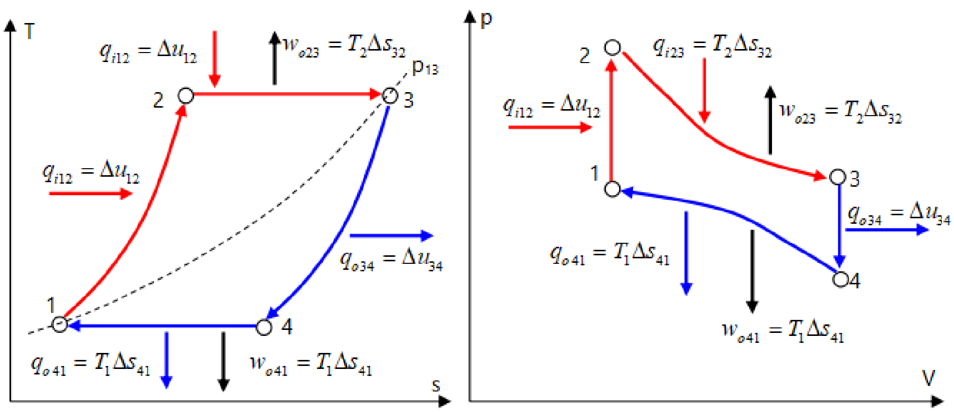

Figure 4: Single VTVT closed processes-based thermal cycle. (a): T-s diagram. (b): p-V diagram [14-15]

Process (3)-(4) corresponds to a closed isochoric heat extraction process in which the TWF is cooled decreasing pressure at its minimum value without any work being done because of the constant volume process. Then the heat extracted cooling the TWF to generate a vacuum is:

$$q_{o34} = \Delta u_{34} = u_3 - u_4 = Cv \cdot (T_3 - T_4) \tag{4}$$

Process (4)-(1): corresponds to a closed isothermal heat transfer (cooling) associated to closed isothermal contraction process (cylinder chamber volume decreases due to the piston displacement returning to the initial position doing contraction-based work, while pressure increases at the initial reference value). Thus, the thermal energy transferred is converted into mechanical work by changing only entropy and pressure while internal energy remains constant, provided that the piston or other corresponding device can move freely to permit doing work during contraction of the TWF.

Therefore, the heat extracted which is converted into useful mechanical work by contraction is

$$q_{o41} = T_1 \Delta s_{41} = T_1 (s_4 - s_1) \tag{5}$$

And the corresponding contraction work done due to contraction of the TWF is

$$w_{o41} = w_{ocont} = q_{o41} = T_1 \Delta s_{41} = T_1 (s_4 - s_1) \tag{6}$$

The total amount of useful work corresponds to the partial works done by expansion and contraction.

$$w_n = w_{o\exp} + w_{ocont} = w_{o23} + | w_{o41} | = T_2 \Delta s_{23} + T_1 \Delta s_{41} = (T_2 + T_1) \cdot \Delta s \tag{7}$$

The total amount of added heat corresponds to the partial heats due to increasing internal energy and isothermal expansion work done:

$$q_{i13} = q_{i12} + q_{i23} = Cv \cdot (T_2 - T_1) + T_2 (s_3 - s_2) \tag{8}$$

The total amount of extracted heat corresponds to the partial heats due to decreasing internal energy and isothermal contraction work done:

$$q_{o31} = q_{o34} + q_{o41} = Cv \cdot (T_3 - T_4) + T_1 (s_4 - s_1) \tag{9}$$

3.2 Properties of VTVT ideal cycle

The T-s diagram of the thermal cycle VTVT depicted in Fig. 3 is characterized by exhibiting interesting functional relationship of proportionality and symmetrical similarity or functional symmetry relationships. Therefore, the ideal VTVT thermal cycle (the characteristic of ideal cycle implies the absolute absence of irreversibilities) studied and composed by closed processes exhibit interesting thermodynamic properties in terms of symmetries between changes in entropy, temperature, internal energy, pressures and volumes. Such properties come from both empirical evidence and experimental observations.

High-low temperatures, coincident with (top-bottom) because of isothermal transformations

$$T_1 = T_3\,,\; T_2 = T_4 \tag{10}$$

direct consequence of (10):

$$T_2 - T_1 = T_3 - T_4 = \Delta T \tag{11}$$

direct consequence of (11):

$$\Delta u_{12} = \Delta u_{34} = \Delta u \tag{12}$$

Symmetries of changes in entropy due to isothermal processes

$$s_3 - s_2 = s_4 - s_1 \tag{13}$$

direct consequence of (1):

$$s_3 - s_2 = s_4 - s_1 = \Delta s \tag{14}$$

From (14), the amounts of heat added and extracted are respectively

$$q_{i13} = \Delta u + T_2 \Delta s\,,\; q_{o31} = \Delta u + T_1 \Delta s \tag{15}$$

As consequence of (15) the following implications take place

$$T_2 > T_1 \Rightarrow T_2 \Delta s > T_1 \Delta s \Rightarrow w_{o23} > w_{o41} \tag{16}$$

Eq. (16) means that if T_2 tends to T_1, then w_{o23} tends to w_{o41}. This means that in any real cycle —irreversible— such this condition cannot be achieved since

For $T_2 = T_1$ then, $w_{o23} = w_{o41} = 0$.

Consequently, in any real VTVT cycle $T_2 = T_1$ doesn't work; it is impossible or not realizable.

3.3 Consequences derived from the ideal VTVT cycle properties:

Since Δs is a constant of the VTVT cycle, depending on the RIT for a given pressure gradient follows that,

$$T_1 \Delta s < T_2 \Delta s \Rightarrow T_1 < T_2 \qquad (17$$

$$T_1 < T_2 \Rightarrow q_{o31} < q_{i13} \tag{18}$$

$$T_1 < T_2 \Rightarrow w_{o41} < w_{o23} \tag{19}$$

As consequence of (18) and (19),

$$T_1 < T_2 \Rightarrow T_1 / T_2 = RIT < 1 \tag{20}$$

In summary, the temperature difference between T_2 and T_1 has to be significant enough to complete a given thermal power plant or the SSPP with the minimum number of power units such that it operates with an acceptable SSI from a technical and economic sustainable criterion.

3.4 Analysis of a discontinuous motion-based VTVT cycle

Figure 5 illustrates the energy (heat-work) flow diagram of a double VTVT thermal cycle. This system performs work using as HTF commercial thermal oil through closed isothermal expansion and contraction while simultaneously transferring heat via closed isochoric heat addition and extraction. The process operates under an alternating and intermittent timing control to meet heating and cooling demands efficiently. The heat transfer fluid: HTF and CTF responsible for heating and cooling demands is the same; in general, when operating within a range of conventional temperatures industrial thermal oil could be used. For special cases of cryogenic temperatures, nitrogen, helium and even hydrogen would be useful.

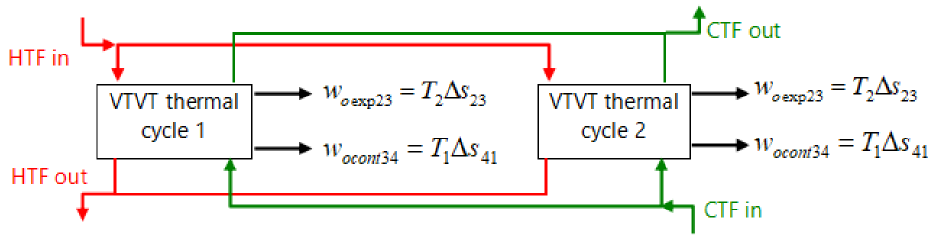

Figure 5: Double-VTVT (2VTVT) Thermal Cycle Energy Flow Diagram, following the structure depicted in Fig. 2. In this structure, every continuous motion PU of the SSPP is composed by two single PU of the VTVT type.

Regarding to **heat transfer circuits**, the diagram depicts the circuits responsible for adding and extracting heat to/from both intermittent VTVT cycles executed in parallel. Each VTVT cycle remains stationary during the heat addition and extraction phases, ensuring optimal thermal transfer.

With regard to **discontinuous operation and PU Structure**, the execution of each discontinuous VTVT cycle necessitates a discontinuous-type PU structure. Consequently, a continuous motion PU requires two VTVT cycles operating alternately and intermittently. This configuration allows for seamless operation while maximizing energy efficiency and thermal management.

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

Added input heat:

$$q_{i13} = q_{i12} + q_{i23} = \Delta u_{12} + T_2\Delta s = Cv(T_2 - T_1) + T_2(s_3 - s_2) \tag{21}$$

Extracted output heat

$$q_{o41} = q_{o34} + q_{o41} = \Delta u_{34} + T_1\Delta s_{41} = Cv(T_3 - T_4) + T_1(s_4 - s_1) \tag{22}$$

Net useful output work

Expansion work: $$w_{o\exp} = w_{o23} = w_{o\exp} = T_2\Delta s_{23} = T_2(s_3 - s_2) \tag{23}$$

Contraction work: $$w_{ocont} = w_{o41} = q_{o41} = T_1\Delta s_{41} = T_1(s_4 - s_1) \tag{24}$$

$$w_o = w_{o\exp} + |\, w_{ocont} \,| = T_2(s_3 - s_2) + |\, T_1(s_4 - s_1) \,| \tag{25}$$

Therefore, the thermal efficiency is given by the ratio of the net mechanical work (expansion and contraction works) to the added input heat, yielding

$$\eta_{th} = \frac{w_n}{q_i} = \frac{w_{o23} + |\, w_{o41} \,|}{\Delta u_{12} + T_2\Delta s} = \frac{T_2(s_3 - s_2) + |\, T_1(s_4 - s_1) \,|}{Cv(T_2 - T_1) + T_2(s_3 - s_2)} = \frac{T_2\Delta s + |\, T_1\Delta s \,|}{\Delta u_{12} + T_2\Delta s} \tag{26}$$

However, since an important fraction of the useful work is carried out by a vacuum or thermal contraction, it is interesting to consider the proportions of useful work obtained by thermal contraction due to cooling concerning those obtained by thermal expansion. Therefore, the partial thermal efficiencies corresponding to expansion and contraction works (η_{th_exp} and η_{th_cont}) are given by the respective ratios of the partial mechanical works (expansion or contraction works) to the added input or output heats, yielding:

$$\eta_{th\_\exp} = \frac{w_{o\exp}}{q_i} = \frac{w_{o23}}{\Delta u_{12} + T_2\Delta s} = \frac{T_2(s_3 - s_2)}{Cv(T_2 - T_1) + T_2(s_3 - s_2)} = \frac{T_2\Delta s}{\Delta u_{12} + T_2\Delta s} \tag{27}$$

$$\eta_{th\_cont} = \frac{w_{ocont}}{q_o} = \frac{|\, w_{o41} \,|}{\Delta u_{34} + T_1\Delta s} = \frac{|\, T_1(s_4 - s_1) \,|}{Cv(T_3 - T_4) + T_1(s_4 - s_1)} = \frac{|\, T_1\Delta s \,|}{\Delta u_{34} + T_1\Delta s} \tag{28}$$

3.5 Influence of the type of thermal cycle on the specific work of each PU and the SSPP

The fact of obtaining a high specific work —work per unit of thermal fluid processed— contributes to the reduction of the volume and weight of the mechanical structure of the thermo-actuators. For this reason, it is important to apply appropriate techniques to achieve high specific work.

The prototype's cascaded PUs proposed in the study of this prototype operates on a VTVT thermal cycle, which is notable for its high specific work output. The consequences of using such thermal cycle can be summarized as low ratio of actuator volume and weight to specific work. However, in order to analyze its behavior in terms of variable parameters such as pressure and temperature the following modeling considerations are useful for the concerning analysis. Therefore, let's define a Specific Work Ratio (SWR) to be incorporated as a useful criterion of performance index of a VTVT cycle with respect to a VsVs cycle:

The SWR ids defined as the ratio of the specific work of a VTVT cycle to the specific work of a VsVs cycle is according to the following model as

$$SWR = \frac{w(VTVT)}{w(VsVs)} = \frac{T_2(s_3 - s_2) + |T_1(s_4 - s_1)|}{Cv(T_2 - T_3) + Cv(T_1 - T_4)} = \frac{(T_2 + T_1)\Delta s}{\Delta u_{23} + \Delta u_{14}} \tag{29}$$

Since the processes of adding and extracting heat in closed processes 1-2 and-3-4 are carried out at constant volume, the following relations must be considered:

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \Rightarrow \frac{p_1}{T_1} = \frac{p_2}{T_2}$$
$$\frac{p_1}{T_1} = \frac{p_2}{T_2} \Rightarrow \frac{p_1}{p_2} = \frac{T_1}{T_2} = RIT \tag{30}$$

The result achieved by Eq. (30) is useful to be incorporated into Eq. (29) yielding

Since $\frac{T_1}{T_2} = RIT$, then $T_2 + T_1 = T_2 + T_2 \cdot RIT = T_2 \cdot (1 + RIT)$ (31)

Consequently, Eq. (29) can be represented as

$$SWR = \frac{w(VTVT)}{w(VsVs)} = \frac{(T_2 + T_1) \cdot \Delta s}{\Delta u_{23} + \Delta u_{14}} = \frac{T_2(1 + RIT) \cdot \Delta s}{\Delta u_{23} + \Delta u_{14}} \tag{32}$$

Eq. (32) indicates us that SWR is a proportional function in T_2 of the RIT that affect the numerator of Eq. (32). This do not mean that changing T_2 and/or the RIT values, then the SWR changes also, since the denominator of the Eq. (32) will change accordingly. However, conclusive information can be extracted by taking into account the influence of the loss factors —irreversibilities— associated with each type of cycle.

Table 1: Data corresponding to the ratio of the specific works (SWR) of the VTVT cycle and the VsVs cycle, when the losses in the VTVT cycle changes from 0.49 to 1, while losses on cycle VsVs remain constant in 0.85 *0.95

LF*RF (VsVs)						0.85*0.95						
SWR	1.03	1.10	1.18	1.26	1.34	1.43	1.61	1.70	1.80	1.90	2.0	2.10
LF*RF (VTVT)	0.49	0.52	0.525	0.60	0.64	0.68	0.76	0.81	0.85	0.90	0.95	1.00

T_2=800 K, RIT = 0.9, LF*RF= 0.85. 0.95 = 0.807

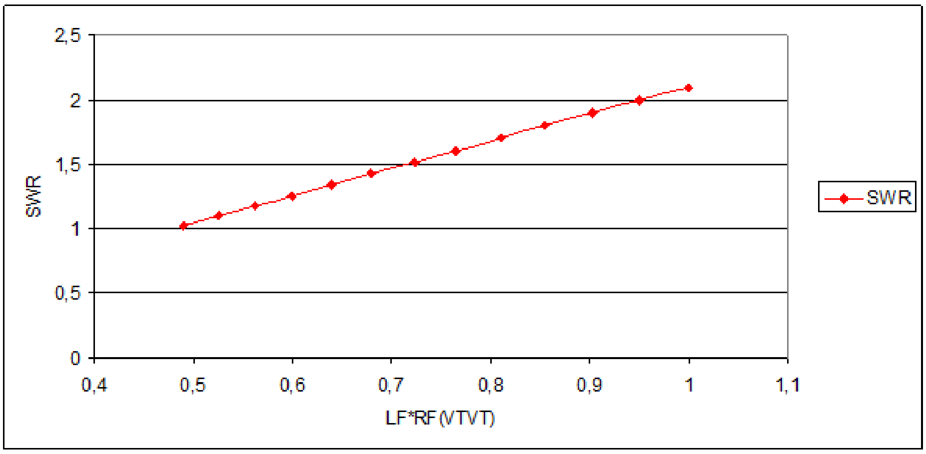

Figure 6: Diagram illustrating the ratio of the specific works (SWR) between a VTVT cycle and the VsVs cycle, when the irreversibilities (mechanical and thermal losses) in the VTVT cycle changes from 0.49 to 1, while losses on cycle VsVs remain constant in 0.85 *0.95*0.95 = 0.767 where electrical conversion losses are included

In order to clarify the results of SWR depicted in Table 1, there are graphically depicted in Fig. 6. The influence of irreversibilities on the SWR is highlighted. Thus, in Fig. 6 it is shown that the value of the SWR of a VTVT cycle increases proportionally to the reduction of losses, for a given constant value of the losses in the VsVs cycle. According to the graph shown in Fig. 6, based on the SWR model described in Eq. (32), the irreversibilities inherent to the VTVT thermal cycle not only influence the thermal efficiency of the cycle but also influence the specific work ratio SWR. Among the appropriate techniques to achieve high specific work are those regarding to the irreversibilities —such is the TWF chosen— apart from other factors such as mechanical losses, leaks, appropriate structural design, or heat transfer effectiveness, among others.

4 Validation of the SSPP prototype by means of cascaded PUs operating with VTVT cycle

The devices used to carry out the validation studies of the SSPPs equipped with cascaded PUs implemented with any RDAA are characterized by operating in discontinuous motion mode requiring thermo-volumetric reservoirs inside the actuator and therefore located within the active volume of the actuator. Discontinuous intermittent motion requires a thermal cycle enabled to allow heat transfer to/from the actuator under discontinuous intermittent mode. This characteristic gives rise to the need for two VTVT cycles per PU composed by two single-cycles PU.

The prototyping proposed cases consists of the study of two SSPPs, each equipped with 5 discontinuous-motion thermal cycles of the type VTVT operating respectively with helium and air as TWFs. In both cycle types the top temperature T_2 is fixed at 800 K for the VTVT cycle. The temperature T_1 for each PU is fixed in a value such that, assuming the RIT as T_1/T_2 for VTVT cycle then T_1 = RIT(PUi).T_2. Thus, the selected RIT for each case considered is assumed as 0.9. Along the analysis carried out in this work, the thermodynamic data properties of the TWFs are taken from Lemmon E. W, et all, [18].

4.1 Considered criteria to carry out the following SSPP prototyping tasks

As mentioned in previous papers regarding to this topic, the criteria to be taken into account obey to the previous studies along this work as well as previous results from references [14-17 and 19]. Therefore, the key innovative concepts proposed for improving thermal contraction efficiency in the SSPPs systems are summarized by four disruptive and strategic considerations:

a- Utilizing thermal contraction to generate useful work:

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

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

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

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

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

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

c- Disruptive strategy on efficient heat recovery and reuse tasks:

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

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

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

d- Working Fluid Selection:

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

- The choice of working fluid, such as helium versus air, has a major impact on the thermal contraction efficiency and overall performance of the SSPP.

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

Based on the criteria taken into consideration, in this same section the necessary studies are carried out for the design and implementation of the prototypes corresponding to two SSPP structures characterized by PUs consisting of thermo-hydraulic actuators equipped with volumetric heat reservoirs located inside the thermo-actuator systems. Furthermore, having the reservoirs inside the thermo-actuator systems implies the implementation of continuous motion devices by means of double-discontinuous motion PUs and thermal cycles. As consequence of these contributions on such disruptive result implies the urgent need to revise some conventional axioms related to the fundamental principles of physics concerning thermodynamics

4.2 The structure of a SSPP based on Thermo-Hydraulic actuators

The studies for the development of two main types of prototypes at simulation level are proposed. In such studies the necessary condition to satisfy the above-mentioned abilities have been imposed. It consists of two discontinuous-intermittent motions PUs with a thermal cycle of the VTVT type and reservoirs of the thermal working fluid reservoirs located inside the thermomechanical or thermo-hydraulic actuators, illustrated in Fig. 2 and 3. In these prototypes, it is intended to eliminate such drawbacks inherent to thermo-mechanical accessories, simplifying the installation by means of a common mechanical coupling consisting of a shaft comprising all the plant-based PUs driving a unique electric generator.

4.2.1 Design task considerations

A SSPP must be characterized by its ability to operate indefinitely without an external energy input [16-19]. This essential characteristic must overcome the irreversibilities inherent in any real machine, which may approach over 23%. This means it must surpass the limitations of second-kind perpetual motion machines, whose operation involves a combination of mechanical and thermal transformations that are inherently affected by dissipative forces. These include irreversibilities due to mechanical losses, primarily from friction and sound energy, as well as thermal losses, including isentropic losses due to flow work caused by thermal fluid friction, heat leaks, and heat transfer losses (due to conduction, convection, and radiation).

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

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

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

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

--4. Ability to upgrade the recovered heat in order to increment the thermal potential energy to be efficiently reused.

However, these essential factors must satisfy some key strategies such as:

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

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

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

This heat management strategy is illustrated in Fig. 7. Thus, in Fig. 7(a) and (b) it is depicted the Heat Transfer Fluid (HTF) recirculation circuit used to feed thermal cycles of the VTVT type whose thermal cycle diagram is depicted in Fig. 4(a) and (b). 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.

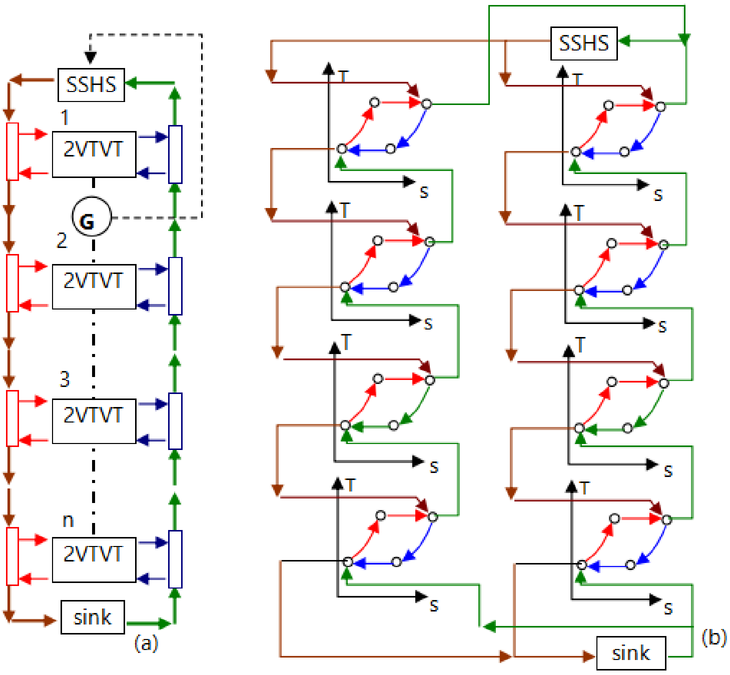

Figure 7: Flowchart of the closed HTF circuit responsible for heat energy supply (brown) and heat energy recovery (green) of a SSPP, following the structure depicted in Fig. 2. Scheme composed by PUs based on reference [22]. Every continuous motion-based PU is composed by two discontinuous motion type PUs driven by a double VTVT cycle

Fig. 7(a) depicts the SSPP implemented with cascaded PUs operating with the continuous motion VTVT cycle depicted in Fig. 7(b). Both VTVT cycles are characterized by exhibiting thermal working fluid reservoirs located inside the thermomechanical or thermo-hydraulic actuators.

4. 3 Case studies: Implementation an SSPP with PUs operating with VTVT 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 (PU1) of the cascade, is represented in Fig.8. 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 PU1, while the remaining electrical power is sent to the distribution network.

The fraction of electrical power sent to the PU1 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.

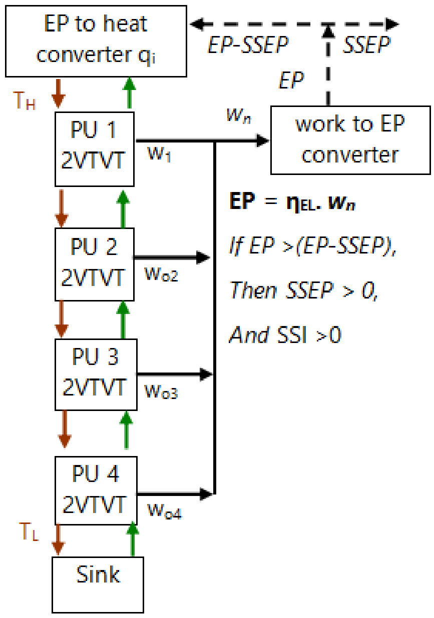

Figure 8: Generic schematic structure of a SSPP showing the work flow diagram. Acronyms used are: EP, electrical power; SSEP, self-sustaining electrical power; added heat qi = EP-SSEP. The condition to achieve a positive SSEP is that (EP-SSEP) < EP

On the basis of the plant structure depicted in Fig. 8, energy balance is carried out according to the following model:

The total mechanical work is defined as,

$$w_n = \sum_{j=1,n} w_j \tag{33}$$

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

$$q_{i(PU1)} = EP - SSEP \tag{34}$$

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

$$IF\ w_n > q_{i(PU1)}\ THEN\ SSEP > 0 \tag{35}$$

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

$$IF\ w_n > q_{i(PU1)}\ THEN\ EP > q_{i(PU1)} \tag{36}$$

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

Energy management in each SSPP is carried out in accordance with the flow diagram of energy manipulated in heat-work-electrical energy interactions shown in Fig. 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 SSPP in terms of the amount in percentage of nominal design power of energy obtained at free cost:

$$SSI(\%) = \frac{\eta_{th} - 100}{100} \tag{37}$$

According Eq. (37), 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 Case study: SSPP design procedure with VTVT cycle for air and helium as working fluids

To determine or estimate the viability of a plant prototype, it is necessary to carry out a case study of the SSPP prototype. To do this, four cases corresponding to the RIT values of 0.75, 0.80, 0.85 and 0.90 are taken into consideration. The objective is to choose the most satisfactory case according to the criteria of maximum useful work with the minimum implementation cost. These results are described in four RIT values distributed along the range of temperatures available between power supply and heat sink, of which are shown in Tables 3, 5, 7 and 9 respectively, and the general summary of which is shown in Table 10. Thus, tables 2, 4, 6 and 8 depict the VTVT cycle's state data necessary to realize the cycle analysis.

The study includes irreversibilities assumed to three factors — mechanical losses (LF), thermal losses (RF) and electrical conversion losses ($\eta_{\_el}$) —. Thus, considering LF as 0.85, RF as 0.95 and $\eta_{\_el}$ as 0.95, a global irreversibility factor of 0.767 is taken into account which is the product of the mechanical, thermal and electrical conversion losses.

The data resulting from processing the VTVT cycle states for air and helium at each cascaded PU are shown in Tables 2, 4, 6 and 8 using real gas values obtained from the NIST database. The data related to TWFs belongs to Lemmon E. W., et all, (2007), [18].

Table 2: VTVT cycle data for air and helium as TWFs with RIT = 0.75, to operate three cascaded PUs

sp	T(K)	p(bar)	V(m^3/kg)	u(kJ/kg)	s (kJ/kg-K)		T(K)	p(bar)	V(m^3/kg)	u(kJ/kg)	s(kJ/kg-K)
			PU1-Air						**PU1-He**		
1	600.00	1	0.8563	561.18	4.398	1	600.00	1	6.19340	30.154	
2	800.00	1.6716	0.8563	718.77	4.625	2	800.00	1.6710	6.19340	31.050	
3	800.00	1	1.1417	718.77	4.707	3	800.00	1	8.25690	31.648	
4	600.00	0.4965	1.1417	561.18	4.481	4	600.00	0.4967	8.25690	30.751	
			PU2-Air						**PU2-He**		
1	450.00	1	0.6421	448.91	4.100	1	450.00	1	4.64590	28.660	
2	600.00	1.6722	0.6421	561.13	4.316	2	600.00	1.6710	4.64590	29.556	
3	600.00	1	0.8563	561.13	4.398	3	600.00	1	6.19340	30.154	
4	450.00	0.4962	0.8563	448.91	4.183	4	450.00	0.4967	6.19340	29.257	
			PU3-Air						**PU3-He**		
1	337.50	1	0.4813	367.11	3.809	1	337.50	1	3.4852	27.166	
2	450.00	1.6732	0.4813	448.83	4.018	2	450.00	1.6710	3.4852	28.062	

3	450.00	1	0.6421	448.83	4.101	3	450.00	1	4.6459	28.660
4	337.50	0.4958	0.6421	367.11	3.892	4	337.50	0.4967	4.6459	27.763

Table 3: Performance results of the SSPP equipped with three PUs operating with the VTVT cycle under a RIT of 0.75

TWF	**Air**				**He**			
PU	1	2	3	total	1	2	3	total
LF	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
RF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
η_el				0.95				0.95
RIT	0.75	0.75	0.75	**0.75**	0.75	0.75	0.75	**0.75**
T2	800.00	600.00	450.00		800.00	600.00	450.00	
T1	600.00	450.00	337.50		600.00	450.00	337.50	
qi_12/PU	223.75	161.90	119.07	504.72	1101.60	826.20	619.70	2547.50
q_rec	207.21	149.53	109.77	443.18	981.40	736.05	552.09	2156.06
q_feed	q_feed=qi_PU1+(qi-qrec)			285.29	q_feed=qi_PU1+(qi-qrec)			1493.04
Tm_qrec	600.00	450.00	337.50		600.00	450.00	337.50	
η_th	35.52	36.88	37.70		52.13	52.13	52.12	
wn(kJ/kg)	93.49	70.24	52.81	**216.54**	675.55	506.67	380.00	**1562.22**
EP (kJ/kg)	EP=η_el*wn			**205.71**	EP=η_el*wn			**1484.11**
η_{th_SSPP}				**75.90**				**104.63**
SSI	SSI=EP-100			**-24.10**	SSI=EP-100			**4.63**
SSEP (kJ/kg.cy)				**-79.58**				**-8.93**

Table 4: VTVT cycle data for air and helium as TWFs with RIT = 0.80, to operate four cascaded PUs

	T(K)	p(bar)	v(m^3/kg)	u(kJ/kg)	s(kJ/kg. K)
			PU1-He		
1	640.00	1	6.60610	1999.30	30.489
2	800.00	1.5033	6.60610	2497.90	31.184
3	800.00	1	8.25690	2497.90	31.648
4	640.00	0.5974	8.25690	1999.30	30.952
			PU2-He		
1	512.00	1	5.28550	1600.50	29.33
2	640.00	1.5033	5.28550	1999.30	30.025
3	640.00	1	6.60610	1999.30	30.489
4	512.00	0.5974	6.60610	1600.50	29.793
			PU3-He		
1	409.60	1	4.2291	1281.40	28.171
2	512.00	1.5032	4.2291	1600.50	28.867

3	512.00	1	5.2855	1600.50	29.33
4	409.60	0.5974	5.2855	1281.40	28.635
			PU4-He		
1	327.68	1	3.38390	1026.10	27.012
	409.60	1.5033	3.38390	1281.40	27.708
3	409.60	1	4.22910	1281.40	28.171
4	327.68	0.5974	4.22910	1026.10	27.476

Table 5: Performance results of the SSPP equipped with four PUs operating with the VTVT cycle under a RIT of 0.80

			Air		
PU	1	2	3	4	total
LF	0.0	0.85	0.85	0.85	0.85
RF	0.95	0.95	0.95	0.95	0.95
η_el					0.95
RIT	0.80	0.80	0.80	0.80	**0.80**
T2	800.00	640.00	512.00	409.60	
T1	640.00	512.00	409.60	327.68	
qi_12/PU	178.12	138.22	108.28	85.69	510.31
q_rec	167.93	130.00	101.70	80.41	408.03
q_feed	q_feed=qi_PU1+(qi-qrec)				280.40
Tm_qrec	640.00	512.00	409.60	327.68	
η_th	35.59	36.73	37.56	38.09	
wn(kJ/kg)	74.59	59.72	47.85	38.40	**220.56**
EP (kJ/kg)	PE=η_el*wn				**209.53**
$\eta_{\_th\_SSPP}$					**78.66**
SSI	SSI=EP-100				**-21.34**
SSEP (kJ/kg.cy)					**-70.87**
			He		
PU	1	2	3	4	total
LF	0.0	0.85	0.85	0.85	0.85
RF	0.95	0.95	0.95	0.95	0.95
η_el					0.95
RIT	0.80	0.80	0.80	0.80	0.80
T2	800.00	640.00	512.00	409.60	
T1	640.00	512.00	409.60	327.68	
qi_12/PU	869.80	695.76	556.16	444.94	2566.66
q_rec	794.92	635.86	509.15	407.34	1995.18
q_feed	q_feed=qi_PU1+(qi-qrec)				1441.28

Tm_qrec	640.00	512.00	409.60	327.68	
η_th	52.68	52.68	52.71	52.71	
wn(kJ/kg)	539.02	431.22	344.89	275.91	**1591.05**
EP (kJ/kg)	PE=η_el*wn				**1511.49**
η_{th_SSPP}					**110.39**
SSI	SSI=EP-100				**10.39**
SSEP(kJ/kg.cy)					**70.22**

Table 6: VTVT cycle data for air and helium as TWFs with RIT = 0.85, to operate six cascaded PUs

	T(K)	p(bar)	v(m³/kg)	u(kJ/kg)	s(kJ/kg.K)
			PU1-He		
1	680.00	1	7.01880	2124.00	30.804
2	800.00	1.3553	7.01880	2497.90	31.310
3	800.00	1	8.25690	2497.90	31.648
4	680.00	0.6980	8.25690	2124.00	31.141
			PU2-He		
1	578.00	1	5.96650	1806.10	29.960
2	680.00	1.3552	5.96650	2124.00	30.466
3	680.00	1	7.01880	2124.00	30.804
4	578.00	0.6980	7.01880	1806.10	30.297
			PU3-He		
1	491.30	1	5.0720	1536.00	29.116
2	578.00	1.3552	5.0720	1806.20	29.622
3	578.00	1	5.9665	1806.20	29.960
4	491.30	0.6980	5.9665	1536.00	29.453
			PU4-He		
1	417.61	1	4.31170	1306.40	28.272
	491.30	1.3552	4.31170	1536.00	28.778
3	491.30	1	5.07200	1536.00	29.116
4	417.61	0.6981	5.07200	1306.40	28.609
			PU5-He		
1	354.96	1	3.66540	1111.10	27.428
2	417.61	1.3553	3.66540	1306.40	27.934
3	417.61	1	4.31170	1306.40	28.272
4	354.96	0.69800	4.31170	1111.10	27.765
			PU6-He		
1	301.72	1	3.11610	945.24	26.584
2	354.96	1.3552	3.11610	1111.20	27.090

3	354.96	1	3.66540	1111.20	27.428
4	301.72	0.69804	3.66540	945.24	26.921

Table 7: Performance results of the SSPP equipped with six PUs operating with the VTVT cycle under a RIT of 0.85

Air							
PU	1	2	3	4	5	6	total
LF	0.85	0.85	0.85	0.85	0.85	0.85	0.85
RF	0.95	0.95	0.95	0.95	0.95	0.95	0.95
η_el							0.95
RIT	0.85	0.85	0.85	0.85	0.85	0.85	**0.85**
T2	800.00	680.00	578.00	491.30	417.61	354.96	
T1	680.00	578.00	491.30	417.61	354.96	301.72	
qi_12/PU	133.07	110.41	92.00	77.18	65.03	55.01	477.69
q_rec/PU	127.47	105.70	87.95	73.68	62.09	52.57	388.36
q_feed	q_feed=qi_PU1+(qi-qrec)						222.40
Tm_qrecov	680.00	578.00	491.30	417.61	354.96	301.72	
η_th	35.65	36.56	37.25	37.87	38.25	38.51	
wn(kJ/kg)	55.81	47.49	40.32	34.39	29.26	24.92	**207.27**
EP (kJ/kg)	EP=η_el*wn						**196.90**
η_{-th_SSPP}							**88.54**
SSI	SSI=EP-100						**-11.46**
SSEP (kJ/kg.cy)							**-25.49**
He							
PU	1	2	3	4	5	6	total
LF	0.85	0.85	0.85	0.85	0.85	0.85	0.85
RF	0.95	0.95	0.95	0.95	0.95	0.95	0.95
η_el							0.95
RIT	0.85	0.85	0.85	0.85	0.85	0.85	0.85
T2	800.00	680.00	578.00	491.30	417.61	354.96	
T1	680.00	578.00	491.30	417.61	354.96	301.72	
qi_12/PU	644.30	547.74	465.56	395.66	336.45	285.94	2389.71
q_recov/PU	603.06	512.69	435.77	370.33	314.92	267.64	1901.25
q_feed	q_feed=qi_PU1+(qi-qrec)						1132.76
Tm_qrec	680.00	578.00	491.30	417.61	354.96	301.72	
η_th	53.22	53.21	53.21	53.22	53.20	53.21	
wn(kJ/kg)	403.39	342.89	291.45	247.73	210.57	178.99	**1496.04**
EP (kJ/kg)	PE=η_el*wn						**1421.24**
η_{-th_SSPP}							**125.47**

SSI	SSI=EP-100	**25.47**
SSEP (kJ/kg.cy)		**288.48**

Table 8: VTVT cycle data for air and helium as TWFs with RIT = 0.90, to operate nine cascaded PUs

	T(K)	p(bar)	v(m³/kg)	u(kJ/kg)	s (kJ/kg. K)
			PU1-He		
1	720.00	1	7.43150	2248.60	31.100
2	800.00	1.2237	7.43150	2497.90	31.429
3	800.00	1	8.25690	2497.90	31.648
4	720.00	0.7987	8.25690	2248.60	31.319
			PU2-He		
1	648.00	1	6.68870	2024.20	30.553
2	720.00	1.2237	6.68870	2248.60	30.882
3	720.00	1	7.43150	2248.60	31.100
4	648.00	0.7987	7.43150	2024.20	30.772
			PU3-He		
1	583.20	1	6.0201	1822.30	30.006
2	648.00	1.2237	6.0201	2024.30	30.334
3	648.00	1	6.6887	2024.20	30.553
4	583.20	0.7987	6.6887	1822.30	30.225
			PU4-He		
1	524.88	1	5.41840	1640.60	29.459
	583.20	1.2237	5.41840	1822.30	29.787
3	583.20	1	6.02010	1822.30	30.006
4	524.88	0.7987	6.02010	1640.60	29.678
			PU5-He		
1	472.39	1	4.87690	1477.10	28.912
2	524.88	1.2237	4.87690	1640.60	29.240
3	524.88	1	5.41840	1640.60	29.459
4	472.39	0.79869	5.41840	1477.00	29.131
			PU6-He		
1	425.15	1	4.38950	1329.90	28.365
2	472.39	1.2237	4.38950	1477.10	28.693
3	472.39	1	4.87690	1477.10	28.912
4	425.15	0.79869	4.87690	1329.90	28.584
			PU7-He		
1	382.64	1	3.95090	1197.40	27.818

2	425.15	1.2237	3.95090	1329.90	28.146
3	425.15	1	4.38950	1640.60	28.365
4	382.64	0.79869	4.38950	1197.40	28.036
			PU8-He		
1	344.37	1	3.55610	1078.10	27.270
2	382.64	1.2237	3.55610	1197.40	27.599
3	382.64	1	3.95090	1197.40	27.818
4	344.37	0.79869	3.95090	1078.10	27.489
			PU9-He		
1	309.94	1	3.20090	970.85	26.723
2	344.37	1.2236	3.20090	1078.10	27.052
3	344.37	1	3.55610	1078.10	27.270
4	309.94	0.79874	3.55610	970.85	26.942

Table 9: Performance results of the SSPP equipped with nine PUs operating with the VTVT cycle under a RIT of 0.90

					Air					
PU	1	2	3	4	5	6	7	8	9	total
LF	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
RF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
η_el										0.95
RIT	0.9	0.9	0.9	0.9	0.90	0.90	0.90	0.90	0.90	0.9
T2	800.00	720.00	648.00	583.20	524.88	472.39	425.15	382.64	344.37	
T1	720.00	648.00	583.20	524.88	472.39	425.15	382.64	720.00	309.94	
qi_12/PU	88.42	78.27	69.38	61.64	54.87	48.97	43.84	39.29	35.29	519.99
q_rec	86.00	76.08	67.42	59.87	53.33	47.54	42.55	38.13	34.24	429.40
q_feed	q_feed=qi_PU1+(qi-qrec)									179.01
Tm_qrec	720.00	648.00	583.20	524.88	472.39	425.15	382.64	344.37	309.94	
η_th	35.75	36.35	36.90	37.39	37.86	47.54	38.44	38.61	38.61	
wn(kJ/kg)	37.19	33.47	30.12	27.11	24.44	21.96	19.83	17.85	16.11	**228.09**
EP (kJ/kg)	PE=η_el*wn									**216.68**
η_{th_SSPP}										**127.41**
SSI	SSI=EP-100									**27.41**
SSEP (kJ/kg.cy)										**37.67**
					He					
PU	1	2	3	4	5	6	7	8	9	total
LF	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85

RF	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
η_el										0.95
RIT	0.9	0.9	0.9	0.9	0.90	0.90	0.90	0.90	0.90	0.9
T2	800.00	720.00	648.00	583.20	524.88	472.39	425.15	382.64	344.37	
T1	720.00	648.00	583.20	524.88	472.39	425.15	382.64	720.00	309.94	
qi_12/PU	424.50	381.36	343.91	309.42	278.45	250.65	225.61	203.10	182.32	2599.32
q_rec	406.98	366.31	329.62	296.65	267.05	240.31	526.61	194.72	175.13	2382.88
q_feed	q_feed=qi_PU1+(qi-qrec)									640.95
Tm_qrec	720.00	648.00	583.20	524.88	472.39	425.15	382.64	344.37	309.94	
η_th	53.82	53.79	53.81	53.83	53.84	240.31	53.70	53.81	53.81	
wn(kJ/kg)	268.80	241.34	217.73	195.96	176.36	158.72	142.54	128.57	115.43	**1645.45**
EP (kJ/kg)	PE=η_el*wn									**1563.18**
η_{-th_SSPP}										**256.72**
SSI	SSI=EP-100									**156.72**
SSEP (kJ/kg.cy)										**922.23**

5 Analysis of results

It has been shown in Table 1, and graphically depicted in Fig. 6 that the influence of irreversibilities on the SWR is a key factor in VTVT cycles, since the performance of the cycle increases proportionally to the reduction of losses, for a given constant value of the losses in the VsVs cycle. Furthermore, the irreversibilities inherent to the VTVT thermal cycle not only influence the thermal efficiency of the cycle but also influence the specific work ratio SWR. As shown in Table 1 and Fig. 6, the SWR of a VTVT cycle can be increased from to 2 if irreversibilities were reduced 50%. Consequently, this factor should be taken into account when implementing the designed prototype.

Another interesting topic deals with the results of the case studied as shown in Table 10. Table 10 shows a summary of the most relevant findings. In order to facilitate the analysis of the results in terms of comparison between the options studied with the different RIT values, the summary of the results is presented in Table 10 assuming an irreversibility factor of 0.767 corresponding to the product of the mechanical, thermal and electrical conversion losses.

Table 10: Summary of results

RIT	**0.75**		**0.80**		**0.85**		**0.9**	
Case/No[PUs]	**1/ [3]**		**2/ [4]**		**3/ [6]**		**4/ [9]**	
TWF	**Air**	**He**	**Air**	He	**Air**	He	Air	He
W_n (kJ/kg.cy)	126.54	1562.22	220.56	1591.05	207.27	1496.04	228.09	1645.45
EP (kJ/kg.cy)	205.71	1484.11	209.53	1511.49	196.90	1421.24	216.68	1563.18
η_{th}(%)	**75.90**	**104.63**	**78.66**	110.39	**88.54**	125.47	127.41	256.72
SSI	**-24.10**	**4.63**	**-21.34**	10.39	**-11.46**	25.47	27.41	156.72
SSEP (kJkg.cy)	**-79.58**	**-8.93**	**-70.87**	70.22	**-25.49**	288.48	37.67	922.23

To analyse the thermal cycle of each PU that makes up the cascade of PUs corresponding to the SSPP prototype, the value assigned to each PU is used as a starting point. Due to previous studies [17-20], it is known that the RIT value must be the same for each PU that makes up the cascade of PUs required implementing a SSPP prototype.

To evaluate the data in Table 10, four RIT values have been taken, which requires the study of four cases. The data for the four cases are found in Tables 2, 4, 6 and 8 respectively. The results of the four individual analyses of SSPP prototypes for RIT values of 0.75, 0.80, 0.85 and 0.90 are shown in Tables 3, 5, 7 and 9.

Based on the data shown in Tables 3, 5, 7 and 9, a summary of the results is shown in Table 10. Therefore, in table 10, it can be seen in red colour that:

-- when operating with air as TWF, the prototype cases with RIT equal to or less than 0.85 do not satisfy the conditions of SSPM —self-sustaining power machine— because to operate they require the assistance of energy from an external source of thermal energy or heat.

-- when operating with helium as TWF, the prototype cases with RIT less than 0.80 do not satisfy the conditions of SSPM —self-sustaining power machine— because to operate they require the assistance of energy from an external source of thermal energy or heat.

-- operating with air as TWF, only a prototype equipped with 9 PUs in cascade is empirically feasible or possible to meet the conditions required by a SSPM —self-sustaining power machine—

-- on the other hand, operating with helium as TWF, any prototype equipped with 6 or 9 PUs in cascade seems feasible to meet the conditions required by a SSPM —self-sustaining power machine—

Specifically, the design task of experimental tests with prototypes based on this study are restricted to cases designed to operate with RITs of 0.9 for air and RITs between 0.8 and 0.9 for helium as TWF.

The comparison of values found in the analysis of the VTVT thermal cycle using the empirical formulation corresponding to the thermodynamic description of the VTVT cycle allows us to obtain prototype design criteria useful for the implementation of an approach towards an optimised prototype:

-- Choice of the thermal working fluid

-- Appropriate RIT value

-- Number of coupled PUs in a cascade resulting from the application of the RIT. This means that the number of PUs is determined by the RIT

-- Adjustment of structural dimensions of each PU with data obtained from tables 2, 4, 6, and 8 of the analysis of the VTVT thermal cycle.

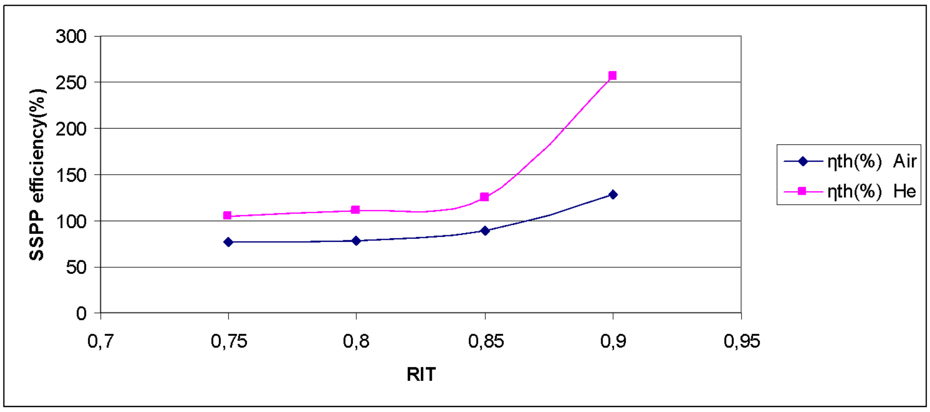

Figure 9: Depiction of the efficiency (%) of a Self-Sustaining Power Plant (SSPP) as function of the RIT assigned to each Power Unit of a Self-Sustaining Power Plant Prototype for air and helium as working fluids

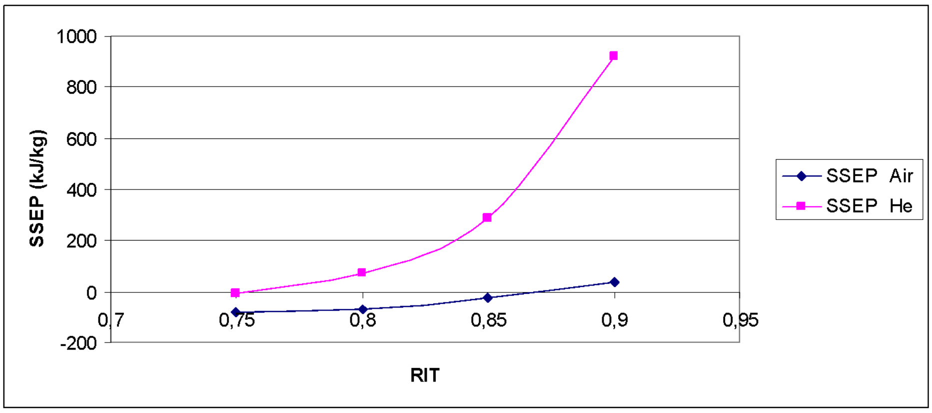

Figure 10: Depiction of the Self-Sustaining Electric Power (SSEP) as function of the RIT assigned to each Power Unit of a Self-Sustaining Power Plant Prototype for air and helium as working fluids

The amount of PUs associated with any studied case is strictly a function of the RIT value. The higher the RIT value, the greater the number of PUs necessary to take advantage of the range of temperatures available between the power supply and the heat sink. Therefore, the implementation cost of the SSPP increases consequently. However, the SSPP efficiency, the SSI and consequently the SSEP increases accordingly. From this reasoned argument it follows that it is necessary to determine a compromise value that relates the number of PUs and the SSI value in order to optimize the SSPP.

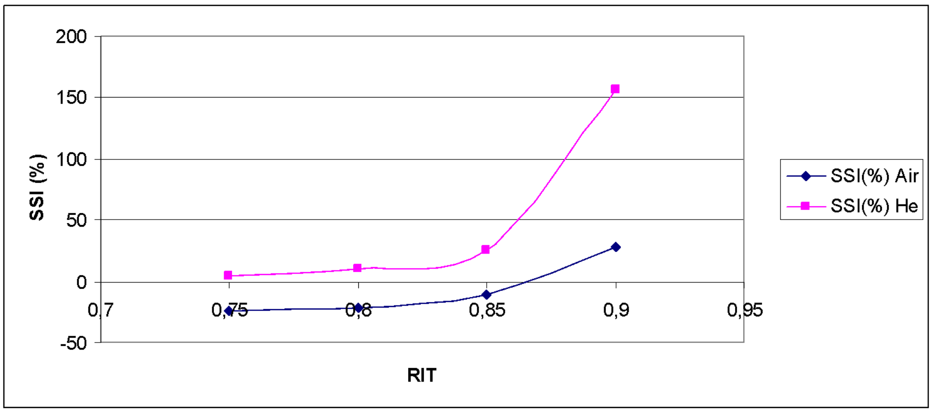

Figure 11: Depiction of the Self-Sustaining Index (SSI) as function of the RIT assigned to each Power Unit of a Self-Sustaining Power Plant Prototype for air and helium as working fluids

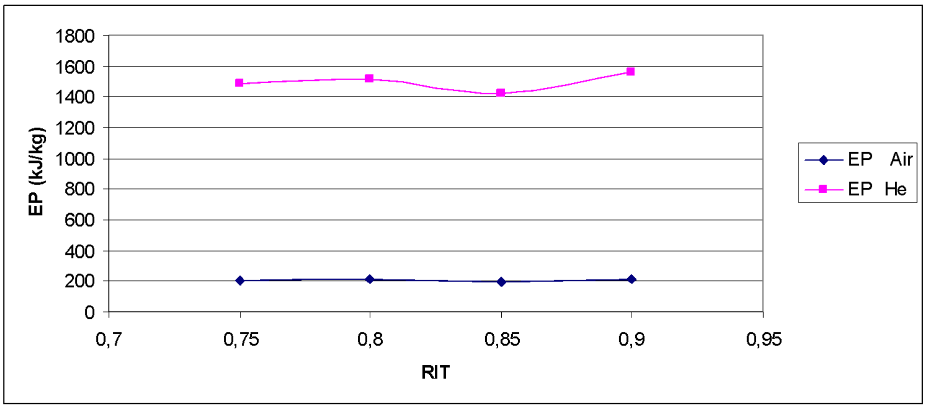

Figure 12: Depiction of the Electric Power (EP) as function of the RIT assigned to each Power Unit of a Self-Sustaining Power Plant Prototype for air and helium as working fluids

Table 11 Estimated viable results to implement SSPP prototype structures

RIT	**0.80**	**0.85**	**0.9**	
Case/No [PUs]	**2/ [4]**	**3/ [6]**	**4/ [9]**	
TWF	He	He	Air	He
W_n (kJ/kg.cy)	1591.05	1496.04	228.09	1645.45
EP (kJ/kg.cy)	1511.49	1421.24	216.68	1563.18
η_{th}(%)	110.39	125.47	127.41	256.72
SSI	**10.39**	**25.47**	**27.41**	**156.72**
SSEP (kJkg.cy)	**70.22**	**288.48**	**37.67**	**922.23**

In order to facilitate the task of comparing the impact of RIT on the most relevant parameters in terms of technical-economic viability for air and helium as TWFs, the SSPP efficiencies, the net electrical production

(SSEP), the SSI index and the corresponding amount of electrical energy produced are shown in Figures 9 to 12 respectively. The data needed to make the graphs represented in figures 9-12 have been taken from table 10.

The results shown in Table 10 include information that allows discarding or selecting those designs that deserve to be tested experimentally by implementing the corresponding prototypes. As a consequence, those that contribute with an acceptable SSI value are chosen, which are shown in Table 11, resulting in that to operate with air as TWF only a prototype model is eligible that requires a RIT value of 0.9 and 9 PUs coupled in a shell to give a SSI of 27.4 and a SSEP production of 37.67 kJ/kg.cy.

In contrast, taking helium as TWF, the following would be eligible:

-- a prototype model requiring a RIT value of 0.8 and 4 PUs coupled in cascade to give an SSI of 10.4 and a SSEP yield of 70.2 kJ/kg.cy

-- a prototype model requiring a RIT value of 0.85 and 6 PUs coupled in cascade to give an SSI of 25.5 and a SSEP yield of 288.5 kJ/kg.cy

-- a prototype model requiring a RIT value of 0.9 and 9 PUs coupled in cascade to give an SSI of 156.72 and a SSEP yield of 922.2 kJ/kg.cy

Looking at the results, it is notable that increasing the RIT requires a larger number of PUs coupled in cascade, which increases the implementation cost but also contributes to a significant increase in the energy obtained at zero cost.

6. Conclusions

The research and development of the Self-Sufficient Power Plant (SSPP) prototype represents a significant advancement in energy production efficiency and self-sufficiency. The innovative design, which utilizes cascaded power units operating on a VTVT thermal cycle, demonstrates promising results, particularly when using helium as the thermal working fluid. Empirical validation highlights the prototype's ability to achieve high specific work output and thermal efficiency through a disruptive heat recovery technique.

Key Findings

-- The SSPP can operate self-sufficiently under specific conditions.

-- Helium-based prototypes show greater feasibility at lower RIT values compared to air-based prototypes.

-- Minimizing irreversibilities is crucial for enhancing cycle performance.

-- The number of PUs required is directly related to the RIT value, impacting both efficiency and implementation costs.

The SSPP prototype demonstrates potential for significant contributions to sustainable power generation. However, further experimental validation is needed to optimize design parameters and confirm long-term viability.

Performance Factors

Assuming irreversibilities of 23% in the conversion of thermo-hydraulic energy to useful electric power, the SSPP achieves a high Self-Sufficiency Index (SSI) by leveraging:

-- Contraction-based work

-- Cascaded heat recovery

-- Upgraded heat recovery

-- Preselected constant RIT value of 0.9 within each cycle

Case Study Results

The study demonstrates the performance of an irreversible SSPP composed of cascaded PUs operating with air and helium under VTVT cycles. The focus is on the SSI as a function of RIT values greater than 0.85.

Disruptive Contributions and Controversies

The research challenges conventional thermodynamic principles, particularly regarding:

--Traditional exergy concepts

--First law of thermodynamics (due to energy balance in thermal cycles with contraction-based work)

-- Energy balance of SSPPs

-- Aspects of the second law of thermodynamics

These findings necessitate a deep revision of established theories to align with observed empirical and experimental facts.

Implications and Future Steps

The proposed SSPP and its claimed ability to achieve efficiencies greater than 100% represent a significant departure from conventional thermodynamic principles. If experimentally verified, such findings would have profound implications for our understanding of energy and power generation. However, it's crucial to approach these claims with scientific skepticism. The extraordinary nature of the propositions demands equally extraordinary evidence. Therefore, prototyping and rigorous experimental validation are critical next steps. The author expresses willingness to collaborate with research groups or entrepreneurial organizations interested in carrying out a prototyping project, subject to favorable contractual arrangements for the transfer of existing patent rights.

References

1. Wikipedia. Thomas Savery. https://en.wikipedia.org/wiki/Thomas_Savery
2. Wikipedia. Thomas Newcomen. https://en.wikipedia.org/wiki/Thomas_Newcomen
3. Wikipedia. James Watt: https://en.wikipedia.org/wiki/James_Watt; https://en.wikipedia.org/wiki/Watt_steam_engine
4. Müller. Gerald. The atmospheric steam engine as energy converter for low and medium temperature thermal energy. Renewable energy. 2013. vol. 53. p. 94-100. https://doi.org/10.1016/j.renene.2012.10.056
5. 5 Gerald Müller. George Parker. Experimental investigation of the atmospheric steam engine with forced expansion. Renewable Energy. Vol. 75. 2015. pp 348-355. ISSN 0960-1481. https://doi.org/10.1016/j.renene.2014.09.061.
6. Vítor Augusto Andreghetto Bortolin. Bernardo Luiz Harry Diniz Lemos. Rodrigo de Lima Amaral. Cesar Monzu Freire & Julio Romano Meneghini. Thermodynamical model of an atmospheric steam engine. Journal of the Brazilian Society of Mechanical Sciences and Engineering Vol. 43. 493 (2021). https://doi.org/10.1007/s40430-021-03209-9.
7. Ferreiro R. Ferreiro B. Isothermal and Adiabatic Expansion Based Trilateral Cycles. British Journal of Applied Science & Technology. 2015; (8) 5: 448-460. https://www.doi.org/10.9734/BJAST/2015/17350.
8. Ferreiro R. Ferreiro B. The Behavior of Some Working Fluids Applied on the Trilateral Cycles with Isothermal Controlled Expansion. British Journal of Applied Science & Technology. 2015; (9) 5: 694 450-463. https://www.doi.org/10.9734/BJAST/2015/18624.
9. Ramon Ferreiro Garcia, Jose Carbia Carril. Closed Processes Based Heat-Work Interactions Doing Useful Work by Adding and Releasing Heat. International Journal of Emerging Engineering Research and Technology. Volume 6. Issue 11. 2018. pp 8-23. ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online). Accessed at: https://www.ijeert.org/papers/v6-i11/2.pdf; https://www.ijeert.org/v6-i11.
10. Ramon Ferreiro Garcia, Jose Carbia Carril, Manuel Romero Gomez and Javier Romero Gomez. Energy and entropy analysis of closed adiabatic expansion based trilateral cycles. Energy Conversion and Management 119 (2016) 49–59. http://dx.doi.org/10.1016/j.enconman.2016.04.031 .
11. Ramon Ferreiro Garcia. Reply to: Comment on "Energy and entropy analysis of closed adiabatic expansion based trilateral cycles" by Garcia et al. Energy Conversion and Management 119 (2016) 49–59. Energy Conversion and Management 123 (2016) 646–648. http://dx.doi.org/10.1016/j.enconman.2016.06.05 .
12. Ramon Ferreiro Garcia, Jose Carbia Carril. Combined Cycle Consisting of Closed Processes Based Cycle Powered by A Reversible Heat Pump that Exceed Carnot Factor. Journal of Advances in Physics, Volume 15, (2018), Pages: 6078-6100. ISSN: 2347-3487. DOI: 10.24297/jap.v15i0.8034.
13. Ramon Ferreiro Garcia. Study of the disruptive design of a thermal power plant implemented by several power units coupled in cascade. Energy Technol. 2023, 2300362 (1-17). Published by Wiley-VCH GmbH. DOI: https://doi.org/10.1002/ente.202300362
14. Ramón Ferreiro Garcia. Efficient disruptive power plant-based heat engines doing work by means of strictly isothermal closed processes. Journal of Advances in Physics Vol 22 (2024), p 30.53, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9587. DOI: https://doi.org/10.24297/jap.v15i0.9587 .
15. Ramón Ferreiro Garcia. Design study of a disruptive self-powered power plant prototype. Journal of Advances in Physics Vol 22 (2024), p 62.92, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9596. DOI: https://doi.org/10.24297/jap.v22i.9596 .
16. Ramón Ferreiro Garcia. Prototyping a Disruptive Self-Sustaining Power Plant enabled to overcome Perpetual Motion Machines. Journal of Advances in Physics Vol 22 (2024), p 141.178, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/963. DOI: https://doi.org/10.24297/jap.v22i.9633.

17. Ramón Ferreiro Garcia. Prototyping Self-Sustaining Power Machines with Cascaded Power Units Composed by Pulse Gas Turbines. Journal of Advances in Physics Vol 22 (2024), p 141.178, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9648. DOI: https://doi.org/10.24297/jap.v22i.9648
18. E. W. Lemmon, M. L. Huber, M. O. McLinden, NIST Reference Fluid Thermodynamic And Transport Properties - REFPROP Version 8.0, User's Guide, NIST, Boulder, CO. 2007.
19. Ramón Ferreiro Garcia. Prototyping disruptive self-sufficiency power machines composed by cascaded power units based on thermo-hydraulic actuators. Journal of Advances in Physics Vol 22 (2024), p 141.178, ISSN: 2347-3487. https://rajpub.com/index.php/jap/article/view/9662. DOI: https://doi.org/10.24297/jap.v22i.9662
20. Patent: Planta térmica con máquina de doble efecto, acumuladores térmicos, convección forzada y alimentación térmica reforzada con un ciclo Brayton inverso y procedimiento de operación. Thermal power plant with double-effect machine, thermal accumulators, forced convection and reinforced thermal supply with a reverse Brayton cycle and operating procedure. Ramon Ferreiro Garcia, Jose Carbia Carril. application number 201700667 and publication number 2 696 950 B2. Accessed at: https://consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=m9dTemLOqYgGbpax1wR4K+aC.ConsultasC1
21. Patent: Procedimiento de operación de una máquina alternativa de doble efecto con adición y extracción de calor y convección forzada. Operating procedure of a double-acting reciprocating machine with heat addition and extraction and forced convection and operating procedure. Jose Carbia Carril, Ramon Ferreiro Garcia, application number P201700718 and publication number 2 704 449 B2. Accessed at: consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=-wHy58sbfVYQutIYN8s0+JKK.ConsultasC1
22. Patent: Planta termoeléctrica multiestructural policíclica y procedimientos de operación. Polycyclic multi-structure thermal power plant and operating procedures. Ramon Ferreiro Garcia, application number P202200035 and publication number 2 956 342 B2. Accessed at: consultas2.oepm.es/ceo/jsp/busqueda/busqRapida.xhtml;jsessionid=-wHy58sbfVYQutIYN8s0+JKK.ConsultasC1