HOT AIR ENGINE, DEVELOPED AND PATENTED BY TRAIAN VUIA, A ROMANIAN PERFORMANCE FOR 21st CENTURY

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Abstract. After thoroughly researching data from national archives, libraries, and important technical studies from Romania and abroad, I concluded that the hot air and closed-circuit engine built, tested, and patented by Romanian engineer Traian Vuia (1872–1950), is superior in its thermodynamic performances to similar engines investigated today. For this engine, almost as perfect thermodynamic Carnot engine, Traian Vuia has achieved ten (10) patents, during 1908-1916 years. Therefore, this engine unjustified forgotten or ignored over a century should be considered a wealth, which belongs (inter) national technical heritage. It represents a great challenge to bring this engine back to the scientific and industrial circuit and, in order to do so, this paper clarifies the following issues:

- How evolved over time thermal cycling of different engines, as target perfect thermodynamic engine Carnot;
- Which was the thermal process used at Vuia engine for isothermation of compression and expansion;
- Today "*isodiabate heat release and receipt*" at Vuia engine can be qualified as an isentropic process for ideal conditions or adiabatic process for real conditions, with irreversibility, or others;
- Which device used Traian Vuia for "*isodiabate heat release and receipt*";
- Which is the construction and operation of Vuia engine;
- If thermal cycle and engine Vuia has been recognized internationally.

Key words: Carnot, Stirling, Ericsson, Joule, Brayton, engines, almost perfect thermodynamic engines Vuia and Pomojnicu, engines with external combustion, isothermate compression and expansion, isentropic, adiabatic, isodiabatic heat release and receipt, regenerator, recuperator.

1. INTRODUCTION

At a time when the steam engine showed signs of technical ageing, causing numerous accidents due to explosion of boilers and high consumption of coal, experts turned their attention to regenerative engines with open or closed circuits,

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that used other working agents such as: the *exhaust gas engine*, released by George Cayley [1] in 1807, the *air machine* invented by Robert Stirling [2] in 1816, the *caloric engine* invented by John Ericsson [3] in 1833, *the air engine* released by James Prescott Joule [4] in year 1851, *the constant pressure and internal combustion engine* invented by George Brayton [5] in May 1872, and others.

Using a regenerator for the very first time rendered the Stirling engine the first industrial engine to rival the steam engine [10, 11]. In 1833, John Ericsson [3] replaced Stirling's regenerator with a shell and tube heat exchanger previously used as a condenser for steam engines, thus creating his first "*caloric engine*". For the engine build in 1851, however, Ericsson returns to Stirling's regenerator.

Based on this historical evolution, aiming for the almost-perfect thermodynamic Carnot engine after gaining experience from building the engine for his own flying machine, Traian Vuia focused on the study and construction of a hot air engine, a regenerative one with closed circuit. Thus, between the years 1908–1909 Traian Vuia developed an engine based on the performance of the isothermal compression and expansion engines built by Robert Stirling and John Ericsson. As a further step, to close the ideal Carnot cycle [6] he replaced the isoentropic compression and expansion with a "*isodiabate*" thermodynamic process of heat release and receipt. This represented the appearance of the first quasi perfect thermodynamic engine. From the descriptions and claims raised in the ten (10) patents obtained for this engine, it clearly results that the Vuia engine, was recognized as one that operates on a thermal cycle consisting of two compression and expansion isotherms and two "*isodiabates*" for releasing and receiving heat. These historical concerns continued to be raised and today they evolve around the quasi perfect thermodynamic engine, Pomojnicu [7], whose thermal cycle contains only isotherm and adiabatic compression and expansion, just like the Carnot cycle.

2. THE EVOLUTION OF QUASI PERFECT THERMODYNAMIC ENGINE, OR FROM THE IDEAL CARNOT ENGINE TO ALMOST PERFECT THERMODYNAMIC ENGINES VUIA AND POMOJNICU

To better understand the exceptional thermodynamic performance of the Vuia engine, we must first observe the historical evolution of thermodynamics in regenerative engines.

When comparing the Vuia engine to the thermodynamics of the engines of Ericsson, Joule and Brayton one can identify other situations that require clarification. According to the GB 6409 (1833) patent, the Ericsson engine, which has a recuperator type shell and tube heat exchanger (and not a regenerator type Stirling) in its mechanical structure, works on a thermal cycle that was released by J.P. Joule in 1852 and recognized [5] by the US 125,166 (1872) and US 151,468 (1877) patents, both authored by George Brayton. This thermal cycle, known as the "*thermal cycle Joule-Brayton*" relies on an isobaric heat release and receipt process [40]. As for engines patented later, John Ericsson used a Stirling type regenerator, applied preheating to the admitted gas, and forced the internal convection by forming the piston while externally heating the expander cylinder, and externally cooling the compressor cylinder. In the case of this thermal cycle recognized as the "*Ericsson ideal cycle*" the release and receipt of heat are isobaric [40]. Since, according to the GB 6409 (1833) patent, the Ericsson engine uses a recuperator and not a regenerator, just like the Vuia engine, one might conclude that in the case of the Vuia engine the release and receipt of heat is also an isobaric one. Accordingly, the thermal cycle developed for the Vuia engine is the same as the ideal Ericsson thermal cycle.

At this point, it is important to consider Ion Pomojnicu's point of view, who in the foreword of the book "*ENGINES VUIA, Ericsson, Joule Brayton, confusion, duplication or novelty*" [12] states the following: "*The (Vuia) Engine is a Ericsson type engine, which allows greater accuracy of the functional heat cycle composed of four known transformations: isotherm compression – isochoric heat input of the regenerator – isotherm expansion – isochoric releasing heat regenerator.*" This logic-based reasoning is impossible to contradict, considering Pomojnicu's great expertise in building engines.

The entire evolution in time of thermodynamics, aiming for the quasi-perfect thermodynamic engine, is presented in Table 1.

Table 1

The thermal cycles used for the main external combustion engines

Engine/ Thermal cycle	Expansion	Heat release	Compres-sion	Heat receipt
Stirling engine (1816)	isotherm	isochore	isotherm	isochore
Ideal engine Carnot (1824)	isotherm	isentropic expansion	isotherm	isentropic compression
Caloric engine Ericsson Patent GB 6409 /1833 Cycle Joule – Public presentation from 1851	isentropic	isobar	isentropic	isobar
Engine Ericsson, Patent US 8,481 /1851	isotherm	isobar	isotherm	isobar
Engine Brayton Patent US 125,166 /1872 and US 151,468 /1877	idem cycle Joule	idem cycle Joule	idem cycle Joule	idem cycle Joule
Engine Vuia Patent BE 205.058 /1908 and US 1,169,308 /1908	isotherm	"*isodiabate*" *) (adiabat isochore isobar)	isotherm	"*isodiabate*"*) (adiabat isochore isobar)
Engine Pomojnicu (1982) Patent Chrisoghilos US 4,502,284 /1985	isotherm	adiabat expansion	isotherm	adiabat compression
*) This contradictory process I will try to clarify in the following.				

The entire development of hot air engines occurred after Sadi Carnot [6], published his work regarding the perfect thermodynamic engine, in 1824. His theory did not help to improve the efficiency of engines directly, but rather explained why a certain practice may be superior to another. Literature shows that the real impact of the thinking Carnot was found only in 1894, after Rudolf Diesel used this theory [13] to design the Diesel engine [14], whose hot side temperature is much higher than that of a steam engine, resulting in a more efficient engine.

In reality, the first application of the Carnot thinking on an engine with external combustion should be attributed to Traian Vuia. Not only did Vuia increase the temperature difference between the hot and the cold side for his engine, as Rudolf Diesel did later, but he also came closest to Carnot's thermal cycle through a "*isodiabate*" process of heat release and receipt.

For clarity purposes, but also for better appreciation, I will present below how Traian Vuia scientifically argued for the approach of the thermodynamic process Carnot, through a "*isodiabate*" process of heat release and receipt, using a recuperator. The citation below belongs to Traian Vuia, US patent 1,169,308 "*Hot-Air Engine with Closed Circuit*" [15], applied at 06 January 1916.

*«The yielding up of heat to the regenerator **e e^1** takes place during the delivery of air from the cylinder **a** into the cylinder **b** (in the right figure below on the line **BC'**). The absorption of heat from the regenerator **e e^1** takes place during the delivery of air from the cylinder **b** into the cylinder **a** (in the left figure below on the line **AE**).*

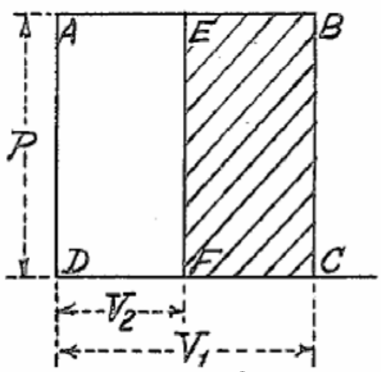

FIG.5.

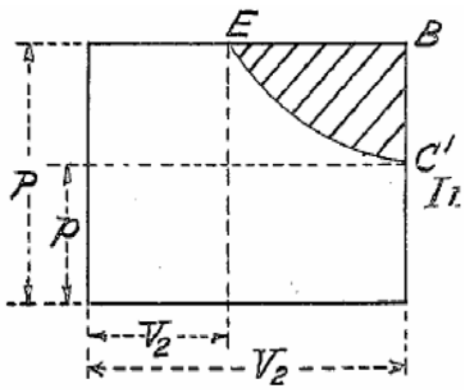

FIG.8.

*The quantity of heat given out by the fluid on the line **BC'** is equal to that which is absorbed on the line **AE.** In this case for the two transformations **BC'** and **AE**.*

$$\int \frac{\mathrm{d}Q}{T} = 0$$

*and if **Q_1** and **Q_2** are the same quantities of heat used up following **EB** and **C'E** :*

$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$

where:

$$\int = \frac{Q_1 - Q_2}{T_1} = \frac{T_1 - T_2}{T_1} \quad \text{(see footnote } ^2 \text{)}$$

This cycle has thus a maximum as in Carnot's cycle, under the condition that it would be possible to store the heat yielded by the fluid. Accordingly, all the difficulties which oppose the realization of the Carnot cycle in hot air, machines are avoided by reason of the use of a regenerator.»

Based on this scientific background, Traian Vuia concluded that the lower the T_2/T_1 ratio, the higher the engine performance. Namely, the performance increases as the difference in temperature between the hot and the cold side reaches the highest possible value. Thus, he claimed [16] a hot temperature level of 400–500 °C and a cold temperature level of 15–20 °C, as opposed to John Ericsson [17] who kept the hot temperature of certain engines at 384°F (195 °C) in order to avoid the corrosion of valves, pistons and other operating parts. Today, the French School represented by UPPA – Pascal Stouffs [18, 19] raises the hot temperature to a value as high as 800 °C. This condition is very strict as it favors the cooking of lubricants and increases the risk of explosion for oxygen-lubricants mixtures.

In addition to the Carnot procedures of improving the efficiency of thermal machines, Traian Vuia also based his theory on the fact that the hot air engine is more flexible than the steam one, since the increase of the power and therefore of useful mechanical work can occur in three ways:

- By increasing the pressure without increasing the temperature in the heater;
- By increasing the heater temperature;
- By simultaneously increasing both pressure and temperature.

Thus, along with raising the temperature of the hot section, he boldly grows the pressure of the working fluid at 15–16 bar.

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[2] For clarity purposes, but also for better appreciation, I have presented exactly how Traian Vuia scientifically argued for the approach of the thermodynamic process Carnot, through an "*isodiabate*" process [15] of heat release and receipt, using a recuperator. In order to preserve the historical truth, I have replayed this mathematical foundation as presented in US 1,169,308 "*Hot Air Engines*", although there may be differences in the symbols used today in editing formulas, printing errors, or other errors.

To sum up, the following preliminary conclusions can be drawn from this first study:

- A perfect thermodynamic (ideal) Carnot engine operates on a thermal cycle consisting of four thermodynamic processes, two isotherms and two isentropics;
- The thermal cycle, known today as the "*thermal cycle Joule-Brayton*" used by John Ericsson for the *caloric engine* built in 1833, was considered again by James Prescott Joule's when developing the *air engine* [4] in 1851 and was physically created only [5] in 1872 by George Brayton;
- The thermal cycle with isothermal compression and expansion applied to the engine built by John Ericsson in 1851 is known today as the "*Ericsson ideal thermal cycle*";
- The isothermal compression and expansion that resulted from the Stirling engine (1816) has proven to be interesting to John Ericsson for the engine built in 1851, and was subsequently applied by Traian Vuia (1908) and Ion Pomojnicu (1982);
- The Vuia and Pomojnicu engines are the only ones to get close to the Carnot engine, the difference between them lying in the way they achieved the transfer process between isotherms: in case of the first, by releasing and receiving heat and the second, by applying compression and expansion.

3. THE TECHNICAL SOLUTIONS USED BY TRAIAN VUIA FOR ISOTHERMIC COMPRESSION AND EXPANSION

Any specialist who tried to understand the operation and rebuild the Vuia engine today would come up with the following question: *Is the Vuia engine one with an isothermal compression and expansion and if so, which constructive solution was used in obtaining this?*

To identify the constructive solutions that helped Traian Vuia develop the isothermal compression and expansion one should be familiar with the methods that were being used in that period. An elucidating study in this matter is the one conducted by W.C. Unwin [20] and published in a period in which both industrial and domestic activities were relying on compressed air instead of electricity. In this study the addressed thermodynamic processes are explained on a scientific level that has not been matched so far. The most noteworthy process is the isothermation through preheating of the expanded air or precooling of the compressed air.

It would also be of use to identify the procedures that led to the isothermic compression and expansion of similar engines built in that period, or prior to the Vuia engine. In order to identify the mentioned procedure, it is useful to study the GB 3404 patent "*Hot Air Engine*" where John Ericsson explains the isothermal compression, as follows [23]:

«This pump is represented as delivering its water through a jacket, K, which surrounds the upper part of the engine-cylinder, for the purpose of cooling that part of the said cylinder, and so effecting a more rapid cooling of the air on its

transference from the lower to the upper part of the said cylinder. This jacket is not, however, necessary to the successful cooling of the air in the cylinder itself. Being very long, it presents a large radiating surface, which may be further increased by corrugating the external surface of its upper part.»

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and C. Church's study [24], which describes the role of the regenerator to isothermate expansion:

«This "regenerator" was the result of many years of study and careful experiment to determine the most effective means of preventing the loss of heat, for Ericsson had discovered that it was necessary to maintain the air in his working cylinder at a high temperature until the end of the piston's stroke. The cylinder for compressing the air was surrounded by a water-jacket, to keep down the temperature and protect the leather fastenings from the high heat.»

These two clarifications allow us to conclude that the Ericsson motor enabled the maintenance of a constant temperature in the compressor cylinder by being very long and having a high radiating surface. The same was possible for the expander cylinder due to the regenerator that prevents heat loss and maintains a high level in temperature throughout the stroke.

A comparison could be drawn to the Rider compression engine, a Stirling-type engine (without valves) [25], but with Franchot engine mechanical architecture (1840) [26, 27, 28], replacing the double acting piston with a simple action piston. This engine was manufactured in England (1876), at Messrs. Hayward-Tyler and Co. under the license of Rieder-Ericsson, a copy being exhibited at the National Technology Museum, in Bucharest. It is important to refer also to the compression engine, since the mechanical architecture of the Franchot engine is the same as the one of the Vuia engine, with a two-piston dual action, driven by the same crankshaft, and the Rider-Ericsson engine has detailed accompanying documentation [26] in which its construction and ways of functioning are being explained.

From studying the compression engines, it can be concluded that the isothermal expansion and compression was obtained on an engine whose stroke / piston diameter report equals 1.25, the speed equals 100-160 rpm, the compressor cylinder is provided with a cooling water jacket, and the heater and piston of the expander cylinder are designated to improve the convection inside the cylinder.

With reference to descriptions of the patents obtained for the Vuia engine it results that the compression is done without cooling and in one single step, a construction which is explained only in the BE 205.058 patent "*Moteur à air chaud à cycle fermé*" [29] in which Traian Vuia said:

«Cette machine supprime la compression nécessitant un refroidissement; elle permet l'emploi de très hautes pressions et l'utilisation de tous les combustibles, aussi bien solides que liquides ou gazeux. Aucun des organes qui travaillent n'étant soumis à des températures élevées, le graissage est aisé.»

As for how the the isothermate expansion was achieved, Traian Vuia explains this in the FR 395.754 patent "*Moteur à air chaud, à cycle fermé*" (in English: "Hot air motor, with closed cycle") [30] making notice that the engine consists of a generator or a reheater, among its other components. The text is vague and could create many interpretations; it could even lead us to think of a preheating procedure meant to facilitate the isothermal expansion.

By recalling that the double cam was claimed by Traian Vuia as a technical solution, the thought leads to the isotherm method Pomojnicu [29] by *thermal microcycles during a stroke of the piston*, which could be an option for solving isotherm expansion by using a profiled cam.

Despite all these assumptions, some open questions remain: *Was the Vuia engine one with isothermal compression and expansion or not?* A convincing answer gives Traian Vuia himself in letter #14 dated January 26th, 1912 addressed to the Patent Office of the United States, amended by letters #15, dated February 29th, 1912 and # 16, dated April 3rd, 1912 as shown in the application file [32] for Patent US 1,169,308, "*Hot-air engine with closed circuit*". This "*important archival discovery*" proves that: *Traian Vuia successfully developed and tested his hot air and closed-circuit engine and it demonstrates that it is not an invention but a very useful reality.*

Additionally, it is worth taking note of the entire content of the letter, in which Traian Vuia explains the means that allow a constant maintenance of temperature in the expander and compressor cylinders, as in fact, the letter concludes, and I quote:

«The new claim (nr. 7) brings out the fact that the work cylinder is normally at a uniformly high temperature, which Fell's is not, and that means are provided which co act with said cylinder and with certain of the recited apparatus to maintain the pump cylinder at substantially its lowest temperature during its whole filling stroke.»

In conclusion, obtaining a quasi-isothermation for the historical Vuia engine would have been possible by the following:

- an "*induced isothermation*" respectively by a correlation between <*heat exchange surface – piston speed – working gas state*> or
- pre-heating or pre-cooling the work gas in the heater or in the cooler.

Today Ion Pomojnicu [33] and Arpad Torok [34] argue that *induced isothermation* is possible to obtain if an exponential variation of volume compared with piston speed is produced, or after the experience UPPA – Pascal Stouffs [18, 19], concomitant with an optimum <*surface heat exchange – piston speed – state working agent*> applied an additional heating/ cooling of cylinders and piston, especially for high speeds.

As none of these methods have been applied to the historical Vuia engine, the only possible isothermal process in this case, is that of pre-heating/ pre-cooling the working agent in the heater/ cooler, while the ratio stroke/ piston diameter is over 1.25 and a severe decrease in speed below 100 rpm is taking place. This is only a hypothesis that requires virtual or physical testing of the historic Vuia engine.

4. THE THERMAL PROCESS REPRESENTED BY "ISODIABATE". THE VUIA RECUPERATOR.

Despite all these clarifications one other issue still remains open: *Was the heat release and receipt, at the Vuia engine, an represented by "isodiabate", isobaric, or isochoric process, or of a different kind?* In order to answer this, the meaning of the historic term "*isodiabate*" used by Traian Vuia must first be clarified. This clarification, essential for understanding the thermodynamic performance of this engine, should be made in the context of the "*perfect thermodynamic Carnot engine and Vuia recuperator*" in the scientific concept of that time, but also in the present concept.

The process of transfer between isotherms from the Carnot cycle was studied in most scientifically and didactically mode by William Thomson in "*An Account of Carnot's Theory*" [41]. This work, not overlooked until today, must to be studied with great attention by specialists who want to approach to the near-perfect thermodynamic engine.

For this, in the following I will try to clarify this contradictory thermal process, represented by "*isodiabate*", used at Vuia's engine. The historical study of scientifically value, for thermal process within a regenerator, represented through "*isodiabate*", was developed by John Pringle Nichol [35]. An extract of that is presented below:

«<u>26. Thermo-dynamic Engines of maximum Efficiency</u>. Between given limits of temperature, the efficiency of Thermo-dynamic engine is the greatest possible, when the whole reception of heat takes place at the higher limit, and the whole

rejection of the heat at the lower; that is to say, when the engine is an elementary engine; and the theoretical efficiency of such an engine is independent of the nature of fluid employed.

27. Of the Heat – Economizer, or Regenerator

To fulfill strictly the above condition of maximum efficiency between given limits of temperature, the elevation of the temperature of the fluid must be performed wholly by compression, and the depression of its temperature wholly by expansion: operations which are in many cases impracticable, from the great bulk of cylinders which their performance would require. – This difficulty is almost entirely avoided by the following process, for producing alternate elevation and depression of temperature with a small expenditure of heat, invented about the year 1816 by the Rev. Doctor Robert Stirling, and subsequently improved and modified by Mr. James Stirling, Captain Ericsson, and others – The fluid whose temperature is to be lowered is passed through the interstices of an apparatus called an <Economizer> or <Regenerator>, formed by a number of thin plates of metal or other solid conducting substance, or of network of wires, exposing a great surface within small space.

The material of the economizer becomes heated by the cooling of the fluid. When the temperature of the fluid is again to be raised, it is passed through the interstices of the economizer in the contrary direction, and the heat which is had previously given out is in part restored to it. It is impossible to perform this process absolutely without waste of heat; but by giving a sufficient mass and surface to economizer, the waste may be reduced to a small amount. In some experiments by Mr. Siemens on air, the waste of heat at each stroke appears to have been about one twentieth part of the heat alternately abstracted from and restored to the air.

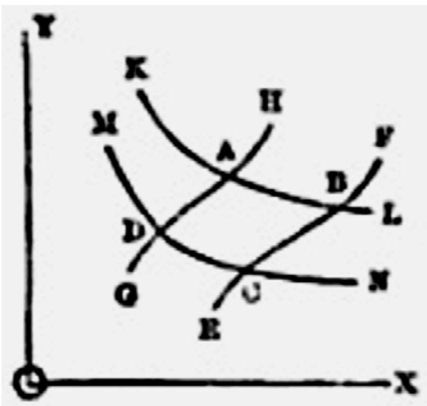

Figure: Isodiabatic Lines

*<u>27A. Isodiabatic Lines.</u> – One condition of the economical working of the economizer is, that the quantity of heat given out by the fluid during any given stage of the lowering of its temperature shall be equal to the quantity received by it during the corresponding stage of the raising of its temperature. This condition is realized in the following manner. – Let **EF** be an arbitrary line representing the mode of variation of the pressure and volume of the fluid during the lowering of its temperature. – Let **GH** be the corresponding line for the raising of temperature of the fluid. – Let **KL, MN**, be any pair of isothermal lines, intersecting in **GH** in **A** and **D**, and **EF** in **B** and **C**, respectively. Let be the Thermo-dynamic functions for these four points.*

$$\phi_A, \phi_B, \phi_C, \phi_D$$

Then if, for every possible pair of isothermal lines,

$$\phi_B - \phi_A = \phi_C - \phi_D$$

*the lines **EF** and **GH** have the required property and are said to be Isoadiabatic with respect to each other.»*

For proper understanding should define the terms used today, which are related to the process represented by"*isodiabate*", invoked by Traian Vuia, as presented in the study "*Adiabatic Process*" [36]:

«In thermodynamics, an adiabatic process or an isocaloric process is a thermodynamic process in which no heat is transferred to or from the working fluid. The term "adiabatic" literally means impassable, coming from the Greek roots: ἀ- ("not"), διὰ- ("through"), and βαῖνειν ("to pass"); this etymology corresponds here to an absence of heat transfer. Conversely, a process that involves heat transfer (addition or loss of heat to the surroundings) is generally called diabatic. Although the terms adiabatic and isocaloric can often be interchanged, adiabatic processes may be considered a subset of isocaloric processes; the remaining complement subset of isocaloric processes being processes where net heat transfer does not diverge regionally such as in an idealized case with mediums of infinite thermal conductivity or non-existent thermal capacity.

(...)

In an adiabatic irreversible process, $dQ=0$ is not equal to TdS ($TdS>0$). $dQ=TdS=0$ holds for reversible processes only. For example, an adiabatic boundary is a boundary that is impermeable to heat transfer and the system is said to be adiabatically (or thermally insulated); an insulated wall approximates an adiabatic boundary. Another example is the adiabatic flame temperature, which is the temperature that would be achieved by a flame in the absence of heat loss to *the surroundings. An adiabatic process that is reversible is also called an isentropic process. Additionally, an adiabatic process that is irreversible and extracts no work is in an isenthalpic process, such as viscous drag, progressing towards a nonnegative change in entropy.*

One opposite extreme – allowing heat transfer with the surroundings, causing the temperature to remain constant – is known as an isothermal process. Since temperature is thermodynamically conjugate to entropy, the isothermal process is conjugate to the adiabatic process for reversible transformations.

A transformation of a thermodynamic system can be considered adiabatic when it is quick enough that no significant heat is transferred between the system and the outside. At the opposite extreme, a transformation of a thermodynamic system can be considered isothermal if it is slow enough so that the system's temperature remains constant by heat exchange with the outside.»

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and in the study "*Isentropic processes in thermodynamic systems*" [37]:

«In thermodynamics, an isentropic process is an idealized thermodynamic process that is adiabatic and in which the work transfers of the system are frictionless; there is no transfer of heat or of matter and the process is reversible. Such an idealized process is useful in engineering as a model of and basis of comparison for real processes.

The word <isentropic> is occasionally, though not customarily, interpreted in another way, reading it as if its meaning were deducible from its etymology. This is contrary to its original and customarily used definition. In this occasional reading, it means a process in which the entropy of the system remains unchanged, for example because work done on the system includes friction internal to the system, and heat is withdrawn from the system, in just the right amount to compensate for the internal friction, so as to leave the entropy unchanged.

For an isentropic process, which by definition is reversible, there is no transfer of energy as heat because the process is adiabatic. In an irreversible process of transfer of energy as work, entropy is produced within the system; consequently, in order to maintain constant entropy within the system, energy must be removed from the system as heat during the process.

For reversible processes, an isentropic transformation is carried out by "thermally insulating" the system from its surroundings. Temperature is the thermodynamic conjugate variable to entropy, thus the conjugate process would be an isothermal process in which the system is thermally "connected" to a constant-temperature heat bath.»

In order to achieve the adiabatic process of heat release and receipt, Traian Vuia used a recuperator. Today these types of heat exchangers are typically found in the refrigeration industry.

Fig. 1 – The Vuia Heat Recuperator. Source: Doucette Industries Inc.

Its construction was best described in the patent US 1,169,308 *"Hot-Air Engine with Closed Circuit"* [15]:

«The exchanger-regenerator can be constituted by two concentric tubes forming a coil or by a plurality of similar elements connected in series, or by a tube containing a nest of smaller tubes. The fluid traverses these tubes in opposite directions. The hot fluid issuing from the driving cylinders ***a*** *in entering the central tube, yields up its heat to the outer tube through which the cold fluid coming from the cylinder* ***b*** *passes. There is therefore a continuous exchange of temperature between the two currents.*

(...)

The machine, which is the object of the present invention, indicates for the first time in what way it is necessary to proceed to secure a cycle not comprising adiabatic transformations and permitting the use of a regenerator. This machine has distinct heating and cooling chambers working with high initial pressures. This process avoids all the difficulties relating to the use of a regenerator. Its volume is no longer an objection. While in the regenerator hitherto it set up a mean and consequently prejudicial temperature, in the present regenerator the process is carried out in such a way that the air becomes heated in three or four stages, which permits a very high temperature to be established in the apparatus. Finally, this regenerator is a heat exchanger, for it possesses two chambers of which the one is traversed by hot air and the other by cold air. The two currents pass in *opposite directions the one to the other and cross each other in the apparatus. The exchange of heat operates thus without throttling or counter-pressure.»*

The conclusions of this short thermodynamic study clarifying the term "*isodiabate*" could be the following:

- Instead of the Sadi Carnot proposed thermal processes for the perfect thermodynamic engine, Robert Stirling proposed a regenerative thermal cycle where the adiabatic compression and expansion of the Carnot engine is replaced with a process of heat release and receipt, made possible with the help of a regenerator;
- The heat release and receipt in the regenerator is achieved isochoric in the case of the regenerative Stirling engine, and isobaric in the case of the Ericsson and Joule-Brayton ones;
- Traian Vuia claims a device that allows the development of a process of heat release and receipt, represented by "*isodiabate*";
- It remains an open question if the process represented by curves "isodiabate" can be considered an adiabatic or isentropic process when talking about real (irreversible) or ideal processes (without irreversibility);
- The isothermal process developed during compression and expansion, is a slow process compared to the corresponding adiabatic process developed in the recuperator, which is a fast one;
- The adiabatic compression and expansion of Pomojnicu's [7] thermal cycle refers to a real cycle, with irreversibility.

Once these terms have been clarified, one can conclude to what extent Traian Vuia and Ion Pomojnicu, that had the same target, the proximity to the Carnot thermal cycle, did so. One thing is certain, both engines developed by them represents an evolution in time compared to engines developed by Stirling, Ericsson and Brayton Joule engines. Perhaps history will remember this contribution and will continue to refer to their engines. The difference between these two ways of thinking lies in the transfer process between isotherms, the Vuia engine being one with heat release and receipt, while the Pomojnicu engine being one with compression and expansion of the working fluid.

5. THE VUIA ENGINE'S MECHANICAL ARCHITECTURE AND KINEMATICS

Being influenced by the engine he developed for his first flying machine, Traian Vuia proposed in his first patents (in French language), as in Figs. 3 and 4, an engine with two pistons driven by the same crankshaft, and only later added the simultaneous construction, in tandem. Both have clearly been influenced by technical details of the Gardner-Serpollet engine that has been modified for his flying machine. The distribution of both engines is controlled at expander, using a twin-cam claimed by patents, and by automatic valves at compressor.

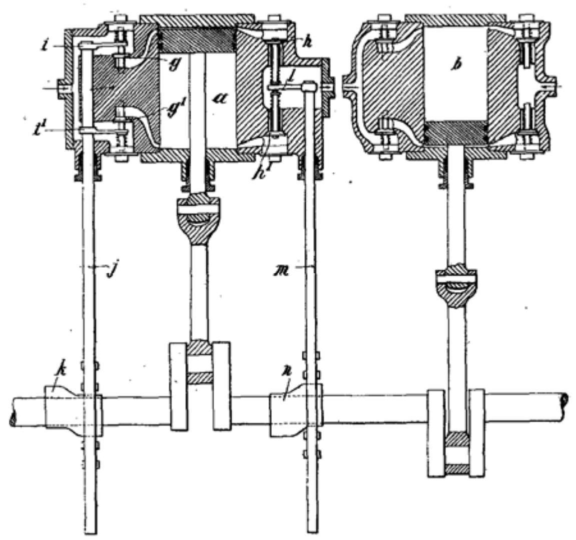

Fig. 2 – The engine with hot air and closed circuit, with two double-acting reciprocating pistons and driven by the same crankshaft. Source: Patent FR 395.754 /1907 “*Moteur à air choud à cycle fermé*” [30].

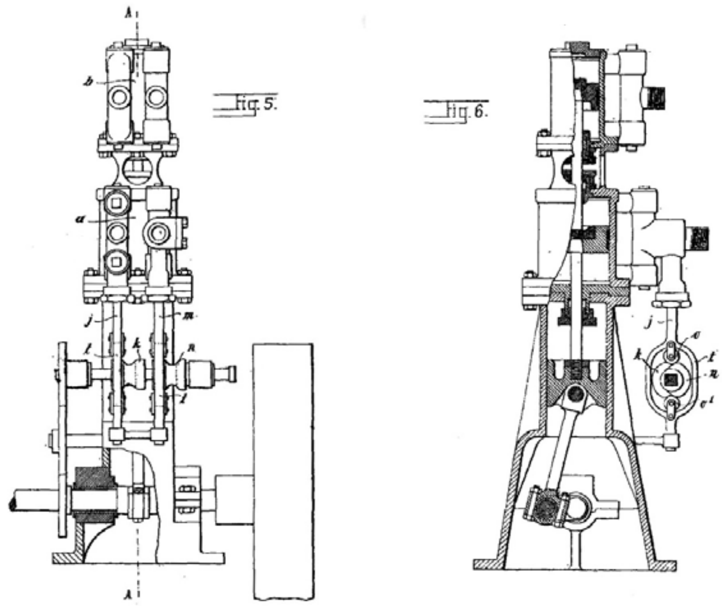

Fig. 3 – The engine with hot air and closed circuit, with double-acting pistons and driven in tandem. Source: Patent GB 27,033 /1909 “*An Improved System of Hot Air Engine with Closed Circuit*” [16].

A discussion about the historic engine as built and tested by Traian Vuia could not take place today, if its execution drawings (Fig. 4) had not been recovered from France.

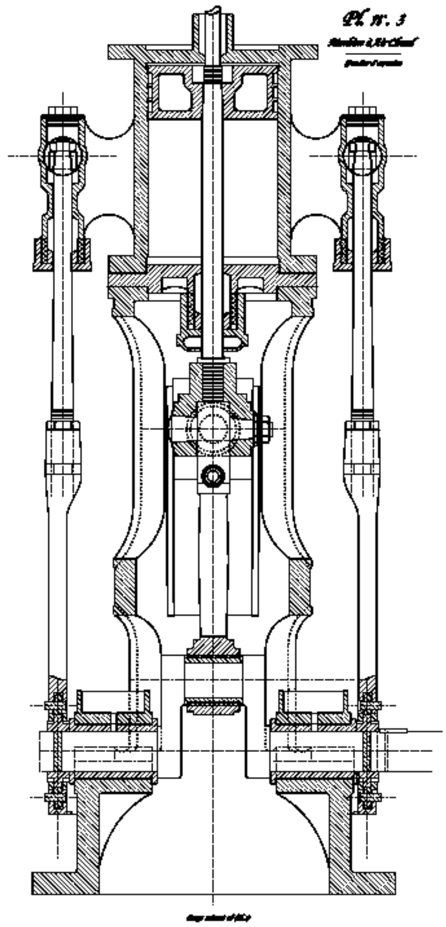

Fig. 4 – The assembly drawing of Vuia historical engine, with hot air and closed circuit, architecture in tandem and double effect (Drawing processed from the original at the Library of Romanian Academy).

Particularly important here are the side notes on these drawing: “*Moteur à Air Chaude*” and “*Grandeur d’Execution*”. They prove that they are was about the hot air engine and that the recovered drawing is realized on a 1:1 scale. These facts made a restoration of the original drawing possible and enabled the direct measurements of the main dimensions. Taking as reference the dimension of 236 mm inside the bedframe, allowed us to determine an overall height of 1200 mm, when leaving out the compressor. On this basis I estimated a total height of 1700 mm, including the compressor cylinder and the intermediate part between it and the expander. Through direct measurement I revealed the expander cylinder bore and the piston stroke. For calculating the compressor bore, I applied empirical sizing Ericsson [21], i.e.:

«Thus in using atmospheric air or other gases permanent the difference of the area of the pistons may be nearly two-to-one (1/2), while in using fluids – such as oils – which dilate but slightly the difference of area should much not exceed one-tenth (1/10).»

Taking into account the thermodynamic parameters as were presented in patents, may present in Table 2, first technical specification for engine Vuia, compared with the specification for engines Ericsson and UPPA – Pascal Stouffs [18].

Table 2
The comparative technical specifications for the historic Vuia engine

Parameter	UM	The engine		
		Ericsson [4] GB 6409 from 1833	Vuia [16] GB 27,033 from 1908	UPPA – Pascal Stouffs [18]
Diameter cylinder compressor	mm	260	120	420/281
Diameter cylinder expander	mm	356	180	452
The stroke compressor and expander	mm	457	190	452
The report stroke / diameter piston compressor		1,28	1,58	1
Shaft speed	rpm	56		500
Compressor cylinder volume		24 cm^3		62/28 dm^3
Expander cylinder volume		45 cm^3		145 dm^3
Airflow	kg/h	189,6		
	kg/s			2226
The pressure at the outlet of the compressor (input expander)	bar	3,65 (3,7 at)	10-15	6
Pressure at the outlet of the expander (input recuperator)	bar	1		1
Heater surface	m^2			2×6,7
Recuperator surface	m^2			2×6,7
Temperature at the outlet of the heater	ºC	525	400-500	800
Temperature at the inlet of the compressor	ºC	20	15-20	20
Temperature of the hot gas at the inlet in recuperator	ºC	276		405
Temperature of the hot gas at the outlet of the recuperator	ºC	153		189
Temperature of the cold gas at the inlet in recuperator	ºC	153		146
Temperature of the cold gas at the outlet of the recuperator	ºC	276		362
Indicated power		8,36 CP		

From this synthetical study it may be noticed that Traian Vuia energizes the working fluid by increasing pressure, as opposed to Pascal Stouffs procedure, who chooses to increase the temperature. Both solutions have their disadvantages, but Vuia's procedure is more advantageous. The low speed and high stroke/piston ratio used for the Ericsson and Vuia engines should also be emphasized, as they facilitate heat exchange between the cylinder and the environment, both being declared with isotherm compression and expansion.

6. THE INTERNATIONAL RECOGNITION OF VUIA'S HOT AIR AND CLOSED-CIRCUIT ENGINE, AS AN ALMOST PERFECT THERMODYNAMIC ONE.

Extensive historical and technical studies allow me to say that I have identified all of Vuia's work and I fully reconstructed his technical and scientific ways of thinking around his hot air and closed-circuit engine. Particularly important for studying Vuia's engine was the recovery of a copy made after the original file application # 470943 of January 6, 1909, found in the National Archives in Kansas City, United States of America. The files were initiated at the request addressed by Traian Vuia to the Patent Office of the United States of America, to grant a patent for the invention of the "*Hot Air Engine with Closed Circuit*". This voluminous record consisting of 125 pages contains the correspondence between Traian Vuia and this office, between January 6th, 1909 and December 30th, 1915, and reveals unpublished information, of great historical, technical and even scientific value.

While patent offices in Europe, such as the Belgium one, released patents "*immediately*", based on a simple declaration supporting a priority and without confronting the claims with ones of opposable patents, in the United States of America this confrontation were done very rigorously. Initially, the US Patent Office considered the following patents as opposable to Traian Vuia's engine:

- Edward Thuemuller, US 232,660/1880, "*Air-Engine*";
- Jambs Woodbury, US 10,081/1853, "*Air-Engine*";
- Jerome Chase, US 417,857/1889, "*Hot-Air-Engines*" and
- Wiliam Meyers, US 668,200/1901, "*Hot Air Engine*".

Traian Vuia showed in letter # 3 dated October 28, 1909 of the same file, that these patents cannot be considered opposable and justified his statement technically. In reply, the United States Patent Office proposed new patents as opposable, in letter # 8 dated March 23, 1910:

- Thomas Fell, US 287,917/1883, "*Process of obtaining motive power*";
- Wiliam Newton, GB20 /1853, "*Atmospheric Engines*",

and in letter # 317 dated April 12th, 1912, extends the list further with the patent:

- John Ericsson, GB 6409/1833, "*Caloric Engine*".

Fig. 5 – The four beams from the application folder US 1,169,308, “Hot Air Engine with Closed Circuit”. Source: National Archives in Kansas City, United States of America.

Letter #14 dated January 26th, 1912 shows that the technical dispute with the Patent Office of the United States reached a level that led Traian Vuia to bringing out the most convincing argument, and I quote:

> *«The present invention has been practically embodied, and experiments thereon have proven very highly satisfaction. It is not therefore a paper invention, but one of real merit and utility.»*

This is a historical breakthrough of particular importance, which demonstrates the engine’s performance through experiments. Finally, after investigating the opposability to the remaining patents, the Patent Office of the United States of America decides and states the following in letter #470 943 – K.O. D2-181 dated October 27th, 1915:

> *«Sir Trajan Vuia: Your APPLICATION for a patent for a IMPROVEMENT in Hot Air Engine with Closed Circuit, filled Jan. 06, 1909, has been examinated and ALLOWED.»*

So finally, after seven (7) years of clarifying correspondence (January 1909 – December 1915), the Vuia thermal cycle and the quasi perfect thermodynamic Vuia engine get recognition from the United States of America, the country in which John Ericsson and George Brayton designed and manufactured their own engines.

Traian Vuia was convinced of his engine's performance which is why he insisted protecting it by several patents. On the basis of the "*Annex at Patent Application*" requested on the December 18th, 1908 and registered at the Patent Office of the USA as # 3108 of January 6th, 1909, I was able to compile a list of patents as presented in Table 3, some not yet known.

Table 3
List of patents obtained for engine Vuia

No.	Patent	Title	Content	Application Date	Publication Date
1	GB 11,181	Improved airplane motor		1904	
2	BE 205 058	Moteur à air chaud à cycle fermé	8 pages description 1 image 2 claims	09 Jan. 1908	31 Jan. 1908
3	FR 395.754	Moteur à air chaud à cycle fermé	3 pages description 4 images 2 claims	28 Oct. 1908	17 Mars 1909
4	BE 211 606	Moteur à air chaud à cycle fermé – Brevet de perfectionnement pour brevet principal BE 205 058	8 pages description 4 images 2 claims	31 Oct. 1908	16 Nov. 1908
5	DE			04 Dec. 1908	
6	AU			07 Dec. 1908	
7	CH 48145	Heisluftmaschinenanlage	2 pages description 1 image 1 claim	09 Dez. 1908	16 Sept. 1910
8	GB 27,033	An improved system of hot air engine with closed circuit	4 pages description 6 images 4 claims	12 Dec. 1908	13 Dec. 1909
9	HU 47071	Zart korfolyammal biro holeggep	4 pages description 6 images 4 claims	18 Dec. 1908	19 Nov. 1909
10	CA 1.18376	Systems of hot air engine with closed circuit	12 pages description 6 images 7 claims	08 Jan. 1909	18 May 1909
11	US 1,169,308	Hot-Air Engine with Closed Circuit	3 pages description 8 images 1 claim	06 Jan. 1909	25 Jan. 1916

7. CONCLUSIONS

Through this presentation I tried to prove that the engine, built and tested by Traian Vuia, internationally recognized through ten patents, is a quasi-perfect thermodynamic engine, superior today to any other similar engines. Therefore, a virtual reconstruction and testing of this historical engine [38] as well as the development of a modernized version of the engine is a scientific obligation. The comprehensive technical study which I published, through these also the book "*Engines Vuia, Ericsson, Joule Brayton, confusion, duplication or novelty*" (in Romanian language) [12].

If the virtual reconstruction and testing of the historical engine don't raise any technical problems, then a modernized version of it must be brought to the attention of specialists with experience in developing external combustion engines, the trend today is to build such motors using components taken from the series production, modified to obtain isothermal compression and expansion. If for reciprocating piston machines were developed and tested several isothermation processes, at volumetric machines type rotary piston, scroll, helicoidal, etc., the option may be Pomojnicu isothermation procedure. For this I released the books "*TRAIAN VUIA – Inventor of the hot air engine with closed circuit* [42]", "*TRAIAN VUIA – Integrity of inventions claimed for hot air engine with closed circuit engine*" [43], "*TRAIAN VUIA – Study for rebuilding the hot air engine with closed-circuit engine*" [44], and "*POMOJNICU-CHRISOGHILOS ENGINE, a contemporary version of a Stirling engine type, isothermated*" [7], all in Romanian language.

I am convinced that after rebuilding and testing the historical engine Vuia, specialists target from major universities, will be not only about applications of engines Stirling, Ericsson or Joule-Brayton, also engines which works after the thermal cycle Vuia-Pomojnicu. Applications with Vuia engine, upgraded, will be the most diverse and most certainly where apply today Stirling engine, i.e., domestic and industrial cogeneration units, propulsion transport means, etc.

Despite the extent of the studies presented in this paper, several questions remained unanswered so this Vuia and Pomojnicu engines should be subject to scientific projects, especially Masters and PhD studies.

Acknowledgements. This article is an *acknowledgment* of engineer Traian Vuia technical initiative, to build an almost perfect thermodynamic, idea developed after a century in an original approach and a high scientific level, by engineer Ion Pomojnicu. He can be considered one of the greatest contemporary Romanian specialists with extensive experience in internal and external combustion engines. He promoted the revolutionary idea of isothermation expansion and compression for an engine with external combustion by multiple fragmentations during a stroke of the piston. Because of these engineers today we can talk about Romanian almost perfect thermodynamic engine, and about two original mechanical architectures for engine Vuia with reciprocating piston and engine Pomojnicu with rotative piston.

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