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Research Article

Characterization of Energy Fluxes in LENR Reactors –Excess Heat, Coefficient of Performance and Conditions for Self-sustained Operation

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Abstract

LENR reactors are considered as units that operate at a temperature above ambient and need an excitation provided by a supply powered by electricity. Different modes of operation are described following the characteristics of the heat and energy balance. LENR reactors may be characterized by different parameters, Coefficient of Performance (COP) or Energy Amplification factor (A). The thermal insulation plays an important role. LENR reactors that require external heating in small units may become self-sustained for large sizes. The production of electricity involves the coupling with a thermal machine. The system is able to export power if the COP and the temperature are high enough.

Keywords: Carnot, COP, Ericsson, Excess heat, Gain, Insulation, ORC, Self-sustained, Stirling, Thermal engine

1. Introduction

In the present paper, we consider LENR systems producing heat in such quantities that it is possible to transform the heat into mechanical energy thanks to a thermodynamic engine, and into electricity via a generator.

The LENR reactor consumes some energy to sustain its operation, but if the generator produces a larger amount of power, an excess of electricity is available for export. The ultimate goal of LENR systems will be to produce electrical energy. The purpose of this paper is to clarify the parameters that are required to make such an operation possible. Figure 1 shows the sketch of an LENR generator incorporating a reactor and a thermal engine.

2. Hypotheses

The LENR reactor generates an energy output. We suppose here that this energy is in the form of heat, delivered at a temperature T_r above the ambient environment one T_a. The LENR reactor requires some energy input to trigger and control the operation. We assume that this energy input is in the form of electricity. The electrical energy consumed as input is called “excitation”. Following the type of reactor, the excitation may include DC electricity for electrolysis, high voltage pulses, electrical resistance heating, etc. [1–6].

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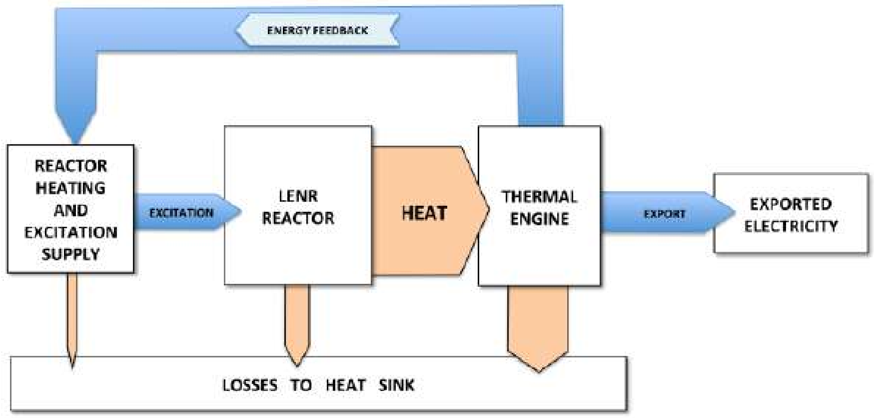

Figure 1. Sketch of an LENR generator incorporating a reactor and a thermal engine.

The reactor is a closed system in thermodynamic terms. This means that no matter enters nor leaves the reactor during operation. For example, if the reactor is an electrolysis cell, the gases are recombined within the reactor assembly.

The reactor is *thermally insulated* in order to control the losses and recover most of the heat for a useful purpose. The thermal insulation is an important feature of the system being considered. If we want to detect excess heat and harvest usable energy, the heat losses must be minimized. Figure 2 shows schematic of a simple LENR reactor.

3. Calibration

The efficiency of the insulation must be first determined via a calibration procedure. For that purpose, the reactor is brought to its working temperature by an auxiliary internal heating source. During the calibration, measures are taken to make sure that no LENR can take place. Figure 3 summarizes the calibration process. The reactor is heated by an electrical input E_1 All that energy goes away as thermal loss via the thermal insulation. Several measures can be repeated for various input power steps. This makes it possible to draw the relationship between the reactor temperature T_r and the heat loss, equal to the input H_1. The relationship is valid for a given ambient temperature T_a. This one must be kept constant during the whole test campaign, or the measures have to be repeated for the different values of T_a that may be encountered.

The measure of each point of the curve presupposes that the thermal equilibrium is reached after a change of the input power or the outside temperature. Otherwise the transient heat flows introduce errors. Calibration may therefore be a time consuming task, especially for large reactors.

4. Heated Reactor – MODE 1 of Operation

In some cases, the reactor works at a high temperature, and thermal losses must be compensated. If the LENR energy generation is not sufficient, additional heating must be provided to maintain the operation temperature (Fig. 4).

The corresponding energy flowchart is shown in Fig. 5. This first example gives the opportunity to introduce some definitions. The LENR reactor is supplied by two electrical inputs:

- E_e: Excitation (depending on the reactor type),

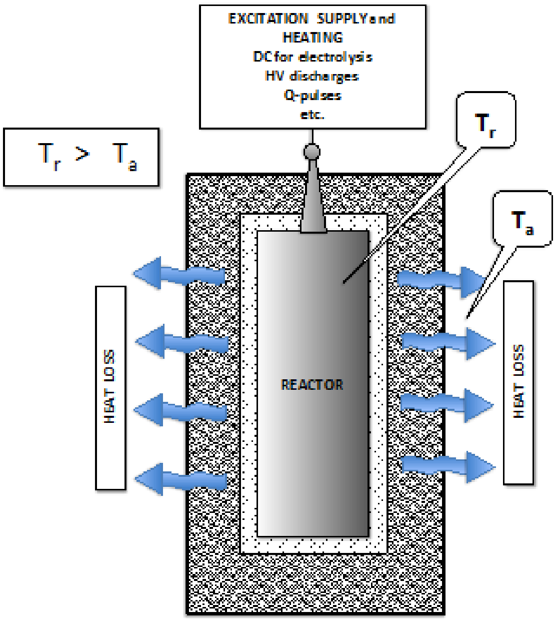

Figure 2. Schematic of a simple LENR reactor. (a) Here, the heat flux is merely lost into the environment. No use can be made of the heat in this configuration. (b) Note however the presence of the thermal insulation, a compulsory feature of the system if we want to detect that $T_\mathrm{r} > T_\mathrm{a}$.

- E_h: additional heating to maintain the desired reactor temperature T_r.

These two quantities correspond to the total energy injected into the reactor

$$E_1 = E_\mathrm{e} + E_\mathrm{h}. \tag{1}$$

The electrical energy entering the reactor does not come directly from the mains, but is processed by a dedicated power supply. For instance, in the case of an electrolytic reactor, the power supply transforms the line power into an appropriate direct current. Similarly, the heating current intensity is controlled. The power supply is not perfect, so

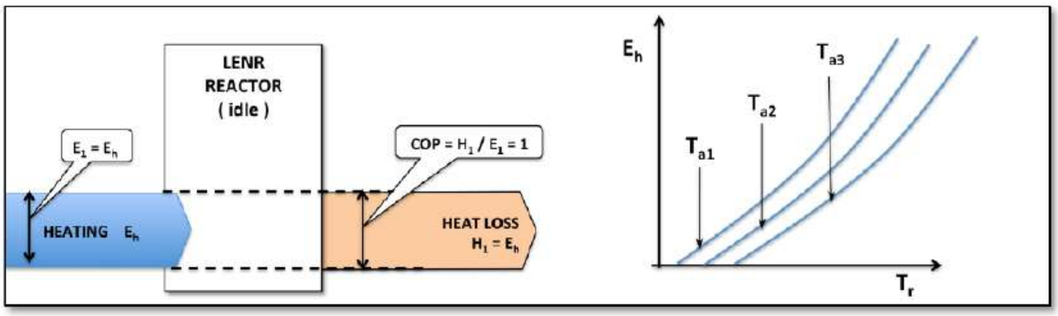

Figure 3. Calibration of the relationship temperature–heat loss ($T_\mathrm{r} - H_1$) – Different curves may be required if the ambient temperature T_a is likely to vary.

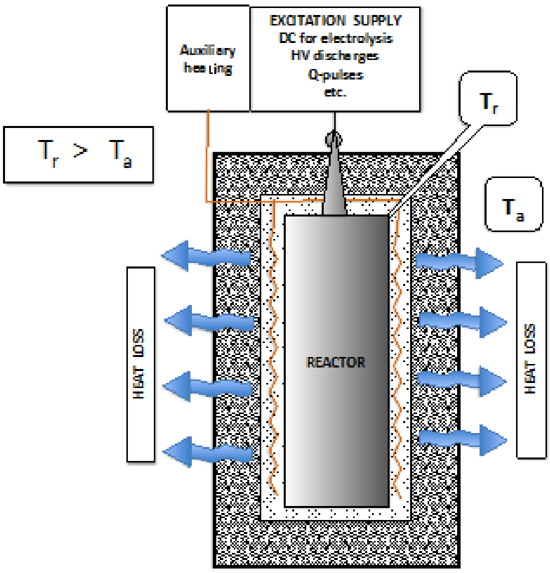

Figure 4. MODE 1. (a) The heat flux is lost into the environment. No use can be made of the heat in this configuration (Compare with Fig. 9). (b) The LENR heat and the additional electrical heating compensate the heat loss.

that some losses must be taken into account. The power consumed from the mains is

$$E_0 = (1/\alpha)E_1. \tag{2}$$

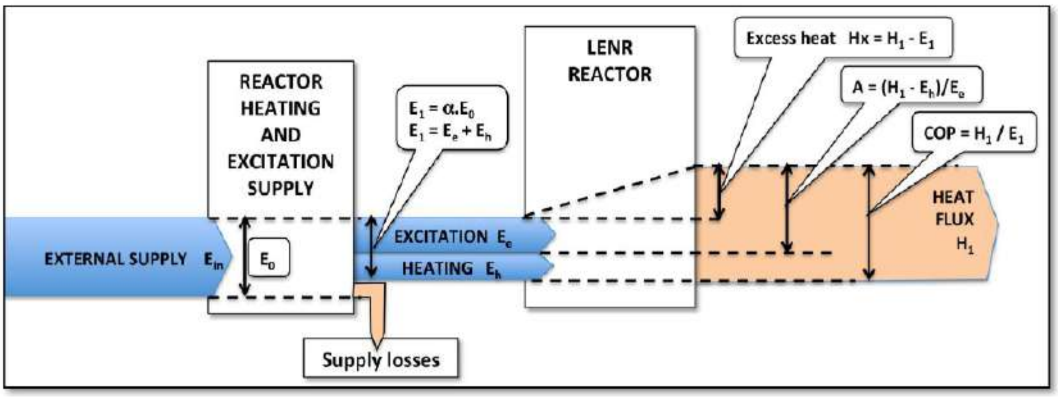

Figure 5. Energy flowchart for a heated LENR reactor (MODE 1) – Electrical energies are shown in blue, heat in orange.

The LENR reactor generates a heat flux H_1. Because some reactions give off energy in the reactor, H_1 is larger than E_1. We can define excess heat and coefficient of performance by the following formulas:

$$\text{Excess heat:} \quad H_\mathrm{x} = H_1 - E_1, \tag{3}$$

$$\text{Coefficient of performance (COP):} \quad \mathrm{COP} = H_1/E_1. \tag{4}$$

The inputs E_e and E_h are not equivalent. The heating E_h depends on the quality of the thermal insulation and is not directly related to LENR phenomena. Conversely, E_e is the driving force that triggers LENR heat. It is therefore interesting to evaluate the reactor efficiency via a number independent of E_h. We define the energy amplification factor A as follows:

$$\text{Amplification factor:} \quad A = (H_1 - E_\mathrm{h})/E_\mathrm{e}. \tag{5}$$

Reactors of the same technology built with different thermal insulations or simply differing by their size will have different COP values, but should be characterized by similar A values. The energy amplification factor is therefore more representative than the coefficient of performance to estimate the efficiency of a LENR reactor, at least if auxiliary heating is required.

5. Cooled Reactor – MODE 2 of Operation

If the excess power of the reactor is sufficient, the auxiliary heating is no longer required to maintain the internal temperature. We have

$$E_\mathrm{h} = 0, \tag{6}$$

$$E_1 = E_\mathrm{e}. \tag{7}$$

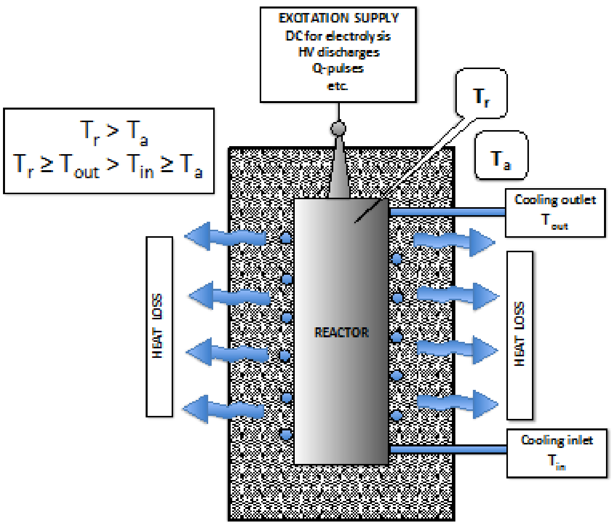

Figure 6. MODE 2 (a) While in operation, the LENR heat is sufficient to compensate the heat loss. (b) The additional heat is evacuated by a cooling system.

On the contrary, the heat produced must be evacuated by a cooling system in order to avoid an overheating. This operation type is called MODE 2 (Fig. 6).

The heat is removed by the circulation of a fluid through a heat exchanger arranged in direct contact with the reactive unit, underneath the thermal insulation blanket. The cooling power for a given T_{r} can be modulated via the fluid flow rate and inlet temperature.

Figure 7 shows the energy flowchart for a cooled reactor. In this MODE 2, we have:

$$\text{Excess heat:} \quad H_{\mathrm{x}} = H_1 + H_2 - E_{\mathrm{e}}. \tag{8}$$

$$\text{Amplification factor:} \quad A = \text{ COP} = (H_1 + H_2)/E_{\mathrm{e}}. \tag{9}$$

The energy input to the reactor is limited to the excitation E_{e}. Heat output H_2 goes to the cooling system. The heat leaves the reactor unit at a temperature equal or less than T_{r}. It can be transferred to a user at a temperature T_{u} inferior to T_{r}, but ideally higher than T_{a}. Heat H_1 is lost through the thermal insulation. In Fig. 7, this heat is dissipated in the surroundings at the temperature T_{a} . However, another configuration is possible, as explained in Section 7.

In the particular case of a reactor that does not need an excitation power supply, we have$E_{\mathrm{e}} = 0$. The MODE 2 is then equivalent to a self-heated or self-sustained operation. The amplification factor and the COP are infinite and do not represent relevant parameters.

6. Importance of the Thermal Insulation

Let us consider the heat balance of a reactor. The LENR excess energy H_{x} is essentially proportional to the mass of reacting matter, hence to the internal volume V of the reactor, as well as the excitation energy input E_{e}.

The heat loss H_1 depends on the external surface S of the enclosure, but also on the quality of the insulation material and its thickness t. If L is the characteristic dimension of the reactor, V is proportional to L^3 and S to L^2. We write

$$E_{\mathrm{e}} + H_{\mathrm{x}} = AL^3, \tag{10}$$

$$H_1 = (B/t)L^2, \tag{11}$$

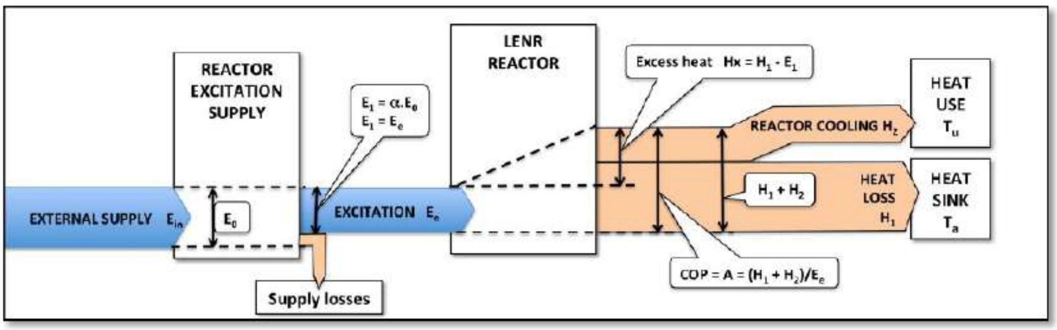

Figure 7. Energy flowchart for a cooled reactor (MODE 2).

where

- A is a factor characteristic of the reactor technology.
- B is a factor characteristic of the thermal insulation design, such as the material thermal conductivity. We suppose in the above equation that the heat loss is governed by the heat conduction through the insulation lagging and that the external surface temperature is low enough to neglect the influence of the cooling by radiation

$$\frac{H_1}{E_e + H_x} = \frac{B/t}{AL}. \tag{12}$$

We see that the ratio of the heat loss to the internal heat flux decreases as the dimension L increases. In addition, when the dimension of the reactor is enlarged, it is frequently easy to increase the insulation thickness t to the same proportion. Equation (12) becomes

$$\frac{H_1}{E_e + H_x} = \frac{B/t}{AL} = \frac{B'}{AL^2}. \tag{13}$$

The ratio is now inversely proportional to the square of the size. Figure 8 compares two situations.

7. Active Cooling

An active cooling configuration is characterized by a thermal insulation that is continuously swept by a flow of gas going inward [7]. The gas flow rate is carefully selected in order to maintain the outer surface just at ambient temperature. The heat removed by this gas flow is then equal to the heat loss of the insulation. If the gas flow rate is lower than this optimum one, the outer surface is warmer than the ambient temperature, and heat is lost across the hot surface.

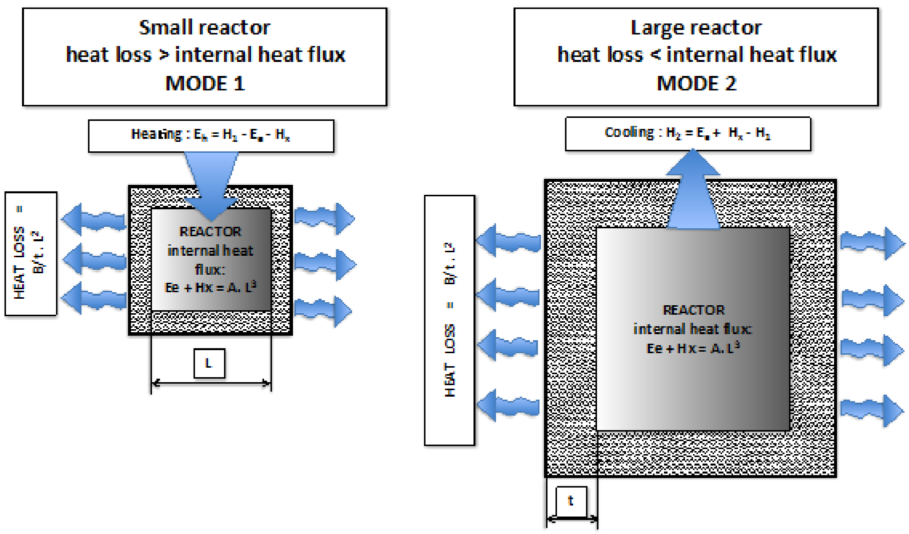

Figure 8. Influence of the reactor size – A larger unit may accommodate a thicker insulation – A given reactor technology operated in MODE 1 as a small unit may become a MODE 2 reactor in a larger size.

If the gas flow rate is too high, too much heat is subtracted from the reactor by the active cooling, so that less heat is available for the main cooling system.

The active cooling does not eliminate the heat loss, but the loss is now in the form of sensible heat that may have a usage. However, a clear distinction should be made between the reactor cooling itself, and the active cooling of the insulation:

- The energy is transferred to the reactor cooling circuit at the high temperature $T_{\rm out}$. It can for example provide the latent heat required to vaporize water at that temperature if the reactor is designed as a boiler.
- The energy recovered by the active cooling is sensible heat. It could not vaporize a liquid at $T_{\rm u}$, but could for instance preheat the flow of liquid water going to a boiler

Active cooling may be applied to all systems, including MODE 1. The reader is invited to compare Figs. 4 and 9 and imagine how to improve the design illustrated in Fig. 4.

8. MODE 2 with Feedback

A heat flux available at a temperature higher than $T_{\rm a}$ can be processed by a thermal engine to produce mechanical energy, easily transformed into electrical energy by a generator [8]. Theoretically, the thermal machine may also be an array of thermocouples able to elaborate electricity directly from the heat.

The electrical production $E_{\rm out}$ can be reintroduced at the supply input, so that the excitation power required from the external supply is reduced to $E_0 - E_2$ (Fig. 10).

9. MODE 3 of Operation

If the quantity of electricity produced by the generator exceeds the need of the power supply, there is a surplus of electricity that can be exported. This is the definition of autonomous or self-sustained operation, called here MODE 3 (Fig. 11).

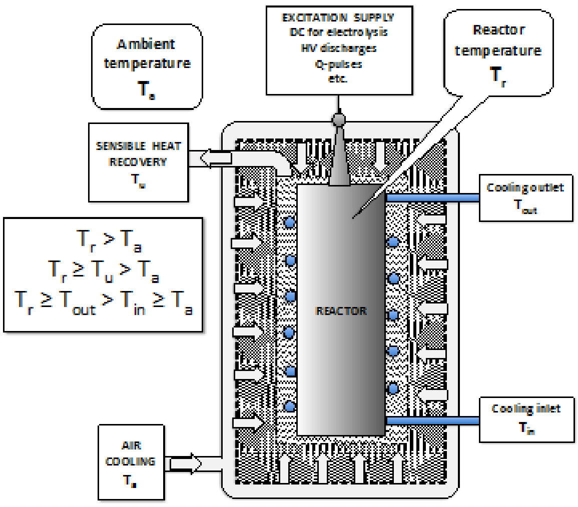

Figure 9. Active cooling. The thermal insulation is fitted with a laminar flow of gas that percolates inward. The gas leaves the enclosure at a temperature $T_{\rm u}$ that is higher than $T_{\rm a}$ and may be as high as $T_{\rm r}$ The heat loss is recovered at a temperature above $T_{\rm a}$ and may have an usage.

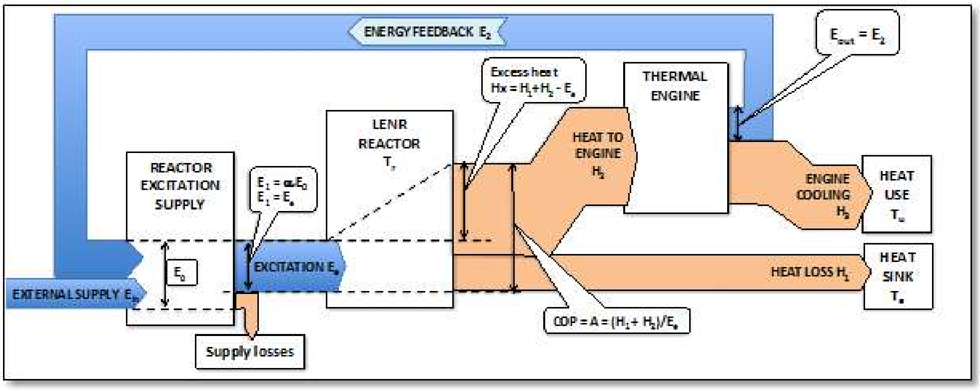

Figure 10. Mode 2 with feedback – The excess heat is transformed into electricity by a thermal engine coupled to a generator. This electrical energy E_{out} is fed back (E_2) to the supply, reducing the external energy consumption.

It is admitted in MODE 3 that an external power supply may still be temporarily required for the starting phase and for the safety of the control system. Following the design of the thermal engine and its performance, the heat output H_3 of the thermal engine may be recovered at an intermediate temperature for ancillary use (cogeneration). Similarly, active cooling may make it possible to find a use for the heat loss H_1. This is shown in Fig. 12.

Let us consider the complete arrangement: Excitation supply – Reactor – Thermal engine. We can define the energy gain Z:

$$\text{Energy Gain :} \quad Z = E_{\mathrm{out}}/E_0 - 1, \tag{14}$$

where Z represents the gain of the system measured in electrical energy.

- If $Z = -1$, the system consumes electricity for the excitation supply and does not produce power. This is the case in MODE 1 and in MODE 2 if no thermal engine is incorporated.

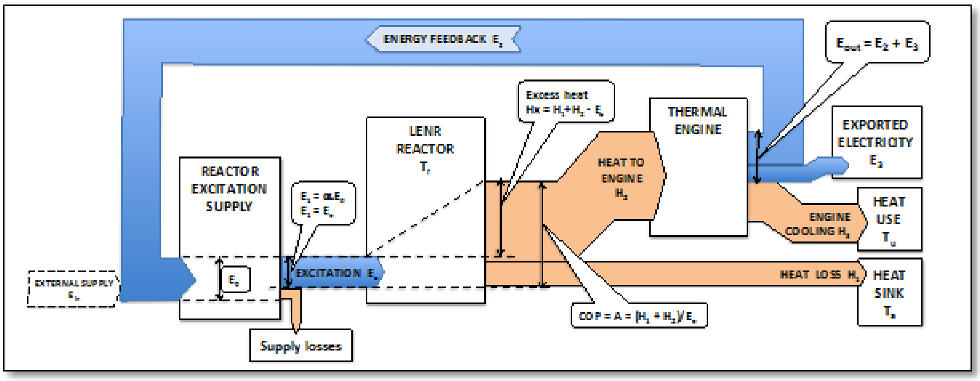

Figure 11. MODE 3 of autonomous operation – The electricity production E_{out} exceeds the consumption of the reactor excitation supply E – The surplus E_3 is exported.

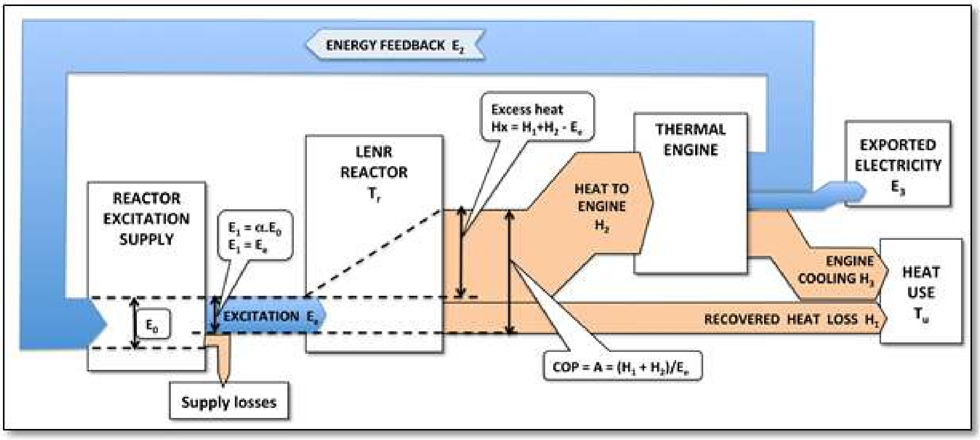

Figure 12. MODE 3 with recovery of the engine thermal output and active cooling.

- Z between $-\%1$ and 0 corresponds to Mode 2 with feedback,
- $Z > 0$ describes an autonomous system.

10. Conditions of Autonomous Operation

Different types of thermal engines are known, and it is not the purpose of this paper to describe them in detail. The thermodynamics teaches that these engines must take heat ($H_{\rm in}$) from a source at a high temperature ($T_{\rm hot}$) and reject a fraction at the heat sink at a lower temperature ($T_{\rm cold}$) [9]. They are characterized by their efficiency:

$$\eta = E_{\rm out}/H_{\rm in}. \tag{15}$$

The efficiency is limited by the Carnot formula

$$\eta_{\rm c} = 1 - T_{\rm cold}/T_{\rm hot}. \tag{16}$$

The engines are not perfect, so that the effective efficiency is lower than the theoretical one

$$\eta = \eta_{\rm c}\eta_{\rm m}, \tag{17}$$

where $\eta_{\rm m}$ is the machine efficiency. The machine efficiency includes all losses, e.g. the energy lost during the transformation of the mechanical energy into electricity, or the energy required to drive ancillary components like pumps, fans, control, etc. Figure 13 shows the efficiencies attained by different types of thermal engines.

These equations can be utilized to determine the COP required in order to obtain a given Z value. We write

$$E_1 = \alpha E_0, \tag{18}$$

$$\lambda = \frac{T_{\rm r}}{T_{\rm a}}. \tag{19}$$

The heat loss is written as a ratio of E via the formula

$$H_1 = f\,(\lambda - 1)\,E_0. \tag{20}$$

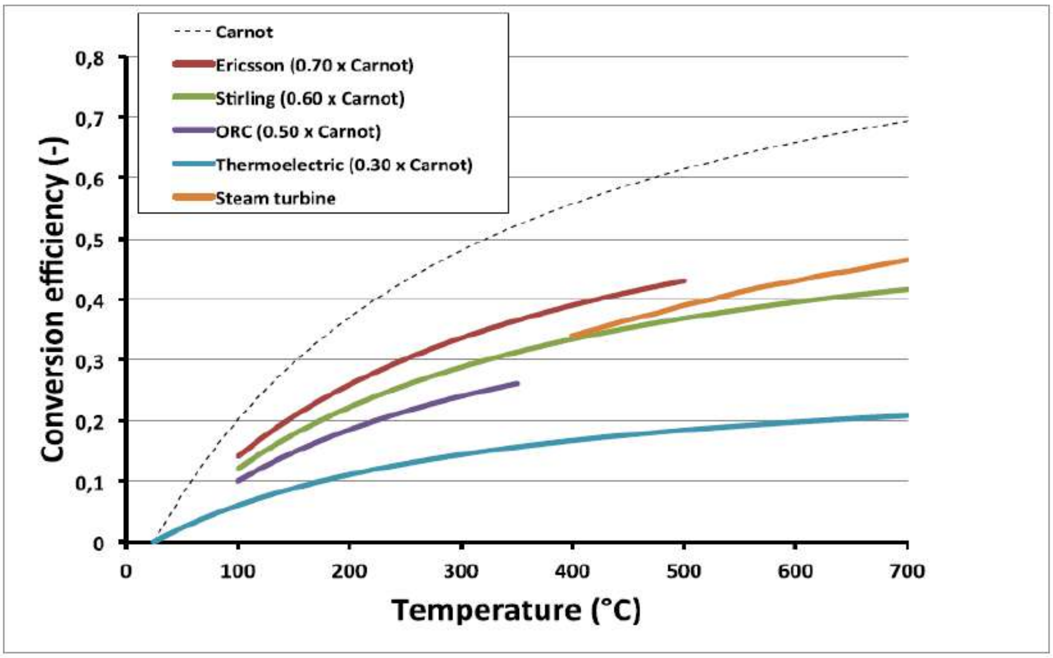

Figure 13. Relationship between the temperature of the heat source ($T_{\rm hot}$) and the typical efficiency of various thermal engines – $T_{\rm cold} = 25°$C.

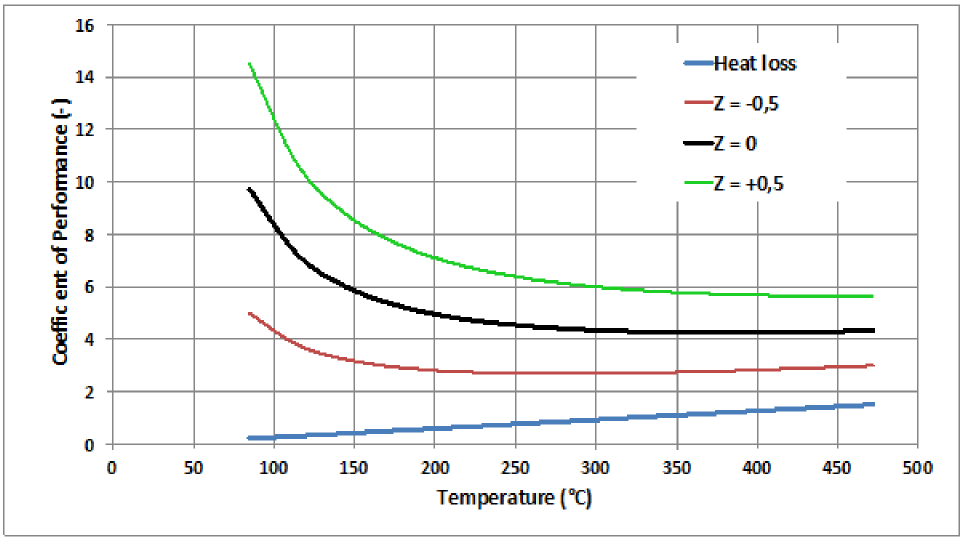

Figure 14. Relationship between the temperature and the COP for different Z values – $\eta_{\rm m} = 0.7 - f = 1 - T_{\rm cold} = 25°$C.

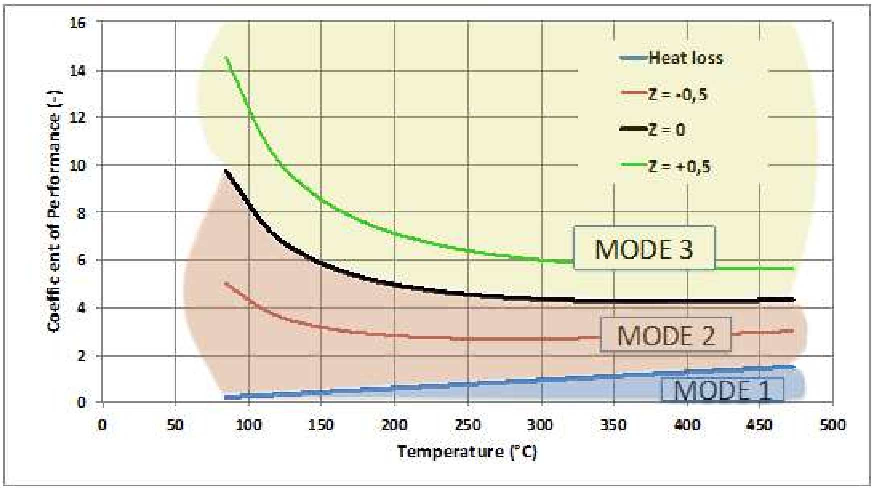

Figure 15. Operation mode domains as a function of the temperature and the COP – $\eta_{\mathrm{m}} = 0.7 - f = 1 - T_{\mathrm{cold}} = 25°\mathrm{C}$.

The efficiency is

$$\eta = \eta_{\mathrm{m}}(\lambda - 1)/\lambda. \tag{21}$$

The energy balance gives

$$E_{\mathrm{out}} = E_2 + E_3 = (1 + Z)E_0 = \eta H_2, \tag{22}$$

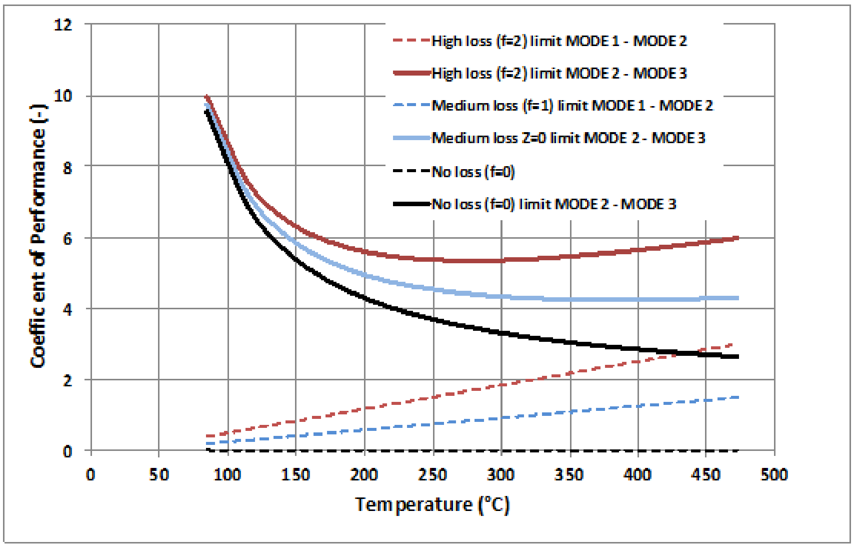

Figure 16. Limits of the different domains for several heat loss factors – $\eta_{\mathrm{m}} = 0.7 – T_{\mathrm{cold}} = 25°\mathrm{C}$.

$$H_2 = (1 + Z)E_0/\eta, \tag{23}$$

$$\text{COP}\,\alpha\,E_0 = H_1 + H_2, \tag{24}$$

$$\text{COP}\,\alpha\,E_0 = f(\lambda-1)E_0 + (1 + Z)E_0/\eta. \tag{25}$$

This yields

$$\text{COP} = \frac{f(\lambda - 1)}{\alpha} + \frac{(1 + Z)\,\lambda}{\alpha\eta_{\text{m}}(\lambda - 1)}. \tag{26}$$

Equation (26) allows the calculation of the COP required for a given heat loss factor and a desired COP. Figure 14 presents an example of results.

The different operation modes are delineated in Fig. 15. The limits between the domains depend on the heat loss factor, as shown in Fig. 16. The COP required for an autonomous operation is reduced if the heat losses are low. It also decreases when the temperature increases, because of the better Carnot efficiency. Figure 16 shows that autonomous mode is difficult to attain for reactors operated at a temperature below 150°C.

11. Conclusions

LENR reactors may be characterized by different parameters. Different modes of operation are described. The COP is not the best indicator for a reactor that requires external heating. The energy amplification factor should be preferred. The thermal insulation plays an important role. LENR reactors that require external heating in small units may become self-sustained for large sizes.

The production of electricity involves the coupling with a thermal machine. The system is able to export power if the COP and the temperature are high enough.

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