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Research Article

Basic Design Considerations for Industrial LENR Reactors

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Abstract

LENR reactors able to deliver heat at a high temperature can be coupled with heat engines to generate electric power. The conditions of temperature and COP to achieve self-sustaining operation are given. According to the literature, the heat generation rate of some LENR processes increases rapidly with the temperature. This phenomenon dictates the cooling criteria to maintain a stable reactor operation. Power control can be obtained through appropriate temperature regulation. Several types of heat engines can be coupled to LENR reactors with appropriate power control. Heat losses must be minimized with sufficient thermal insulation. The insulation enclosure is also useful to recover the leaks of light gas, if any are present in the system.

Keywords: Gas leakage, Heat engines, Power control, Runaway, Self-sustaining, Stability, Thermal insulation

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1. Introduction

Even if it is presently difficult to predict a precise timeframe, it can now be reasonably predicted that LENR reactors will one day produce a sizeable source of power [1]. We focus in this paper on the particular class of LENR systems that produce excess heat at a temperature level sufficient to envisage the conversion of the heat into mechanical and electrical energy.

Future progress in the field will form the basis of the technology applied for industrialization. Although it is not yet possible to describe the precise technology that will be utilized, some features that must be integrated in future reactors can already be listed:

- Unless the reactor directly transforms the LENR phenomena into electricity, the reactors will produce heat that will be converted into power via conventional heat engines.
- Because heat engines can only work with heat sources at a temperature above ambient, LENR reactors will preferably operate at high temperature levels.
- LENR reactors require some form of excitation (in general in an electrical form), at least for the start-up phase. It is assumed here that the generation of LENR energy can be controlled to some extent via the regulation of the excitation input.
- It has now been reported by several authors that the energy generation increases with the temperature. The design of the reactor must take this positive feedback into account.

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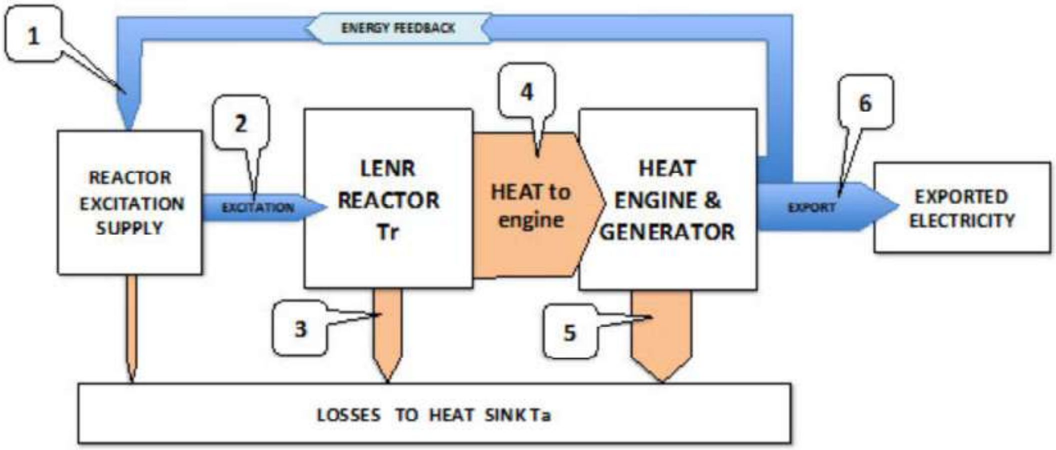

Figure 1. Schematic diagram of an LENR generator including a reactor coupled with a heat engine. Electrical energies (power) are shown in blue, heat fluxes in orange. The sketch shows the following inputs/outputs. 1: Power input to the excitation supply, E_0. 2: Excitation input to the reactor, $E_1 = \alpha E_0\,(\alpha < 1)$. 3: Reactor heat loss: H_1. 4: Heat input to the engine at temperature T_r: H_2. 5: Heat rejected by the engine at temperature T_a, H_3. 6: Electricity exported, E_2. Note that the engine produces the electrical power $E_\mathrm{out} = E + E_2$

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This paper is a discussion of the above points.

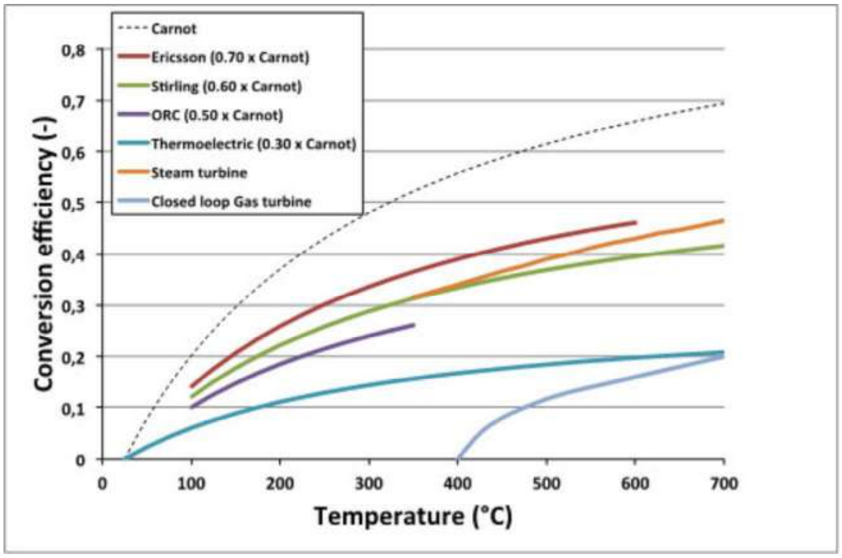

Figure 2. Relationship between the temperature of the heat source (T_hot) and the typical efficiency of various thermal engines, $T_\mathrm{cold} = 25°\mathrm{C}$. Compilation of various data by the author.

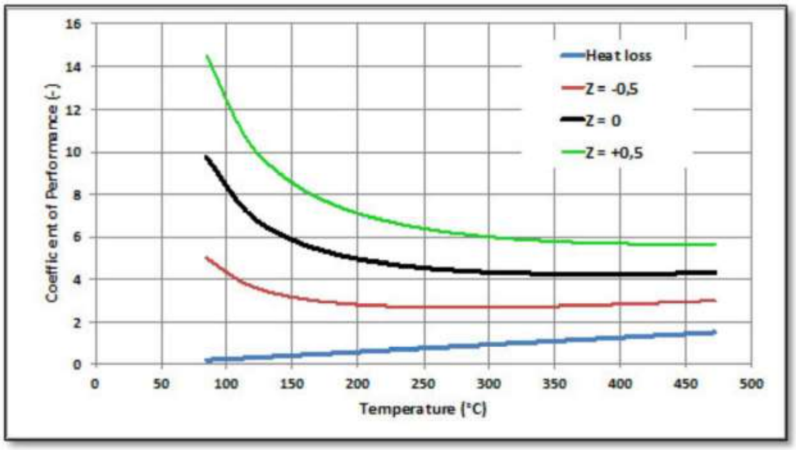

Figure 3. Relationship between the temperature and the COP for different Z values, $\eta_m = 0.7$, $f = 1$, $T_{\text{cold}} = 25°\text{C}$.

2. Self-sustaining Operation

An LENR reactor consumes some energy to sustain its 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-sustaining operation. The parameters required to make such an operation possible are presented in [2] and reproduced here.

Different types of heat engines have been developed [3]. The thermodynamics teaches that such engines must take heat (H_{in}) from a source at a high temperature (T_{hot}) and reject a fraction to a heat sink at a lower temperature (T_{cold}) [4]. They are characterized by their efficiency:

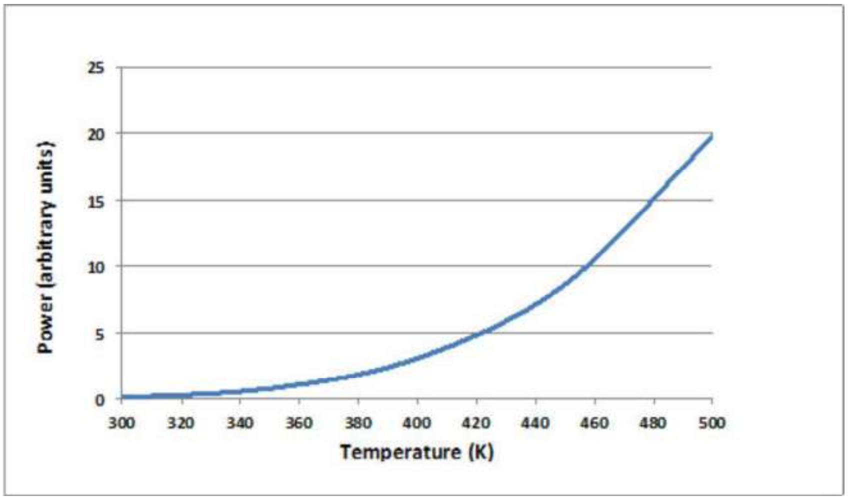

Figure 4. Plot of Eq. (16) between 300 and 500 K. The power is given in arbitrary units.

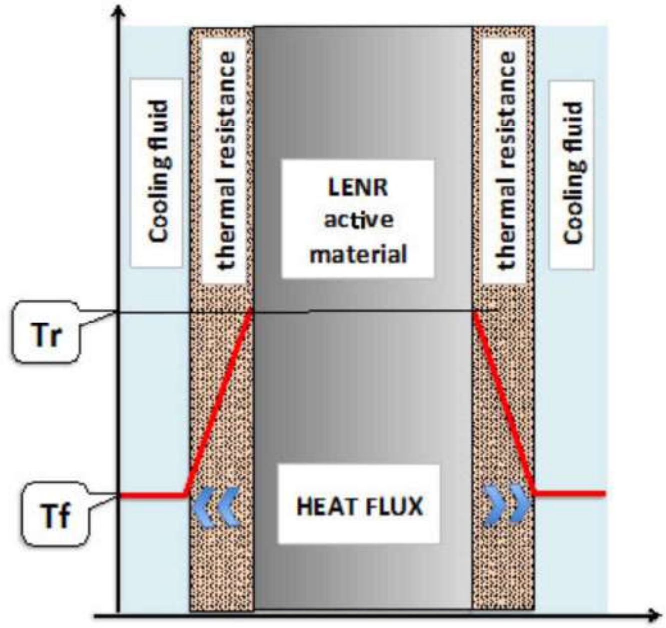

Figure 5. Schematic temperature profile of an LENR reactor separated from the cooling medium by a heat resistance layer.

$$\eta = E_{\text{out}}/H_{\text{in}}. \tag{1}$$

The efficiency is limited by the Carnot formula:

$$\eta_{\text{c}} = 1 - T_{\text{cold}}/T_{\text{hot}}. \tag{2}$$

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

$$\eta = \eta_{\text{c}}\,\eta_{\text{m}}, \tag{3}$$

where η_{m} is the relative 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 system, etc. Figure 2 shows the typical efficiencies attained by different types of thermal engines.

These equations can be utilized to determine the coefficient of performance (COP) required from the LENR reactor to obtain a self-sustained operation. The nomenclature of the energy fluxes is listed in Fig. 1. We write:

$$E_1 = \alpha E_0, \tag{4}$$

$$\lambda = T_{\text{r}}/T_{\text{a}}. \tag{5}$$

The heat loss H_1 is written as a ratio of E using a dimensionless heat loss factor f:

$$H_1 = f\,(\lambda - 1)\,E_0. \tag{6}$$

The efficiency is

$$\eta = \eta_{\mathrm{m}}(\lambda - 1)/\lambda. \tag{7}$$

The electrical power produced by the engine is

$$E_{\mathrm{out}} = E_0 + E_2 = \eta H_2. \tag{8}$$

We introduce the energy gain Z defined by

$$Z = \frac{E_{\mathrm{out}}}{E_0} - 1 = \frac{E_2}{E_0}. \tag{9}$$

A self-sustained operation is characterized by $Z > 0$

$$E_{\mathrm{out}} = E_0 + E_2 = (1 + Z)E_0 = \eta H_2, \tag{10}$$

$$H_2 = (1 + Z)E_0/\eta, \tag{11}$$

$$\mathrm{COP}\,\alpha E_0 = H_1 + H_2, \tag{12}$$

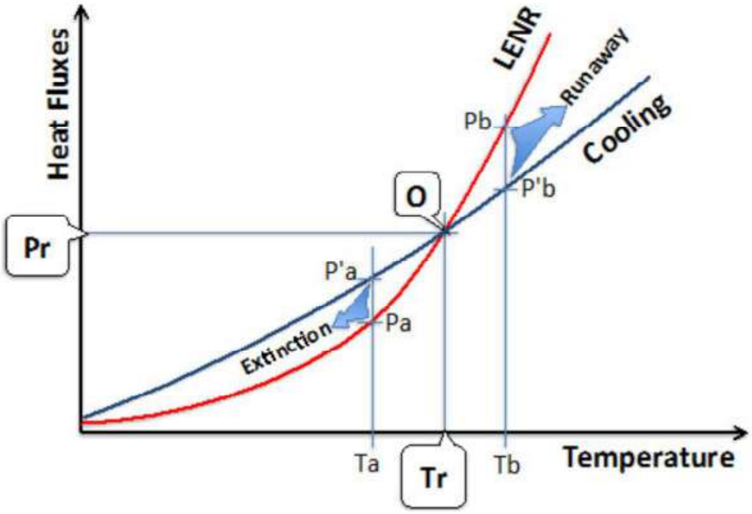

Figure 6. Cooling of an LENR reactor across a heat resistance. Any deviation of the temperature develops an instability.

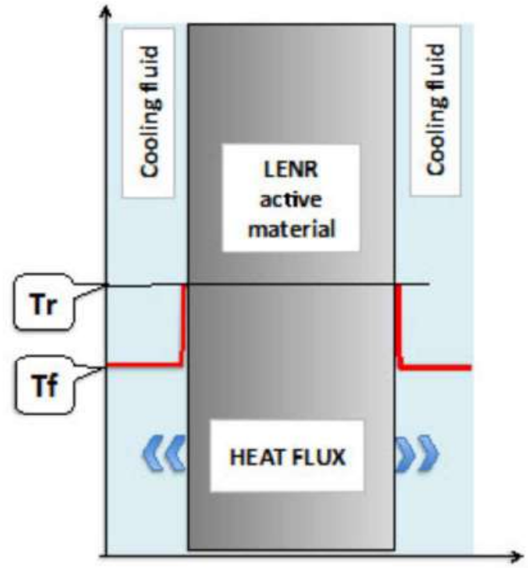

Figure 7. Cooling of an LENR reactor by a convective fluid flow. The temperature profile exhibits a pinch $T_\mathrm{r} - T_\mathrm{f}$ on the surface.

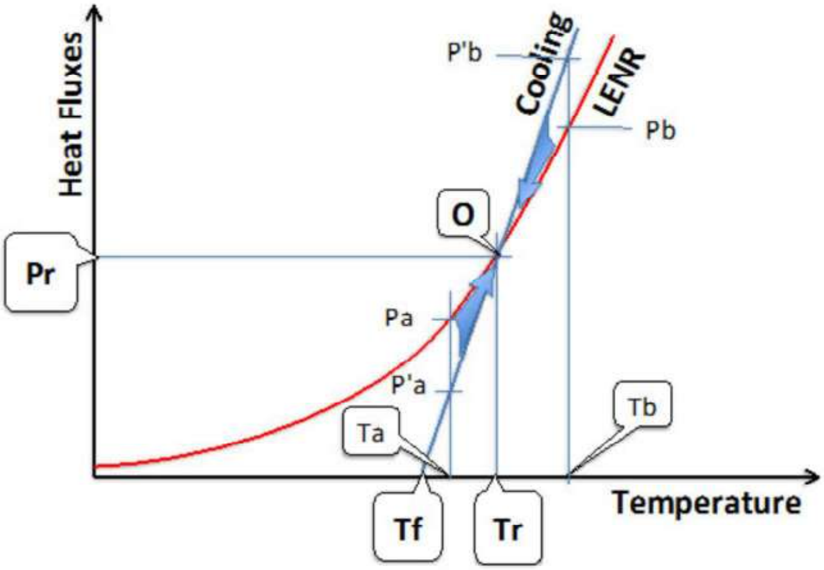

Figure 8. Cooling of an LENR reactor by a convective fluid flow. Any deviation of temperature is compensated by the system, the operation is stable.

$$\mathrm{COP}\,\alpha E_0 = f(\lambda - 1)E_0 + (1 + Z)E_0/\eta. \tag{13}$$

This yields

$$\mathrm{COP} = \frac{f(\lambda - 1)}{\alpha} + \frac{(1 + Z)\,\lambda}{\alpha\eta_{\mathrm{m}}(\lambda - 1)}. \tag{14}$$

Equation (14) allows the calculation of the COP required for a given heat loss factor and a desired Z value. Figure 3 presents an example of results for an arbitrary set of parameters.

Figure 3 shows that the reactor temperature is a very important parameter to obtain self-sustaining operation. It also shows that the heat loss through the insulation is obviously a detrimental factor that must be controlled as much as possible.

3. Reactor Stability

3.1. Influence of the temperature

Several authors report that the LENR power measured in the experiments increases with the temperature [5–8].

Arrhenius' theory teaches that the rate of a process, for instance heat-producing reactions, is a function of an activation energy E and the fuel temperature T [9].

$$W = A\mathrm{e}^{-E/kT}, \tag{15}$$

where W is the heat-production power, A, the pre-exponential factor, E, the activation energy, k, the Boltzmann's constant, and T the absolute temperature of the reactive medium.

If an experiment performed at different temperatures T_1 and T_2 yields the heat power levels W_1 and W_2, the above equation makes it possible to determine the activation energy:

$$\log(W_1) = \log(A) - \frac{E}{kT_1}, \tag{16}$$

$$\log(W_2) = \log(A) - \frac{E}{kT_2}, \tag{17}$$

$$\log(W_1/W_2) = \frac{E}{k}\left(\frac{1}{T_2} - \frac{1}{T_1}\right), \tag{18}$$

$$E = k\log(W_1/W_2)\,\frac{T_1T_2}{T_1 - T_2}. \tag{19}$$

In a recent paper [8], Storms reports a heat power curve well approximated by the equation:

$$\log W = 4.54 - 1621/T. \tag{20}$$

The corresponding activation energy is 1.8 kJ/mol. This value is close to the activation energy for deuterium diffusion in the lattice (1.9 kJ/mol). According to Storms, it is an indication that the role of the temperature is related to its influence on the hydrogen diffusion coefficient.

Equation (20) is equivalent to

$$W = 34\,600\,\mathrm{e}^{-3732/T}. \tag{21}$$

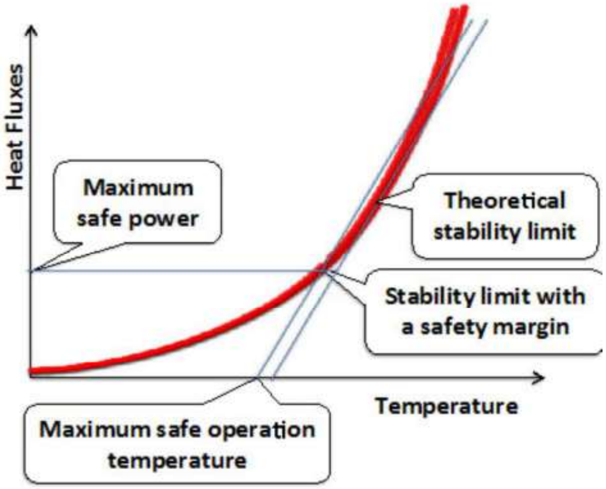

Figure 9. Schematic evaluation of the safe power limit. The LENR heat output involves bursts and fluctuations that must be taken into account to determine the safe conditions of operation.

Figure 4 shows the corresponding curve for temperatures up to 500 K, although this is beyond the actual experiments presented in [8].

The influence of the temperature must be taken into account in the design of the future reactors for the reasons that are discussed in the following.

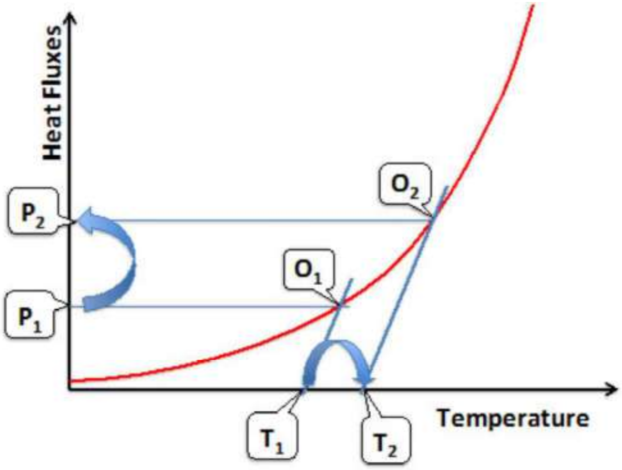

Figure 10. Power control increase. The fluid temperature is increased from T_1 to T_2. The power is raised from P_1 to P_2.

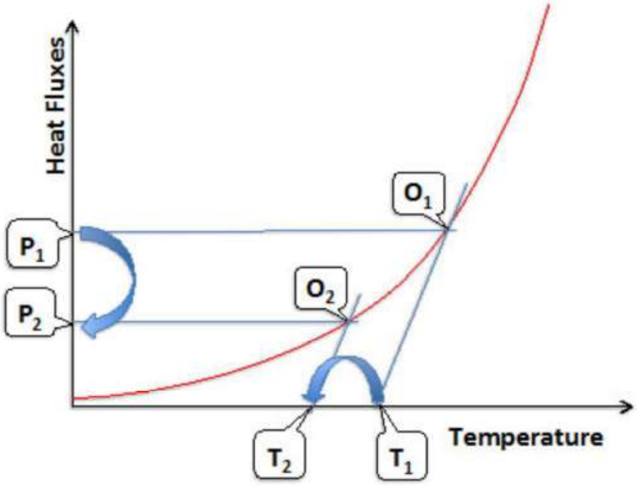

Figure 11. Power control decrease. The fluid temperature is decreased from T_1 to T_2. The power is reduced from P_1 to P_2.

3.2. Thermal stability

Let us first consider Fig. 5. The reactor is separated from the cooling fluid by a thermal resistance layer. This configuration is found in many experimental setups. The heat flux is basically proportional to the difference between the reactor temperature T_r and the fluid temperature T_f.

Figure 6 compares the relationships between the temperature, the heat flux to the cooling fluid and the LENR heat output The theoretical operating point is located at point O, intersection of the two curves. The temperature at the interface of the reactive material and the resistance layer is T_r, the heat power of the reactor is P_r. If the temperature for any reason is changed to $T_\mathrm{a} < T_\mathrm{r}$, the LENR power decreases to P_a, while the cooling heat exchange becomes P'_a. Figure 6 shows that $P_\mathrm{a} < P'_\mathrm{a}$. This means that in such a case, the temperature can only drop further. The reaction slows down and the reactor stops.

Conversely, if the temperature is higher than T_r, the LENR power P_b is larger than the cooling capacity P'_b. The temperature increases continuously. The reactor goes out of control. Cooling the reactor through a heat resistance layer leads therefore to an unstable configuration. The occurrence of an LENR excess heat may easily result in a runaway reaction.

Another configuration is shown in Fig. 7. The reactor is directly cooled by the fluid with a bulk temperature of T_f. The heat exchange between the reactor and the fluid can be described by the equation:

$$P_{\mathrm{cooling}} = h\,(T_\mathrm{r} - T_\mathrm{f})\,, \tag{22}$$

where h is the heat exchange coefficient, measured in $\mathrm{W\,m^{-2}K^{-1}}$.

The superposition of the LENR power curve and a cooling curve according to Eq. (22) is shown in Fig. 8. It is supposed that T_f and the heat exchange coefficient h are such that the cooling curve intersects the power curve at point O. If the temperature becomes $T_\mathrm{a} < T_\mathrm{r}$, the power P_a exceeds the cooling flux P'_a, so that the reactor returns to the operating point. Inversely, if the temperature is higher than T_r, the cooling exceeds the LENR power, and the temperature returns to T_r. We see that the intersection point O is stable.

The configuration shown in Fig. 7 allows stable operation. The reactor heat must be evacuated by a flow of fluid organized in order to achieve a satisfactory exchange coefficient. The condition to be satisfied is given by the

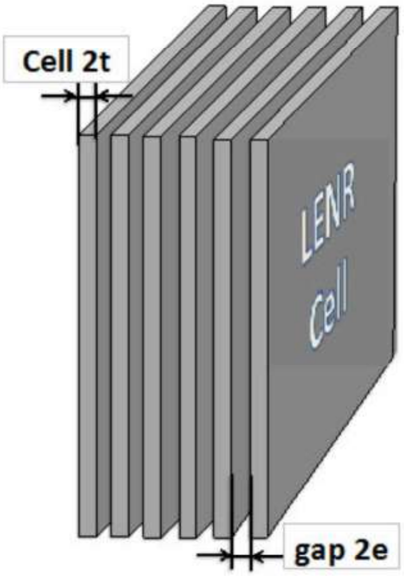

Figure 12. Schematic layout of an hypothetical LENR reactor. The thickness of the LENR cells is $2t$. The cells are separated by gaps filled by the cooling fluid. Gap thickness is $2e$.

relationship between the heat exchange coefficient and the slope of the power curve as given by the derivative of the power curve equation:

$$h > \mathrm{d}P_{\mathrm{LENR}}/\mathrm{d}T. \tag{23}$$

This condition must be obeyed in the system at any moment and any location. In fact, it is known that LENR sometimes occur as local bursts of heat. The LENR power curve drawn in the above figure is therefore a simplification of the actual phenomena. Figure 9 presents a more realistic picture. The power curve is blurred, to illustrate that the local heat flux fluctuates even for a given temperature. In order to avoid instability, it is advisable to control the fluid temperature and the power under safe limits.

3.3. Control of the reactor power

The power of LENR reactors can be controlled to some extent via the excitation energy input. However, some LENR devices produce heat after death, meaning that the reaction proceeds even in the absence of excitation [5,6]. In such cases, it is necessary to develop another method to control the energy output. The sensitivity of LENR to the temperature can advantageously provide this additional mode of power control.

Figure 10 illustrates an LENR power curve and two different cooling lines. Let us suppose that the reactor is initially operated at point O_1. The cooling fluid temperature is then T_1. Now, let us slightly increase the fluid temperature. The reactor temperature increases. The power rises to P_2. This can be easily obtained via a temporary decrease of the fluid flow rate. This can also be accomplished by an external reheating of the fluid, especially during the startup phase, when the whole reactor system must be warmed up. This mode of control is called Power Control Increase or PCI.

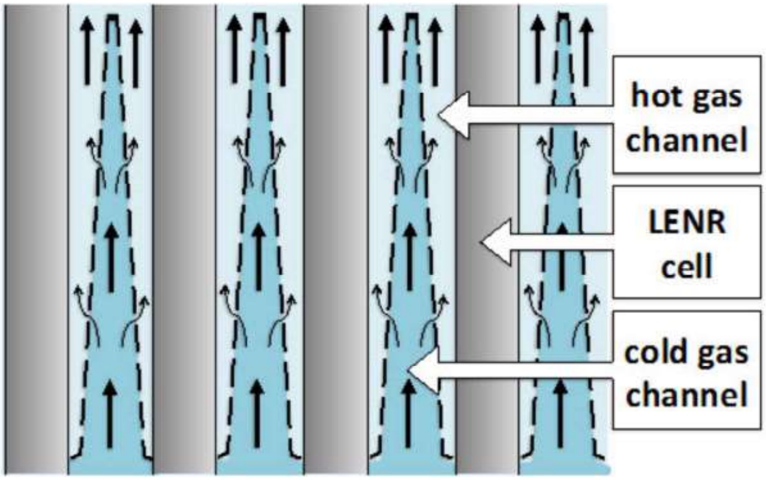

Figure 13. Schematic LENR reactor with gas cooling. The gas is distributed to obtain an uniform temperature T_f all over the surface of the cells.

Similarly, the power can be reduced at will. Figure 11 shows that if the fluid temperature is lowered from T_1 to T_2, the reactor power is decreased from P_1 to P_2. This can be obtained via an additional cooling of the fluid before it enters the reactor. This mode of control is called Power Control Decrease or PCD.

If it is desired to stop the reactor, it is possible to quench it by circulating cold fluid for a sufficient time.

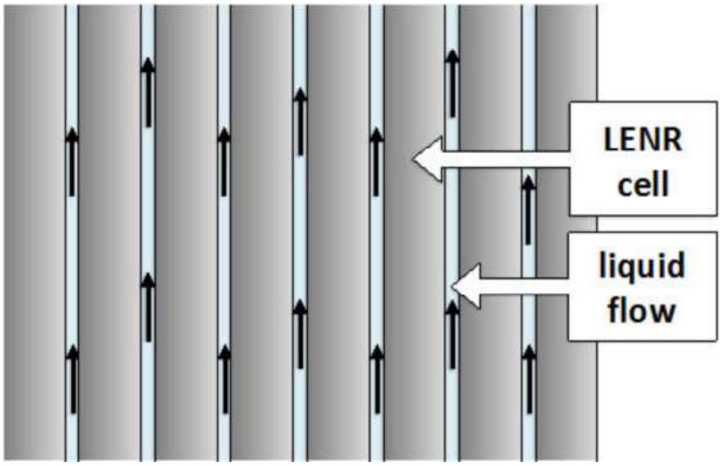

Figure 14. Schematic arrangement of an LENR reactor cooled by a forced flow of liquid (oil, molten salt or liquid metal) between the cells.

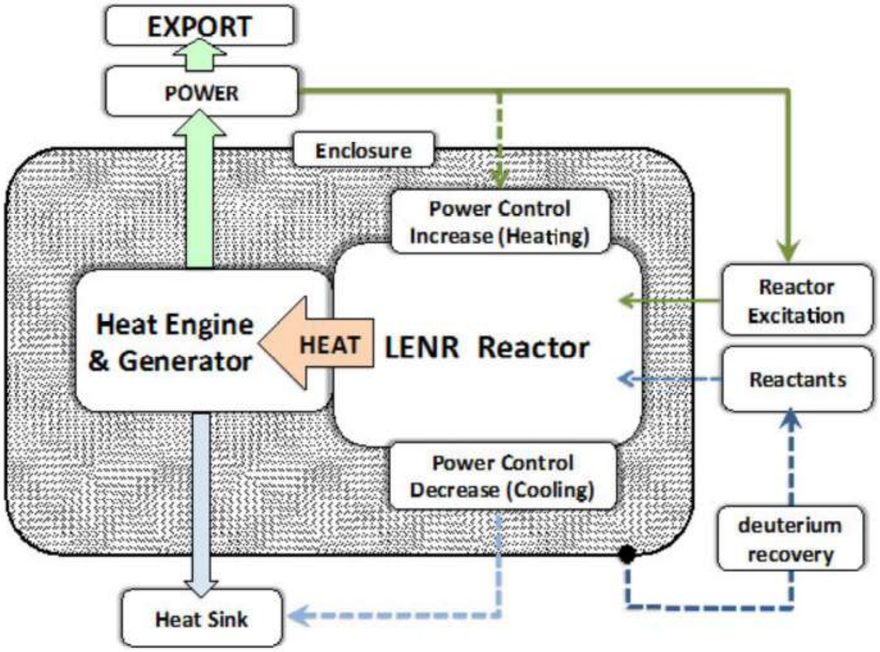

Figure 15. Schematic block diagram of an LENR power generator.

4. Potential Design of LENR Generators

4.1. Basic cooling methods

The above discussion leads to the basic design of an industrial LENR reactor. The LENR reactor must be cooled so that the criteria of Eq. (23) is satisfied. The cooling fluid (gas or liquid) is hot, at a temperature slightly below T_r. To

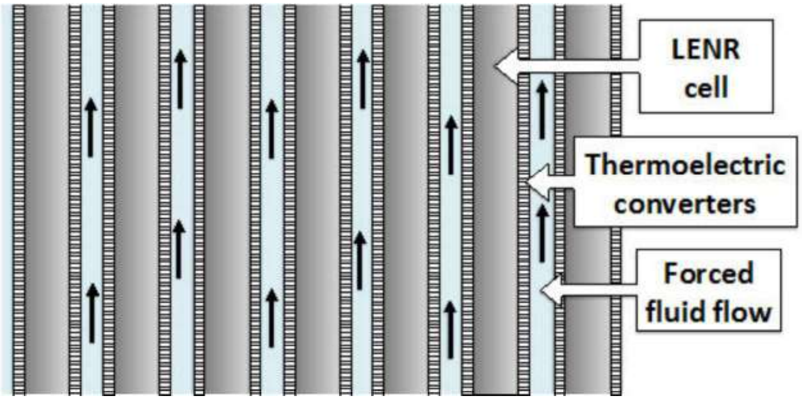

Figure 16. Schematic configuration of an LENR reactor with thermoelectric converters (TEC). The TEC elements are intercalated between the LENR cells and the cooling fluid.

make the heat flow out of the LENR active material possible, this material is confined in multiple cells. The shape of the cells is prismatic, planar or tubular. The gap between adjacent cells is filled by the forced flow of cooling fluid. The sizing of the cell thickness is governed by the heat flow capacity across the active material, and by the heat flux exchanged with the fluid.

In order to clarify the above, let us consider a theoretical example (see Fig. 12). We imagine a hypothetical LENR system characterized by a power density of 1 W cm $^{-3}$, or 1 MW m $^{-3}$. The supposed operating temperature is 600°C or 873 K. The LENR cells are square slabs 1 m × 1 m with a thickness $2t = 20$ mm. They are cooled on both sides, and the heat flux on each face is 10 kW. The fluid circulates in the gaps between adjacent cells upwards along the whole height. Two different cases are examined in Table 1, cooling by a forced gas flow and a forced flow of liquid.

Table 1. Comparison of the cooling of an hypothetical LENR reactor by a gas or a liquid.

	Gas cooling	Liquid cooling
Heat flux at interface	10^4 W m^{-2}	10^4 W m^{-2}
Typical fluid heat capacity	10^3 J N m^{-3}K^{-1}	10^6 J m $^{-3}$K^{-1}
Fluid flow rate	0.1 N m^{3}s^{-1} (atmospheric pressure)	10^{-3} m^{3}s^{-1}
Gap thickness: $2e$	20 mm	5 mm
Fluid velocity	32 m s^{-1}(atmospheric pressure)	0.4 m s^{-1}
Typical exchange coefficient (9)	10^2 W m^{-2}K^{-1}	10^3 W m^{-2}K^{-1}
Delta T solid–fluid	100 K	10 K
Temperature inlet	400°C	580°C
Temperature outlet	500°C	590°C

In the case of gas cooling, the temperature difference adopted between the gas inlet and the gas outlet is 100 K. A typical gas heat capacity is 103 J N m^{-3}K^{-1}. The evacuation of the heat requires a flow of 0.1 N m^{3}s^{-1}. We suppose that the gap thickness is 20 mm. If the pressure is atmospheric, the gas velocity is 32 m s^{-1}. This is acceptable. However, the velocity is lower if a higher pressure is used. The heat exchange coefficient h between the cell and a gas flow is typically 100 W m^{-2}K^{-1} [10]. The gas enters at 400°C and leaves at 500°C. The engine performance must take these values into account, rather than T_{r}. Figure 13 presents a potential configuration with gas cooling. Because the LENR power is sensitive to the temperature, the gas circulation is organized to obtain a progressive mixing of the cold and the hot gas, so that the value of T_{f} remains constant over the whole cells surface.

In the case of liquid cooling, the temperature difference adopted between the liquid inlet and outlet is 10 K. A typical heat capacity for a liquid medium is 106 J m^{-3}K^{-1}. The evacuation of the heat requires a flow of 103 m^{3}s^{-1}, or 1 l.s^{-1}. We suppose that the gap thickness is 5 mm. The velocity of the liquid in the gap is 0.4 m s^{-1}.

The heat exchange coefficient h between the cell and a forced flow of liquid is typically 103 W m^{-2}K^{-1} [9]. The temperature difference according to Eq. (22) is then 1 K. The liquid enters at 580°C and leaves at 590°C. These values are very close to T_{r}. Figure 14 presents a potential configuration with cooling by a liquid fluid. A simple film flow is suitable. The fluid flow rate is low and a narrow gap is sufficient. Another option is to immerse the cells in a boiling liquid. Heat exchange between a hot surface and a boiling fluid is very high [10]. This type of cooling is, for example, adopted in nuclear boiling water reactors (BWR). Boiling cooling may represent the best option for reactors with a large LENR power density.

4.2. LENR generators generic configuration

Figure 15 presents a schematic block diagram of a complete LENR power generator. The LENR reactor is linked to an excitation system and a supply of reactants. The heat is transferred to a heat engine by direct contact or via a circulating loop of hot fluid.

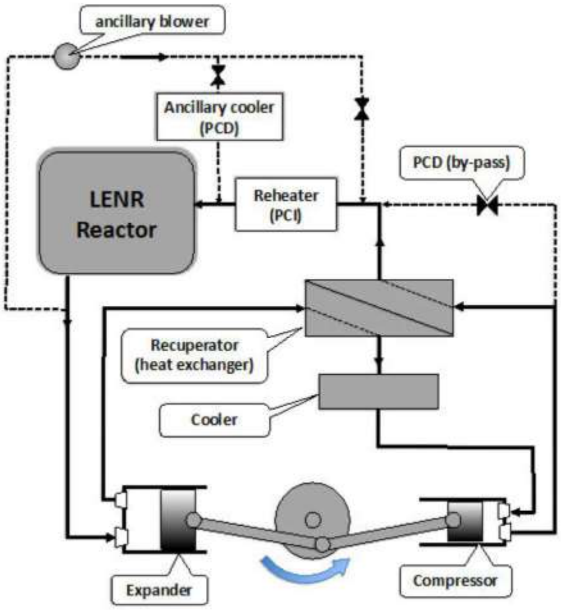

Figure 17. Coupling with an Ericsson engine.

The engine transforms the heat into mechanical power. The engine is coupled to an electrical generator that produces electricity. A fraction of the electrical energy is used to energize the excitation supply and the other control systems. The surplus is exported. The power is controlled via the level of excitation. Additional control is provided with PCI and PCD functions. An enclosure confines the whole assembly. The roles of the enclosure are discussed below.

This general description must be adapted following the exact type of reactor and engine used. In order to explain how these principles can be translated into design features, some examples are detailed in the following.

4.3. Coupling with various heat converters

4.3.1. *Thermoelectric converters*

Figure 16 shows a LENR reactor made of reactive cells covered by thermoelectric heat converters (TEC) [11]. The backsides of these panels are cooled to remove the heat. Initial warming can be obtained by applying a DC current in the TECs to use them temporarily as heaters during the startup phase. The level of power extracted from the reactive cells can be regulated through the amount of electrical current exported. This makes fine PCI or PCD possible. Forced PCD cooling can be obtained with the help of an external DC source to enhance the heat removal. To date, the thermal efficiency of TECs is too low to make this solution viable. The situation may change when new TEC devices become available [12,13]. This type of LENR generator would be attractive because of the absence of moving parts other than the cooling fluid pump.

4.3.2. *Ericsson engine generator*

Figure 17 shows an Ericsson engine, which includes expansion and compression cylinders, fitted with admission and exhaust valves. A heat exchanger recuperates a large part of the heat not transformed into mechanical energy, so that the efficiency is good [14].

The recuperator and the cooler may have large sizes. This reduces the gas pressure drops, and the associated energy losses. The pressure drops are also dramatically reduced if the gas loop is pressurized. The metallurgical heat resistance of the hot parts limits the working temperature of an Ericsson engine to approximately 600°C.

PCI takes the form of an ancillary gas re-heater arranged on the gas line entering the reactor. This re-heater allows the reactor warming for the startup phase. During that period, the engine does not yet produce power. An ancillary blower must provide the gas circulation. Alternatively, the gas is circulated by the engine itself, driven by the generator used temporarily as a motor. PCD can be finely tuned during operation via a by-pass of the recuperator, as shown in the picture. PCD forced cooling is also feasible with another cooler combined with the ancillary blower.

The PCD can be finely tuned during operation via a by-pass of the recuperator, as shown on the picture. The PCD forced cooling is also feasible with another cooler combined with the ancillary blower.

4.3.3. *Brayton gas turbine*

A closed loop gas turbine with the Brayton cycle is a suitable heat engine if the temperature exceeds about 700°C (see Fig. 2) [15]. Figure 18 shows the configuration. It is quite similar to the Ericsson system, except that rotating

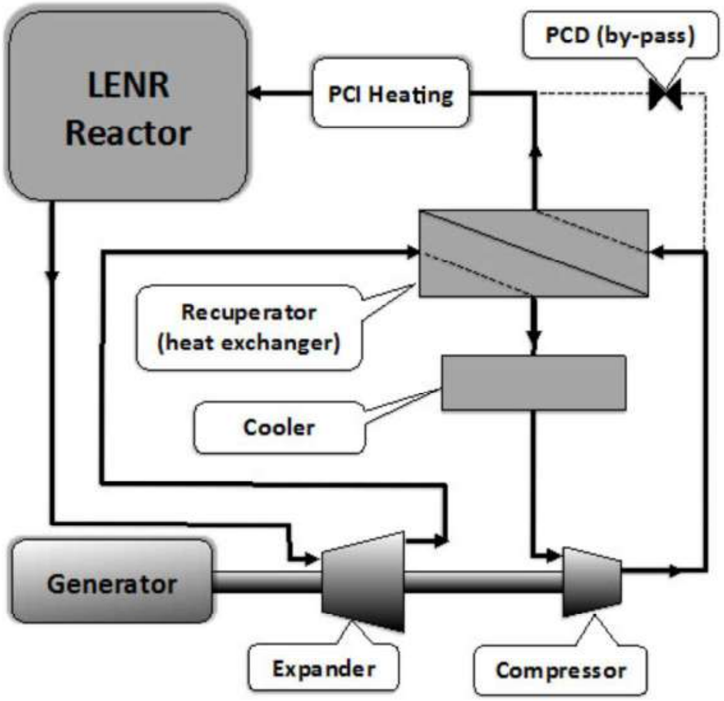

Figure 18. Coupling with a closed cycle gas turbine.

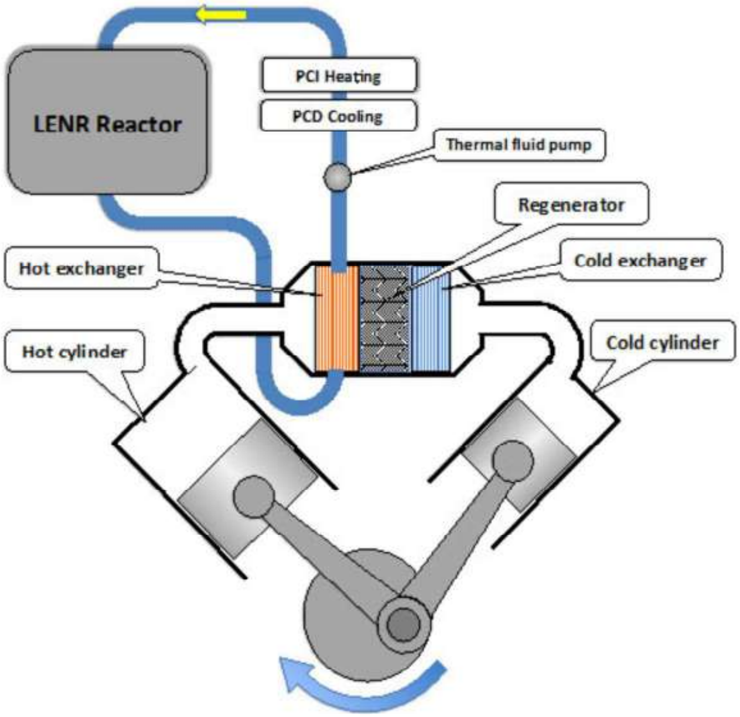

Figure 19. Coupling with a Stirling engine (two pistons type). The heat is transferred from the reactor to the engine hot exchanger by a hot fluid loop.

equipment replaces the volumetric machines. During startup, the generator is used temporarily as a motor. The PCI is included as a gas re-heater before the reactor. A recuperator by-pass line provides the PCD function.

4.3.4. *Stirling engine*

Figure 19 schematizes the coupling of an LENR reactor with a Stirling engine. In this type of engine, a confined mass of gas is alternatively transferred between a cold and a hot cylinder, while being heated or cooled. A heat regenerator greatly improves the thermal efficiency. There are no gas valves. Several types of Stirling engines exist, with different arrangements of the cylinders [16].

The gas volume enclosed in the exchangers and regenerator must be commensurate with the volume swept by the cylinders. The size of the exchangers is therefore limited, and this gives a limit to the actual efficiency and power density of the Stirling engines. The working gas is preferably of high conductivity (H_2 or He). In order to control the effect of the viscous pressure drops, the gas circuit is pressurized The temperature in the hot exchanger is limited below about 700°C to withstand the high pressure. Because of the limited size of the hot exchanger, it is beneficial to input the heat by a fluid (gas or liquid) heat transfer circuit, as shown in Fig. 19. A pump drives the heating fluid circulation. A re-heater installed in the fluid loop provides the PCI function. The PCD is obtained via a cooler also inserted in the circuit. The heating fluid loop is started before and independently from the Stirling engine.

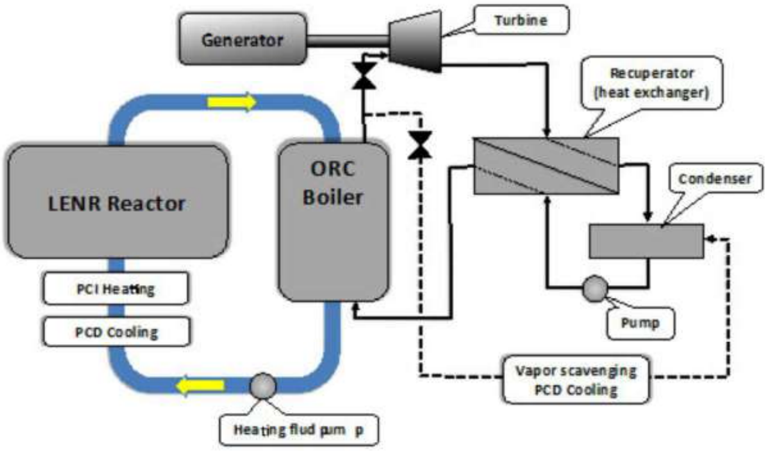

Figure 20. Coupling with an ORC turbine.

4.3.5. *Organic Rankine cycle*

Figure 20 shows the principle of an Organic Rankine Cycle (ORC) turbine coupled with an LENR reactor. An organic fluid is vaporized under pressure in the boiler. The vapor is expanded in the turbine. The residual heat of the low pressure vapor is recovered in the heat exchanger. The vapor is condensed, and the liquid is pumped back to the boiler [17].

This description seems similar to a steam turbine. The use of an organic compound simplifies the overall design, because for a given temperature the pressure level can be much lower than for steam. In most cases, the turbine

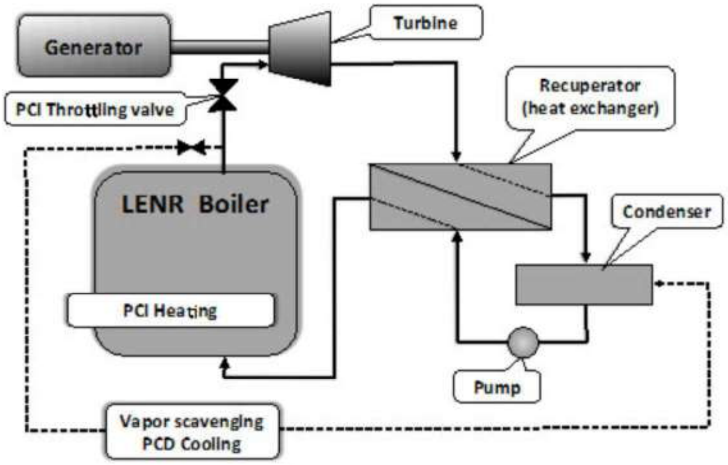

Figure 21. Boiling LENR reactor. The fluid boils between the cell gaps. PCI: The re-heating of the reactor is provided by an ancillary heater immersed in the boiler. PCD: A vapor scavenging line allows the cooling of the boiling fluid.

includes only one or two stages of blades. Contrary to steam, the expansion of the organic vapor does not result in partial condensation. The absence of liquid droplets in the vapor stream eliminates the potential erosion of the turbine blades. Many different compounds are available following the temperature, between 100°C and 350°C [18].

The heat transfer fluid can be oil, a liquid salt or metal. It may also be a diphasic circuit, for example pressurized steam vaporized in the LENR reactor and condensed in the ORC boiler. This last option is interesting if the LENR reactor is a high temperature electrolytic system, provided the COP of the process is sufficient. To increase the power, the LENR reactor is re-heated by a PCI unit arranged on the hot fluid loop or inside the reactor When the operation temperature increases, the vapor pressure in the boiler increases as well. A throttling valve regulates the vapor flow rate admitted in the turbine.

The PCD may be a cooler installed on the fluid loop. A vapor line directly linked between the boiler and the condenser can provide additional cooling. Scavenging vapor results in a fast cooling of the fluid contained in the ORC boiler.

4.3.6. *Boiling reactor*

Figure 21 shows a boiler heated by LENR cells, coupled to a turbine. Future large reactors operated between 200°C and 300°C may use a technology similar to BWR, with water as a cooling fluid and condensing steam turbines [19]. However, as LENR does not suffer of the same constraints as fission reactors in terms of materials and neutron flux, organic fluids or other chemicals may replace water. This will make it possible to operate with modest pressures. Small units are also feasible.

4.3.7. *Classification of the potential techniques*

The different techniques for heat transfer and heat engines are summarized in Fig. 22 according to their typical temperature domain. The range of possibilities is very large and this sketch is only indicative.

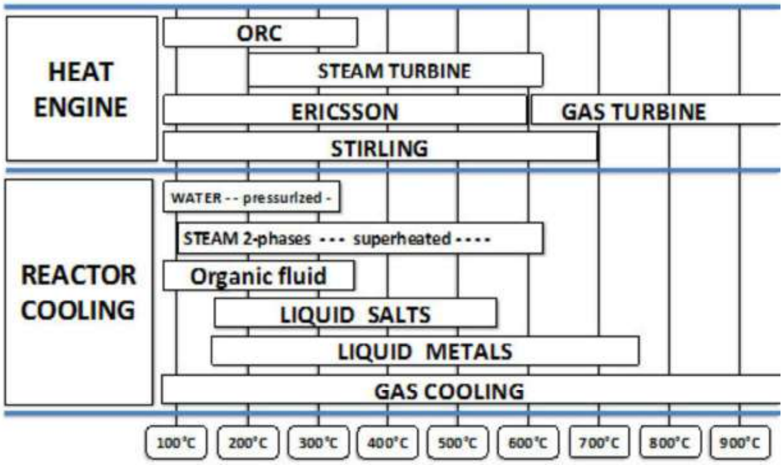

Figure 22. Typical temperature domains for reactor cooling and heat engine types.

4.4. Enclosure design

The last item visible in Fig. 15 is the enclosure that surrounds the whole generator assembly. The enclosure serves a dual purpose:

- Limits the thermal losses to the environment.
- Avoids the hydrogen (deuterium) loss to the atmosphere.

Heat losses originate at the LENR reactor walls, the hot parts of the heat engine, the heating fluid piping. These pieces must be adequately insulated in order to limit heat transfer to the environment by conduction, convection and radiation.

Some LENR processes require the presence of hydrogen (H_2) or deuterium (D_2) to drive the reactions. It is supposed that the LENR cells are inserted in metallic containers. The walls of these containers are hot during operation. At high temperature, H_2 or D_2 diffuse through the metals. This is a problem in the case of D_2, because this expensive gas must be conserved as much as possible.

The light gases leak out of the cells and accumulate in the cooling fluid, gaseous or liquid. The cooling fluid loop must be designed to accommodate their presence. Because the partial pressure of the light gas in the cooling fluid is nonzero, from there, it can diffuse further within the atmosphere of the thermal insulation material. It is supposed that the temperature of the enclosure wall is close to the ambient, and that all passages through the wall are gas tight, so that the enclosure does not leak any H_2 or D_2. The light gas accumulates within the insulation lagging. From there, it may be recovered by a gas separation unit.

The presence of light gases in the insulation increases the gas thermal conductivity and adversely influences the insulation performance. The higher conductivity must be taken into account.

5. Conclusion

The LENR reactors able to deliver heat at a high temperature can be coupled with heat engines to generate electrical power. If the temperature and the COP are sufficient, the power covers the needs for the reactor excitation and surplus electricity is available for external use

According to the literature, the heat generation rate of some LENR processes increases rapidly with the temperature. It is desirable that the R&D related to all LENR processes includes the study of the influence of the temperature. The future industrial reactors will have to be designed in order to guarantee a safe and stable operation. Cooling is achieved by a fluid in direct contact with the reactive cells. Power control can be obtained through an appropriate temperature regulation. Several types of heat engines can be coupled to LENR reactors to generate electricity.

Heat losses must be minimized thanks to a sufficient thermal insulation. The insulation enclosure is also useful to recover the leaks of light gas if any. This may be an important economical factor if deuterium is utilized in high temperature reactors.

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