COMBINED NUCLEAR AND CONVENTIONAL PLANT, OPERATING ON HYDROGEN, ACCORDING TO RANKINE CYCLE

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In the article a novel approach toward a power facility is proposed, focusing on clean electric energy generating, during peak loads of a power system (PS). In such system, the primary energy is generated in a nuclear energetic installation that, by its nature, is suitable for continuous delivery of energy at a relatively constant load. Based of this primary energy, through electrolysis, hydrogen (H) and oxygen (O) can be produced, and stocked in special reservoirs.During peak load, H and O should be recombined in a combustion process, by generating steam at very high temperature. The steam is further sent to a condensation turbine, which is generating in return second level energy that is leveling the peaks in the PS load.

1. **INTRODUCTION**

Recently, hydrogen (H) is mentioned more and more often as a very suitable fuel for the near future. One knows that H does not exist as a free natural pure element on Earth, but in chemical species, such as hydrocarbons, only. As a result, H is not considered to be proper fuel. Classic fossil fuels (coal and hydrocarbons) are rapidly exhausted and also they generate pollutants (SO_2, NO_x or CO) in addition to gases producing the greenhouse effect (CO_2, NO_x) through combustion, consequently one comes the idea that replacing the classic fuel by H, generated by not pollutant procedures, is a sustainable solution. In order to use H as an energy resource in direct combustion or fuel cells, for various purposes (transportation, district heating, energy delivery under special conditions), H should be industrially produced by means of non-polluting technologies; therefore, H might be considered an energy “vector” [1].

One of the frequently applied industrial technology for H production is water electrolysis. Depending of the origin and technology of producing the electricity

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used in electrolysis, such as non-polluting electricity generated by hydropower plants (HPPs) or nuclear power plants (NPPs), and by extension, one might consider H also as a non-polluting fuel, very useful for further energy transformation necessary in field such as transportation, heating, or even for regenerating electricity for special destinations.

According to this chain, H might be considered a non-polluting fuel, and this is the main hypothesis applied by the authors in this article.

At the first approach, it might appear quite illogical to use H to generate electric energy, when this H has been itself obtained through electrolysis, thus consuming much more electric energy. One knows that the efficiency of H generation by means of electrolysis is normally in the rank of (0.56–0.7) [2]. Even state of art, especially improved achievements do not reach values higher than 0.8.

The issue is questionable when considering the complexity of the phenomena for overlapping peaks of load in a PS; we refer primarily to cases when the energy producers in the system have specific features concerning their attributions at running load levels. It is known that the NPPs, as well as the high power HPPs mounted on water streams are typical examples of units able to deliver for the basis of load curve of a PS. In addition, when necessary, the basis of the load is provided by thermopower plants (TPPs), especially operating on coal as main fuel, including cogeneration TPPs (CTPPs).

To illustrate, we will use the example of the Romanian National Power System (NPS); its load curve is characterized by the fact that the total consumption of electric energy was 45910 GWh, out of which [3]:

41 172 GWh in base load (89.7% from the total energy),

4 738 GWh in peak load (10.3% from the total energy).

Out of the total, 14.9% of the base was produced in the NPP Cernavoda (a power unit with nominal power of 700 MW), 29.8% was generated by HPPs – in principal those mounted on the Danube ("Iron Gates" I and II) – and the rest of 55.3% was generated in TPPs running especially on coal and in CTPPs, mainly in the winter time. The base load correspond to an average power of 4 700 MW.

The most significant peaks of load has been registered during the cold season, within November and March; the total reached 3 624 hours, *i.e.* 41.37% out of 8 760 hours. Also, during the mentioned period of peak load, an average energy consumption of 3 431 GWh occurred monthly, in addition on the base regime.

The supplementary energy consumption necessary to cover the peaks has the following structure, expressed in percentages versus the normal load: November – 25.5%, December – 27.2%, January – 21.3%, February – 14.9%, March – 9.6%. In other words, these values represent a supplement of 1 278.4 MW power to cower the maximum overload, along with the normally used 4 700 MW. The energy for the peak load was delivered, according to the necessity, either from HPPs that are mounted on accumulation lakes capable to store water for longer periods, or from

TPPs, mainly working with hydrocarbons. The National Dispatcher Authority in the domain selects the utilization of specific power plants based on a schedule designed according to economic criteria.

Regarding the present standards for environmental protection, in Romania, as in fact in all world, special attention is being paid to promoting the implementation of power plants based on technologies meant to avoid high pollutant emissions, including those with greenhouse effect. From this point of view, the ideal cases are the HPPs and the NPPs. Also, in order to meet the severe up to date standards, drastic measures are implemented in the TPPs in order to reduce the pollutants, especially the SO_2 and NO_x. The emission of CO_2, that is a gas giving a greenhouse effect, is not yet avoidable at industrial scale in case of TPPs operating on coal and hydrocarbons. Only by applying efficient, improved methods such as combined cycles or cogeneration [4] there are chances to successfully limit the CO_2 emissions. At the same time, the possibility of replacing the fossil fuel by H should be considered. The fact that H generates, during combustion with air, water vapors and NO_x is mere common place. The NO_x concentration in the flue gases might be reduced by classic well known technologies, that are peculiar to all fossil fuel combustion technologies [5, 6]. In the case that H is burned only in an oxygen (O) atmosphere, only water vapors is resulting; thus this combustion is considered fairness correctly as non polluting.

Also, it is already noted that the NPPs are non-pollutant plants. If one decides to cover the peak loads with these plants, it will notice that they are not suitable, as they are not very “flexible”; the reason therefore being determined by the fact that they must work both under economic but also safety and security conditions.

In order to implement also a NPP in the process of covering the peak load in the NPS, one proposes an power system composed by a Nuclear Installation (NI) and a TPP equipped with a gas turbine operating with H in a Conventional Installation (CI). The NI is working continuously, at constant load, and is generating the electricity needed for producing H by electrolysis. The CI is using the H during longer or shorter periods along the year, with the specific purpose of covering the peak loads. The longer the operating period of these CI is, the more reduced is the furnished energy. Nevertheless, the delivered energy by CI is proportional to the H quantity produced in NI.

In the following, one will analyze such a global system, characterized by producing clean energy, under the assumption that will burn under stoichiometric conditions, with no air, only using the O generated by electrolysis. The nomination of system means in detail a combined nuclear and conventional power plant, operating on H basis, with the acronym CNIPH (Combined Nuclear Installation of Power by means of Hydrogen). The CNIPH represent effectively a system by which the NPPs designated by excellence to deliver energy in base load for a PS may be turned into power units capable to contribute to covering the peak loads of respective system. Even one will refers especially to CNIPH, it is notable that in the frame of such a combined installation the source for generating H by means of electrolysis a HPP might also be used, the selection being made between those normally used during base load in a PS. Also, H might be produced from renewable resources as solar or wind energy, a.o. Under these circumstances, the unpredictable character of the primary energy is converted to continuity by means of the accumulation reservoir for H and O.

2. **COMBINED NUCLEAR AND CONVENTIONAL POWER INSTALLATION**

The thermodynamic scheme of the principle of the combined plant proposed by the authors is given in Fig. 1.

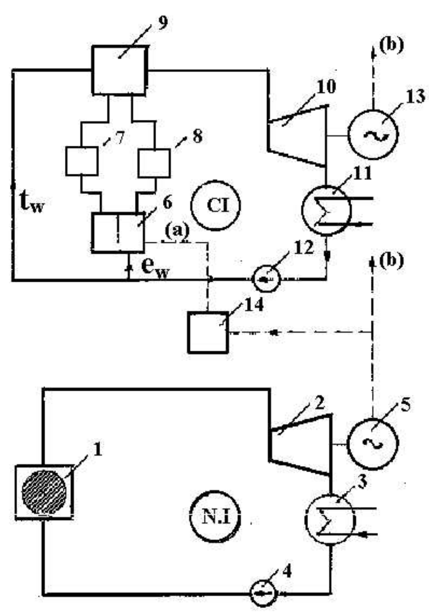

Fig. 1 – Thermal simplified scheme of CNIPH, where:
CI-conventional installation; NI-nuclear installation; 1-nuclear steam production system; 2-steam turbine of NI; 3-steam condenser of NI; 4-feed water pumps; 5-electric generator of NI; 6-electrolyser (EL); 7-H reservoir; 8-O reservoir; 9-combustion chamber (CC); 10-gas turbine; 11-steam condenser of CI; 12-feed water pumps of CI; 13-electric generator of CI; 14-electrical rectifier; a-direct electric current to EL; b-alternative electric current; e_w-water to EL; t_w-(adjusting) water to CC.

The nuclear component of the combined plant (NI) is composed principally of the nuclear steam production system (NSPS) 1, the steam turbine 2, the steam condenser 3, the feed water pumps 4 and the electric generator 5. In order to simplify the scheme, one neglected intentionally some elements, even of relevance, such as the regenerative water pre-heater system, the condensate pumps, the humidity separator, the intermediary super-heater for the steam of the turbine itself etc. The conventional component of the plant (CI) is composed by the electrolyser (EL) 6, the H reservoir 7, the O reservoir 8, the combustion chamber (CC) 9, the gas turbine (GT) 10, the steam condenser 11, the feed water pumps 12 and electric generator 13.

Between the two components NI and CI, on the electric side, it is important to mention the existence of the rectifier 14, which is rectifying the alternative current into direct current, necessary in the electrolysis process occurring in the EL 6. The direct current is sent from the rectifier 14 toward to the EL, by the way (a). Both ways (b) are designed to deliver alternative current to the electric network of the PS. The electricity starts from the electric generator 13 of CI, during peak load, and is completed by the alternative current produced by the generator 5 from the NI, the moment when more energy is needed as the generator 13 might deliver. As the optimum pressure for the electrolysis is in the range of (10 – 50) bar [2], and the pressure in the combustion chamber CC of the modern GTs are comprised in the same interval, one proposes that for the EL6, as well as for the H and O reservoirs (7 and 8), the value of 50 bar as nominal pressure should be made us of. Anyhow, in the CC the pressure should be more reduced in order to permit that reservoirs 7 and 8 should play the role of tank buffer during peak load, when the CC needs superior flows of H and O, as regularly generated by EL6.

In regards to this consideration, one points out another characteristic advantage of the CNIPH, meaning that in its assembly, compressors for H and O are not required. The pumps 12 supplies their role. This highlight is an essential feature in comparison to conventional GTs, using gaseous fuel, for which both fuel and oxidant (air or O) should be compressed until the working pressure of the CC, be means of compressors. In any case, a compressor for whichever fuel is necessary. The compressors require large amount of power in order to perform and are much larger in comparison to pumps.

As already indicated, the combustion of H occurs stoichiometric, as the available O is provided only by the electrolytic decomposition of water in the facility 6. In such a case, the combustion temperature is approx. 2 850 ^{o}C, much higher in comparison to the stoichiometric combustion of H in air, when it might be 2 200 ^{o}C [1]. It is evident that for stoichiometric combustion of H with O this value is considerable. Water is injected into the CC [7] for reducing the gases temperature at the outlet from the CC, before reaching the GT10. Thus, the total flow that is running through the pumps 12 is divided in two:

t_w – water for cooling down, e_w – water for electrolysis. (5)

Studies run for the optimization of the main functional characteristics of the GTs with water injection [8] – turbines that are further on nominated as STIG (Steam Injection Gas Turbine) – demonstrated that, depending on the temperature t_o in the CC, the maximum efficiency is achieved for following pressure domains in the CC:

– for t_o = 875 °C p_o = (10 – 20) bar,
– for t_o = 950 °C p_o = (15.5 – 23) bar,
– for t_o = 1 025 °C p_o = (16 – 28) bar,
– for t_o = 1 100 °C p_o = (18 – 31.5) bar,
– for t_o = 1 175 °C p_o = (20 – 40) bar.

On the other hand, for most the GTs produced by important companies from USA and Europe, the temperature range is between 1 068 °C and 1 500 °C [9].

Under these circumstance, in the frame of the subsequent analysis, one will consider as relevant the following values for the real gas (steam) parameters in the CC: p_o= 30 bar, t_o= 1 200 °C. The turbine 10 is characterized by double features:

– corresponding to the inlet parameters of the gas, the turbine might be considered a gas turbine (GT);

– concerning the nature of the working fluid and according to the fact that in exhaust it reaches the condenser 11, the turbine is comparable to a steam turbine (ST).

In order to illustrate these double features, one will use the acronym of Gas-Steam Turbine: GST.

3. **APPLIANCE OF THE RANKINE CYCLE TO A CNIPH**

Figure 2 presents in the T-s diagram the thermodynamic process that occurs in the GT from CNIPH. The corresponding Rankine cycle has a closed contour a-b-c-d-e-f-g-a.

The parameters of the steam at the GST inlet are p_o = 30 bar, t_o= 1 200 °C, as previously concluded. The steam pressure in exhaust toward the condenser is p_o= 0.04 bar, in correspondence to temperature of the cooling water t_{cw} = 15 °C.

One presumes a theoretic case study, by accepting that between CC9 and GST10 during the steam passing no pressure losses are noticed and that the respective expansion in the GST is a reversible adiabatic process. The mentioned closed cycle a-b-c-d-e-f-g-a posses some characteristic features in comparison with a classic Rankine cycle. For comparison, in Fig. 2 was represented a such classic cycle – a-b'-c'-d'e'-f'-a – for inlet steam parameters p_o = 130 bar, t_o = 535 °C and outlet pressure p_c = 0.04 bar.

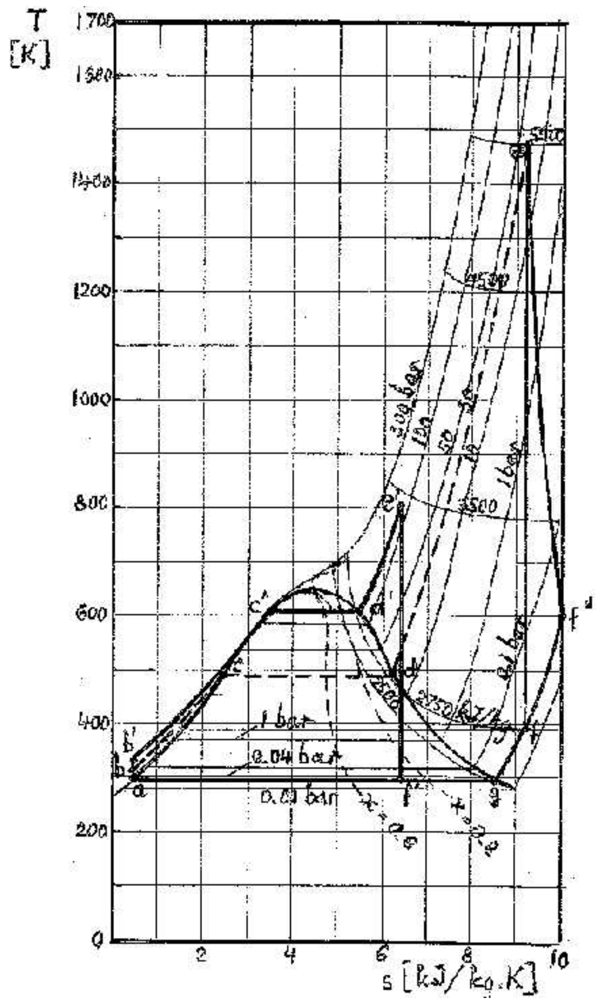

Fig. 2 – Thermodynamic processes in the *T-s* diagram (for CNIPH and a conventional plant).

The cycle a-b-c-d-e-f-g-a is accomplished as follow:

3.1. The pumps 12 increases the pressure of water coming from the condenser 11 and introduces it to EL6 (see segment a-b from Fig. 2);

3.2. The electrolysis of the water fed by pumps 12 is accomplished in EL6. Resulted H and O are stored in the reservoirs 7 and 8 at a pressure of 50 bar, as indicated in the previous chapter. That mince that the pumps 12 will raise the feed water up to 50 bar. Thus, point b from the segment a-b is situated on the 50 bar isobar, at the left side of the saturation curve of the steam, zone that correspond to water in liquid phase.

As all isobars from this zone are very close nearby, one presumed that point b is situated both on the 50 bar isobar as on the 30 bar isobar. At a standard cycle the segment b-c stands for the heating up process of water until the boiling point corresponding to the working pressure, c-d would indicate the water vaporization until reaching the saturating status, and d-e corresponds to the superheating of the steam in the boiler, up to t_o. For the comparison cycle, the corresponding segments are b'-c'-d'-e' and represent also the mentioned processes, accomplished in the boiler.

In the analyzed case, all these processes are replaced by the electrolysis in EL6 and the combustion of H with O, in the CC9. These new processes (electrolysis and combustion) determine that point e of the cycle at the exhaust from the CC9 corresponds to p_o= 30 bar and t_o = 1 200 ^oC. One may presume that these new processes are comprising complex procedure of the heating up of water, its boiling vaporizing and superheating of the results vapors. All are virtual processes. In consequence, section b-c-d-e of the cycle has been drawn with dot line.

One concludes:

– in the classic case, the heat developed through fuel combustion in transferred to the water-steam through the heat exchangers' surfaces;

– in the case of the CNIPH, the heat generated through the combustion of H (resulted itself from electrolysis) in the presence of O is directly taken over by the steam resulted from the reaction $2H_2 + O_2 \rightarrow 2H_2O$. This heat is further "diluted" by water introduced in CC (water injection).

In the following, the process represented by the sequence a-b-c-d-e-f-g-a are described:

3.3. Expansion of the steam in GST10 (part e-f) from p_e= 30 bar to p_c= 0.04 bar. As presented, at the theoretical cycle, the expansion e-f is considered isentropic (s = const.);

3.4. Isobaric cooling of the steam (segment f-g) until it reaches the saturated dry state (point g);

3.5. Condensation of steam in the condenser 11 (segment g-a).

Concerning the partition f-g, one remarks that the steam cooling along it, using cooling water having 15 ^oC, would represent an energetic loss, as point f having approx. 115 ^oC. If one refers to a real expansion in the GST10 and accepts an internal efficiency of η_i = 0.87 [10], the process would be represented by the segment e-f". Point f" is situated on an isotherm of approx. 295 ^oC and the loss would be considerable more. In order to avoid such kind of losses, in connection also to the location of CNIPH and the energy demand from the clients, one of the following methods of heat recovery is proposed:

(i) Utilization of the heat recovery from the GST steam for district heating (cogeneration). This solution is favorable especially during winter, when load peak is requested, as heat consumption is considerable high for district heating. One knows that the maximum water temperature in the secondary circuit in the district heating schemes is (130–160) ^{o}C. Thus, the heat offered by the steam in point f" is satisfactory and adequate.

(ii) In the case when CNIPH is situated near oceans or seas the heat extracted from the GST might be used to water desalinization. Normally these processes require steam with temperature over 200 ^{o}C. As example the desalinization plant for Jebel Ali G in Dubai [11] is given, where pressured steam with 19.5 bar and 212 ^{o}C is used. In such a case, one might combine two important features in an efficient unique solution, as referred in the study "Vision 2000 – Powering tomorrow from the USA". In this case it is mentioned that "…the desalinization of see water and hydrogen production using nuclear power might turn in a very revolutionary solution, of same level of importance as electrification was remarked for the XX century". Also at the international ministry conference "Nuclear power for the 21th century" hold in Paris in 21-22 May 2005 under the auspices of the International Atomic Energy (IAEA) one stressed in the final adopted document the idea that "…nuclear power is a solution that does not favor air pollution or determine any generation of greenhouse effect gases. Nuclear energy secures the electricity supply and can make a valuable contribution to the production of potable water and hydrogen, as energy resource".

(iii) When neither of the mentioned solutions (i) or (ii) for heat recovery is suitable it is obvious that one might use the heat energy to transform it into electricity. Presently such systems are well known and adopted for special systems where low temperature heat is recovered [12]. As an example, one mentions that ORMAT company from Israel, specialized in production of such modular facilities covering a range of the parameters of the steam at the GST inlet are p_o = 30 bar, t_o= = 1 200 ^{o}C, as previously concluded. The steam pressure in exhaust toward the condenser is p_o= 0.04 bar, in correspondence to temperature of the cooling water t_{cw}= 15 ^{o}C.

One presumes a theoretic case study, by accepting that between CC9 and GST10 during the steam passing no pressure losses are noticed and that the respective expansion in the GST is a reversible adiabatic process. The mentioned closed cycle a-b-c-d-e-f-g-a posses some characteristic features in comparison with a classic Rankine cycle. For comparison, in Fig. 2 was represented a such classic cycle – a-b'-c'-d'e'-f'-a – for inlet steam parameters p_o = 130 bar, t_o = 535 ^{o}C and outlet pressure p_c = 0.04 bar. (500–1 300) kW, specially offered in following cases, in respect to the primary energy resource:

Primary fluid	Temperature [^{o}C]
Liquid or condensed vapors	80–200
Hot gases	180–400

The thermal efficiency η_t of the theoretic cycle a-b-c-d-e-f-g-a is given by:

$$\eta_t = 1 - (Q_e / Q_i), \tag{1}$$

where Q_i is the heat introduced in the cycle and Q_e is the heat evacuated from the cycle.

By expressing the input and exhaust heat with the aid of enthalpies variations it results:

$$\eta_t = 1 - [(i_{sf} - i_w) / (i_{si} - i_w)], \tag{2}$$

where i_{sf} is the steam enthalpy in the final stage of the expansion in the GST (point f in Fig. 2), i_{si} is the steam enthalpy in the initial point of the expansion and i_w is the feed water enthalpy after the steam condensation in the condenser 11.

One considered for the water temperature a value of t_w = 40 ^{o}C and thus i_w = 167 kJ/kg. By applying formula (1) and introducing the values for i_{si} and i_{sf} as resulted from *T-s* diagram represented in Fig. 2, one determined, for three different values of the pressure p_o considered 20 bar, 30 bar and 40 bar and for a temperature range between 1 000 ^{o}C and 1 400 ^{o}C. The results are represented in Fig. 3.

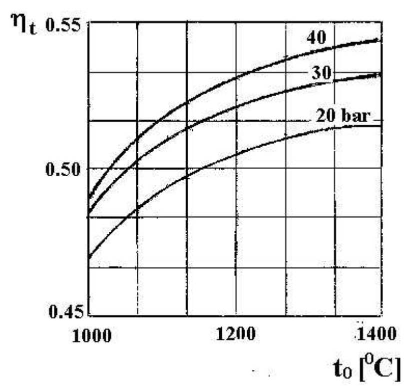

Fig. 3 – The efficiency η_t, function of p_o and t_o.

One concludes that the values for η_t are improved simultaneously with the pressure increase and the temperature enhance. One also remarks the fact that temperature t_o – especially up to 200 ^{o}C – has a larger influence upon the thermal efficiency, in comparison to p_o. For the pair of parameters selected (p_o = 30 bar,

t_o = 1 200 °C) the efficiency becomes η_t = 0.5222. As previously indicated, by heat recovery from the still superheated steam evacuated from the GST one may achieve an improved efficiency, in comparison to the case when no such recovery is applied. The efficiency for the case study a-b'-c'-d'-e'-f'-a with p_o= 130 bar, t_o= = 535 °C, p_c= 0.04 bar is η_t = 0.48. It is obvious that the CI installation of the CNIPH has a thermal efficiency higher than the classic one, operated normally in TPPs, both without superheating. This fact is due especially to the much more improved value of the temperature t_o (1 200 °C), in comparison to the t_o value on the basic case (535 °C). The knowledge concerning the gas turbines theory [6] indicates that more the fluid temperature at the inlet into the turbine is, more influence does it performs upon the efficiency η_t, in comparison to the pressure value. One should not neglect the fact that in the calculus of η_t no energy input into the cycle during the electrolysis process occurred, thus η_t represents rigorously only the thermal efficiency of the cycle and absolute value of the integral process (thermal ones and completed by electrolysis) occurring in the CI. For such global efficiency one should consider also the energetic efficiency of the electrolysis.

Also by means of the diagram outlined in Fig. 2 one may calculate the value of the temperature adjustment (tempering) coefficient β. It represents the ratio of the water flow necessary for reducing the temperature in the CC to a convenient value and the water flow necessary for the electrolysis. By designating both quantities with G_{tw} (*t* stays for tempering) and G_{ew} (e considers the electrolysis process), one regard as:

$$\beta = (G_{tw}/G_{ew}). \qquad (3)$$

The calculus of the β coefficient is accomplished by means of the mass and energy balances, in reference to the system comprising the EL6 and CC9. A simplified scheme of such a system is given in Fig. 4.

In order to achieve the mass balance for the mentioned system, one starts from the basic chemical reaction for the stoichiometric combustion of H with O:

$$H_2 + O \rightarrow H_2O. \qquad (4)$$

By mass, this relation is:

$$2 \text{ kmol } H_2 + 1 \text{ kmol } O \rightarrow 1 \text{ kmol } H_2O, \qquad (5)$$

or, in quantitative form:

$$2 \text{ kg } H_2 + 16 \text{ kg } O \rightarrow 18 \text{ kg } H_2O. \qquad (6)$$

Thus implies that, for any 1 kg H_2O introduced into the EL, it delivers 2 / 18 kg H and 16 / 18 = 8 / 9 kg O through the electrolysis.

Based on the definition of β (see Formula 3), one deduces that for every 1 kg H_2O introduced into the EL, one has to deliver to the same system as a whole (more exactly to the CC) additional β kg H_2O for the temperature adjustment. Thus, from a general balance one concludes that for any 1 kg water introduced into the EL, the system water input and output is (1 + β) kg.

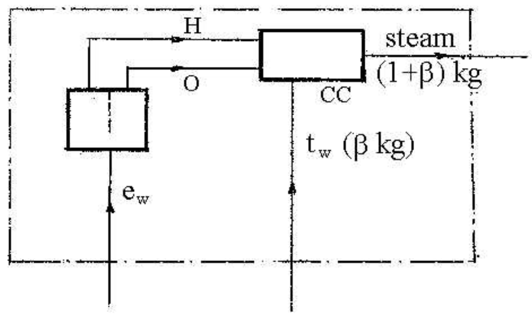

Fig. 4 – Mass and heat flow of the Electrolyser-Combustion Chamber system.

The thermal energy balance will be analyzed only for the CC. The heat delivered to the CC (symbolized as Q_{IN}) must be equal to the output Q_{OU}. For the heat input the energy balance in more detailed form is:

$$Q_{IN} = Q_{ew} + Q_{tw} + Q_C, \tag{7}$$

where Q_{ew} is the heat transported by the inlet water of the EL, Q_{tw} is the heat introduced with the tempering water directly to the CC and Q_C is the heat directly delivered to the CC by the combustion of H.

If one refers to 1 kg water introduced into the EL, $Q_{\rm ew}$ represents exactly the specific enthalpy of the water input into the EL. Thus, for β kg representing the water amount necessary for the temperature adjustment (tempering), in correspondence $Q_{tw} = \beta i_{tw}$. From Fig. 1 it result that $i_{ew} = i_{tw} = i_w$.

Heat Q_C is given by the formula:

$$Q_{\rm C} = \xi m_H H_i \,. \tag{8}$$

where ξ is the non-dimensional emission coefficient in the CC, m_H [kg] is the water amount resulted from 1 kg water, through the electrolysis process and H_i [kJ/kg] is the lower calorific value of the H.

According to [4], the possible figures for ξ are selected from the interval (0.96 – 0.98). One considers ξ = 0.97. We have m_H = 1 / 9 kg, and H_i = 121,000 kJ/kg [5].

By introducing $Q_{\rm ew}$, $Q_{\rm tw}$ and $Q_{\rm C}$ in (7), according to the mentioned definitions, it results:

$$Q_{IN} = (1 + \beta)i_w + (1 / 9)\xi H_i. \tag{9}$$

The heat exhausted by the CC and retained by the steam that gets to the GST, as already mentioned, becomes:

$$Q_{OU} = (1 + \beta)i_{si}, \tag{10}$$

where i_{si} is the enthalpy of the steam in the outlet of the CC and at the inlet of the GST; i_{si} is defined in connection to the determination of the thermal efficiency η_t.

By equaling relations (9) and (10) and introducing the mentioned particular values as indicated, it results:

$$\beta = [13\,041 / (i_{si} - i_w)] + 1. \tag{11}$$

In the performed case study, one considered i_{si} = 5 470 kJ/kg (Fig. 2), i_w = = 167 kJ/kg, thus β = 3.46. One concludes that for every 1 kg water introduced into the EL, additional 3.46 kg water are needed for temperature adjusting. In the mentioned case, the outlet water (steam) quantity from the GST is 4.46 kg.

4. **CONCLUSIONS**

Based on the accomplished remarks, following conclusiveness results might be completed:

4.1. Generally, in a power system (PS), some electrical power plants (PPs) assure the basic load curve per annum. In the Romanian National Power System (NPS) this role is played by the 700 MW Nuclear Power Plant (NPP) from Cernavoda, some hydropower plants (HPPs), and some cogeneration thermopower plants (CTPPs). When the peak load in the NPS is reached, the HPPs installed with this special purpose operates, for a shorter period, and only the TPPs, from which the majority operating with hydrocarbons, are completing the necessity. The NPPs and HPPs adequate to operate on the load curve basis might contribute to the cover the peak load by using hydrogen (H) as energetic vector. This is possible by means of a system in which H and oxygen (O) are delivered through electrolysis, accomplished with the electric energy generated from NPPs or HPPs, with normal continuous functioning at normal load. H and O might be stored in special reservoirs, and used gas turbines (GTs) plants for delivering missing necessary secondary electric energy amount, along shorter or longer intervals, covering the peak load.

A system, where the primary electric energy is generated with the support of nuclear energy, consist mainly of a nuclear installation (NI) and a conventional one (CI), operating with a turbine that uses flue gases delivered by a combustion chamber(CC), where H and O react. The reaction product is in reality water, in steam phase. Taking into account the particular features of the CI with GT, the steam posses a reduced pressure, (20–40) bar, but a very high temperature, (1 000 – 1 400) ^{o}C. The specific feature of the GT resembles to a steam turbine (ST) consists of the detail that the working fluid is also condensing after the expansion. We use the denomination of Gas Steam Turbine (GST).

This system is identified by a name performed as “Combined Nuclear-Conventional Power Installation Operating on Hydrogen Basis”, shortly “Combined Nuclear Installation of Power by means of Hydrogen” (CNIPH).

4.2. The CNIPH is characterized by the following specificities:

– The power installation is totally non-polluting as both NI and CI are operating in closed circuit, and the working fluids in these components is water in different phases liquid or steam;

– The installation is simple, because its components CI is operating with a CC instead of a boiler, thus the used specific metal input and the dimensions of the steam generator are considerable reduced, in comparison to a power classic installation operating with steam;

– As H and O are generated by electrolysis just in the frame of the combined installation, no compressors are necessary for the transport of the gases. The pressure of the two gases is generated in the EL, where the electrolysis is accomplished with water fed in by means of pumps. It is known that a pump is using much more reduced energy in comparison to compressors, and has less dimensional outfit and weight;

– Due to the high steam temperature at the inlet into the GST that represents the maximum cycle temperature, the thermal efficiency of the installation is higher than classic one, using steam at normal steam parameters. The general efficiency of the installation is certainly lower, as it is influenced by the efficiency of the water electrolysis that is approx. (0.6–0.8).

From the technologic point of view, the system is characterized by complexity in reference to a conventional installation, because it comprises additionally one electrolyser and equipment to reverse the alternative electric current generated by the NI to direct current, necessary to operate the electrolysis.

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