Study and Analysis of the Thermal Impact on the Overall Performance of the Proton Exchange Membrane Fuel Cell and Its Management and the Exploitation of PEM Fuel Cells in a Cogeneration System: Review

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Abstract: With the huge interest in clean energy development and the sources of production, appeared the development of fuel cell technology as a clean source of energy which generates electricity releasing only water and heat and which responds the most to the climatic requirement to perpetuate our environment. Current research aims to the development and improving the performance and improving the performance as well as reducing the cost to compete with other current sources of polluting energies. A proton exchange membrane fuel cell has a lot of enticing characteristics however, in parallel to these distinctive and advantages, has also various constraint and a considerable challenge to its widespread commercialization. That we will have to overcome them to make it profitable and accessible, whose one of those challenges that requires the most effort is the thermal management technology that makes this increasingly complex. In this review we will focus on the study of the thermal management of the heat released inside the PEM fuel cell during operation and to study the thermal impact on the performance of PEMFCs. As well as the possibility to rationalize the thermal energy produced using the combined use of heat and energy cogeneration to maximize the energy produced and improves the overall efficiency of the energy system.

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1 INTRODUCTION

The need for energy will continue to increase more and more, mainly following the metaphors and the development of the industrial field which consumes a huge part of world energies, which the largely part comes from fossil energies, presents a huge challenge and creates adverse undesirable environmental effects, emissions at the local level and overall greenhouse gases GHGs, what makes the search for other alternatives a task that persists to preserve our environment. In this order of ideas renewable and clean energies remains as the most appropriate solution to preserve our environment, since they have the lowest carbon footprint (Naimi, et al., 2016)and they are not harmful (Panwar, et al., 2011) (Alper & Oguz, 2016).Of which their major problem is the availability at the time of need which is almost impossible because depends on several climatic factors (Balat, 2008) (Viswanathan, 2017). But in parallel with the development of this technology, it turns out that another technology that is also very promising and even if it is not a primary source but just a carrier of energy, its hydrogen technology (Harris, 2011). This technology boils down to converting the potential energy produced by renewable energy sites into hydrogen using an electrolyzer. This technology can be summarized in the fact to transform the potential energy generated by the sites of renewable energy into hydrogen using an electrolyzer. We use thereafter the Hydrogen produced as needed to produce electricity, unlike the electricity produced by renewable energies which is not always available and depends on environmental factors.

In the manner of renewable energies, the field of fuel cells also remains as a highly promotive domain that can respond to climatic and environmental requirements. There are different types of fuel cells which differs by several characteristics (materials, electrolyte, fuel, ...) in our study we are interested in PEMFC, due to its many advantages, like it is not pollutant, doesn't have a corrosive effect and it offers

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the highest energy density among the others (Lamei, 2012) (Zhang Liyan, 2011) (Zhidong, et al., 2015) (Authayanun, et al., 2015), its low operating temperature between 60 ℃ and 80 ℃ (Song W, 2014) (Yan Z Y, 2013), Its low weight and volume and its immediacy start (fast-star).What makes PEM fuel Cell a promising candidate. However, although the huge progress of PEMFC technology; the development of fuel cells is still limited and presents a lot of the difficulties and intrinsic problems to overcome, which leading to the deterioration of PEMFCs and directly affecting the overall yield of the cell. In this perspective the thermal problem that boils down in the temperature distribution and the thermal management inner the fuel cell is presented as one of the critical elements for an optimal operation of the PEMFC. Therefore, our review focuses in analyzing and managing this crucial element to ensure the balance, stability and efficiency of the PEM fuel cell. As well as studying the exploitation of the PEM fuel Cell in a system of cogeneration and analyzing namely the contextual, of the global art system status and the technological environment. In this paper we present a complete analysis to study and analyze the influence of temperature on the performance of the fuel cell and also tools for its good management of this determining parameter, in order to increase the efficiency of the Fuel cell.

2 PRINCIPLE OF OPERATION OF THE PEMFC

A fuel cell is an electrochemical device its operating principle is to convert the chemical energy stored in the fuel into electrical energy, the principle of the fuel cell process can be described as the inverse of the electrolysis of water. Indeed, this type of battery can operate at room temperature and can deliver a reasonable power for the intended application. It is a controlled electrochemical combustion of hydrogen and oxygen (Air) (Fig.1). The only products of hydrogen decomposition and oxygen reduction are water and heat formed as secondary products with simultaneous generation of electricity.

Both oxidation and reduction reactions (Eq.1) (Eq.2) occur at the triple point areas which is located at the interface between the electrolyte and electrode with the presence of the catalyst (platinum) (Fig.1). The only products of hydrogen decomposition and oxygen reduction are water and heat formed as secondary products with simultaneous generation of electricity, according to the overall chemical reaction (Eq.3).

Oxidation reaction:

$$H_2 \rightarrow 2H^+ + 2e^- \qquad \textbf{(1)}$$

Reduction Reaction:

$${}^{1}\!/_{2}\, O_2 + 2H^+ + 2e^- \rightarrow H_2O \qquad \textbf{(2)}$$

Overall reaction:

$$H_2 + {}^{1}\!/_{2}\, O_2 \rightarrow H_2O \qquad \textbf{(3)}$$

The theoretical potential delivered by a cell equal to $E = 1{,}23\ v$ and calculates by

$$\boldsymbol{E_{th} \equiv {}^{|\Delta G|}\!/_{2F}} \qquad \textbf{(4)}$$

E_{th}: theoretical potential, ΔG: free enthalpy (Gibbs energy of the reaction), F: Faraday constant.

To have a PEM fuel cell that generates a significant amount of electricity must be assembled several cells, in electrical series, which causes a lot of difficulty in the management of the reaction products during its operation of which the temperature increase remain one of the important keys to the proper functioning of the fuel cell that it has a decisive impact, note that the thermal power produced is of the same order of magnitude as the electrical power (Alleau, Révision Octobre 2014). In this manuscript we will study and detail the influence of the increase of heat on the different components of the PEMFC.

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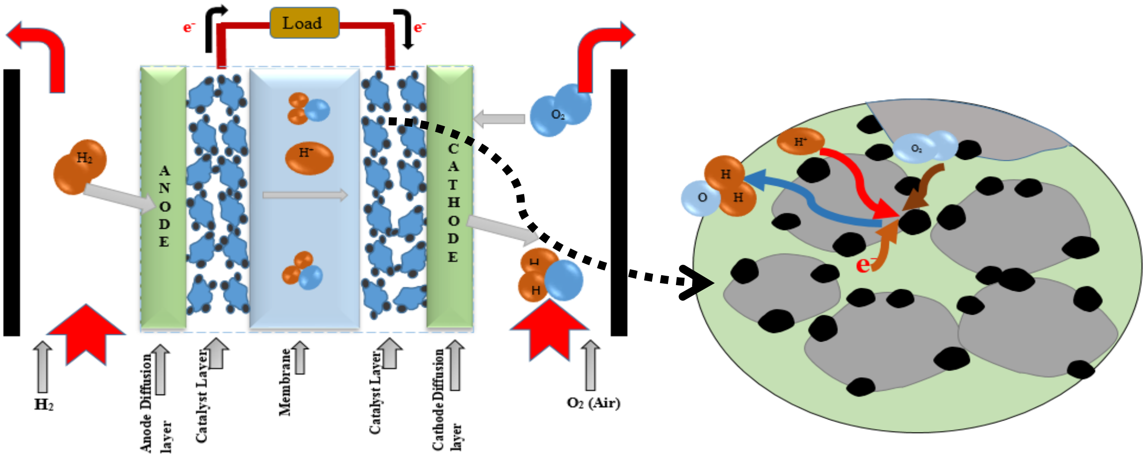

Figure 1: Schematic diagram of the operating principle and components of the membrane proton exchange fuel cell (PEMFC) and the catalytic reaction at the electrode

3 THERMODYNAMIC AND ELECTROCHEMICAL STUDY

The yield of PEM fuel cells generally does not exceed 40% which implies the existence of a large part of energy lost during the operation of the PEM fuel cell and this mainly due to the electrochemical reaction which is accompanied by several irreversible losses. In practice, the existence of irreversible losses will make the reactions exothermic. These losses are actually, electricity transformed into heat.

These different types of losses that affects the electrical efficiency and contribute to the increase of dissipated energy as heat instead of electrical energy, as the losses related to the transport of the different reactant in the electrodes, the activation losses related to reaction kinetics in the active layers, the losses related to the transport of charges (Ohmic losses) in the membrane (protons) and the electrodes (electrons) which led to lowering the fuel cell yield.

The energy produced by the PEMFC specifically comes from the thermodynamic energy that appeared during the electrochemical reactions inside the cell. Fundamentally, this energy comes from the exothermic reaction of the water composition from H_2 and O_2 (Saeeda & Warkozekb, 2015) as in any electrochemical component, only the free energy of the reaction ΔG can be converted into electricity (Eq.4), the maximum amount of electrical energy produced in a PEM cell corresponds to the Gibbs free energy.

$$\Delta G = \Delta H - T\Delta S \qquad \textbf{(5)}$$

ΔH: Enthalpy of the reaction, ΔS: The entropy of the reaction. T: Operating temperature (K).

However, this energy is divided into two parts, electrical and thermal energy, which the thermal energy generated during operation exchanged with the environment in the form of heat. The variation of free enthalpy ΔG depends on the temperature, the pressure, the conditions of the reaction and more specifically reactants activities.

The Raising the temperature reduces voltage losses, therefore a higher temperature led to a higher cell voltage. However, an excessive local cell temperature can cause dehydration of the membrane, a contraction or even a rupture, which adversely affects the proton conductivity which inversely affects the course of the electrochemical reaction in its turn. On the other hand, a low temperature is unfavorable for the kinetics of the reaction, Because it depends directly on the operating temperature, as shows the Nernst equation of the reversible potential which depends directly on pressure and temperature (J. Bvumbe, et al., 2016) (Hosseinzadeh, et al., 2013) (Ozbek, et al., 2013) (Yao, et al., 2004) (Pandiyan, et al., 2008) (Authayanun, et al., 2015).

$$E_r\left(T, P_{ref}\right) = E_r(T_{ref}, P_{ref}) - \frac{\Delta S}{nF}(T - T_{ref}) + \frac{RT}{nF}\ln\left(\frac{P_{H_2}P_{O_2}^{0,5}}{P_{H_2o}}\right) \qquad \textbf{(6)}$$

P_{ref}Pressure referential, P_{H_2} : hydrogen pressure,P_{O_2} :oxygen pressure,P_{H_2O} :pressure of H_2O.

The internal thermal power produced during operation of the cell defined as the difference between, the chemical power released from the reactants and the electrical power generated. The two relations which follows, presents respectively the chemical power (Eq.7) defined as the chemical energy released by the hydrogen consumption and the electric power (Eq.8)

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$$P_{Chemical} = \Delta H_{H_2O} * {}^{F}/_{2} \qquad \textbf{(7)}$$

$$P_{Electrical} = V * I \qquad \textbf{(8)}$$

The difference between the open circuit cell voltage and the operating voltage, quantified as the amount of energy dissipated as thermal power.

4 ENERGY AND THERMAL PRODUCTION IN PEMFC AND THE THERMAL DISTRIBUTION IMPACT

4.1 Thermal Production and Joule Effect in PEM Fuel Cell

The heat produced and released inside the stack mainly due to the effect of the two terms one of which is derived from the heat of the electrochemical reactions as is already presented in the foregoing, and the other of the Joule effect, due to the Ohmic resistance of the components of the PEM fuel cell assembly.

The joule effect in the membrane is caused by the resistance to proton transfer and is reflected by a volume heat source uniformly distributed in its thickness, which is expressed by the following relation:

$$Q = \frac{R_m i^2}{t_m} \left(\frac{w}{m3}\right) \qquad \textbf{(9)}$$

$\boldsymbol{R_m}$**:** Overall resistance of the membrane.

A study conducted by (Pandiyan, et al., 2008) on the thermal effect of the other components of the pile show as a result of a difference of 10 °C of temperature, it is properly clear that the thermal resistance increases almost three times but on the other side the current increases only by about 50% which implies the existence of a high electrical resistance in the components of the stack. It is clear that the internal electrical resistance of the electrode plays decisive role, Which decreases the current that can be drawn from the PEM fuel cell for each increase in unit temperature, which implies, in parallel with the increase in electrical resistance an increase in the effect, then more energy dissipated as heat, so the characteristics of the electrodes materials have a decisive role to decreasing the internal resistance. In practice, the potential of a PEM cell is lower than the theoretical potential due to internal losses in the fuel cell (Haji, 2011). As we have already presented in the foregoing part, the heat inside the fuel cell generates mainly by the irreversibility of the electrochemical reactions and the Ohmic resistance of the components of the assembly of the stack (joule effect) (Pandiyan, et al., 2008).The Heat also affects the distribution of water by condensation and affects the gas diffusion transport characteristics in multi-component by thermo-capillary forces and thermal buoyancy (Pandiyan, et al., 2008).

The overall yield of a PEMFC varies between 40% and 60% which implies the existence of a large dissipation of chemical reaction energy which is transformed into thermal energy that amount of energy comparable to the electric energy. A study (Alleau, Révision Octobre 2014)reported that the thermal power to be removed is substantially the same for a fuel cell (50% in heat and 50% in electricity), Can go up to 100 kilowatts in automotive applications (Kandlikar, et al., 2007) (Wen C.-Y., 2011) (J. Bvumbe, et al., 2016). Another study (Pandiyan, et al., 2008) has showed that the energy produced inside of the cell comes out in the form of thermal energy as much as electrical energy. For this reason it is clear that for every decrease in operating voltage we will have an increase in thermal output. So, strictly speaking, for each temperature increase we will have a decrease in current. On the other hand, a study (Benmouiza & Cheknane, 2017) has clearly demonstrated that a lower temperature directly affects the performance of fuel cells and worsened the voltage drop. In addition, it also shows that a high temperature ensures rapid reaction that produces more power. Furthermore, at higher temperatures, the electrochemical reaction is faster, it increases the water production in the cathode and better hydrates the membrane, and thus the ionic resistance is reduced.

The temperature clearly affects the performance of the cell; generally adequate operating temperatures are suitable for the efficiency of fuel cell. But in parallel a high or low temperature can (Benmouiza & Cheknane, 2017) amplify the degradation of PEM fuel cell (J. Bvumbe, et al., 2016). As stated above a study (Pandiyan, et al., 2008)also clearly stated that the operating temperature has a decisive impact on the kinetics of electrochemical reactions and its distribution in the cell affects the performance. The same work has shown that the ratio between the electrical output power and the thermal output is unitary. However, when the operating voltage of the cell decreases, the ratio increases to 2 for an operating voltage of 0.5 V. This shows that twice the energy goes out as heat instead of the electrical output. This also supports the studies presented previously. Several studies have shown that the electrode manufacturing process also has a very important role in reducing the internal resistance of the cell in addition to its components the effect of the electrical

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and thermal resistance of a PEM fuel cell has been evaluated (Pandiyan, et al., 2008)and has been observed that the increase in thermal resistance is three times and the current increases by 50% for a temperature change of 10 ℃.Confirming that the internal resistance of the electrode increases by the increase of the current density with respect to temperature change. Then an adequate temperature within the cell is highly useful for the improvement of the kinetics of the electrochemical reaction and the ion transport which gives the improvement of the performances by means of the reduction of the voltage losses. That's why, it is necessary to handle and control the heat produced inside the fuel cell. As well as to manage well its distribution in the various components of the PEM fuel cell.

4.2 Temperature Distribution in the PEM Fuel Cell

The temperature distribution in PEM Fuel Cell is recognized as an important factor for fuel cell stability and efficiency. Because there is a generally fractional relation between temperature and heat diffusion in semi-solid systems such as fuel cell. To avoid amplification of the deterioration of the fuel cell, the lowering of its performance in general, as well as the membrane in a specific way and make it last. This is why we must think of eliminating the excess heat produced, effectively to ensure good thermal distribution inside. Part of this heat is spontaneously dissipate either by convection and radiation to the environment, or by unused reactants. But this part remains nevertheless low by contribution to the heat produced. As well as when the temperature is high these evacuation modes are negligible, which can be thought of dissipated by active cooling to prevent overheating of the PEMFC. In this perspective, several studies have studied the effect of forced cooling. Who let's think of the dissipated by active cooling to avoid overheating of the PEMFC.

5 OVERALL THERMAL MANAGEMENT OF THE SYSTEM

5.1 Adverse Thermal Effect on the Membrane and Its Management

Concerning the membrane and its proper functioning, we must clearly keep a good balance between its temperature and its hydration which many studies have investigated this point in the fuel cells. From a theoretical point of view, a fuel cell involves an exothermic reaction. Due to the different losses that we have already described in advance, which generates a fairly large amount of temperature which heats all of the components, so beyond this point, there is a surplus of heat that must be released towards the outside of the component. And it will cool the component in order to not destroy the membrane, because the current membranes do not withstand temperatures higher than 90 ℃ (Rallieres, 2011). So, an improper thermal management will induce various thermal problems. As dehydration of electrolyte as well as the problem of overflow in the cathode, which imposes more critical challenges on the PEMFC operation.

On the one hand the cathode overflow phenomenon has been the subject of many studies (Lampinen & Fomino, 1997) (Eikerling, 2006) (Abd Elhamid, et al., 2004) (Shimoi, et al., 2004) (Yu, et al., 2006) (Zong, et al., 2006) (Kandlikar & Lu, 2009)which (Kandlikar & Lu, 2009)has exhibited that the phenomenon of overflowing is strongly affected by the distribution of temperature due to its dominance of condensation / evaporation process in the cathode. On the other hand, several causes have been identified for the dehydration of PEMFC which increases the proton conduction resistance. A relatively low humidification, a high stoichiometric ratio with either a high temperature or just a high temperature can easily cause the membrane as a subject of dehydration. An electroosmotic drag, a displacement of the water molecules from the anode to the cathode by a proton flow also leads to dehydration. Like the other difficulties presented, another thermal imposing problem is the non-uniform temperature distribution in the membrane, which exists both through the membrane (Maes & Lievens, 2007) (Lampinen & Fomino, 1997) (Eikerling, 2006) (Berning & Djilali, 2003) (Gloaguen & Durand, 1997) (Kandlikar & Lu, 2009)and along the flow length (Jordan, et al., 2000) (Kandlikar & Lu, 2009). This non-uniformity of temperature, of the order of many degrees, has a considerable impact on the water content of the membrane and the uniformity of current density (Meyers, et al., 2006) (Wilkinson & Vanderleeden, 2003) (Kandlikar & Lu, 2009). But it always remains a need to have an adequate temperature to lead to an improvement of the kinetics of the electrodes as well as the increase of the ionic conductivity in the membrane and the electrodes thus the improvement of power density (Ferng, et al., 2003).A study (Odne, et al., 2014) showed that the thermal conductivity in the membrane clearly depends on the water content, and we will have a 50%

increase in thermal conductivity when the catalytic layer is fairly saturated. Thus an increase of 33% temperature difference between the gas flow field plates and the PEM fuel cell, with a catalytic layer moderately moistened. A high proton conductivity depends essentially on the water content of the membrane (Ben-Attia, 2013). Nevertheless, we have a great correlation between water content and thermal conductivity in the membrane (Burheim, et al., 2010) (Burheim, et al., 2011). The presence of water is known by increasing the thermal conductivity of the Porous Transport Layer (Burheim, et al., 2011) (Wang & Gundevia, 2013) (Burheim, et al., 2013)and the membrane of the PEM fuel cell (Burheim, et al., 2010) (Khandelwal & Mench, 2006) (Odne, et al., 2014). This problem is the subject of many works in order to minimize a study of (Paul, et al., 2011) presented that among the suggested measures is to take in consideration the water content in the materials of the membrane as well as the thickness of the membrane, because more the membrane is thin the water content and the conductivity of the protons also fluctuate.

We realize that to have a good functioning of the cell and have the best performance, we will have to manage the amount of heat and the water content in order to maintain the best operating conditions of the membrane and ensure a balance between the water and humidification rate, while keeping a necessary amount of heat to satisfy the proper functioning.

5.2 Efficient Management and Evacuation of the Thermal Power Produced Inside the PEM Fuel Cell System

Generally, as described above, in the fuel cell the electric power supplied is almost the same as the thermal power and must be evacuated to avoid overheating hence the degradation of the components of PEM fuel cell and especially the membrane. An appropriate thermal management of the heat generated inside the cell ensures a uniform distribution in space and time in order to avoid high temperature points in the cell generally and specifically in the membrane, as well as to ensure a higher electrical efficiency. Therefore the cooling system must be efficient and ensure a proper coolant circulation and provide a more uniform temperature distribution in the stack of fuel cell (Ravishankar & Arul Prakash, 2014)to optimize the system and ensuring a high overall cell yield (Pandiyan, et al., 2008). In the same vision a study carried out (Rojas, et al., 2015)has showed that a good distribution of water channels can homogenize the temperature variation throughout the stack. So following the effect of cooling by the distribution of water in the channels, the temperature of the cells in a Stack is fairly similar and that the greatest temperature difference is close to the last plates (In the first cell, the temperature is higher due to the lack of water channels between the first side plate and the first cell. And that the last cell of the series has a lower temperature, because of the presence of water channel, and there is no production of electricity between the last cells in the second side plate). This study clearly stated that heat can be dissipated in an effectively by this cooling system achieve, this method has prevented overheating of the cells to ensure the stability of operation and to maintain the cell. But the effectiveness of this system cells must be under operating conditions identical to each other. What in reality is not feasible for different reasons such as the location of the cell and channel cooling and the general design of the fuel cell, therefore a control system is strongly recommended to ensure the efficiency in order to properly maintain and control the uniform distribution of heat (Strahl, et al., 2014) (J. Bvumbe, et al., 2016). Moreover, a poorly designed cooling system accelerates the general deterioration of the components of PEM fuel cell, involving the lowering of the overall yield, that means a good thermal management maintain the overall system functionality and improves the overall yield. In this context the study by (Alleau, Révision Octobre 2014)proposed some measures in order to successfully achieve heat evacuation, firstly one of the essential is to ensure a circulation of a coolant in the bipolar plates every 2 to 3 cells, then for a more efficient heat evacuation, we can equip the bipolar plates with the cooling fins to promote its cooling, put a system of forced circulation of air to the outside, as well as the injection of the air humidify with water at the entrance of the PEMFC which will remove an amount of heat by partial evaporation.

The system must be continually examined to ensure the durability of the different functions of all components by a control set. In addition to ensure proper functionality of the membrane and have a good protonic conduction, we will have to ensure both a temperature distribution and an adequate humidification, as well as appropriate drainage of the water produced by the reaction during operation by an air flow introduced to the cathode. This airflow must be important for a better distribution of the oxygen concentration and for the drainage of produced water. One last point to have a good performance and better performance in each cell of the PEMFC we will have a supply of pure hydrogen and oxygen in order to have optimal operation (Baek, et al., 2011). A very high purity of gases is required, because the membrane / electrode assembly is extremely sensitive to all impurities in the water (Varkaraki, et al., 2003) (Colliera, et al., 2006) (RABIH, 2008).The more pure the reactants, the more we will not have impurities which hinders the reactions in both electrodes reaction, which implies optimal functioning.

6 HEAT AND POWER COMBINATION (COGENERATION) (CHP)

The catalytic oxidation during operation of the PEM fuel cell is an exothermic reaction, therefore this oxidation generates a very significant amount of energy as heat. Its temperature generally ranges from 60 to 80 ° C, that we must adapt it effectively to avoid overheating the PEMFC. On other hand all the same we need to keep an adequate temperature for the system to ensure proper functioning. The figure (Fig.3) shows the overall distribution of thermal evacuation, while a part evacuated by the reagent of overloading a second part by spontaneous heat transfer, as well as a part is dissipated by vaporizing some of the water produced and the remaining part of heat requires an appropriate cooling system.

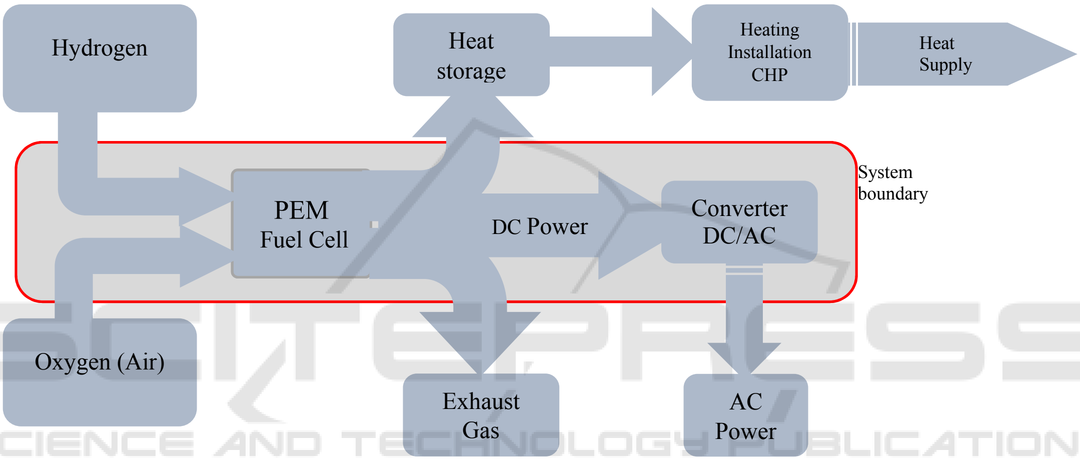

Figure 2: Fuel cells used in CHP application.

The temperature difference between the PEMFC and the ambient temperature of the environment constitutes a challenge for the design of a slight cooling system that can work in a desirable manner (Kandlikar & Lu, 2009) (Rogg, et al., 2003) (Islam, et al., 2015). But although the principle of cooling is simple, its implementation is a real industrial and technological challenge. The production of the electricity by PEM fuel cell always leads in parallel to a heat generation. With an energy conversion efficiency that tends to 55% (Islam, et al., 2015). This implies the existence of a fairly large amount of produced heat that is in the same order of the electrical power (Barbir, et al., 2005) (Tekin, et al., 2006). So in this case appear the interest of exploiting the heat generated by the PEM fuel cell in a system of cogeneration (combined heat and power CHP). The technology of cogeneration manifests itself as a better solution to avoid the energy dissipation, Whose the overall interest of the use of the technical CHP is lies in the possibility of reusing the heat generated in the other applications combined heat and power (CHP) (Fig.2).

In the case of PEM fuel cell, cogeneration is an ideal way to use residual heat generated, during fuel cell operation to improve its efficiency. The cogeneration has a very efficient form of energy conversion that can improve yields by over 90%. The overall efficiency of cogeneration is the sum of net electrical and thermal efficiency of cogeneration systems operated.

Several researches carried out around this subject which showed the interest of this technology, one of them (Hubert, 2005) showed that the fuel cell (PEMFC) is a promising technology not just an the huge system of cogeneration but also mainly for micro-Cogeneration (CHP).For several years, the research is moving towards this energy sector and especially gas companies and Japanese industrial groups are very active in research and development on the use of PEMFCs for micro-cogeneration (Inaka & Al, 2002) (Geiger & Cropper, 2003) (Hubert, 2005).In order to have a qualitative and quantitative understanding of this type of system; many research projects are carried out on PEMFC operated on cogeneration in several European countries such as Belgium and Germany (Pokojski, 2004) (Frey, et al., 2004), these projects have been able to deliver good electrical efficiencies that have been able to go up to 38% and 40% of thermal efficiency. Nevertheless, in parallel with these progress different technical complications and the high operating and maintenance costs have occurred to limit its exploitation. The cogeneration technology remains unmatched in terms of efficiency and yield in this power field. The study of (Hubert, 2005) has exhibited that small stationary fuel cell systems powered by natural gas and exploited in cogeneration are at a phase of technological and commercial development which suggests a close commercialization if we manage to reduce its high cost and stringent maintenance requirements which prevent it from being widely marketed.

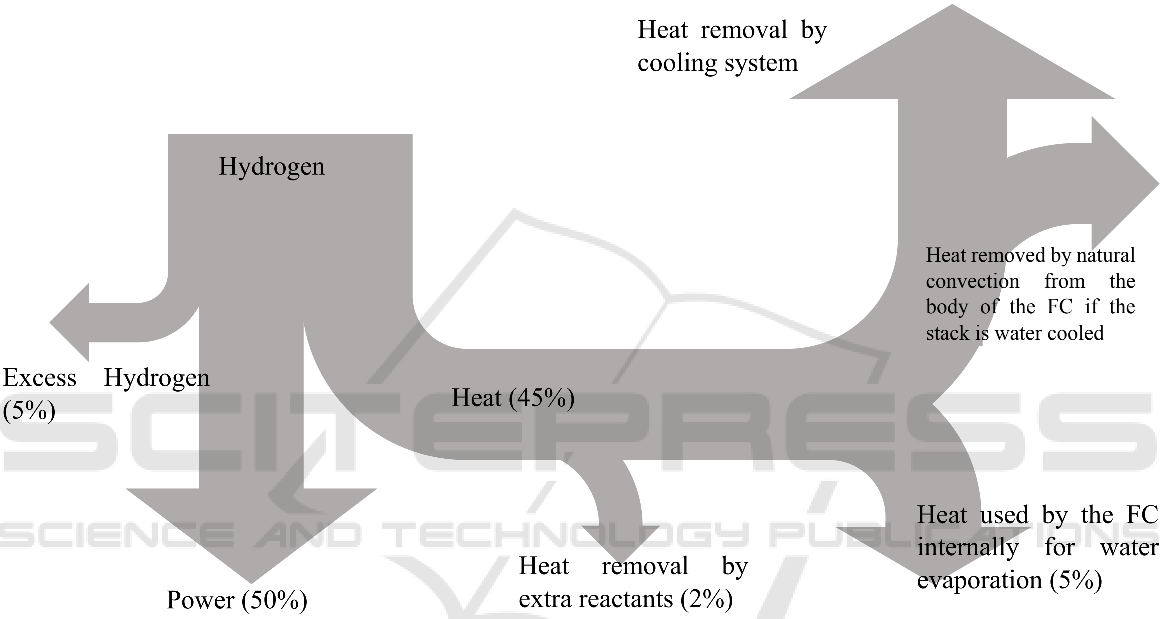

Figure 3: Sankey diagram of the energy distribution produced by the PEMFC (Islam, et al., 2015)

7 CONCLUSION

A large amount of thermal energy has been retained in the stack, so it is necessary to evacuate this energy to avoid excessive heating, which can lead to many problems. In this manuscript we showed and analyzed the influence of the heat produced inside the PEM fuel cell and the tools for leading to the dissipation of this thermal energy, to avoid precipitous deterioration of the PEM fuel cell. As well as s the possibility of exploiting it by cogeneration in another system, in order to avoid losses and achieve higher profits from the chemical energy wasted in the form of thermal energy instead of electrical during reaction. So the use of residual heat produced by PEMFC that is normally rejected by conversion systems. Cogeneration technology is one of the promising solutions, having real potential to save primary energy and improve overall yield. The main reason for this potential is to save primary energy and exploit the thermal energy instead of throwing it away. Finally, we generally realize that the improvement of the materials used, the optimization of the overall operation and the knowledge of the phenomena taking place in the heart of the pile, these are the keys to better optimization for the system but still require significant research efforts. This study allowed us to have a good understanding on the manipulation of the different parameters influencing the thermal management during operation As well as to understand what is happening inside the studied environment. Although the operating principle of the fuel cell is simple, its implementation remains a real industrial and technological challenge.

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