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Thermal and Structural Simulation for Bipolar Plate in Polymer Electrolyte Membrane Fuel Cell (PEMFC) Stack

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Abstract- Thermal and structural analysis is one of the basic elements desired to guarantee great performance polymer electrolyte membrane fuel cell (PEMFC) stacks and plays a necessary part in fuel cell stack performance ,comprehensive system efficiency and durability .The choice of the great performance stack upon on the particular application, weight, size, complexity, cost and design. This study presents a three-dimensional model includes the structural and the thermal analysis into a novel Model bipolar plate in (PEMFC).The Analysis was performed to evaluate the temperature distribution and structural deviation as well as displacement values in three dimensional models. Also, this advance model combines the effect of stresses due to temperature gradient and external load. The modeled field was forming from three various domains and there are various material models current for both titanium and aluminum. The results showed that maximum temperature occurs at the second domain and decrease gradually as we head toward the surrounding of the plate and it is a minimum at outer surfaces. On the other hand the thermal loads create stresses that are one order quantity of magnitude bigger than those produced by the exterior pressure loads. The maximum stresses gradient occur at the buffer region between the first domain and the third domain and the stresses is almost uniformly distribution at the second domain and some part of the first domain. Furthermore, the loads are far from the dangerous values; however the displacements can be significantly more critical.

Keywords- Polymer electrolyte fuel cell Stack; Thermal Analysis; structure Analysis and bipolar plate.

I. INTRODUCTION

Providing safe sources of energy is the most important concern for the world's governments. Fossil fuels are no longer a reliable source. On the one hand, it is near its depletion in addition to the sudden fluctuation of its prices, which negatively affects the economies of the world as a whole [1]. On the other hand, when it is burned, it emits number of serious environmental pollutants that caused serious global issues such as climate change and global warming [2]. The search for alternative sources of fossil fuels was confined to the important concept that these sources must be renewable and environmentally friendly. These energies include solar [3, 4], wind [5, 6], waves [7, 8], geothermal [9, 10], biofuels [11, 12], and fuel cells [13, 14].

Among these renewable energies, solar energy is the most widespread in terms of different applications. For example of these applications there are heating water [15], heating air [16], heating and ventilating the rooms using a Trombe wall [17, 18], heat production using solar ponds [19, 20], and solar distillation [21]. In generating electricity there are several main methods such as solar chimney [22, 23], concentrated solar power plants [24- 25], and solar cells [26-30]. The disadvantage of solar systems is the fluctuation of their production affected by weather conditions [31, 32], energy storage [33, 34], and the negative impact of dust [35, 36], shade [37, 38], and clouds on their productivity [39].

Many researchers consider the future of solar energy to be stored as hydrogen produced by solar electrolysis of water [40, 41], or by concentrated solar water heating [42, 43]. The production of solar hydrogen from water and then its use in fuel cells will result in water only with heat and thus the solar energy has been stored and then used to produce energy and water note that water is available around the world. Fuel cells are Energy units that product power out of electrochemical responses. In fuel cell (PEMFC), a membrane isolates oxidation while decrease half responses [44, 45]. The hydrogen gas was used as a fuel and the immaculate or surrounding air was used as an oxidant [46, 47]. Heat and water are the main side effects of this response. PEMFC are considered as futurity gadgets to versatile, fixed, and compact force implementations due to their high power adequacy, nil emission, minimum clamor and possibility utilize of renewable energizes. Nonetheless, PEMFC frameworks are not right now practical; expanding their proficiency for stationary and transportation implementations can enhance their marketing [48-50].

Transition of energy, mass, species, charges and momentum are the complex processes that happen in one time through working of a PEMFC. Parts of a PEMFC are collected from cathode flow channels, anode, the membrane, diffusion layers of gas (GDLs)), and layers of catalyst. In the working, atoms of hydrogen followed to the anode and Detachable to electrons and protons. The cell membrane leads protons toward cathode and electrons are supplied cycle an outside circuit. Also, a current is produced to cathode from anode by means of electric burden. Oxygen is expended in the cathode and responds with the particles of hydrogen, delivering heat and water [51-53].

Since its inception and until today, fuel cells are experiencing rapid development in terms of the use of new and improved materials [54], new structures [55, 56], higher energy productivity [57, 58], high improvement in their components and assembly methods [59, 60], which clearly reflected fuel cell performance, efficiency, ease of manufacturing, and production costs.

Impact of Temperature on Performance of Fuel Cell

A simple method to enhance the cell performance is when the device works at its highest permitted temperature. When temperature increases, electrochemical activities rise and reaction happens at a maximum rate, which thus raises the efficiency. Furthermore, operating temperature influences the ultimate theoretical voltage at which a fuel cell can work. Higher temperature agrees with minimizing theoretical efficiency and smaller theoretical maximum voltage [61-65].

Also, the fuel cell temperature affects humidity of fuel cell, which greatest impacts on ionic conductivity of membrane. Consequently, it leads an indirect impact in the product energy and its influence in the water volume for the membrane. The maximum working temperature must be lower than 100°C during a PEMFC works at low pressure [66, 67].

In addition, the cell temperature increases with increased membrane electrolyte strength, causing its long-term degradation [68]. Here, the membrane electrolyte can be determined from PEMFCs, especially when using Nafion® polymers, which have a glass transition temperature of 80 to 120°C, resulting in MEA damage [69]. Indoh et al. [70] explained that polymer fluorofluorosulfone when used in low humidity conditions and temperatures close to 80°C cause the cell to suffer from deterioration in its performance. The durability of the Nafion® membrane is another variable to be considered as it limits the maximum working temperature to 80 ° C.

The cell's operating temperature must be predetermined by ensuring the strength of the electrolyte and the safety limits of the PEMFC thermal reaction. The main purpose of thermal management in a fuel cell is to ensure that the stack operates within a predefined range of temperatures. Within this range, thermal management can be provided to produce a more uniform distribution of temperature in the fuel cell [71, 72]. Therefore, providing an effective design solution for stack performance needs a detailed understanding of its role. Oosterkamp [73] demonstrated that he prefers heat transfer to approved systems to provide a safer operating environment for cells. The preparation of a thermal model is important to study the effectiveness of various thermal management procedures.

Several researches are accessible on numerical modeling Also; a less number of these researches have focused in the area of management and thermal modeling. Many researchers studied PEMFCs using CFD models. Ref. [74] presented an extensive review of CFD models in literature, ranging from one-dimensional models to 3D models. The study focused on research that focused on mass and heat transfer. The study included common procedures and assumptions, applications of solutions and numerical algorithms, as well as mathematical methods. The researcher also presented a review of commonly used simulations [75].

Amongst the computational heat transfer models, Yu and Jung [75] built up a (2-D) model of a cell and examined a transfer of heat administration for cells that extensive effective cell regions. Also, they were collected of models with the transport of water. that model of heat was centered around rejection of heat from cell to the water and incorporated the heat conduction into rejection of heat (by convective) to gases and water stream. The model (thermal management) of consists of radiator, pump (for cooling) and fan for exploring the trade-off between the temperature allocation effect and losses parasitic.

Pharoah and Burheim [76] displayed thermal model in (2-D) distributions of temperature in a cell in the surface perpendicular on cathode stream. In this work, transfer of heat conduction was calculated. Shimpalee and Dutta [77] developed thermal model of a three-dimensional, which resolved the equation of energy to prophesy the temperature allocation in a cell channel. They studied the heat produced outcome by the reactions of electro-chemical on the performance of cell.

The dynamic model of a three-dimensional model was developed by Adzakpa et al. [78]. This model was a single cell to demonstrate phenomena, for example, the voltage degradations and cell humidity. Their model of heat transfer consists of the heat generation and conduction in body of cell while the convective on the surface. Convection Heat was not considered in the model of.

Sinha and Wang [79]. presented A comprehensive model of three-dimensional which computed analysis in a one-channel of transport heat, charge, and species in They researched the PEMFC performance at maximize temperature. Also, a condition of fixed wall temperature was considered on all the outside bodies.

Ju et al. [80] displayed the thermal model of a three-dimensional, combined with mass and electrochemical transport to compute water and thermal management in cell. This work demonstrates that the impact of heat on cell turns out to be more basic at maximum intensity and/or minimum gas conductivity.

This article aims to evaluate the impact of thermal and structural stresses using computer simulation software (COMSOL Multiphysics 4.4).

II. MODEL DESCRIPTION

This research presents a three-dimensional model that combines the structural and the thermal analysis into a bipolar plate in (PEMFC).The stack of fuel cell consists of unit cell of cathode, membrane, and anode associated in arrangement through bipolar plates. Also, the bipolar plates render like gas distributors for air and hydrogen that is fed to the cathode and anode compartments, respectively. Figure 1 demonstrates a schematic designing of a fuel cell stack.

One of the most robust alternatives for car applications is The PEMFC which has the capability of delivering energy to a car with a higher efficiency, from oil to drive, than the interior ignition motor .The PEMFC works at temperatures just underneath 100 °C, which implies that it should be heated at starting work. Also, that heating process creates thermal stresses into bipolar plates. This analysis shows the nature and magnitude of these stresses.

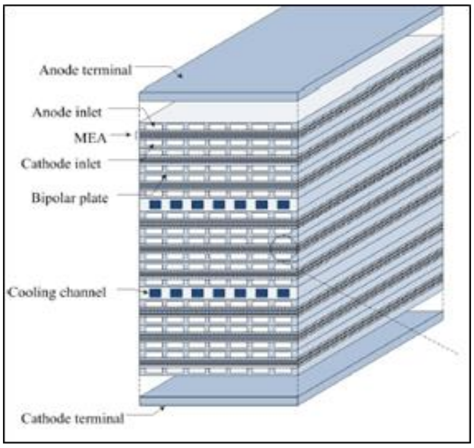

Figure 1: A schematic of a fuel cell stack [12].

Figure 2 demonstrates the exhaustive model geometry. The bipolar plates consists the slits of gas that shape the gas paths or channels in the fuel cell, punctures for the tie bars that hold the stack with each other, and the elements of heating, which are situated in the midst of the gas supply channels .Because of symmetry, it is conceivable to reduce the model to 1/8 of the real size of the bipolar plates.

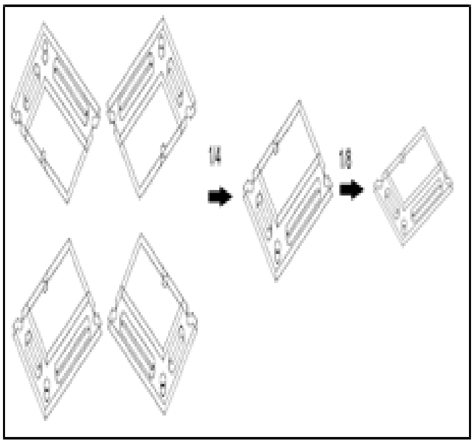

Figure 2: The model geometry

The study involves analysis (thermal-structural) .In the next specification of the issue various of constants are utilized; their constants are recorded in the next table. The constant Q1 defines a power of 200 W divided on the hole out of the 25 bipolar plates in the stack.
The general equation:

$\nabla \cdot (-k\nabla T) + Q = 0$ …… heat equation in steady-state
Where
k = thermal conductivity of the materials
T = temperature
and Q= a heat sink or heat source.

Table I

CONST.	VALUE	DESCRIPTION
$Q1$	200/25/(π0.005^2·0.01) W/m3	Volume power
$h1$	5 W/(m2·K)	Surroundings Heat transfer coefficient
$h2$	50W/(m2·K)	gas channels Heat transfer coefficient
$P1$	9.82·105 N/m2	active part Pressure
$P2$	7.85·106 N/m2	the manifold Pressure

The modeled field was forming from three various domains. The main domain coincides to the cell active part, and the electric power is delivered and the current is connected. The generation and connection of current include some losses. It is supposed that the fuel cell is heated before operation. This implies that the model does not consider for the heat sources because of the generation and connection of current as shown in the Figure 3. The second domain relates to the heating component into the bipolar plate and made from aluminum. The power of this component is supposed to be uniformly divided in the short cylindrical domain. The last domain shapes the manifold into cell. Also, it is made of titanium as shown in Figure 3. In this domain, just heat conduction is available.

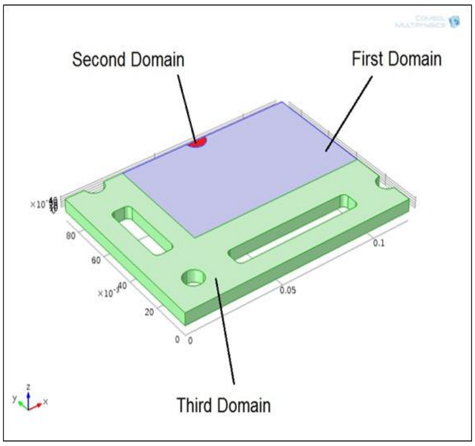

Figure 3: The domains of the model geometry

There are various material models current for both titanium and aluminum. The boundary conditions for the thermal analysis are symmetry and convective conditions as demonstrates in figure 5. The symmetry condition expresses that the flux over the boundary is zero.

$(-k\nabla T) \cdot \mathbf{n} = 0$

The convective conditions are the heat flux commensurate to the temperature difference through the fluid outside and the temperature in the boundary see Figure 4 .The coefficient of heat transfer is the proportion constant:

$(-k\nabla T) \cdot \mathbf{n} = h(T - T_{fluid})$

In this equation,
h = heat transfer coefficient.
T = temperature

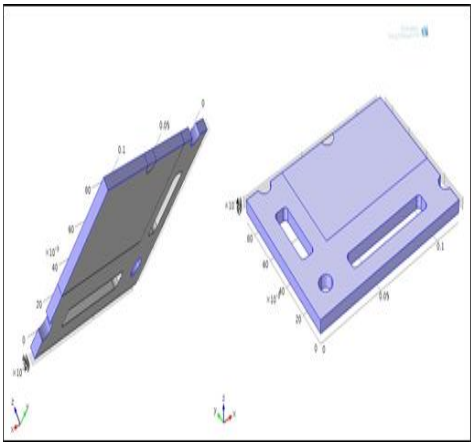

Figure 4: The symmetry boundaries

The thermal extension creates the stresses in the plate. The thermal stresses are proportional to the difference in temperature between the reference case and the real temperature. The constrains are mandatory on the symmetry planes as shown in Figure 5 .The value of displacements vertical to the boundary is equal to zero.

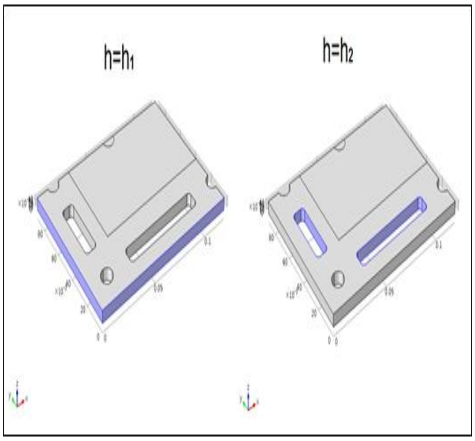

Figure 5: The convective boundaries

Also, the load connected by the tie bars on the stack is connected in the active part and the manifold at the bipolar plate. The pressure is diverse in these two domains, as demonstrates in Figures 6 & 7. The pressures and constraints on other boundaries are thought to be insignificant. In this setting, the only doubtful assumption is the possible pressures and constraints mandatory by the tie bars on the punctures in the bipolar plate. Furthermore, it is conceivable to couple a model for the bars with a model of the plate. In all probability the pressure on these different parts would demonstrate different gradients.

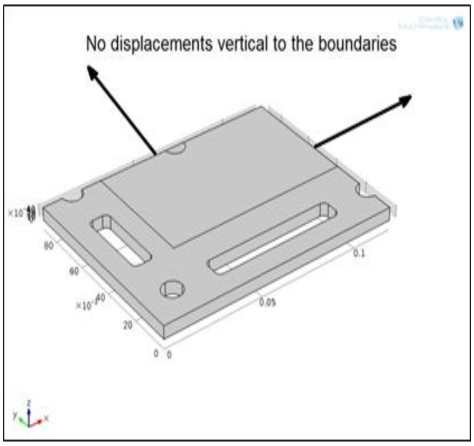

Figure 6: The symmetry boundaries

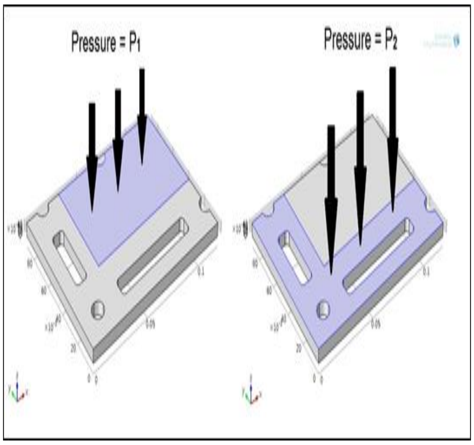

Figure 7: Pressure due to the bar connection

Grid Independency

COMSOL Multiphysics 4.4 software was used to generate the computational model domain (see Figure 8).

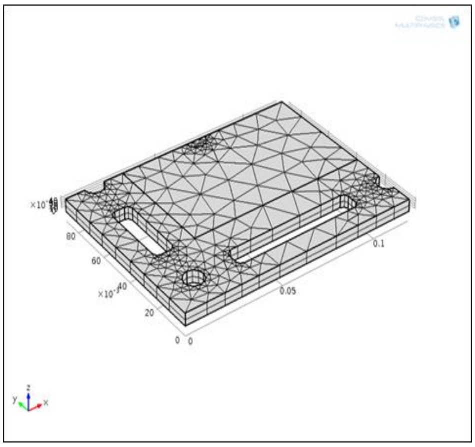

Figure 8: The mesh of model geometry

The network was divided into three different levels (3.1 × 105, 6.9 × 105 and 1.5 × 106) and was compared to local temperature conditions and changes of pressures and speeds to ensure a comprehensive network analysis. The results of the test showed a deviation of 1.1% for the size of the network (6.9 × 105) compared to the size of the network (1.5 × 106). For the case of network (6.9 × 105) results showed that the deviation rises to 6.8% compared to the size of the network (3.1 × 105). Hence, a mesh size nearly (6.9×105) was sufficient to the computational investigation purposes .

III. RESULTS AND DISCUSSION

Industrialization of such fuel cell required industrialization process technology which was impossible in Iraq, therefore, a numerical simulation was utilized and model of bipolar plate was investigated.

To solve the model of differential equations, the COMSOL Multiphysics 4.4 was used. A system of network independence is created and tested by solving an existing situation and by examining several sizes of the influencing elements' sizes, which can be used to obtain similar results. In this study, the air temperature was 20°C while the gas temperature was 80°C and the heat source in plate was (200/25/ (pi*0.005^2*0.01))w.

In this study there are two types of Analysis, thermal and structure analysis. Simulation conclusions give a detailed visualization about temperatures distribution, stresses and displacement. As results of the modeling of bipolar plate and during operation the heat was generation in plates due to heating source in the second domain and this is the main reason to increase the temperature in the plate as shown in the Figure 9, which reveals the contours of temperature profile at (x-y) plane. From this figure we see that the highest temperature happens at the second domain and decrease gradually as we head toward the surrounding of the plate and it is a minimum at outer surfaces. Also, figures (10) and (11) exhibit the temperature distribution in (y-z) and (x-z) respectively.

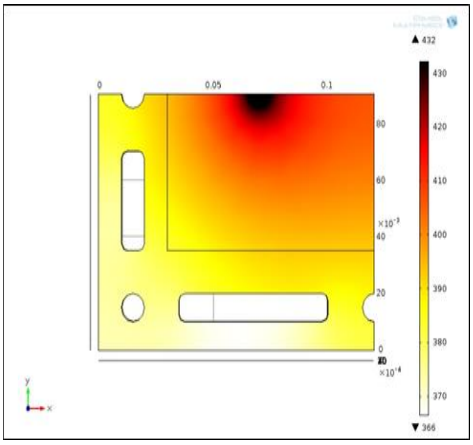

Figure 9: The contours of temperature profile in Kelvin at (x-y) plane

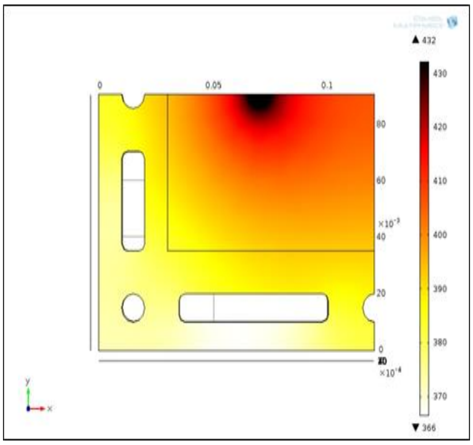

Figure 10: The temperature profile in Kelvin at (y-z) plane

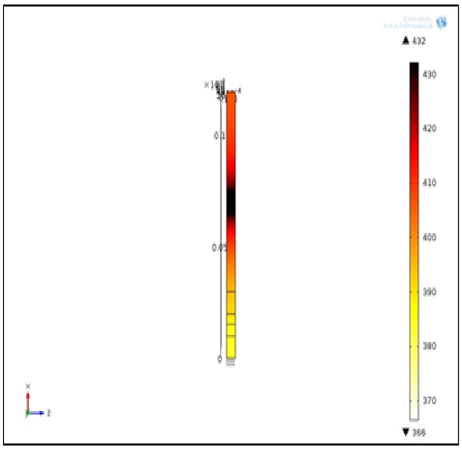

Figure 11: exhibit the temperature distribution in Kelvin at (x-z) plane

Furthermore, the temperature around button gas channel is less than the temperature around side gas channel, that is due to the size of channel at the button channel is bigger than that in side channel as shown in the Figure 12. This leads the convection heat transfer in button gas channel is larger than the convection heat transfer in side gas, which is due to area of convection heat transfer in button gas channel is larger than that in side gas channel as demonstrates in Figure 12.

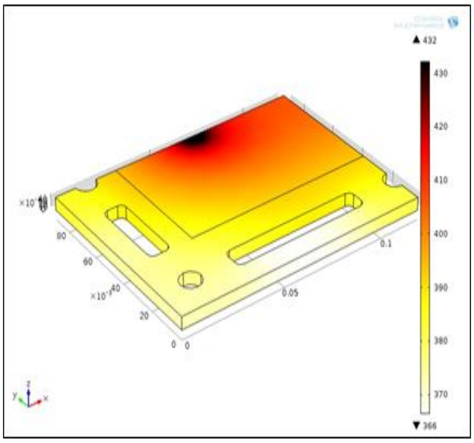

Figure 12: The contours of temperature profile (3-D) in Kelvin

Figure 13 exhibits the stress distribution for the modeling of bipolar plate at (x-y) plane and this indicated that the maximum stresses gradient occur at the buffer region between the first domain and the third domain. This is because of maximum temperature gradient at this region.

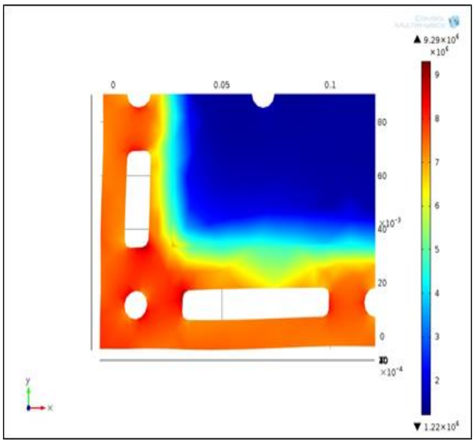

Figure 13: The stress distribution in (N/m^2) at (x-y) plane

Also, the stresses is almost uniformly distribution at the second domain and some part of the first domain, this is because assumed that the plate is heated prior operation. And stresses start to deform as we head toward the third domain due to temperature deviation at this region. Also, Figures (14) and (15) clearly the stresses distribution in (y-z) and (x-z) respectively.

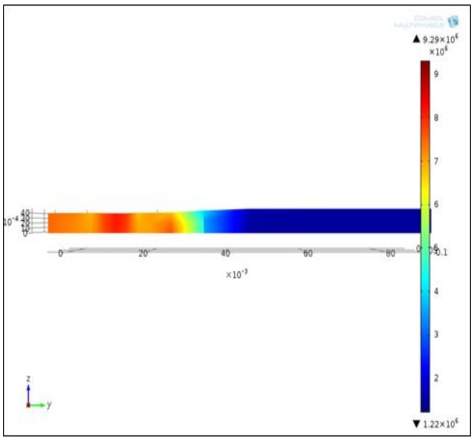

Figure 14: stress in (N/m^2) at (y-z) plane

Moreover, Figure 16 demonstrates that the thermal loads create stresses that are one order quantity of magnitude bigger than those produced by the exterior pressure loads (which you can calculation by stop the thermal expansion). The loads are far from the dangerous values; however the displacements can be significantly more critical. The displacements must be sufficiently little to give that the membrane can satisfy its job in separating oxygen and hydrogen in the cathode and anode compartments, respectively. The displacement in the z-component is shown in Figure 17.

Also, the stresses value near button gas channel is less than that near side gas channel that is because of the temperature gradient near the button channel is less than that in side channel as shown in the figure 17.

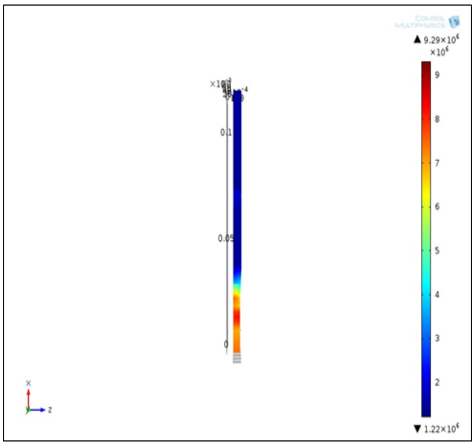

Figure 15: stress in (N/m^2) at (x-z) plane

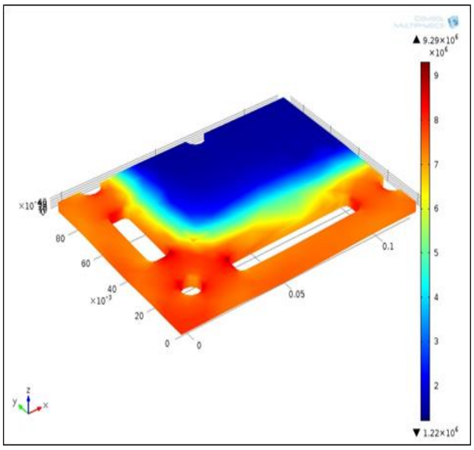

Figure 16: demonstrates the stresses (3-D) in (N/m^2) because of external loads and temperature

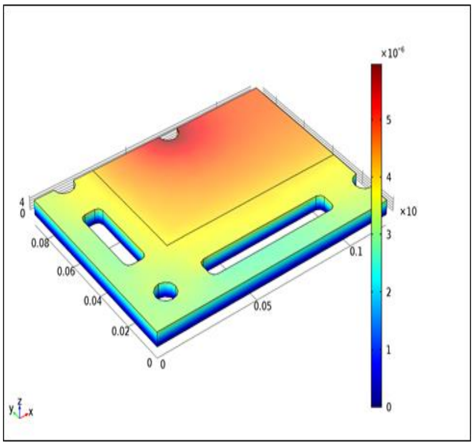

Figure 17: The displacement in the z-direction in (m)

IV. CONCLUSION

With a specific end goal to create systems with great performance and high efficiency of Cell, computational demonstrating is a suitable technique that has been highly reliability in last years. In the presents research a (3-D) model includes the structural and the thermal analysis into an Advance Model bipolar plate in (PEMFC).The proposed plate can be utilized and optimization for PEMFC systems. The Analysis was performed to evaluate the temperature distribution and structural deviation as well as displacement values in three dimensional model. The results showed that maximum temperature occurs at the second domain and decrease gradually as we head toward the surrounding of the plate and it is a minimum at outer surfaces. On the other hand the thermal loads create stresses that are one order quantity of magnitude bigger than those produced by the exterior pressure loads. The maximum stresses gradient occur at the buffer region between the first domain and the third domain and the stresses is almost uniformly distribution at the second domain and some part of the first domain. Furthermore, the loads are afar from the dangerous values; however the displacements can be significantly more critical. For the next study, it is additionally conceivable to combine the present (thermal - structural) model with an execution model to research the impacts of parameters, like humidity, that impact the plate performance and lastly change the generation of heat in the stack.

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