

INVESTIGATION OF FUEL CELL MODELS AND CREEP EXPERIMENTS

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Glossary of Terms in table:

Anode: The electrode at which oxidation (a loss of electrons) takes place. For fuel cells and other galvanic cells, the anode is the negative terminal; for electrolytic cells (where electrolysis occurs), the anode is the positive terminal.

Aqueous solution: a: of, relating to, or resembling water b : made from, with, or by water.

Catalyst: A chemical substance that increases the rate of a reaction without being consumed; after the reaction, it can potentially be recovered from the reaction mixture and is chemically unchanged. The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly or at a lower temperature. In a fuel cell, the catalyst facilitates the reaction of oxygen and hydrogen. It is usually made of platinum powder very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so the maximum surface area of the platinum can be exposed to the hydrogen or oxygen. The platinum-coated side of the catalyst faces the membrane in the fuel cell.

Cathode: The electrode at which reduction (a gain of electrons) occurs. For fuel cells and other galvanic cells, the cathode is the positive terminal; for electrolytic cells (where electrolysis occurs), the cathode is the negative terminal.

Electrolyte: A substance that conducts charged ions from one electrode to the other in a fuel cell, battery, or electrolyzer.

Fuel Cell Stack: Individual fuel cells connected in a series. Fuel cells are stacked to increase voltage.

Matrix: something within or from which something else originates, develops, or takes form.

Membrane: The separating layer in a fuel cell that acts as electrolyte (an ion-exchanger) as well as a barrier film separating the gases in the anode and cathode compartments of the fuel cell.

Molten carbonate fuel cell (MCFC): A type of fuel cell that contains a molten carbonate electrolyte. Carbonate ions (CO_3^{2-}) are transported from the cathode to the anode. Operating temperatures are typically near 650 °C.

Phosphoric acid fuel cell (PAFC): A type of fuel cell in which the electrolyte consists of concentrated phosphoric acid (H_3PO_4). Protons (H^+) are transported from the anode to the cathode. The operating temperature range is generally 160–220 °C.

Proton exchange membrane fuel cell (PEM): A fuel cell incorporating a solid polymer membrane used as its electrolyte. Protons (H^+) are transported from the anode to the cathode. The operating temperature range is generally 60–100 °C.

Solid oxide fuel cell (SOFC): A type of fuel cell in which the electrolyte is a solid, nonporous metal oxide, typically zirconium oxide (ZrO_2) treated with Y_2O_3 , and O^{2-} is transported from the cathode to the anode. Any CO in the reformat gas is oxidized to CO_2 at the anode. Temperatures of operation are typically 800–1,000 °C.

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ABSTRACT

We aimed to determine to investigate fuel cells technologies and mechanical experiments for detailed research with models. These models provide information on mechanical properties. Fuel cell's technology types and parts were analyzed. Articles were reviewed. The results of the creep and relaxation experiments of the materials were analyzed and graphed using Matlab. The results of the tests are detailed with graphics. Theoretical results were analyzed. Maxwell and Kelvin models were compared. In summary: we are determinig the effects of mechanical effects on fuel cell.

ÖZET

Yakıt hücresi teknolojisi ve mekanik modeller incelenerek deney sonuçları incelenmiştir. Modeller, mekanik özellikler hakkında bilgi vermiştir. Yakıt hücresi teknolojisi, türleri ve kullanılan malzemeler araştırılmıştır. Makaleler incelenmiştir. Farklı malzemelere uygulanan sürünme ve gevşeme deneyleri analiz edilmiştir. Deney sonuçları Matlab kullanılarak grafik haline getirilmiştir. Teorik değerler incelenmiştir. Maxwell ve Kelvin modelleri karşılaştırılmıştır. Özetle, mekanik etkilerin yakıt hücresi üzerindeki etkilerini belirlenmiştir.

1. INTRODUCTION

There are many ways to convert energy into electricity. Mostly combustion reactions are used. For it, reserves such as oil and natural gas are needed but their reserves are rapidly depleted. Furthermore, this situation pollutes the environment and damages the nature and humanity. It causes serious problems such as global warming. Alternative energy has come to the fore to avoid this. One of the alternative energy sources is hydrogen. The main energy source of the universe. The hydrogen element was discovered in the 1500s, and in the 1700s it was recognized that it was capable of burning. Hydrogen has the highest energy content per unit mass in all known fuels. The energy of 1 kg of hydrogen has the energy of 2.1 kg of natural gas or 2.8 kg of oil. However, the volume per unit energy is high. The product thrown into the atmosphere is only water and / or water vapor. Hydrogen is an average 33% more efficient fuel than petroleum fuels. During the generation of energy from hydrogen, no gas and harmful chemicals are used to pollute the environment and increase the greenhouse effect except water vapor. It provides highly efficient and clean energy. hydrogen is the most abundant element (%74.5) in the universe. The energy it carries can easily be converted into electrical energy. Fuel cell technology that provides hydrogen electricity generation is also a renewable energy source of the future. In a Fuel cell it is possible to convert the energy of the fuel directly into electrical energy. The fuel and oxidizer are located in different compartments and do not mix. Their union is only carried out by ion and electron transfer between these compartments. Proton exchange membrane (PEM) fuel cells work with a polymer electrolyte in the form of a thin, permeable sheet. This membrane is small and light, and it works at low temperatures (about 80 degrees C, or about 175 degrees F). Other electrolytes require temperatures as high as 1,000 degrees C. Hydrogen atoms are stripped of their electrons, or "ionized," at the anode, and the positively charged protons diffuse through one side of the porous membrane and migrate toward the cathode. The electrons pass from the anode to the cathode through an exterior circuit and provide electric power along the way. At the cathode, the electrons, hydrogen protons and oxygen from the air combine to form water. For this fuel cell to work, the proton exchange membrane electrolyte must allow hydrogen protons to pass through but prohibit the passage of electrons and heavier gases. The energy efficiency of a fuel cell is generally between 40–60%; however, if waste heat is captured in a cogeneration scheme, efficiencies up to 85% can be obtained. An external reformer is required to convert fuels such as methanol or gasoline to hydrogen. The fuel cell market is growing, and in 2013 Pike Research estimated that the stationary fuel cell market will reach 50 GW by 2020. The first fuel cells were invented in 1838. The first commercial use of fuel cells came more than a century later in NASA space programs to generate power for satellites and space capsules. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. They are also used to power fuel cell vehicles, including forklifts, automobiles, buses, boats, motorcycles and submarines.

2. LITERATURE RESEARCH

TYPES OF FUEL CELLS

There are a lot of types of fuel cells. They are made up of three adjacent segments: the anode, the electrolyte, and the cathode. Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices, normally referred to as the load. At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electric current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide.

Design features in a fuel cell include; the electrolyte substance, which usually defines the type of fuel cell, and can be made from a number of substances like potassium hydroxide, salt carbonates, and phosphoric acid. The fuel that is used. The most common fuel is hydrogen. The anode catalyst, usually fine platinum powder, breaks down the fuel into electrons and ions. The cathode catalyst, often nickel, converts ions into waste chemicals, with water being the most common type of waste. Gas diffusion layers that are designed to resist oxidation.

A typical fuel cell produces a voltage from 0.6 V to 0.7 V at full rated load. Voltage decreases as current increases, due to several factors ; activation loss, ohmic loss (voltage drop due to resistance of the cell components and interconnections), mass transport loss (depletion of reactants at catalyst sites under high loads, causing rapid loss of voltage).

To deliver the desired amount of energy, the fuel cells can be combined in series to yield higher voltage, and in parallel to allow a higher current to be supplied. Such a design is called a fuel cell stack. The cell surface area can also be increased, to allow higher current from each cell. Within the stack, reactant gases must be distributed uniformly over each of the cells to maximize the power output.

Fuel cells are classified primarily by the kind of electrolyte they employ. This classification determines the kind of electro-chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications.

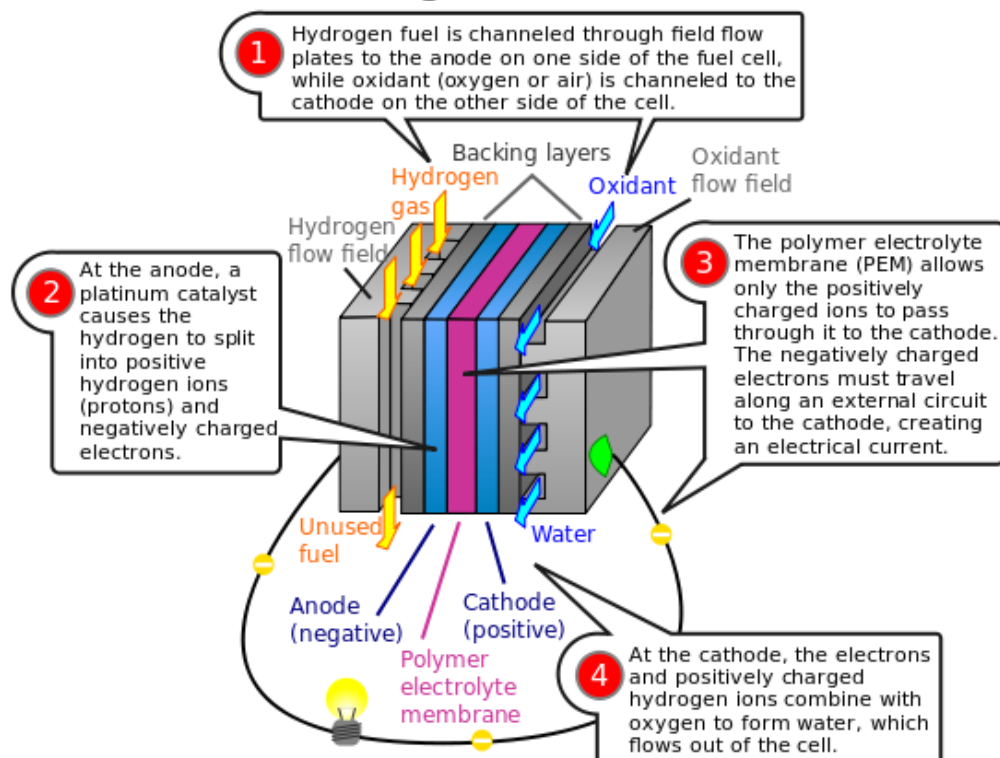
Proton exchange membrane fuel cells (PEMFCs)

Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume compared with other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst. They need only hydrogen, oxygen from the air, and water to operate. They are typically fueled with pure hydrogen supplied from storage tanks or reformers.

PEM fuel cells operate at relatively low temperatures, around 80°C (176°F). Low-temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to carbon monoxide poisoning, making it necessary to employ an additional reactor to reduce carbon monoxide in the fuel gas if the hydrogen is derived from a hydrocarbon fuel. This reactor also adds cost.

PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

Proton exchange membrane fuel cell



Direct methanol fuel cells

Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. Direct methanol fuel cells (DMFCs), however, are powered by pure methanol, which is usually mixed with water and fed directly to the fuel cell anode.

Direct methanol fuel cells do not have many of the fuel storage problems typical of some fuel cell systems because methanol has a higher energy density than hydrogen—though less than gasoline or diesel fuel. Methanol is also easier to transport and supply to the public using our current infrastructure because it is a liquid, like gasoline. DMFCs are often used to provide power for portable fuel cell applications such as cell phones or laptop computers.

Alkaline fuel cells

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water on-board spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. In recent years, novel AFCs that use a polymer membrane as the electrolyte have been developed. These fuel cells are closely related to conventional PEM fuel cells, except that they use an alkaline membrane instead of an acid membrane. The high performance of AFCs is due to the rate at which electro-chemical reactions take place in the cell. They have also demonstrated efficiencies above 60% in space applications.

A key challenge for this fuel cell type is that it is susceptible to poisoning by carbon dioxide (CO₂). In fact, even the small amount of CO₂ in the air can dramatically affect cell performance and durability due to carbonate formation. Alkaline cells with liquid electrolytes can be run in a recirculating mode, which allows for electrolyte regeneration to help reduce the effects of carbonate formation in the electrolyte, but the recirculating mode introduces issues with shunt currents. The liquid electrolyte systems also suffer from additional concerns including wettability, increased corrosion, and difficulties handling differential pressures. Alkaline membrane fuel cells (AMFCs) address these concerns and have lower susceptibility to CO₂ poisoning than liquid-electrolyte AFCs do. However, CO₂ still affects performance, and performance and durability of the AMFCs still lag that of PEMFCs. AMFCs are being considered for applications in the W to kW scale. Challenges for AMFCs include tolerance to carbon dioxide, membrane conductivity and durability, higher temperature operation, water management, power density, and anode electrocatalysis.

Phosphoric acid fuel cells

Phosphoric acid fuel cells (PAFCs) use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and porous carbon electrodes containing a platinum catalyst. The PAFC is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially. This type of

fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses. PAFCs are more tolerant of impurities in fossil fuels that have been reformed into hydrogen than PEM cells, which are easily "poisoned" by carbon monoxide because carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. PAFCs are more than 85% efficient when used for the co-generation of electricity and heat but they are less efficient at generating electricity alone (37%–42%). PAFC efficiency is only slightly more than that of combustion-based power plants, which typically operate at around 33% efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. They require much higher loadings of expensive platinum catalyst than other types of fuel cells do, which raises the cost.

Molten carbonate fuel cells

Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide matrix. Because they operate at high temperatures of 650°C (roughly 1,200°F), non-precious metals can be used as catalysts at the anode and cathode, reducing costs. Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric acid fuel cells. Molten carbonate fuel cells, when coupled with a turbine, can reach efficiencies approaching 65%, considerably higher than the 37%–42% efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be over 85%. Unlike alkaline, phosphoric acid, and PEM fuel cells, MCFCs do not require an external reformer to convert fuels such as natural gas and biogas to hydrogen. At the high temperatures at which MCFCs operate, methane and other light hydrocarbons in these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost. The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that double cell life from the current 40,000 hours (~5 years) without decreasing performance.

Solid oxide fuel cells

Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the electrolyte. SOFCs are around 60% efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 85%. SOFCs operate at very high temperatures—as high as 1,000°C (1,830°F). High-temperature operation removes the need for precious-metal catalyst, thereby reducing cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system.

SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types can. In addition, they are not poisoned by carbon

monoxide, which can even be used as fuel. This property allows SOFCs to use natural gas, biogas, and gases made from coal. High-temperature operation has disadvantages. It results in a slow startup and requires significant thermal shielding to retain heat and protect personnel, which may be acceptable for utility applications but not for transportation. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology. Scientists are currently exploring the potential for developing lower-temperature SOFCs operating at or below 700°C that have fewer durability problems and cost less. Lower-temperature SOFCs have not yet matched the performance of the higher temperature systems, however, and stack materials that will function in this lower temperature range are still under development.

Reversible fuel cells

Reversible fuel cells produce electricity from hydrogen and oxygen and generate heat and water as byproducts, just like other fuel cells. However, reversible fuel cell systems can also use electricity from solar power, wind power, or other sources to split water into oxygen and hydrogen fuel through a process called electrolysis. Reversible fuel cells can provide power when needed, but during times of high power production from other technologies (such as when high winds lead to an excess of available wind power), reversible fuel cells can store the excess energy in the form of hydrogen.

Comparison of fuel cell types

Fuel cell name	Electrolyte	Qualified power (W)	Working temperature (°C)	Efficiency (cell)	Efficiency (system)	Status	Cost (USD/W)
Metal hydride fuel cell	Aqueous alkaline solution		> -20 (50% P_{peak} @ 0 °C)			Commercial / Research	
Electro-galvanic fuel cell	Aqueous alkaline solution		< 40			Commercial / Research	
Direct formic acid fuel cell (DFAFC)	Polymer membrane (ionomer)	< 50 W	< 40			Commercial / Research	
Zinc-air battery	Aqueous alkaline solution		< 40			Mass production	
Microbial fuel cell	Polymer membrane or humic acid		< 40			Research	
Uplow microbial fuel cell (UMFC)			< 40			Research	
Regenerative fuel cell	Polymer membrane (ionomer)		< 50			Commercial / Research	
Direct borohydride fuel cell	Aqueous alkaline solution		70			Commercial	
Alkaline fuel cell	Aqueous alkaline solution	10 – 200 kW	< 80	60–70%	62%	Commercial / Research	
Direct methanol fuel cell	Polymer membrane (ionomer)	100 mW – 1 kW	90–120	20–30%	10–25% ^[34]	Commercial / Research	125
Reformed methanol fuel cell	Polymer membrane (ionomer)	5 W – 100 kW	250–300 (Reformer) 125–200 (PBI)	50–60%	25–40%	Commercial / Research	
Direct ethanol fuel cell	Polymer membrane (ionomer)	< 140 mW/cm ²	> 25 ? 90–120			Research	
Proton exchange membrane fuel cell	Polymer membrane (ionomer)	1 W – 500 kW	50–100 (Nafion) ^[55] 120–200 (PBI) ^[56]	50–70%	30–50% ^[54]	Commercial / Research	50–100
RF-C – Redox	Liquid electrolytes with redox shuttle and polymer membrane (ionomer)	1 kW – 10 MW				Research	
Phosphoric acid fuel cell	Molten phosphoric acid (H ₃ PO ₄)	< 10 MW	150–200	55%	40% ^[54] Co-Gen: 90%	Commercial / Research	4–4.50
Solid acid fuel cell	H ⁺ -conducting oxyanion salt (solid acid)	10 W - 1 kW	200–300	55–60%		Commercial / Research	
Molten carbonate fuel cell	Molten alkaline carbonate	100 MW	600–650	55%	45–55% ^[34]	Commercial / Research	
Tubular solid oxide fuel cell (TSOFC)	O ²⁻ -conducting ceramic oxide	< 100 MW	850–1100	60–65%	55–60%	Commercial / Research	
Protonic ceramic fuel cell	H ⁺ -conducting ceramic oxide		700			Research	
Direct carbon fuel cell	Several different		700–850	80%	70%	Commercial / Research	
Planar Solid oxide fuel cell	O ²⁻ -conducting ceramic oxide	< 100 MW	500–1100	60–65%	55–60% ^[34]	Commercial / Research	
Enzymatic Biofuel Cells	Any that will not denature the enzyme		< 40			Research	
Magnesium-Air Fuel Cell	Salt water		-20 to 55	90%		Commercial / Research	

PARTS OF A FUEL CELL

The heart of a PEM fuel cell is the membrane electrode assembly (MEA), which includes the membrane, the catalyst layers, and gas diffusion layers (GDLs).

Hardware components used to incorporate an MEA into a fuel cell include gaskets, which provide a seal around the MEA to prevent leakage of gases, and bipolar plates, which are used to assemble individual PEM fuel cells into a fuel cell stack and provide channels for the gaseous fuel and air.

Membrane Electrode Assembly

The membrane, catalyst layers (anode and cathode), and diffusion media together form the membrane electrode assembly (MEA) of a PEM fuel cell.

Polymer Electrolyte Membrane

The polymer electrolyte membrane, or PEM (also called a proton exchange membrane)—a specially treated material that looks something like ordinary kitchen plastic wrap—conducts only positively charged ions and blocks the electrons. The PEM is the key to the fuel cell technology; it must permit only the necessary ions to pass between the anode and cathode. Other substances passing through the electrolyte would disrupt the chemical reaction. For transportation applications, the membrane is very thin—in some cases under 20 microns.

Catalyst Layers

A layer of catalyst is added on both sides of the membrane—the anode layer on one side and the cathode layer on the other. Conventional catalyst layers include nanometer-sized particles of platinum dispersed on a high-surface-area carbon support. This supported platinum catalyst is mixed with an ion-conducting polymer (ionomer) and sandwiched between the membrane and the GDLs. On the anode side, the platinum catalyst enables hydrogen molecules to be split into protons and electrons. On the cathode side, the platinum catalyst enables oxygen reduction by reacting with the protons generated by the anode, producing water. The ionomer mixed into the catalyst layers allows the protons to travel through these layers.

Gas Diffusion Layers

The GDLs sit outside the catalyst layers and facilitate transport of reactants into the catalyst layer, as well as removal of product water. Each GDL is typically composed of a sheet of carbon paper in which the carbon fibers are partially coated with polytetrafluoroethylene (PTFE). Gases diffuse rapidly through the pores in the GDL. These pores are kept open by the hydrophobic PTFE, which prevents excessive water buildup. In many cases, the inner surface of the GDL is coated with a thin layer of high-surface-area carbon mixed with PTFE, called the microporous layer. The microporous layer can help adjust the balance between water retention (needed to maintain membrane conductivity) and water release (needed to keep the pores open so hydrogen and oxygen can diffuse into the electrodes).

Hardware

The MEA is the part of the fuel cell where power is produced, but hardware components are required to enable effective MEA operation.

Bipolar Plates

Each individual MEA produces less than 1 V under typical operating conditions, but most applications require higher voltages. Therefore, multiple MEAs are usually connected in series by stacking them on top of each other to provide a usable output voltage. Each cell in the stack is sandwiched between two bipolar plates to separate it from neighboring cells. These plates, which may be made of metal, carbon, or composites, provide electrical conduction between cells, as well as providing physical strength to the stack. The surfaces of the plates typically contain a “flow field,” which is a set of channels machined or stamped into the plate to allow gases to flow over the MEA. Additional channels inside each plate may be used to circulate a liquid coolant.

Gaskets

Each MEA in a fuel cell stack is sandwiched between two bipolar plates, but gaskets must be added around the edges of the MEA to make a gas-tight seal. These gaskets are usually made of a rubbery polymer.

FUEL CELL SYSTEMS

The design of fuel cell systems is complex, and can vary significantly depending upon fuel cell type and application. However, several basic components are found in many fuel cell systems:

Fuel cell stack

Fuel processor

Power conditioners

Air compressors

Humidifiers

Fuel Cell Stack

The fuel cell stack is the heart of a fuel cell power system. It generates electricity in the form of direct current (DC) from electro-chemical reactions that take place in the fuel cell. A single fuel cell produces less than 1 V, which is insufficient for most applications. Therefore, individual fuel cells are typically combined in series into a fuel cell stack. A typical fuel cell stack may consist of hundreds of fuel cells. The amount of power produced by a fuel cell depends upon several factors, such as fuel cell type, cell size, the temperature at which it operates, and the pressure of the gases supplied to the cell.

Fuel Processor

The fuel processor converts fuel into a form usable by the fuel cell. Depending on the fuel and type of fuel cell, the fuel processor can be a simple sorbent bed to remove impurities, or a combination of multiple reactors and sorbents.

If the system is powered by a hydrogen-rich, conventional fuel, such as methanol, gasoline, diesel, or gasified coal, a reformer is typically used to convert hydrocarbons into a gas mixture of hydrogen and carbon compounds called "reformat." In many cases, the reformat is then sent to a set of reactors to convert carbon monoxide to carbon dioxide and remove any trace amounts of carbon monoxide remaining and a sorbent bed to remove other impurities, such as sulfur compounds, before it is sent to the fuel cell stack. This process prevents impurities in the gas from binding with the fuel cell catalysts. This binding process is also called "poisoning" because it reduces the efficiency and life expectancy of the fuel cell.

Some fuel cells, such as molten carbonate and solid oxide fuel cells, operate at temperatures high enough that the fuel can be reformed in the fuel cell itself. This process is called internal reforming. Fuel cells that use internal reforming still need traps to remove impurities from the unreformed fuel before it reaches the fuel cell. Both internal and external reforming release carbon dioxide, but due to the fuel cells' high efficiency, less carbon dioxide is emitted than by internal-combustion engines, such as those used in gasoline-powered vehicles.

Power Conditioners

Power conditioning includes controlling current (amperes), voltage, frequency, and other characteristics of the electrical current to meet the needs of the application. Fuel cells produce electricity in the form of direct current (DC). In a DC circuit, electrons flow in only one direction. The electricity in your home and workplace is in the form of alternating current (AC), which flows in both directions on alternating cycles. If the fuel cell is used to power equipment that uses AC, the direct current will have to be converted to alternating current.

Both AC and DC power must be conditioned. Current inverters and conditioners adapt the electrical current from the fuel cell to suit the electrical needs of the application, whether it is a simple electrical motor or a complex utility power grid. Conversion and conditioning reduce system efficiency only slightly, around 2%–6%.

Air Compressors

Fuel cell performance improves as the pressure of the reactant gases increases; therefore many fuel cell systems include an air compressor, which raises the pressure of the inlet air to 2–4 times the ambient atmospheric pressure. For transportation applications, air compressors should have an efficiency of at least 75%. In some cases, an expander is also included to recover power from the high pressure exhaust gases. Expander efficiency should be at least 80%.

Humidifiers

The polymer electrolyte membrane at the heart of a PEM fuel cell does not work well when dry, so many fuel cell systems include a humidifier for the inlet air. Humidifiers usually consist of a thin membrane, which may be made of the same material as the PEM. By flowing dry inlet air on one side of the humidifier and wet exhaust air on the other side, the water produced by the fuel cell may be recycled to keep the PEM well hydrated.

VISCOELASTISITY

Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Viscous materials, like water, resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched and immediately return to their original state once the stress is removed. A viscoelastic material has properties where hysteresis is seen in the stress–strain curve, stress relaxation occurs (step constant strain causes decreasing stress), creep occurs (step constant stress causes increasing strain).

Types of Viscoelasticity

Linear viscoelasticity is when the function is separable in both creep response and load.

$$\varepsilon(t) = \frac{\sigma(t)}{E_{\text{inst,creep}}} + \int_0^t K(t-t') \dot{\sigma}(t') dt'$$

or

$$\sigma(t) = E_{\text{inst,relax}} \varepsilon(t) + \int_0^t F(t-t') \dot{\varepsilon}(t') dt'$$

where

- t is time
- $\sigma(t)$ is stress
- $\varepsilon(t)$ is strain
- $E_{\text{inst,creep}}$ and $E_{\text{inst,relax}}$ are instantaneous elastic moduli for creep and relaxation
- $K(t)$ is the creep function
- $F(t)$ is the relaxation function

Linear viscoelasticity is usually applicable only for small deformations.

Nonlinear viscoelasticity is when the function is not separable. It usually happens when the deformations are large or if the material changes its properties under deformations.

An anelastic material is a special case of a viscoelastic material: an anelastic material will fully recover to its original state on the removal of load.

Constitutive Models of Linear Viscoelasticity

Viscoelastic materials, such as amorphous polymers, semicrystalline polymers, biopolymers and even the living tissue and cells, can be modeled in order to determine their stress and strain or force and displacement interactions as well as their temporal dependencies. These models, which include the Maxwell model, the Kelvin–Voigt model, the Standard Linear Solid model, are used to predict a material's response under different loading conditions. Viscoelastic behavior has elastic and viscous components modeled as linear combinations of springs and dashpots, respectively. Each model differs in the arrangement of these elements, and all of these viscoelastic models can be equivalently modeled as electrical circuits. In an equivalent electrical circuit, stress is represented by voltage, and strain rate by current. The elastic modulus of a spring is analogous to a circuit's capacitance (it stores energy) and the viscosity of a dashpot to a circuit's resistance (it dissipates energy).

The elastic components, as previously mentioned, can be modeled as springs of elastic constant E , given the formula:

$$\sigma = E\epsilon$$

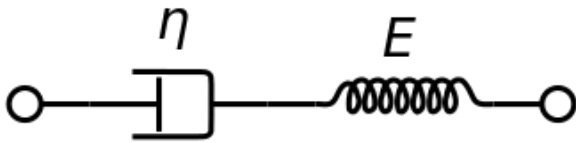
where σ is the stress, E is the elastic modulus of the material, and ϵ is the strain that occurs under the given stress, similar to Hooke's Law.

The viscous components can be modeled as dashpots such that the stress–strain rate relationship can be given as,

$$\sigma = \eta \frac{d\epsilon}{dt}$$

where σ is the stress, η is the viscosity of the material, and $d\epsilon/dt$ is the time derivative of strain.

The Maxwell Model



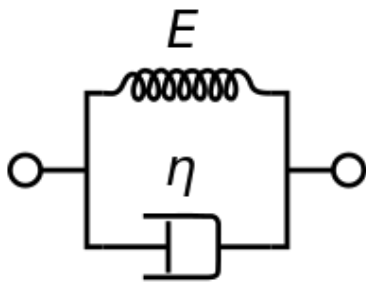
The Maxwell model can be represented by a purely viscous damper and a purely elastic spring connected in series, as shown in the diagram. The model can be represented by the following equation:

$$\sigma + \frac{\eta}{E} \dot{\sigma} = \eta \dot{\epsilon}$$

Under this model, if the material is put under a constant strain, the stresses gradually relax. When a material is put under a constant stress, the strain has two components. First, an elastic

component occurs instantaneously, corresponding to the spring, and relaxes immediately upon release of the stress. The second is a viscous component that grows with time as long as the stress is applied. The Maxwell model predicts that stress decays exponentially with time, which is accurate for most polymers. One limitation of this model is that it does not predict creep accurately. The Maxwell model for creep or constant-stress conditions postulates that strain will increase linearly with time. However, polymers for the most part show the strain rate to be decreasing with time. Applications to soft solids: thermoplastic polymers in the vicinity of their melting temperature, fresh concrete (neglecting its aging), numerous metals at a temperature close to their melting point.

Kelvin–Voigt Model

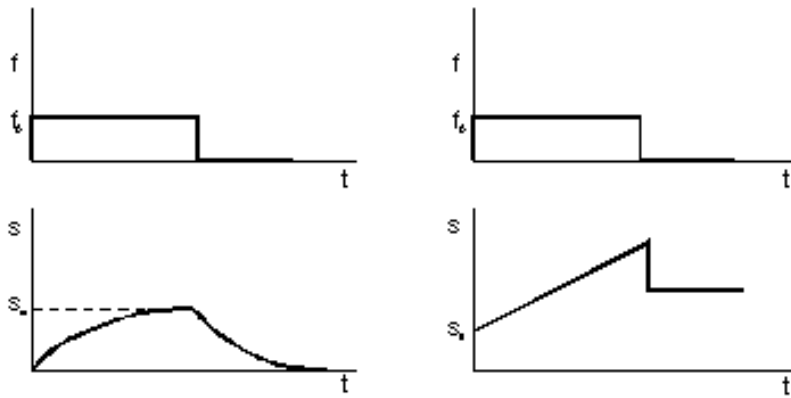


The Kelvin–Voigt model, also known as the Voigt model, consists of a Newtonian damper and Hookean elastic spring connected in parallel, as shown in the picture. It is used to explain the creep behaviour of polymers.

The constitutive relation is expressed as a linear first-order differential equation:

$$\sigma = E\epsilon + \eta\dot{\epsilon}$$

This model represents a solid undergoing reversible, viscoelastic strain. Upon application of a constant stress, the material deforms at a decreasing rate, asymptotically approaching the steady-state strain. When the stress is released, the material gradually relaxes to its undeformed state. At constant stress (creep), the Model is quite realistic as it predicts strain to tend to σ/E as time continues to infinity. Similar to the Maxwell model, the Kelvin–Voigt model also has limitations. The model is extremely good with modelling creep in materials, but with regards to relaxation the model is much less accurate. Applications: organic polymers, rubber, wood when the load is not too high.



The response of Kelvin Voigt's and Maxwell's environments to the tension impulse (s=strain, t=time)

Standard Linear Solid Model

The standard linear solid model, also known as the Zener model, consists of two springs and a dashpot. It is the simplest model that describes both the creep and stress relaxation behaviors of a viscoelastic material properly. For this model, the governing constitutive relations are:

Maxwell representation	Kelvin representation
$\sigma + \frac{\eta}{E_2} \dot{\sigma} = E_1 \varepsilon + \frac{\eta(E_1 + E_2)}{E_2} \dot{\varepsilon}$	$\sigma + \frac{\eta}{E_1 + E_2} \dot{\sigma} = \frac{E_1 E_2}{E_1 + E_2} \varepsilon + \frac{E_1 \eta}{E_1 + E_2} \dot{\varepsilon}$

Under a constant stress, the modeled material will instantaneously deform to some strain, which is the instantaneous elastic portion of the strain. After that it will continue to deform and asymptotically approach a steady-state strain, which is the retarded elastic portion of the strain. Although the Standard Linear Solid Model is more accurate than the Maxwell and Kelvin–Voigt models in predicting material responses, mathematically it returns inaccurate results for strain under specific loading conditions.

Creep (Deformation)

In materials science, creep (sometimes called cold flow) is the tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses. It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and generally increases as they near their melting point.

Relaxation

Relaxation usually means the return of a perturbed system into equilibrium. Each relaxation process can be categorized by a relaxation time τ . The simplest theoretical description of relaxation as function of time t is an exponential law $\exp(-t/\tau)$.

2.1.ARTICLE RESEARCH

In a study by V Garaev, S Pavlovica, I Reinholds and G Vaivars in 2013, the Nafion 112 membrane impregnated with 2- hydroxyethylammonium carboxylate ionic liquids have been investigated. The used ionic liquids were 2-hydroxyethylammonium formate [HEA]F, acetate [HEA]A and lactate [HEA]L. Prepared composite membranes Nafion/ionic liquid are characterized by mechanical testing, such as tensile test and creep test. It is found that ionic liquids decrease elastic modulus and creep compliance, but do not have significant effect on the tensile strength. Also, composite membranes were studied by wide angle X-ray diffraction. All ionic liquids shift the peak maximum to the lower angle. In this work, only biodegradable ionic liquids were used for composite preparation. [1].

In a study by Amelia Habas-Ulloa, Jose Roberto Moraes d'Almeida and Jean-Pierre Habas in 2012, the creep behavior of a high density polyethylene (HDPE), currently used as raw material for pipe manufacture, was evaluated before and after exposure to oil derivatives using transient rheometry. The creep behavior of the original HDPE was satisfactorily described using a generalized Kelvin-Voigt model based on two retardation times. The values of these critical times were quite different from each other, indicating a large distribution of macromolecular weight. The aging procedure was performed by immersing the polymer in two model fluids chosen to discriminate and understand the action of aromatic and paraffinic fractions of fuel derivatives (white oil, gas-oil). The batch operation was also carried out at two different temperatures to investigate the thermal activation of plausible degrading mechanisms. In the case of the aging performed in the paraffinic fluid, the polymer compliance continuously increased with the immersion duration. This behavior was attributed to a plasticization induced by the diffusion of the liquid in the polymer matrix. The same phenomenon was observed in the early stage of the HDPE aging carried out with the aromatic fluid. However, for longer aging times, the extraction of low molecular weight species produced the stiffening of the thermoplastic [2].

In a study by M. Razavi-Nouri in 2012, Creep and stress relaxation of a polypropylene (PP)-based copolymer, a metalloceneprepared linear low density polyethylene (m-LLDPE) and their m-LLDPE/PP blends have been investigated. Struik and Nutting relationships were used for fitting the data obtained from the creep experiments. A relatively good agreement was found between the Struik model and the experimental data obtained from PP and the 50/50 blend, however, the results showed that the validity of the model is less for the m-LLDPE itself. A good correlation was also found for the Nutting relationship and the experimental data. Maxwell and Kohlrausch-Williams-Watts (KWW) equations were used to fit the data

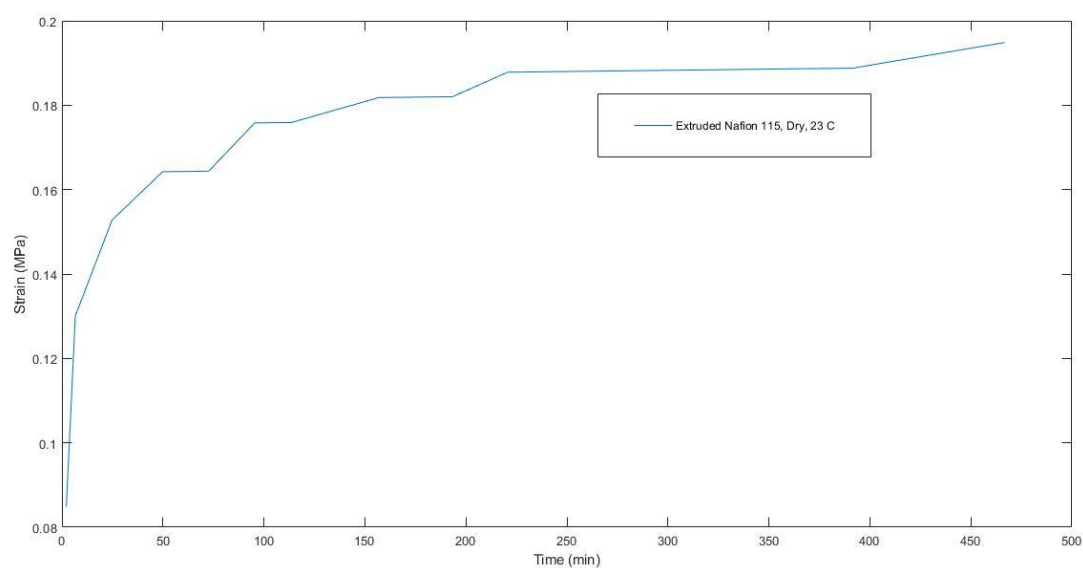
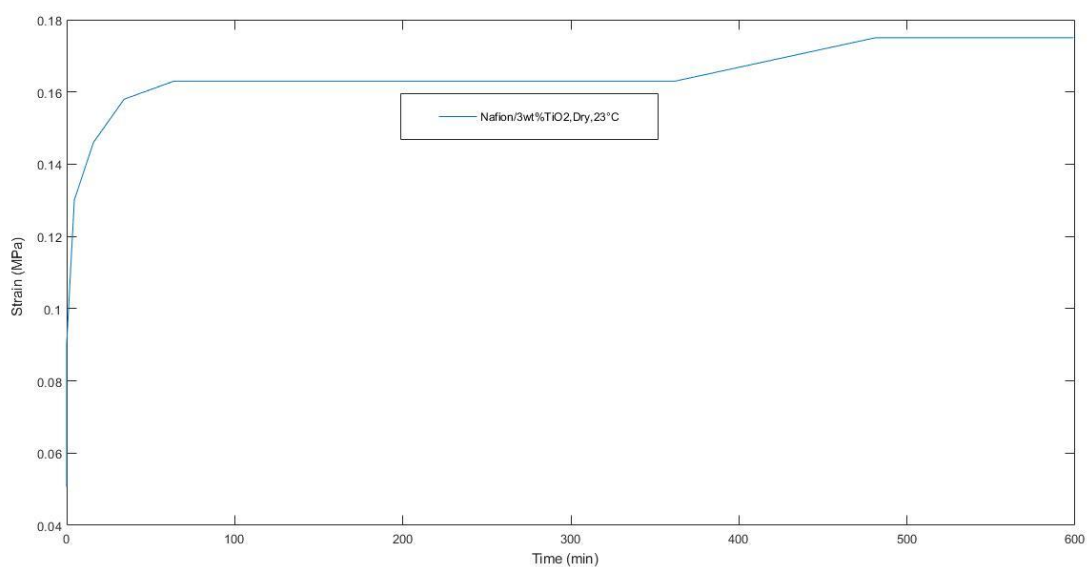
obtained from stress relaxation experiments. The results indicated that while the Maxwell model was not good enough to predict the stress relaxation time, KWW model could fit the data much better. Analysis of the data with KWW equation revealed that the relaxation time increased with m-LLDPE content, but not significantly. However, the factor that describes the width of relaxation time distribution reduced with m-LLDPE, showing that m-LLDPE had the broadest relaxation time distribution compared to that of PP and the blends [3].

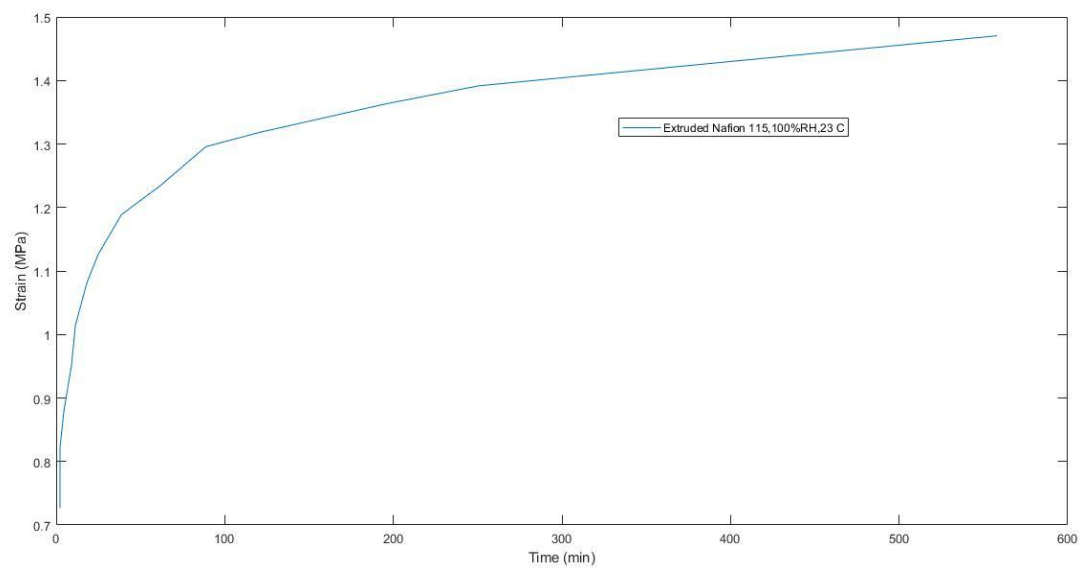
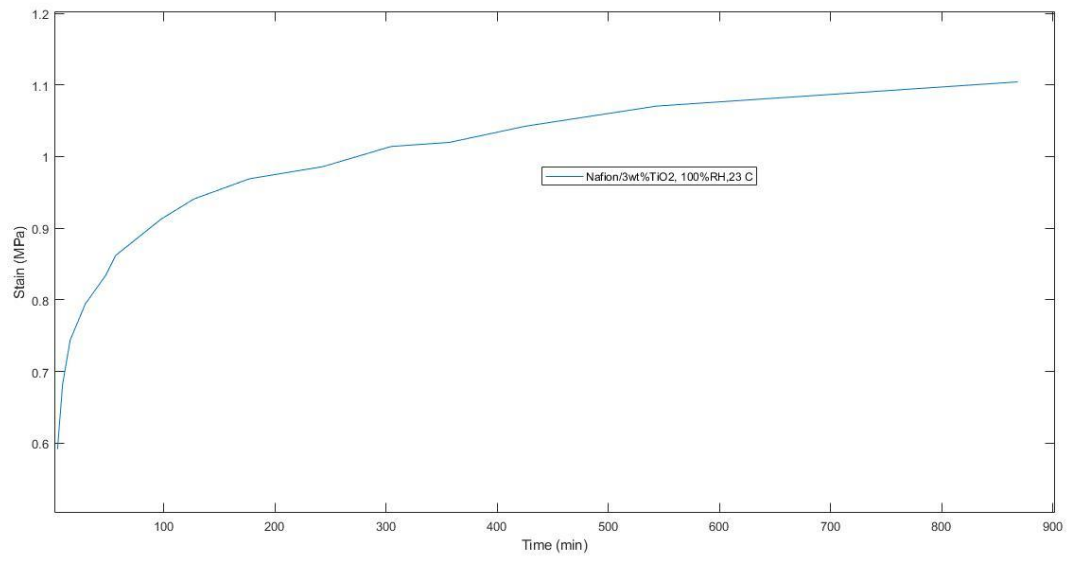
In a study by C. Lechat, A. R. Bunsell, P. Davies in 2011, Ropes made of twisted polyester (PET) yarns have been replacing traditional steel ropes and chains as mooring lines for offshore platforms in deep-sea environments. In order to optimise rope manufacture and the design of mooring systems, a thorough understanding of the material's mechanical behaviour is necessary. Besides PET, other materials can also be considered such as PEN, as it also a polyester similar to PET but stiffer. This paper presents a study and comparison of PET and PEN fibres' mechanical behaviour, based on experiments carried out on single filaments. Both fibres show similar non-linear tensile behaviour, with an evolution of modulus in four steps. The same microstructural model is proposed for both fibres, based on microfibrils aligned along the fibre axis and composed of an alternation of amorphous, mesamorphous and crystalline phases. The shape of the tensile loading curve is explained by the successive loading of these phases. Creep behaviour is also evaluated by considering the evolution of creep rate with applied load. This evolution is again similar for PET and PEN, both from a qualitative and quantitative point of view. The similarity in creep rate values for both fibres indicates that the microstructural mechanisms involved in creep may differ from those involved in short term tension loading [4].

3. RESULTS

3.1. Titania/Nafion Composite Membranes

Creep data for Nafion 115 and Nafion/3 wt % titania 115 at 23 8C for both 0% RH (dry) and 100% RH with an applied engineering stress of 7.5MPa.

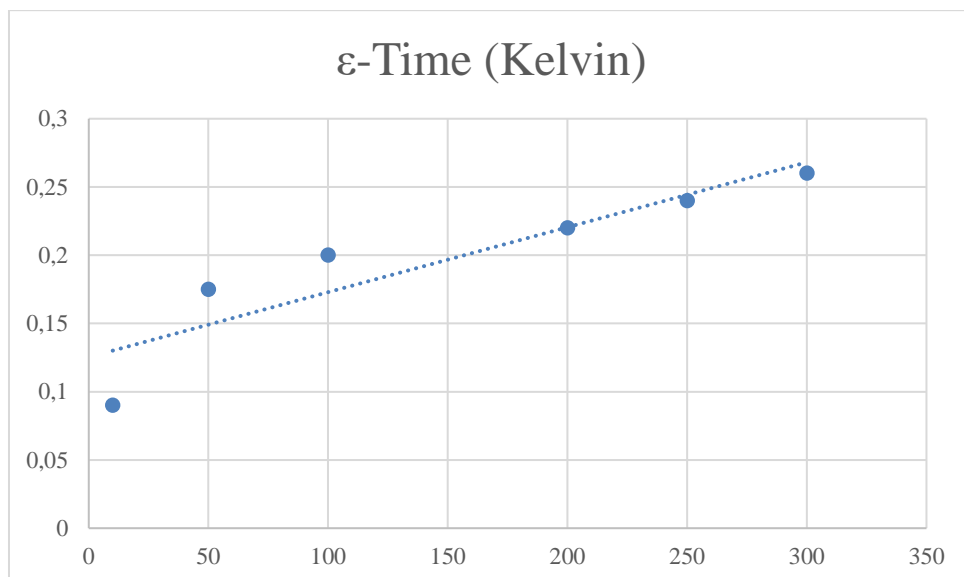
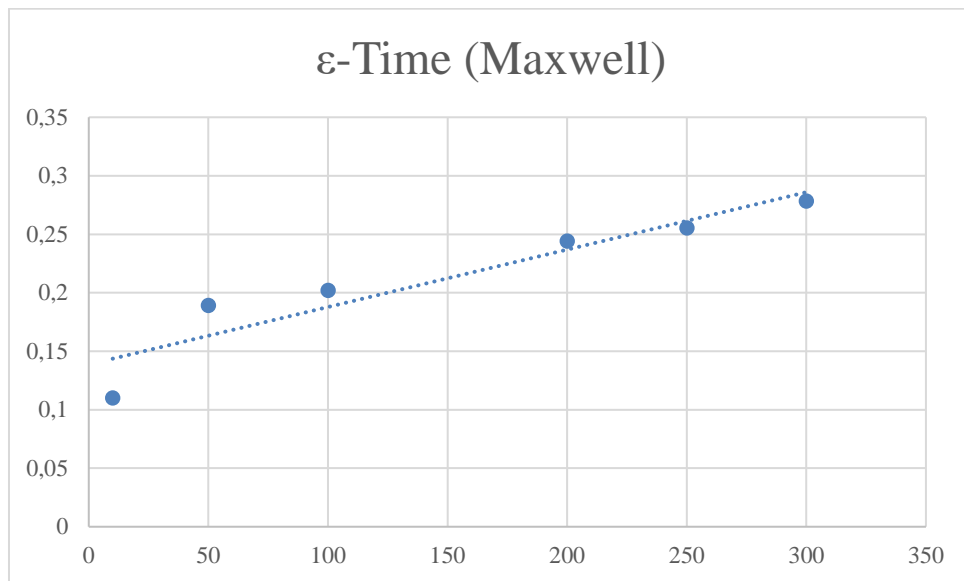




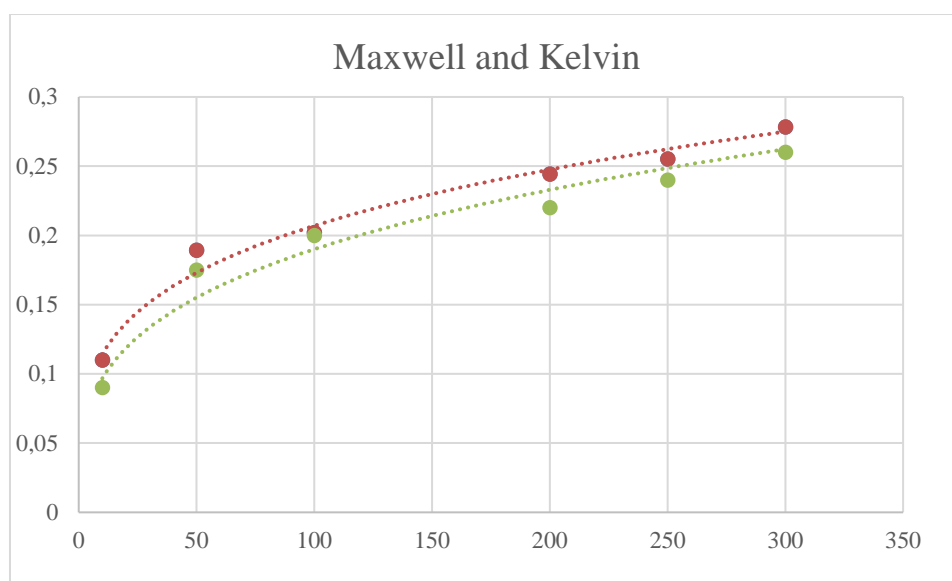
ε -Time (Maxwell) and ε -Time (Kelvin) graphics analyzed. Theoretical experimental results can be represented by the following equations:

$$\varepsilon = (\Gamma/E) + (\Gamma/n) * t \quad (\text{Maxwell})$$

$$\varepsilon = (\Gamma/E) (1 - e^{-(E/n) * t}) \quad (\text{Kelvin})$$



Comparison of maxwell and kelvin models:



4. CONCLUSIONS

Fuel cells technologies and mechanical experiments analyzed for detailed research with models. These models provide information on mechanical properties. The results of the creep and relaxation experiments of the materials were analyzed and graphed using Matlab. The results of the tests are detailed with graphics. Theoretical and experimental results were analyzed. Maxwell and Kelvin models were compared. More effective results can be found by adding various parameters. The effect of mechanical effects on the determination of the effects on the fuel cell was investigated.

5. REFERENCES

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