Dataset of standard tests of Nafion 112 membrane and Membrane Electrode Assembly (MEA) activation tests of Proton Exchange Membrane (PEM) fuel cell

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Abstract:

Reported data in this paper are about Nafion 112 membrane standard tests and MEA activation tests of PEM fuel cell in various operation condition. Dataset include two general electrochemical analysis method, Polarization and Impedance curves. In this dataset, effect of different pressure of H_2/O_2 gas, different voltages and various humidity conditions in several steps are considered. Details of experimental methods has been explained in this paper. Behavior of PEM fuel cell during distinct operation condition tests, activation procedure and different operation condition before and after activation analysis can be concluded from data. In Polarization curves, voltage and power density change as a function of flows of H_2/O_2 and relative humidity. Resistance of the used equivalent circuit of fuel cell can be calculated from Impedance data. Thus, experimental response of the cell is obvious in the presented data, which is useful in depth analysis, simulation and material performance investigation in PEM fuel cell researches.

Highlights:

- Experimentally data useful for investigation and work on PEMFCs.

- Data obtained from various test conditions and changing variables that provides possibility for users to compare curves and resulted parameters.

- Observable graphical data in presented documents help better interpretation for research on PEMFC.

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1- Data Introduction

The experimentally resulted data shows the performance of a PEMFC at several percent of membrane compression, different applied voltages, different pressure of H_2/O_2 gas, and various humidity conditions of cathode and air, which can be used to study behavior of PEMFC that is necessary to research and development of fuel cells. In other words, the dataset help researchers and specialists who investigate and work on PEM fuel cells [1].

Polarization and Impedance curves have obtained from specific empirical operation condition. MEA structure defines as composition of anode, membrane and cathode. Temperature of anode, cathode and cell, pressure and flow rate of H_2/O_2 ($ml.min^{-1}$) have been considered as operation condition during the evaluation. In Polarization curves, cell voltage (V) per current density ($mA.cm^{-2}$) and cell power density ($mW.cm^{-2}$) per current density ($mA.cm^{-2}$) has been obtained at various relative humidity, gas pressure and membrane compression. Impedance analysis were done at the end of the each activation set and procedure at different cell voltages, relative humidity and H_2/O_2 pressure. Also, in each activation procedure, analysis has been accomplished by repeat of activation sets [2].

Obtained data can be useful for simulation of PEMFC and simulation has important role in scientific and applied studies. The report provides necessary results and experimentally parameters such as temperature of anode, cathode and cell, pressure and flow rate of gasses, relative humidity, power density, current density, voltage and resistances of cells which are obligatory data for electrochemical, material, mechanical and electrical simulation of PEMFCs. Hence, obtained data used for simulation of PEM in OPEM [3] simulation software produced by Electrochemistry Simulation (ECSIM) organization research team and those are compatible with the most of used models ,especially, Amphlett model [4] in OPEM software. The reported dataset is available on ECSIM organization GitHub account [5].

2- Report Data

2-1-Standard test of Nafion 112 membrane

2-1-1- Experimental design, method and details

MEA structure for standard cell of Nafion 112 membrane includes anode, cathode and membrane composition. Composition of anode in standard test is Carbon paper Ballard, Platinum-Carbon 20%, Nafion solution (27% weight), 80 *ml* Isopropyl alcohol, and 20 *ml* double distillation water with 0.39 $mg.cm^{-2}$ loading of Platinum. Also, composition of cathode including Carbon paper (CP) Ballard, Platinum-Carbon (Pt/C) 20% , Nafion solution (25% weight), 80 *ml* Isopropyl alcohol and 20 *ml* double distillation water with 0.39 $mg.cm^{-2}$ loading of Platinum. Composition of second cathode is Carbon paper Ballard, Platinum-Carbon 20%, Nafion solution (20% weight), 80 *ml* Isopropyl alcohol, and 20 ml double distillation water with 0.39 $mg.cm^{-2}$ loading of Platinum. Cell temperature is 75 degree centigrade (^{o}C), anode temperature is 80 ^{o}C and Cathode temperature was evaluated 48-59-70-75 ^{o}C. For activation, in first step a constant voltage at 0.6 *V* for 30 minutes applied, and then constant voltage at 0.2 *V* for 10 minutes and constant voltage at 0.7 *V* for 1 minute. In next step, constant voltage at 0.6 *V* for 60 minutes and then, constant voltage at 0.5 *V* for 40 minutes. At the end of activation operation, a constant current at 250 $mA.cm^{-2}$ has been applied for 60 minutes.

Effect of percent of Nafion membrane N (%) and Relative Humidity of the Cathode RHC (%) on cell performance in various compression of membrane at various pressure was analyzed in Polarization curves. Changing in N (%) between 20% and 25%, RHC (%) between 30, 50, 80 and 100%, P between 5, 15 and 25 *psig*, and membrane compression percent (%) lead to change the value of voltage and power density per current density. From each polarization curve, in table (1-2) and figure (1-2), an example of data extracted from the curve and related polarization curve presented, respectively.

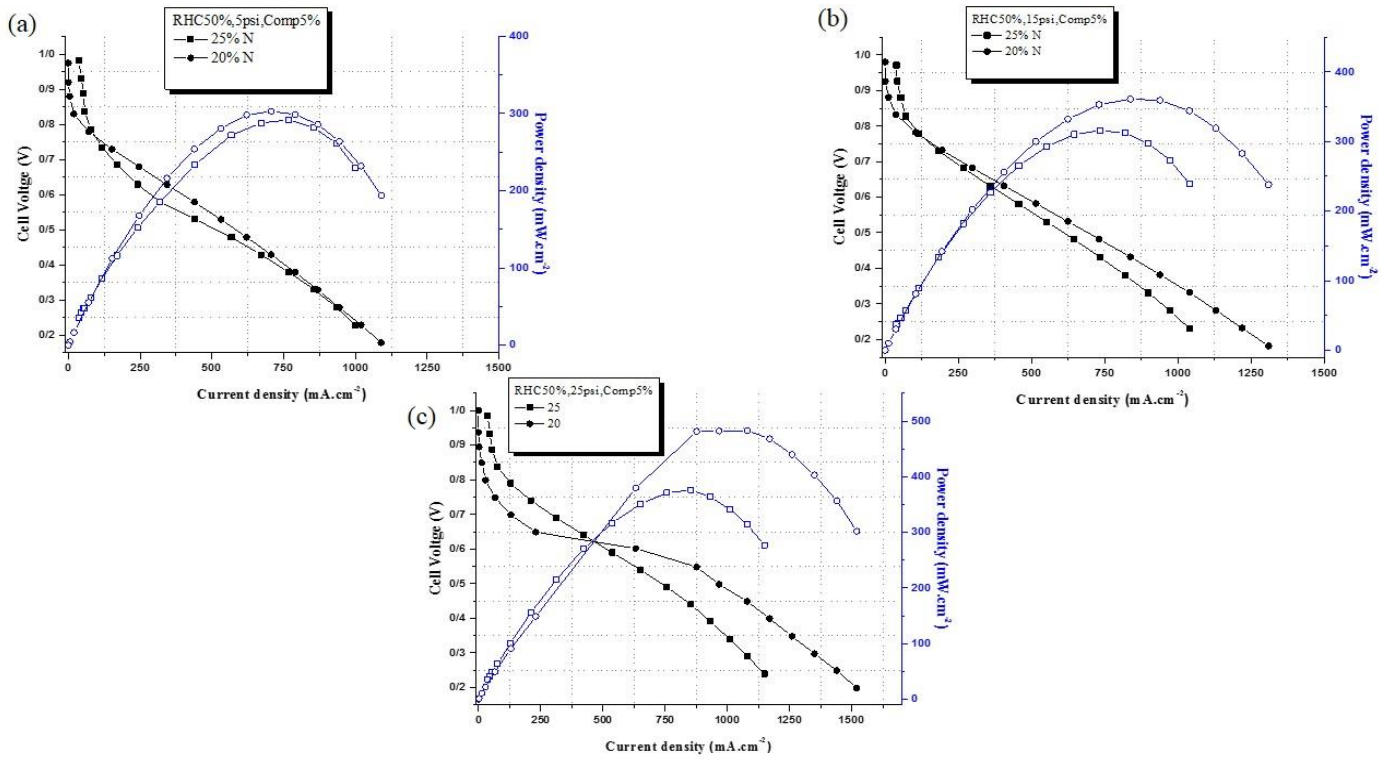

Figure (1-2): Polarization curve of standard test of Nafion 112 membrane at RHC 50%, membrane compression 5% and Nafion Percent 20%, 25%, (a) pressure 5 *psig* (b) 15 *psig* (c) 25 *psig*.

Table (1-2): Extracted data from figure (1-2), the values are: power density, current density and resistance.

P(*psig*)	**N(%)**	**MPD (*mW.cm*$^{-2}$)**	**i(*mA.cm*$^{-2}$) at 0.8*V***	**i(*mA.cm*$^{-2}$) at 0.5*V***	**i(*mA.cm*$^{-2}$) at 0.3*V***	**R(*m*Ω) at 0.5*V***
5	25%	291	60	470	860	190
	20%	304	50	550	890	193
15	25%	316	80	600	910	209
	20%	362	50	650	1100	195
25	25%	376	130	750	1080	206
	20%	490	28	960	1350	147

2-2- Activation test of MEA

The start procedure for a new fuel cell membrane electrode assembly MEA may vary somewhat from application to application. What is important in any research or production environment is to be consistent with break in procedure that can be used. How the MEA is initially

broken-in can have long lasting effects on the ultimate performance of the MEA. Published procedures vary in specifics, but almost all follow a similar sequence:

1. Initial Start-Up
2. Load Cycling
3. Final Performance

The US Fuel Cell Council (USFCC) [7] published a standard for single cell testing that includes specific break-in procedures:

- Fuel: Hydrogen, 1.2 Stoich, 100% RH
- Oxidant: Air, 2.0 Stoich, 100% RH
- Temperature (*C*): 80°
- Pressures (*psig*): 25

Initial Startup: As required to reach 80°C

1. Cycle Step 1 (Perform Once): Hold 0.6 *V* for 60 mins
2. Cycling Step 2 (Perform 9 times): Hold 0.7 *V* for 20 mins, than hold 0.5*V* for 20 mins
3. Constant Current Operation: Hold at 200 $mA.cm^{-2}$ for 720 mins (12 hrs)

Verify break-in status by repeating the polarization curve sequence three times, or as necessary, to ensure that the cell is broken-in. Remain at each sequence step for 20 minutes. The cell is considered broken-in when less than a 5 *mV* deviation from the previous polarization curve is recorded at 800 $mA.cm^{-2}$. A wait period of 10 minutes should be observed between polarization curves. During this period, return the gas flow rates to the equivalent of 10 stoich at 200 $mA.cm^{-2}$ and set the current to 800 $mA.cm^{-2}$.

Four analysis were done in activation tests of MEA; Cycling Potential between 0.2 and 0.7*V*, Constant Current 0.25Acm^{-2}, Constant Voltage 0.6*V* and standard test protocol. In all of them, specific MEA structure and activation procedure were applied and operation condition before and after activation procedure are similar. The membrane is Nafion 112, flow rate of H_2/O_2 measured 200/200 $ml.min^{-1}$, pressure at operation condition is 5 *psig* and temperature of anode, cathode and

cell is 60, 50 and 55^{o}C controlled during all of the tests. After the activation procedure, operation condition in several relative humidity (30%, 50% and 100%), various pressure and flow rate (5 *psig* flow H_2/O_2 200/200 $ml.min^{-1}$, 15 *psig* flow H_2/O_2 300/300 and 25 *psig* flow H_2/O_2 500/500) was determined. Also, temperature of anode, cathode and cell for RH 30% (T_a/ T_c/ T_{cell}: 80/49/75 ^{o}C), RH 50% (T_a/ T_c/ T_{cell}: 80/59/75 ^{o}C) and RH 100% (T_a/ T_c/ T_{cell}: 80/75/75 ^{o}C) were measured. On the other hand, each activation set contains repetition of the items of activation procedure. In other words, numbers of set means number of repetition.

2-2-1-Activation test MEA at cycling potential between 0.2 and 0.7 *V*

2-2-1-1-Experimental design, method and details

MEA structure in this analysis including anode components such as CP (TGP-0120), Pt/C 20%, 30% Nafion, 1.98 $mg\ DL.cm^{-2}$ (C28) with 0.38 $mg.cm^{-2}$ catalyst loading. Cathode composition is CP (TGP-0120), Pt/C 20%, 30% Nafion and 1.98 $mg\ DL.cm^{-2}$ (C28) with 0.38 $mg.cm^{-2}$ Catalyst loading. The membrane is Nafion 112. To start activation procedure, 10 minutes Open Circuit Voltage (OCV) time and then, one minute 0.7 *V*, 10 minutes 0.2 *V* (for five times) was applied. Finally, steps 1 and 2 repeated for three times.

In this analysis, the reported data are related to polarization curves after 1 hour during activation procedure, impedance curves at different voltage 0.3, 0.5, 0.7 and 0.8*V* for set 1, set 2 and set 3, at 60 /50/ 55^{o}C, 5 *psig* flow rate H_2/O_2: 200/200 $ml.min^{-1}$, polarization curves at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15 and 25 *psig*, impedance curves in various voltages at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15, and 25 *psig* in flow rate H_2/O_2: 200/200 $ml.min^{-1}$, polarization curves 0.7 *V* at the end of activation procedure in different cathode humidity condition 30, 50 and 100% at pressure at 5, 15, and 25 and impedance curves in various voltages at the end of activation procedure in different cathode humidity condition 30, 50 and 100% at pressure at 5, 15, and 25. Figures (2-2) and (3-2) represent polarization curves in three sets of activation procedure after 1 hour and impedance curves at different voltages for each sets. Table (2-2) shows the extracted data from related polarization curve.

Table (2-2) extracted data from polarization curve during activation procedure in three sets.

Sets	OCV(*mV*)	MPD (*mW.cm*$^{-2}$)	R(*m*Ω)
st 1	991	442	70
st 2	1003	453	72
st 3	1014	547	70

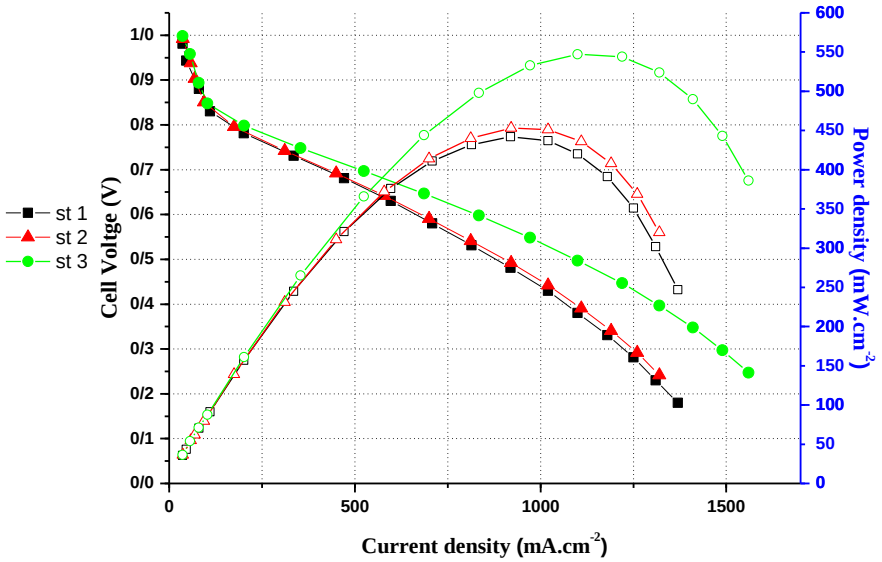

Figure (2-2) Polarization curves during activation procedure (Polarization curves at end of each activation set in three sets).

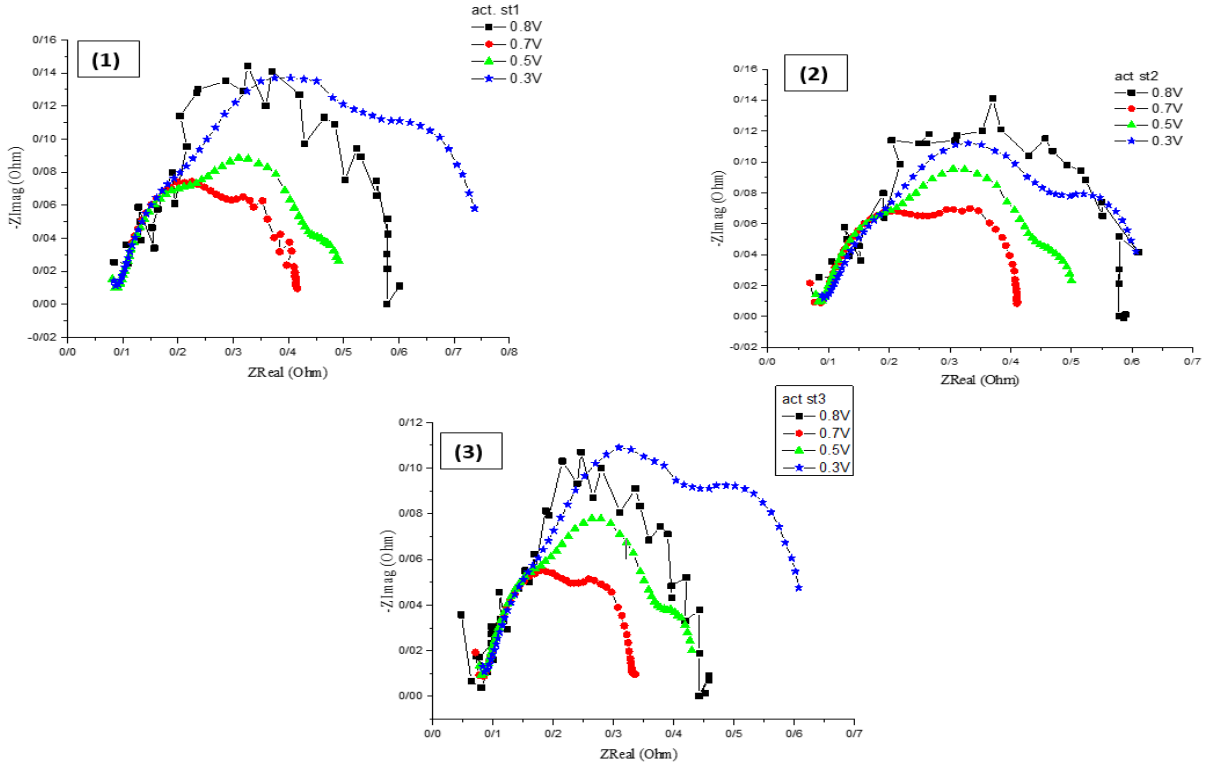

Figure (3-2) impedance curves at different voltage (1) set 1, (2) set 2, (3) set 3, 60 /50/ 55^{O}C, 5 *psig* flow rate H2/O2: 200/200 *ml.min*$^{-1}$.

2-2-2 Activation test MEA at constant current 0.25 $A.cm^{-2}$

2-2-2-1-Experimental design, method and details

MEA structure at constant current 0.25 $A.cm^{-2}$ containing CP (TGP-0120), Pt/C 20%, 30% Nafion, 1.98 $mg\ DL.cm^{-2}$ (C28) with 0.38 $mg.cm^{-2}$ of catalyst loading as anode composition with Nafion 112 membrane. Cathode components are containing CP (TGP-0120), Pt/C 20%, 30% Nafion and 1.98 $mg\ DL.cm^{-2}$ (C28) with 0.38 $mg.cm^{-2}$ of catalyst loading. 10 minutes OCV time as first step in activation procedure. Then, 30 minutes constant voltage 0.6 *V* and constant current 0.25$A.cm^{-2}$ (repeat for 18 time) was applied.

Obtained data from MEA activation test at constant current are summarized to polarization curves at end of each activation set in 17 sets, impedance curves at the end of each activation set at various voltages 0.3, 0.5, 0.7 and 0.8*V* at 60 /50/ 55^{o}C, 5 *psig* flow rate H_2/O_2:200/200 $mlmin^{-1}$, polarization curves at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15 and 25 *psig*, impedance curves in various voltages at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15 and 25 *psig* and flow rate H_2/O_2: 200/200 $ml.min^{-1}$, polarization curves at the end of activation procedure in different cathode humidity condition 30, 50 and 100% at pressure at 5, 15 and 25 *psig*, impedance curves in different voltages at the end of activation procedure in different cathode humidity condition 30 a 50 and 100% at pressure at 5, 15 and 25 *psig*. In table (3-2) extracted data form polarization curves of 17 sets at the end of activation set provided. Figure (4-2) represents polarization curves of 17 sets at the end of activation set. In this figure, just power density was presented because the graph with two Y axis for top number of curves lead to a visualization problem called Chartjunk [8].

Table (3-2) extracted data form Polarization curves at end of each activation set in 17 sets.

Sets	OCV(*mV*)	MPD($mW.cm^{-2}$)	R($m\Omega$)
st 1	968	215	142
st 2	979	345	122
st 3	972	380	116
st 4	990	460	102
st 5	985	508	99
st 6	977	529	94
st 7	978	540	93
st 8	982	594	92
st 9	975	605	89
st 10	975	600	89

st 11	977	600	89
st 12	979	709	84
st 13	976	705	83
st 14	974	700	83
st 15	975	696	83
st 16	980	703	82
st 17	977	694	83
st 18	980	703	82

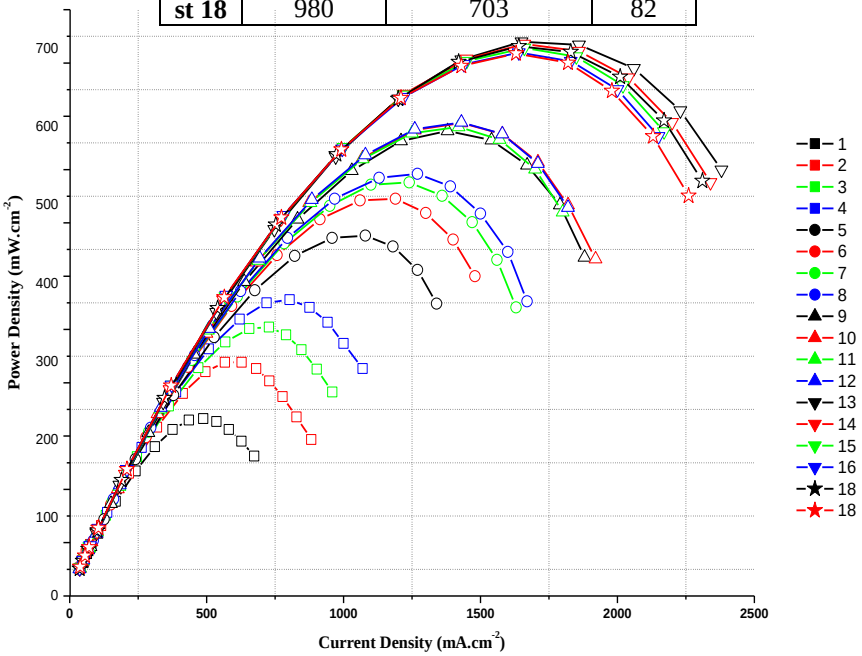

Figure (4-2) Polarization curves at end of each activation set in 17 sets.

2-2-3 Activation test MEA at Constant Voltage 0.6 *V*

2-2-3-1 Experimental design, method and details

Composition of anode including CP (TGP-0120), Pt/C 20%, 30% Nafion, 1.98 *mg DL.cm*$^{-2}$ (C28) with 0.38 *mg.cm*$^{-2}$ of catalyst loading. The Membrane is Nafion 112 and composition of Cathode is CP (TGP-0120), Pt/C 20%, 30% Nafion, and 1.98 *mg DL.cm*$^{-2}$ (C28) with 0.38 *mg.cm*$^{-2}$ of catalyst loading. In activation procedure of this analysis, a constant voltage 0.6 *V* has been applied.

Activation test of MEA at constant voltage 0.6 *V* was analyzed with repeat of activation sets. In this analysis, Polarization curves at end of each activation set in 9 sets, impedance curves at the end of each activation for 0.3, 0.5, 0.7 and 0.8 *V* at 60 /50/ 55^{o}*C*, in 5 *psig* flow rate H2/O2:

200/200 *ml.min*$^{-1}$, polarization curves at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15, and 25 *psig*, impedance curves at various voltages at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15, and 25 *psig* ;flow rate H_2/O_2: 200/200 *ml.min*$^{-1}$, polarization curves at the end of activation procedure in different air humidity condition 30, 50 and 100% at pressure at 5, 15, and 25 *psig*, impedance curves at various voltages, at the end of activation procedure in different air humidity condition 30 a 50 and 100% at pressure at 5, 15, and 25 *psig* have been done. Table (4-2) represents extracted data form polarization curve at the end of each activation set.

Table (4-2): extracted data from Polarization curves at end of each activation set in 9 sets.

Sets	**OCV(*mV*)**	**MPD(*mW.cm*$^{-2}$)**	**R(*m*Ω)**
st 1	965	769	75
st 2	980	925	71
st 3	980	959	70
st 4	980	970	71
st 5	984	967	70
st 6	980	977	70
st 7	983	971	70
st 8	982	1030	66
st 9	986	979	65

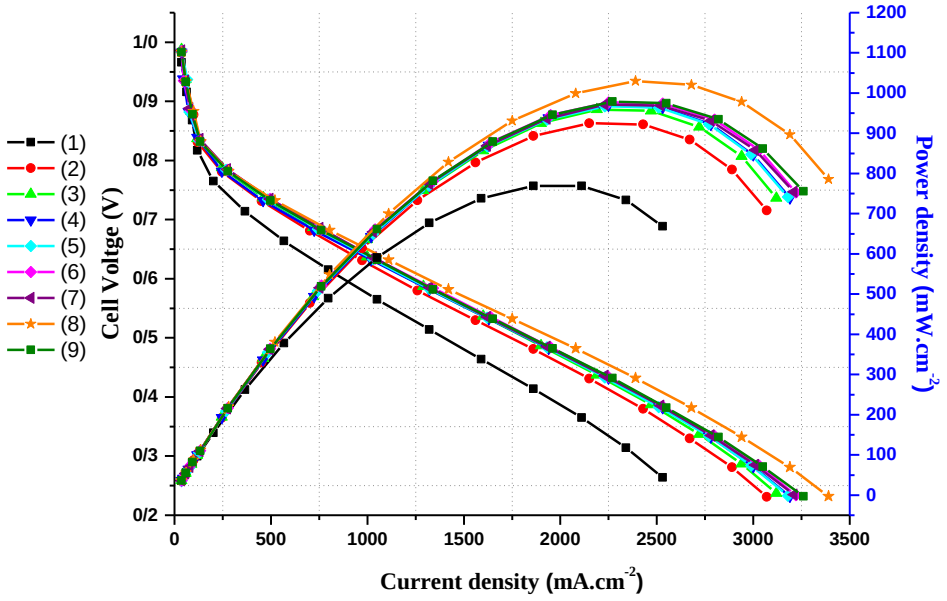

Figure (5-2) Polarization curves at end of each activation set in 9 sets.

Activation of MEA at constant voltage 0.6 *V* repeated in exact MEA structure and operation condition but, after a treatment procedure. In first treatment method, electrodes were ultra-sonicated in 10% Isopropyl solution for 60 min at $60^{o}C$. In Second treatment method, ultra-sonication of electrodes was in water for 60 minutes at $60^{o}C$ but, this treatment method has some differences in MEA structure, anode composition is A16: CP (TGP-0120), Pt/C 20%, 30% Nafion, and 1.98 $mg\ DL.cm^{-2}$ with 0.396 $mg\ .cm^{-2}$ catalyst loading. Also, cathode composition is A16: CP (TGP-0120), Pt/C 20%, 30% Nafion, and 1.98 $mg\ DL.cm^{-2}$ with 0.4 $DL.cm^{-2}$ catalyst loading.

Figures (6-2) and (7-2) show polarization curves at the end of activation set in 9 sets for ultra-sonication in Isopropyl solution and water, respectively. Tables (5-2) and (6-2) represents extracted data from polarization curves of figures (6-2) and (7-2), in order.

Table (5-2) extracted data Polarization curves at end of each activation set in 9 sets for ultra-sonication in Isopropyl solution

Sets	OCV(*mV*)	MPD($mW.cm^{-2}$)	R(*mΩ*)
st 1	973	337	122
st 2	989	377	128
st 3	988	400	124
st 4	987	417	121
st 5	986	538	98
st 6	982	558	98
st 7	981	557	95
st 8	980	542	99
st 9	980	564	99

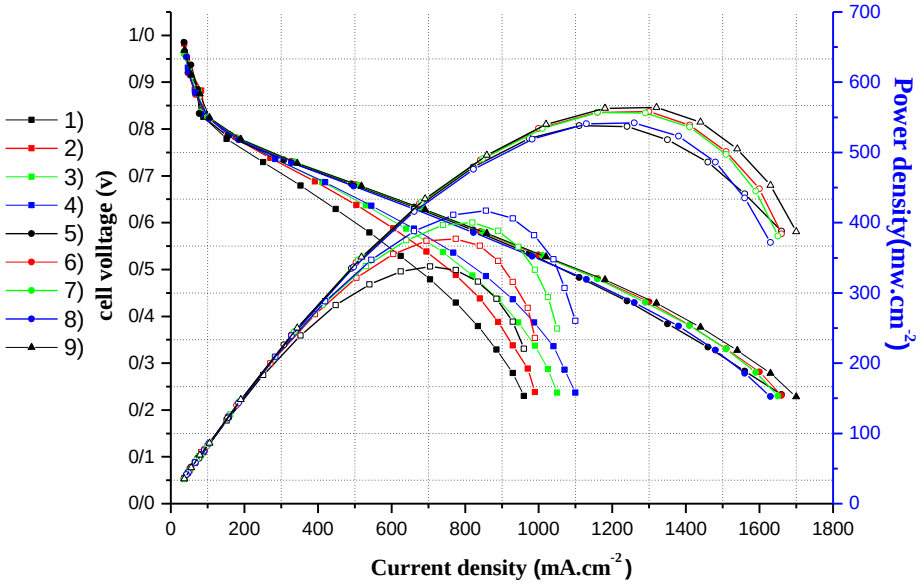

Figure (6-2) Polarization curves at end of each activation set in 9 sets for ultra-sonication in Isopropyl solution

Table (6-2) extracted data from Polarization curves at end of each activation set in 9 sets for ultra-sonication in water

Sets	OCV(*mV*)	MPD($mW.cm^{-2}$)	R(*mΩ*)
st 1	960	330	98
st 2	975	462	92
st 3	978	513	91
st 4	980	536	92
st 5	980	618	87
st 6	968	651	86
st 7	977	665	85
st 8	977	669	86
st 9	980	672	87

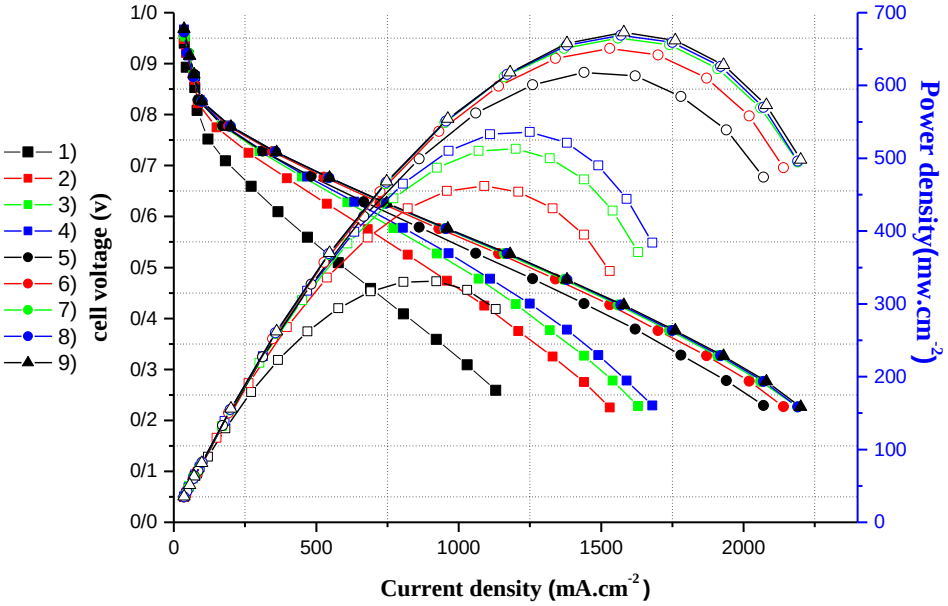

Figure (7-2) Polarization curves at end of each activation set in 9 sets for ultra-sonication in water.

In final step of activation test at constant voltage 0.6 *V*, analysis was done at different MEA structure without treatment procedure. Anode components are C39: CP (TGP-0120), Pt/C 20%, 30% Nafion with 0.42 $mg.cm^{-2}$ catalyst loading. Cathode composition is A16: CP (TGP-0120), Pt/C 20%, 30% Nafion with 0.396 $mg.cm^{-2}$ catalyst loading. Table (7-2) and figure (8-2) are related to polarization curve at the end of activation set in 9 sets.

Table (7-2) extracted data from Polarization curves at end of each activation set in 9 sets.

Sets	OCV(*mV*)	MPD($mW.cm^{-2}$)	R($m\Omega$)
st 1	942	462	82
st 2	978	648	76
st 3	975	714	77
st 4	983	900	72
st 5	980	929	72
st 6	982	930	74
st 7	982	924	74
st 8	985	1014	72
st 9	980	993	77

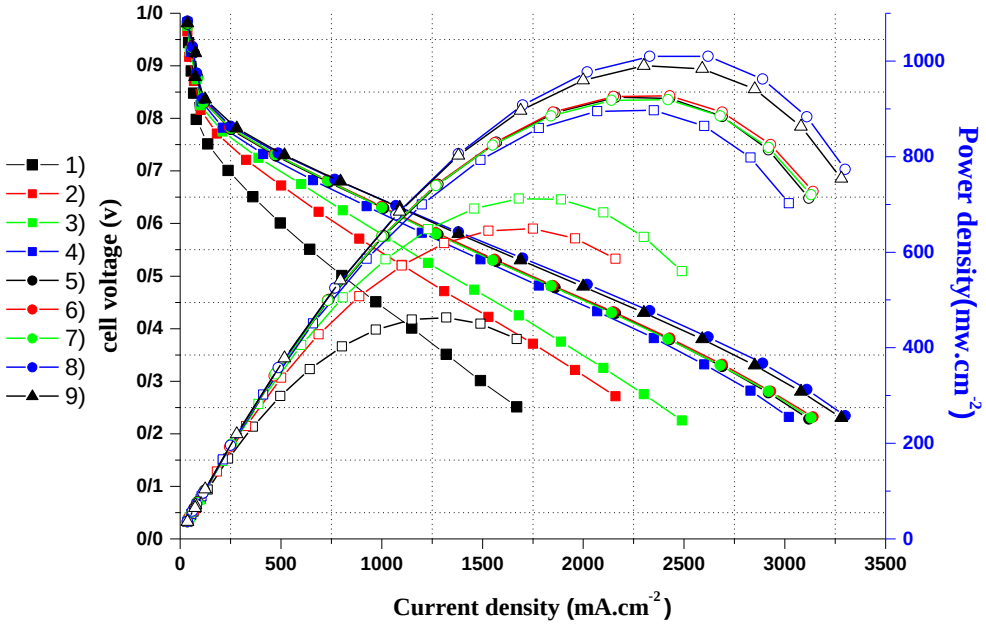

Figure (8-2) Polarization curves at end of each activation set in 9 sets.

2-2-4-Activation test MEA: standard test protocol

2-2-4-1-Experimental design, method and details

MEA structure include anode composition such as CP (TGP-0120), Pt/C 20%, 30% Nafion and 1.98 *mg DL.cm*$^{-2}$ (C29) with 0.377 *mg.cm*$^{-2}$ catalyst loading. Cathode components are CP (TGP-0120), Pt/C 20%, 30% Nafion and 1.98 *mg DL.cm*$^{-2}$ (C29) with 0.377 *mg.cm*$^{-2}$ catalyst loading. In activation procedure, 10 minutes OCV time and then, 60 minutes constant voltage 0.6 *V* was applied. In next steps, 14 minutes cycling potential between 0.7-0.5 *V* repeated for 10 times and a constant current 0.2 *A.cm*$^{-2}$ for 18 hours was applied. Table (8-2) and figure (9-2) presents polarization curves at end of activation set in 24 sets. In the mentioned figure, just power density was presented for Chartjunk problem.

In standard test protocol of MEA activation, reported data related to polarization curves at end of each activation set in 24 sets, impedance curves at the end of each activation set 0.3, 0.5, 0.7 and 0.8 *V* at 60 /50/ 55^{o}*C* with 5psig flow rate H_2/O_2: 200/200 *ml.min*$^{-1}$, polarization curves at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15 and 25 *psig*, impedance curves in various voltages at the end of activation procedure in humidity condition 30, 50, 100% at 5, 15 and 25 *psig* flow rate H_2/O_2: 200/200 *ml.min*$^{-1}$, polarization curves at the end of activation procedure in different air humidity condition 30, 50 and 100% at pressure at 5, 15 and 25 *psig*, impedance curves in various voltages at the end of activation procedure in different cathode humidity condition 30 a 50 and 100% at pressure at 5, 15 and 25 *psig*.

Table (8-2) Extracted data from Polarization curves at end of each activation set in 24 sets.

Sets	OCV(*mV*)	MPD(*mW.cm*$^{-2}$)	R(*m*Ω)
st 1	961	375	103
st 2	963	460	98
st 3	970	505	89
st 4	977	617	85
st 5	975	645	83
st 6	974	650	82
st 7	975	650	80
st 8	982	702	81
st 9	979	703	79
st 10	979	709	79
st 11	979	714	79
st 12	987	758	77
st 13	977	740	77

st 14	977	737	77
st 15	979	736	77
st 16	986	777	75
st 17	979	762	77
st 18	981	768	77
st 19	981	761	77
st 20	990	803	77
st 21	980	780	76
st 22	981	781	76
st 23	981	792	75
st 24	996	869	73

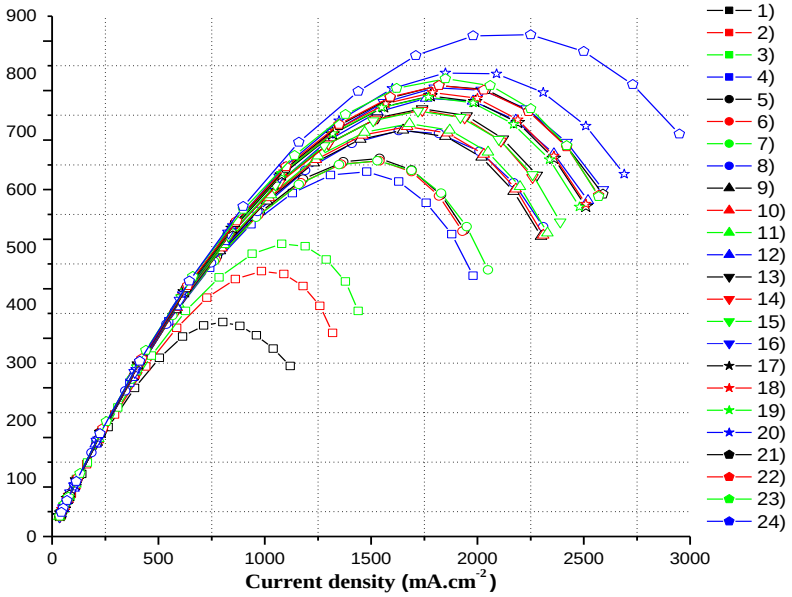

Figure (9-2) Polarization curves at end of each activation set in 24 sets.

Standard test protocol of MEA activation repeated with a difference in 0.38 $mg.cm^{-2}$ catalyst loading in anode and cathode composition as MEA structure (other components of anode and cathode are similar). In activation procedure, 10 minutes OCV time and then, 0.6 *V* constant voltage for 60 minutes applied. In next steps, 14 minutes cycling potential between 0.7-0.5 *V* repeated for 12 times and a constant current 0.2 $A.cm^{-2}$ for 12 hours was applied. Obtained data are the same as before protocol, exactly. Table (9-2) and figure (10-2) presents polarization curves at end of activation procedure in 19 sets. In that figure, there is only power density because, presentation of voltage lead to Chartjunk problem.

Table (9-2) Extracted data from Polarization curves at end of each activation set in 19 sets.

Sets	OCV(*mV*)	MPD($mW.cm^{-2}$)	R(*mΩ*)
st 1	976	771	79
st 2	983	887	76
st 3	981	879	77
st 4	991	542	68
st 5	995	945	77
st 6	995	952	78
st 7	994	943	78
st 8	997	930	78
st 9	992	990	81
st 10	996	963	77
st 11	997	962	77
st 12	994	954	77
st 13	993	954	77
st 14	992	904	93
st 15	998	1022	76
st 16	999	1025	75
st 17	999	1019	74
st 18	999	1010	75
st 19	998	1011	75

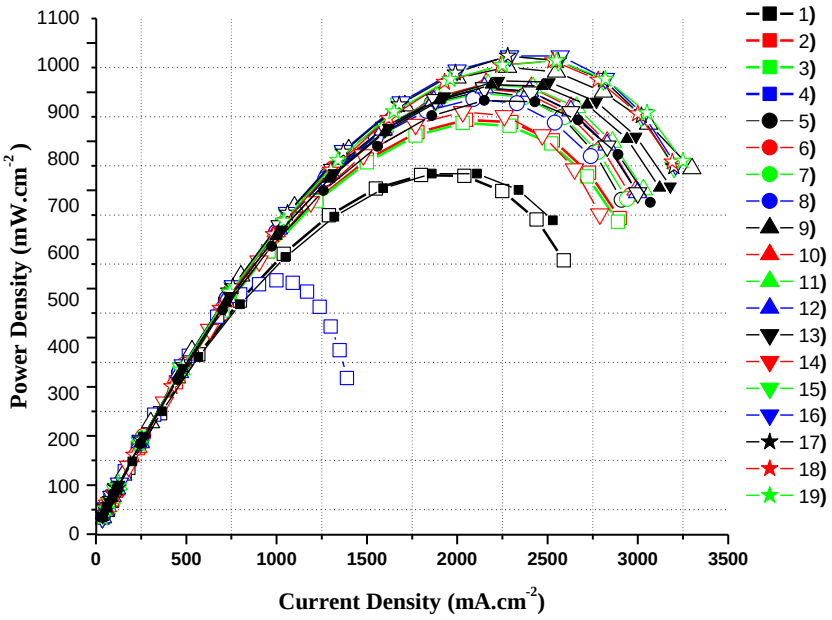

Figure (10-2) Polarization curves at end of each activation set in 19 sets.

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