

Studying The Effect of The Operating Conditions on The PEM Electrolysis by Image Processing

4th ESIREM year internship report

Amerguy Salaheddine

Promotion Materials Engineering, Chrome

Deutsches Zentrum für Luft- und Raumfahrt (DLR)

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DLR supervisor: Mr. Julio Cesar Garcia Navarro

Academic supervisor: Mr. Lionel Combemale

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I express my deepest thanks to Mr. Indro for being attentive to the students and his availability, taking part in advices and guidance and arranged all facilities to make my internship easier. I choose this moment to acknowledge his contribution gratefully.

And to finish I want greeting all PhD student and trainees, for their presence next to me and the beautiful time that we spent together during this internship.

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DLR presentation:

DLR (Deutsches Zentrum für Luft und Raumfahrt) is the national aeronautics and space research Centre of the Federal Republic of Germany.

Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. DLR has approximately 8000 employees at 16 locations in Germany: Cologne (headquarters).



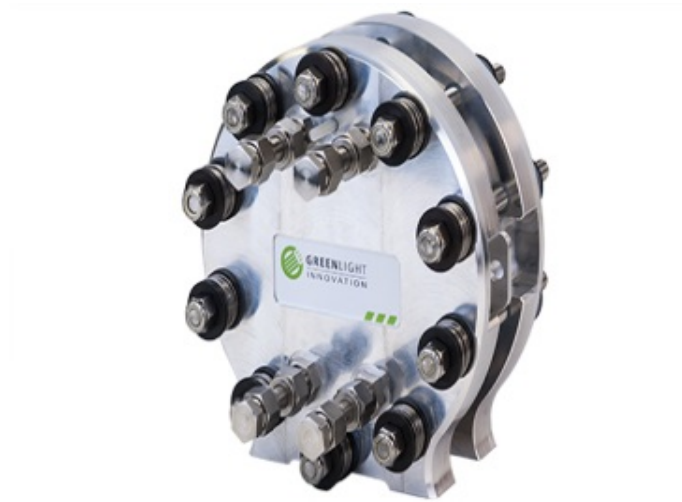
Picture 1 : Institute of Engineering Thermodynamics

The Stuttgart facility is near to Stuttgart-Vaihingen University and currently employs a staff around 700 in six kind of research institute :

- ✓ Institute of Structure and Design
- ✓ Institute of Vehicle Concepts
- ✓ Institute of Technical Physics
- ✓ Institute of Technical Thermodynamics
- ✓ Institute of Combustion Technology
- ✓ Institute of Solar Research

The internship was conducted at the Institute of Technical Thermodynamics (Picture 2), it addresses the development of innovative, high efficient energy conversion technologies, and the use of renewable energies. One of the main investigations ways is Fuel cells (SOFC), Polymer Electrolyte Fuel cells (PEFC) or Alkaline Fuel cells (AFC). During my internship I focused on Polymer Electrolyte Membrane (PEM) Electrolysis.

Introduction



Picture 2: Polymer Electrolyte Membrane (PEM) Electrolysis

High-quality of hydrogen ($\cong 100\%$ hydrogen) can be produced by the electro-chemical conversion of water to hydrogen through a process known as water electrolysis.

Over the last few years, hydrogen is being taken more seriously by the power industry, as a solution to make renewable energy grid ready since the Federal Government in Germany has decided to stop the production of nuclear energy by 2022.

Polymer Electrolyte Membrane (PEM) Electrolysis, operates at medium temperature ($50\text{ }^{\circ}\text{C} - 80\text{ }^{\circ}\text{C}$, and pressure $<30\text{ bar}$). The Principle is to pass a direct current between two electrodes immersed in an electrolyte (*Nafion Membrane*), Hydrogen (H_2) is formed at the cathode and oxygen (O_2) at the anode (positive terminal). The production of hydrogen is directly proportional to the current passing through the electrodes.

Developments of low cost and corrosion resistant of current collectors, high protonic conductivity for the transport of ions, the homogeneous distribution of water inside of the cell, are presently the key technical challenges.

The two examples of research made at the DLR about the PEM electrolysis, an *in-operando* diagnostic tool with a proprietary segmented board [1] ***** (other example of research in DLR ; PEM electrolysis - please)

The aim of this internship is the develop an image processing program, based on Matlab, to study the hydrogen/oxygen bubbles for different operating conditions (pressure , temperature , water flow) inside of the PEM electrolysis . In this report two pictures had been taken from the same operating conditions but from different flow regimes will be processed by Matlab .

The PEM water electrolysis technology

In PEM electrolysis, PEM serves as the electrolyte as well as the barrier between hydrogen H_2 and oxygen O_2 . Charging water with a DC electrical current (from different sources of energy, solar, wind ...) the charge breaks the chemical bond between the hydrogen and oxygen splits apart the atomic components.

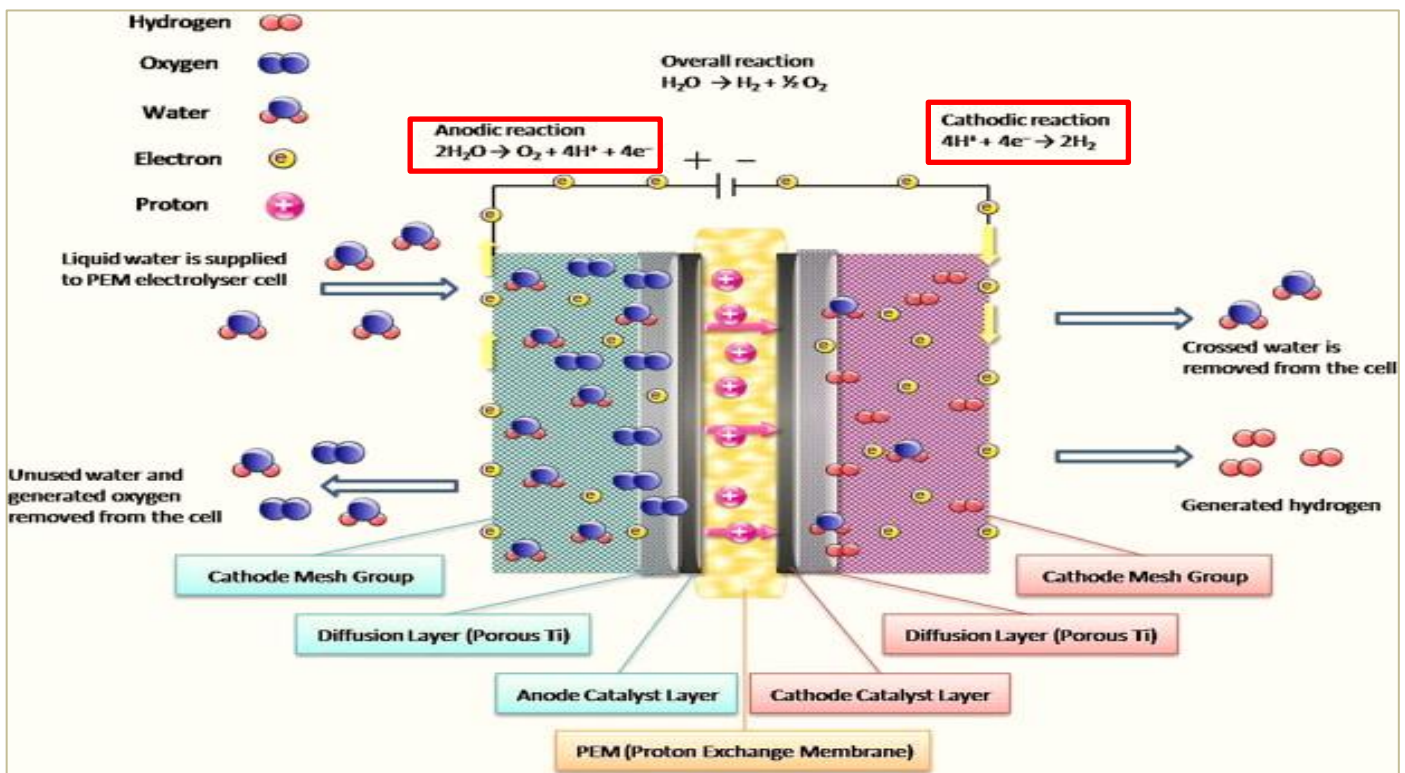
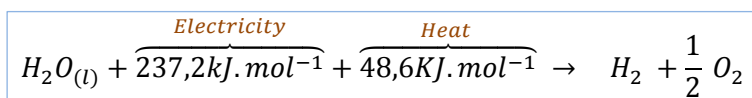


Figure 1: PEM Electrolysis running process

The use of the second law of thermodynamics:
$$\Delta H = \underbrace{\Delta G}_{elec} + T \underbrace{\Delta S}_{heat}$$

Where ΔG is the Gibbs free energy of the reaction, T is the temperature of the reaction and ΔS is the change in entropy of the system. The overall cell reaction with thermodynamic energy inputs then becomes:



The thermal and electrical inputs shown above represent the minimum amount of energy that can be supplied by electricity in order to obtain an electrolysis reaction.

In our case, a segmented cell is realized by a PCB* (Printed Circuit Board), it consists of many resistors for the measurement of the electric current density and temperature inside a fuel cell or electrolysis (there is other parameters,?,...), it's a prominent component to get a feedback and control (detect problems and defects at early state). As a result, we optimize the operating conditions, and long life cycles of the PEM electrolysis can be achieved.

(* PCB can be used as a bipolar plate in stacks as well as in single cells)

Work investigated

1) Experimental setup and methodology:

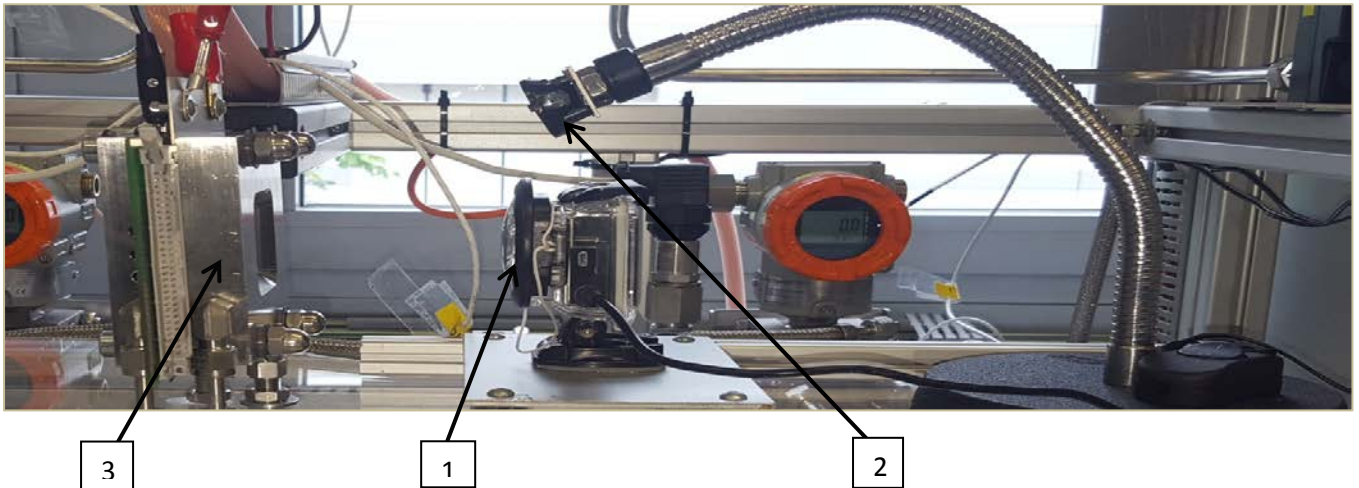


Figure 2: The experimental setup

The main features of the platform are:

- 1- GoPro Hero 4 Black Camera with magnifying lens .Positioned at 5cm from the objective (The bubbles) .The camera films at a frame rates of 240 fps and an image quality of 720 p (HD).
- 2 - The light source is a Roithner LaserTechnik R-HP803NW LED (white) - Temperature 6000K (**The temperature is too high , is it normal?**), 55 lumens at 700 ma – Positioned above the camera
- 3- PEM electrolysis. Catalyst material for the anode is Iridium and Platinum for the cathode. The material of the Proton Exchange membrane is the Nafion serves as an ionic conductor.

In the presence of low PH, strong oxidant, and High temperature, the choice of catalysts becomes more and more decisive. For an effective PEM electrolysis the catalysts should comply with four criteria: (Source)

A - Stability: to be able to withstand the harsh chemical environment within a fuel cell.

B - Selectivity: to make the desired product and minimize the production of undesirable intermediates and side products.

C -Activity: to be able to adsorb the reactant strongly enough to facilitate a reaction but not so strongly that the catalyst becomes blocked by the reactant or products.

D -Poisoning resistance: to be resistant to poisoning by impurities likely to be found in the fuel cell itself and in the feed gases/liquid.

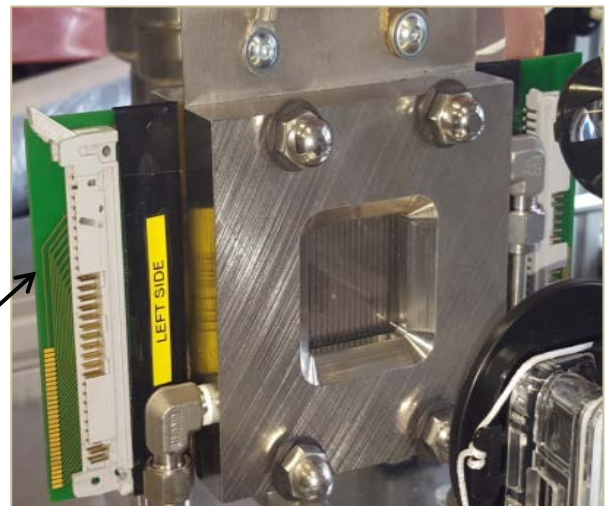


Figure 3- Represent a distilled water pump .with two silo for hydrogen H_2 and O_2 storage.

(Please....can I get some characteristics about the Pump, The water flow is it controlled only by two pumps?, and why we need two ? the change of the regime implied instantly the change inside of the electrolysis or it takes time,)

Figure 3 : Two Water pumps and Hydrogen H_2 - Oxygen O_2 storage

Figure4 – (1) A segmented cell realized by a segmented printed circuit board (PCB) and mounted in the cathode side. The PCB is used as a diagnostic tool to measure the local current density under operating conditions. The segmented board utilized by the DLR can detect the effect of both design parameters (active site distribution, flow field, etc.) and operational parameters (temperature, pressure, reactant flow, etc.). [Source-Julio Publication]



1

Figure 4: The Printed Circuit Board (PCB) connected to the PEM electrolysis.

The figure 4 represent the program LabVIEW connected to the PCB (printed circuit board) , serves for an embedded monitoring and control of the PEM electrolysis .(Please , can you give more information about the parameters that we can control by LabVIEW)

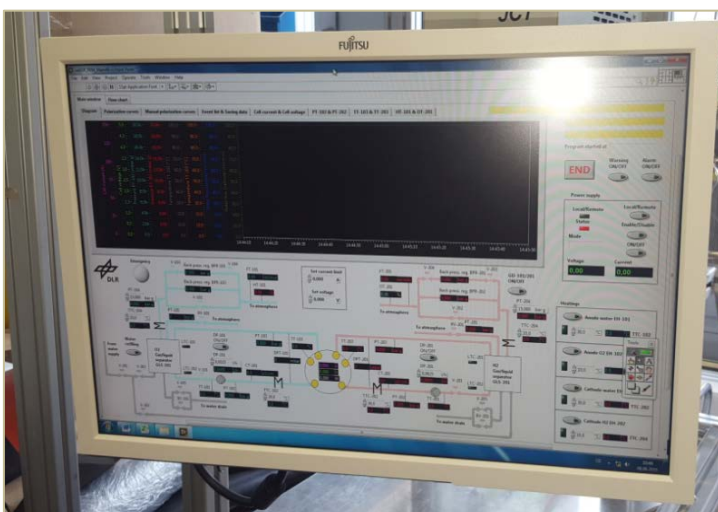


Figure 5 : Panel Control for *****

2) Image processing:

2-1) Introduction:

Image processing is used primarily for extracting useful information from images. Matlab Image Processing Toolbox provides a comprehensive set of reference-standard algorithms, functions, and apps for image processing, analysis, visualization, and algorithm development. It can be used to perform image analysis, image segmentation, image enhancement, noise reduction, geometric transformations, and image registration.

2-1-1) Example N°1:

Matlab Image Processing Toolbox (version 2015) has been used to detect the size and the number of oxygen bubbles, from the images taken by a camera (appendix 2 – Figure1). For more significant results, only the left bottom part, where we have more number of bubbles, with a different shape has been analyzed (figure 6) .

The image are realized in the same conditions of the experimental set-up but not with a camera Go-Pro

The Original Image (Figure 6), has been converted from 8-bit color to 8-bit grayscale (Binary Image), by the function `Rgb2gray`. The Binary Image is composed of different shades of gray color. The value 0 represents black and the value 255 represents white. The range will be between black and white values. Matlab algorithm (appendix N 2)

This image is from the anode (the bubbles are pure Oxygen):

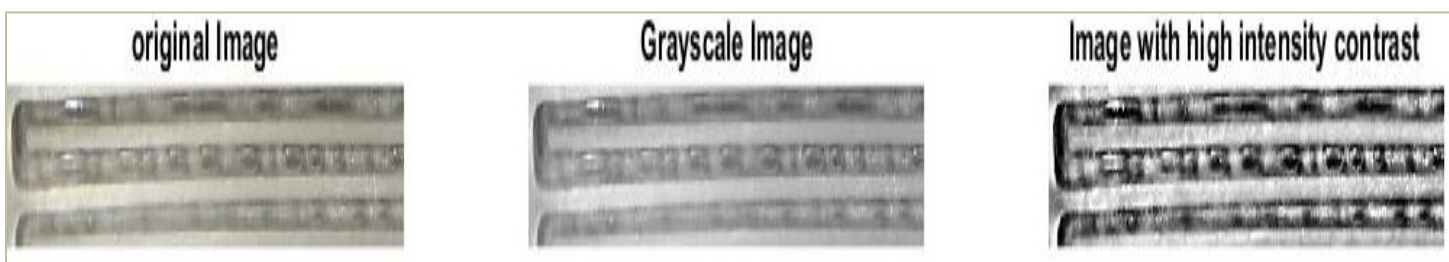


Figure 6 : binarization of image and Enhancement

The operating conditions are as follows

- Pressure: 1 bar absolute
- Temperature: 25 °C
- Water flow: 80 ml/min
- Current density: 1 A/cm² (25 A total)
- Voltage: 1.8 V
- Flow regime: Slug Flow

Histeq

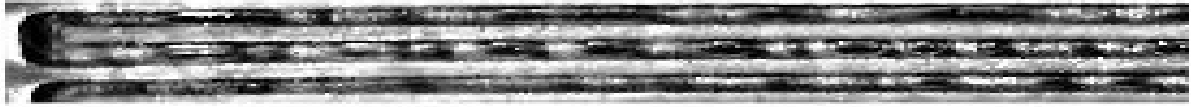


Figure 7 : Image Enhancement

To maximize the intensity contrast in the image, the function *Adaphisteq* enhances the contrast of the binary image by transforming the values using contrast-limited adaptive histogram equalization. In order to perform the enhancement of the image the two defined functions *Imadjust* and *Histeq* have been used

“The presence of oxygen bubbles is blocking a homogenous distribution of water inside of the PEM electrolysis. As a result, the performances of the electrolysis are low, and we should reflect to change the operational and design parameters” - *is that true for all types oxygen bubbles ?*

2-2) Image segmentation:

Segmentation represents the most important part of image processing. It's defined as the process of partitioning a digital image an entire image into several parts which is something more meaningful and easier for further process. The most common segmentation techniques are presented in this graphic.

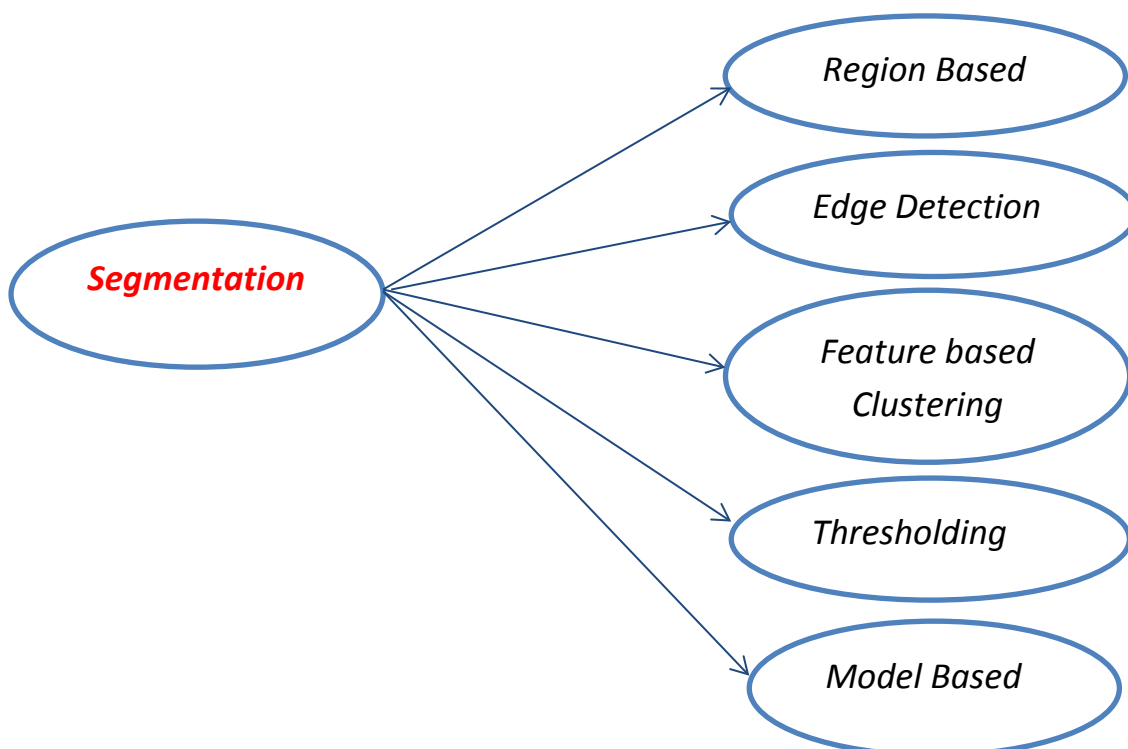


Figure 8 : Various types of Segmentation

Segmentation can be applied to any type of image, but the type of segmentation depends especially on the image and the information that we are looking for to extract from it. For example, locate objects and boundaries (lines, curves).

We can notice on figure 7, that the contrast intensity of the bubbles and the background still close. Moreover, the boundaries of bubbles cannot be detected with precision.

The technique of thresholding is the most used as method of segmentation. In Matlab -Image processing toolbox- we can use the application "Color thresholder". The threshold values are obtained from the histogram of those edges of the original image. The principle of the method is the replace in an image with a black pixel if the image intensity $I_{i,j}$ is less than some fixed constant T (that is $I_{i,j} < T$), or a white pixel if the image intensity is greater than that constant. Color images can also be thresholded. For example in the figure 7 the value of T is fixed at 137 (this value is from the histogram) by the application "Color thresholder".

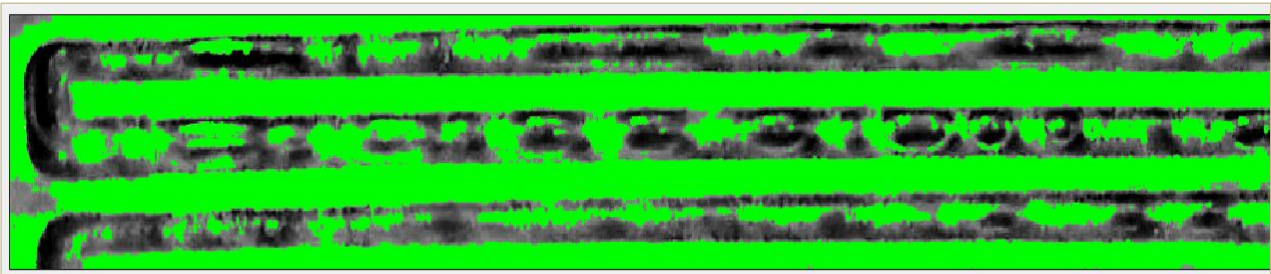


Figure 9 : Automatic Threshold –with superior Opacity

In order, to calculate the number of the bubbles and their size (100 pixel=2.646 cm) . Direct binarization of the figure7, changes completely the shape of the bubbles .Furthermore, the cluster of bubble is detected, and our results became incorrect .

For more accurate results with a better binarization of image, the application "Image region analyzer" on Matlab allows us to draw polygons directly on image (figure 10). Moreover, we can get also the properties of regions in binary images (Area, Perimeter, Major and Minor axis length- Appendix N2)



Figure 10 : the binarization of fig 9 , with drawn polygons

2-1-2) Example N°1:

The Original Image has been taken by a camera from the anode (the bubbles are pure Oxygen), in the same operating conditions as the first example N°1, in order to compare it with it we change only the flow regime from the slug flow to bubbly flow.

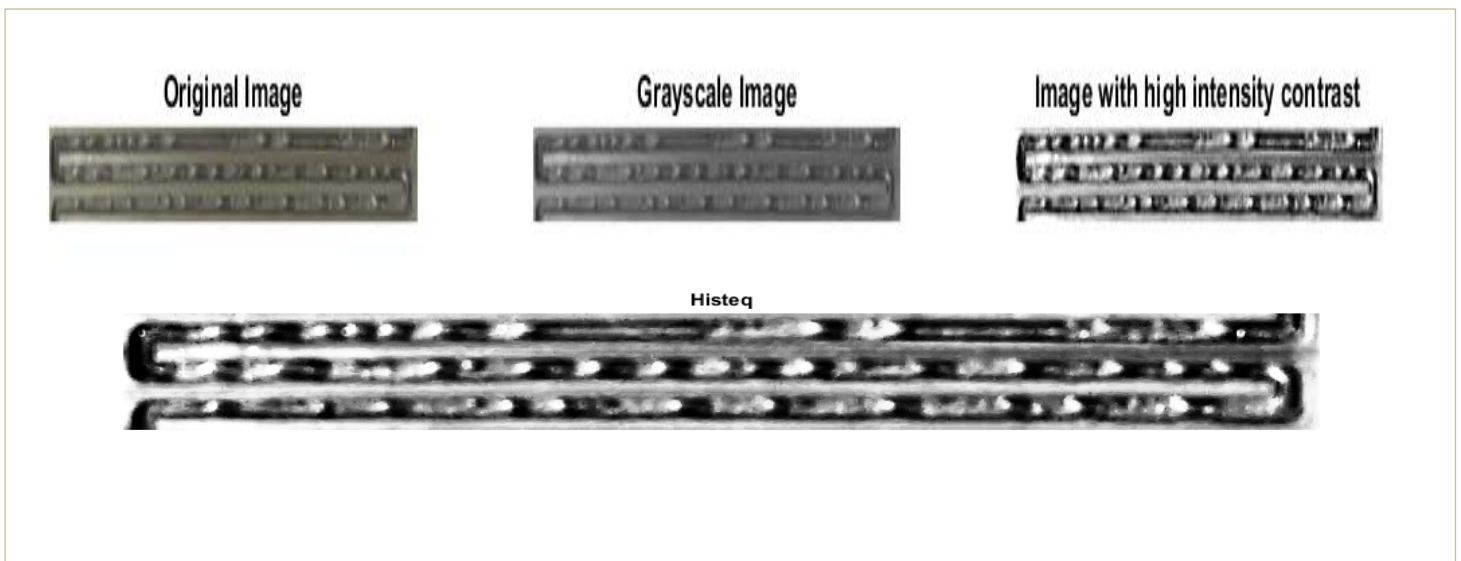


Figure 11 : Binarization of the Original image and enhancement by using defined functions on Matlab

The value of the automatic threshold is fixed at $T= 121,5$ by Matlab application .

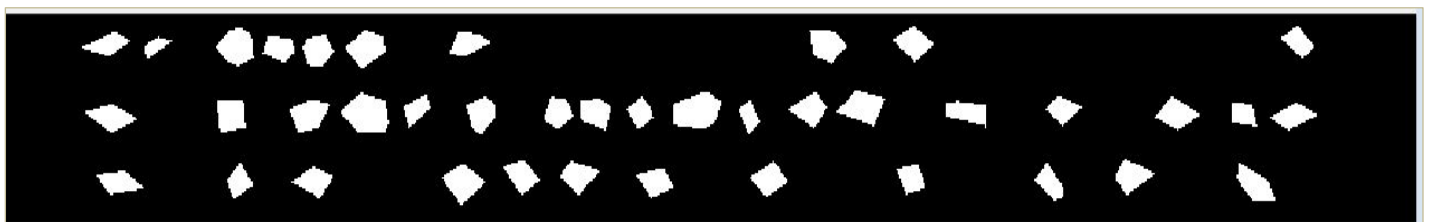


Figure 12 : The binarization of Thresholder image -fig9-, with drawn polygons

Results:

We can observe from image (appendix1) the water gets supersaturated with oxygen from the anode, and hence to release of oxygen at the electrodes nucleates bubbles at the surface of the electrolysis .The grows process may continue even after detachment from the electrode .The bubbles (oxygen or Hydrogen) distribution inside of the PEM electrolysis represent inactive parts due to bubble formation. As a consequence, we have heterogeneous distribution of current density, and low efficiency of the PEM electrolysis.

	Example N°1	Example N°2
Number of bubbles	26	40
Area	927-118	191-172
Perimeter	153-45,21	62,57-49,03
Equiv Diametre	34,35-12,25	15,59-14,7

Figure13 shows the maximum Area, perimeter, and equivalent Diameter, in Pixels.

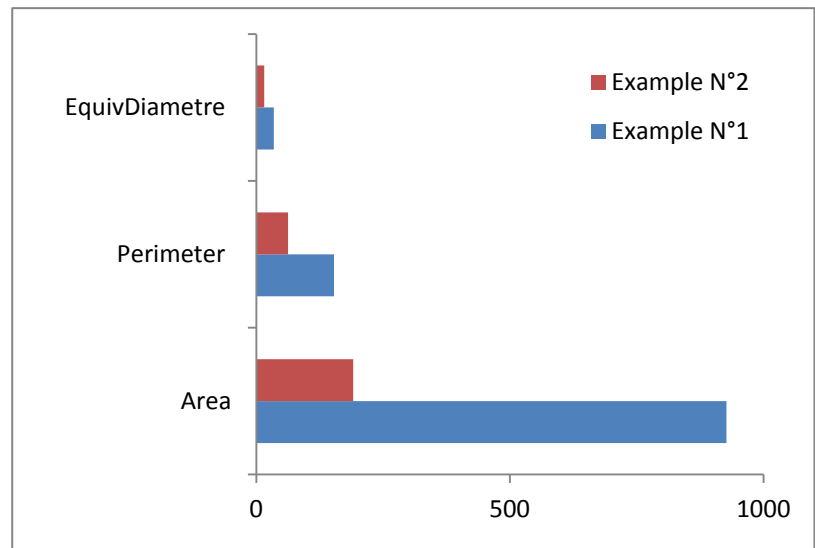


Figure 13: Comparison the results of Image analyzer region

The number of bubbles in the first example is approximately the double of the second one. It can be explained by the bubbly flow regime (Example N 2) characterized by the presence of fast rising bubbles with a diameter equal to or less than the capillary diameter. The Bubbles have a spherical shape (figure11) which can easily recognize and calculated by the application "Image analyzer region". For the slug flow regime (ExampleN 1), which consist of elongated bubbles with lengths greater than the tube diameter (the section), separated by a liquid slug in this case bubbles are less recognized (cluster bubbles).

The flow regime represent an important factor that influences the efficiency of the electrolysis. The choice – (or the regime inside of the cell) the regime should depend on:

Rise velocity of slug bubbles, or pump more water ? is it always good for the electrolysis

how can we make the difference between Hydrogen and oxygen bubbles , if they are inside of the electrolysis ? (I mean not close to the anode or the cathode) -Which parameter (principal one) can influence the presence of more oxygen bubbles than hydrogen?(or the opposite)

Conclusion and perspective

You can add some ideas as perspective ☺

Sources : I DIDN T FINISHED YET THIS PART :

[1] M. Schulze, E. Gülzow, St. Schönbauer, T. Knöri and R. Reissner, *J. Power Sources*, 173(1), 19-27 (2007).

[2] I. Dedigama, P. Angeli, N. van Dijk, J. Millichamp, D. Tsaoulidis, P. R. Shearing and D. J. L. Brett, *J. Power Sources*, 265, 97-103 (2014).

<https://books.google.de/books?id=OFUSUq3M5QMC&pg=PA182&lpg=PA182&dq=Image+processing+is+concerned+primarily+with+extracting+useful+information+from+images&source=bl&ots=0N5BvXINxA&sig=gnT9L9sbbTICrk7P21iQrQkynLM&hl=fr&sa=X&ved=0ahUKEwiKt470gpbNAhVGbhQKHW7WCnUQ6AEIHDA#v=onepage&q=Image%20processing%20is%20concerned%20primarily%20with%20extracting%20useful%20information%20from%20images&f=false> (Le premier paragraph d introduction)

Website of Matlab

<https://books.google.de/books?id=BNuYCgAAQBAJ&pg=PA78&lpg=PA78&dq=catalyst+materials+PEM&source=bl&ots=aDJOZNFb3h&sig=8P-dlZrFPVr25v-DxK-frttNtro&hl=fr&sa=X&ved=0ahUKEwiP0qyarpjNAhXMaxQKHbEYDj0Q6AEIXTAG#v=onepage&q=catalyst%20materials%20PEM&f=false> (Avoir pour qlq informations)

<http://www.sigmaaldrich.com/materials-science/renewable-alternative-energy/pem-fuel-cells.html>

<http://www.technology.matthey.com/article/57/4/259-271/> (pour les quatres criteres)

Il faut pas oublier les axes des graphes ,....les figures momermise en page