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مركز أبحاث تكنولوجيا العمليات الكيميائية
Institute for Chemical Process Technology (ICPT)
http://aecenar.com/institutes/icpt

# ICPT Report Jan 2023 - Mar 2025

## Systems, Mechanical and Testing


Editors:

**Mariam El Rez, Dr. Samir Mourad**

With contribution of:

**Amro Zawit**

**Mariam El Rez**

**Abdullah Kassem**

**Abdullah Mourad**

**Razan Youssef Kaddour (Master Thesis)**

**Rawan ABDELMAJID (Trainee)**

**Muhamad AMOUD**

**Oussama DHAIBI**

**Tarek Tertanni**

**Ghaith al Ali**

**Ali DIB**

**Othman Dhaiby**


Remark: PCS for all Teststands are in separate document


Last Update: 25.03.2025 21:02

Legend:

- Red: Still open
- Yellow: In work
- Green: completed

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**Still open issues:**

- Responsible: Mariam El Rez, Ihab Wehbi
- Timeline: 4-6/25
- Needed Budget: 2,000 $

# ICPT Projects Actual Status Mar 2025

GREEN CHEMISTRY

## Metallurgy Lab (Melting/Annealing/Alloying)

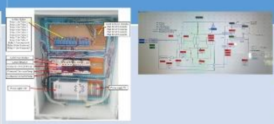
*Next steps: 3 phase furnace development for alloying*

## Monostage Electrolysis Device

**System Design**
https://aecenar.com/index.php/institutes/icpt/icpt-electrolyser/system-concept-system-design/mechanical-design

**Mechanical Realization**
https://aecenar.com/index.php/institutes/icpt/icpt-electrolyser/realization-implementation/mechanical-realization

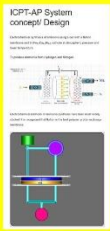
**Automation**
https://aecenar.com/index.php/institutes/icpt/icpt-wedc-testrigs-pcs/electrolyzer-plc-instruments



**System Test**
System test specification
https://aecenar.com/index.php/institutes/icpt/icpt-electrolyser/system-test-specification
System test on 28.6.23
https://aecenar.com/index.php/institutes/icpt/icpt-electrolyser/system-test-cases/electrolyzer-test-28-06-2023

H2 N2 O2

## Hydrogene Storage Device ICTP-AP



*Next step: chemicals and electrodes realization*

| Department | Task/Module | Responsible | Status |
|---|---|---|---|
| | Design | Ihab Wehbi | done |
| Mech | Realization https://aecenar.com/index.php/institutes/icpt/icpt-ap-electrochemical/icpt-ap-system-realization | | in work |
| | | | |
| | | | |
| | | | |

## Multistage Electrolysis Device

*Due Date: May 25*
*Commisioning: 06/25 - …*
*Responsible: Mariam El Rez*
*Still needed Budget: 2,000$*

| Task | Due Date/ timeline | Material Costs |
|---|---|---|
| Contruction of parts | - 31.5.24 | |
| Manufactoring | | 500$ (MECH+AUT) |
| Commisioning | | 1500$ |
| | | |

H2 O2

## LOX Device

*Next steps:*
*Cooling cycle with butane*
*Master thesis (2025 or 2026)*

## H2 Compressor

NH3

Ammonia (Energy Storage, ready for shipping ) ($)

LOX

Liquefied Oxygene (For medical use) ($)

## Fuel Cell


*Due Date: Sep 24*
*Commisioning: 10/24-5/25*
*Responsible: Razan Kaddour*
*Still needed Budget: 1,000$*

| Department | Task/Module | Responsible | Status |
|---|---|---|---|
| Mech | Design | Mariam El Rez | Done |
| | Realization | Razan Kaddour | in work |
| | System Testing | Razan Kaddour | Open |
| | | | |
| | | | |

# Table of Contents

## Preface

This report contains details of the ICPT Institute projects we carried out from  Jan 2023 until March 2025. These projects include the old ones that have been continued, such as the Electrolyser project, the Multistage electrolysis, the Ammonia production project, and the Metallurgical Lab. It also reviews new projects such as the FuelCell, and the Air separation projects

# 1 Introduction

In 2023 and 2024, the ICPT Institute will be responsible for **8 projects**; six were started in previous years and continued this year, and two new projects were attached to the institute this year.

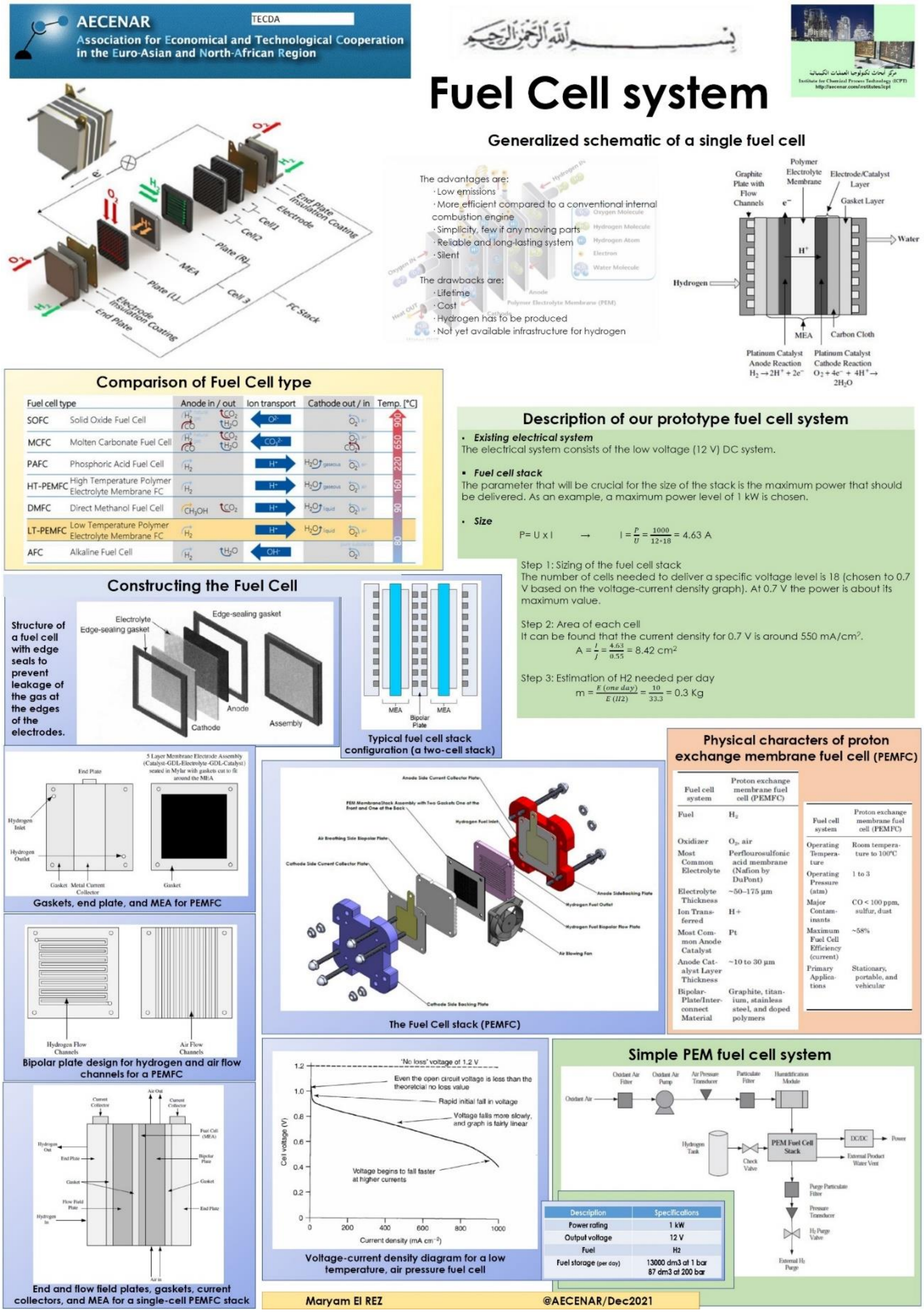
For projects started in previous years (2022 and earlier) and continued in 2023 and 2024: **Electrolyser project, Biogas project, Ammonia production project, Gas turbine project, Multistage electrolyzer project,** and **Metallurgical Lab**.

For the projects added to the ICPT Institute this year (2023 and 2024): **FuelCell**, and **Air Separation projects**.

In the following sections, we will discuss each project in detail: What it is, where it arrived before 2023, details that were added in 2023 and 2024, and finally, what should be completed in each project.

# 2 Posters of projects

## 2.1. Fuel Cell project

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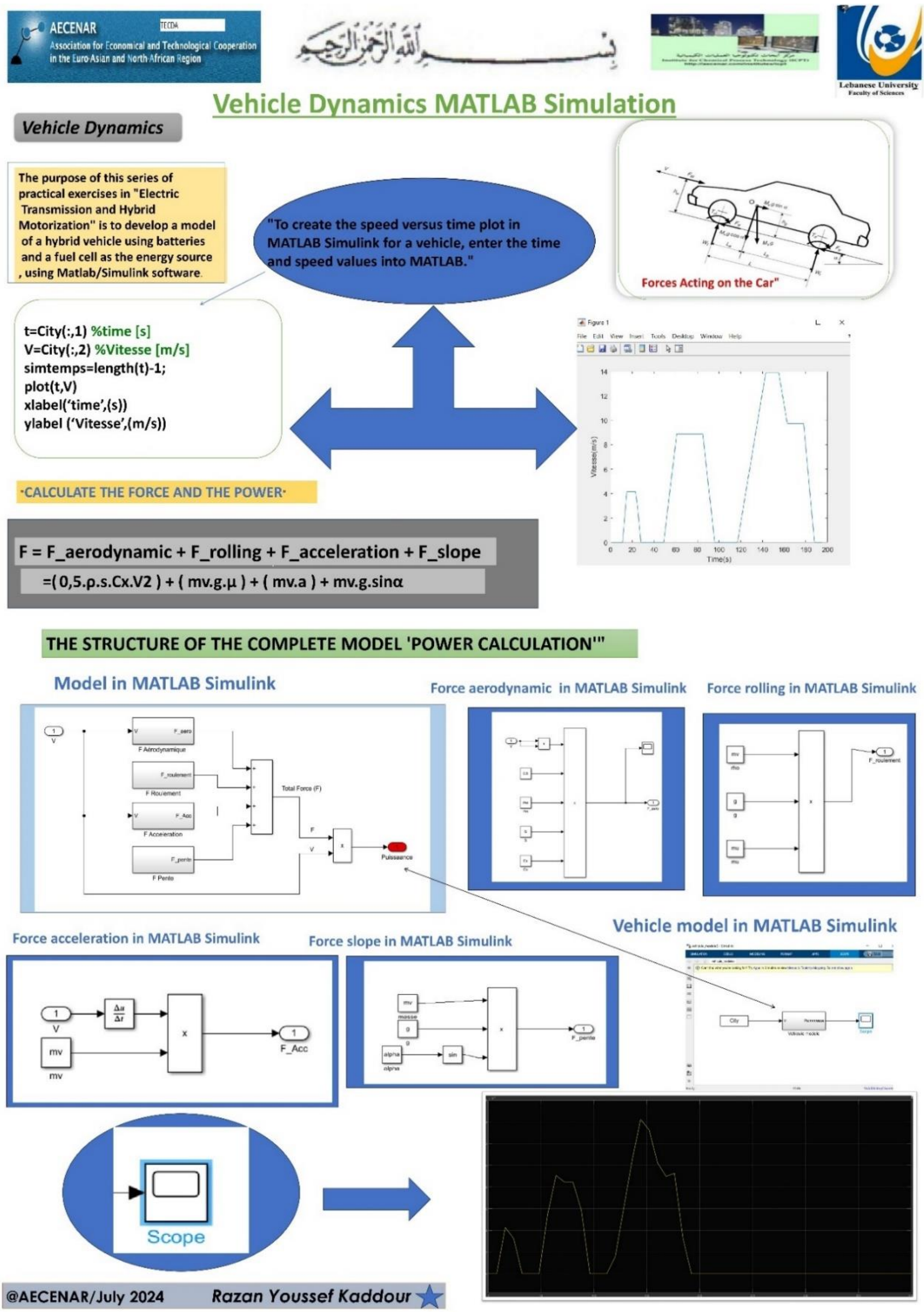
.Introduction:
Fuel Cell & Electrolyser
.Design- Electrolyser & Fuel Cell Free Cad.
Electrolyzer and fuel cells are necessary for the management of hydrogen in various industrial processes as an alternative energy carrier. Electrolyzer produce hydrogen by decomposing water into oxygen and hydrogen through electrolysis. The hydrogen gas is then sent to fuel cells, which convert the chemical energy into alternating current, heat, and water, requiring a supply of fuel and oxidant in return.
Oxygen
Hydrogen
Hydrogen from electrolysis will be used on one side and air on the other side.
Fuel Cell realization
Conducting Test of Fuel Cell and measurements the cell Voltage,Power,Current,and efficiency.
Design of Electrolysis- Free CAD
Design of fuel Cell Free CAD
Simulation of Fuel Cell and carry out measurements under different conditions (temperature ,pressure, gas flow)
Photos of electrolysis
Graphite plates for the Fuel Cell
MEA plate
June 2024
Razan Youssef Kaddour.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TECDA
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بسم الله الرحمن الرحيم
Lebanese University
Faculty of Sciences
Vehicle Dynamics MATLAB Simulation
Vehicle Dynamics
The purpose of this series of practical exercises in "Electric Transmission and Hybrid Motorization" is to develop a model of a hybrid vehicle using batteries and a fuel cell as the energy source , using Matlab/Simulink software.
"To create the speed versus time plot in MATLAB Simulink for a vehicle, enter the time and speed values into MATLAB."
Forces Acting on the Car"
t=City(:,1) %time [s]
V=City(:,2) %Vitesse [m/s]
simtemps=length(t)-1;
plot(t,V)
xlabel('time',(s))
ylabel ('Vitesse',(m/s))
Figure 1
Vitesse(m/s)
Time(s)
·CALCULATE THE FORCE AND THE POWER·
F = F_aerodynamic + F_rolling + F_acceleration + F_slope
=(0,5.ρ.s.Cx.V2 ) + ( mv.g.μ ) + ( mv.a ) + mv.g.sinα
THE STRUCTURE OF THE COMPLETE MODEL 'POWER CALCULATION'"
Model in MATLAB Simulink
Force aerodynamic in MATLAB Simulink
Force rolling in MATLAB Simulink
F Aerodynamique
F Roulement
F Acceleration
F Pente
Total Force (F)
Puissance
Vehicle model in MATLAB Simulink
Force acceleration in MATLAB Simulink
Force slope in MATLAB Simulink
F_Acc
Scope
@AECENAR/July 2024
Razan Youssef Kaddour

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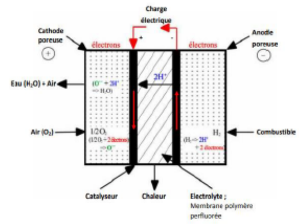
# *Fuel Cell System Simulation in Electric vehicle*

## Problem

The limitation of resources and climate change caused by polluting vehicles that release a large amount of $CO_2$ impose a change in the mode of personal transportation. Therefore, hybrid electric vehicle technologies are considered as one of the most favorable solutions to face the environmental and energy problems caused by the automobile industry.

## Objective

The objective of this study is to determine the mass of hydrogen, $m_{H2}$, needed to operate a vehicle during a driving cycle. We will need to use the vehicle dynamics Simulink model and extract the power and the power required by the fuel cell. The transmission efficiency is 80%. We are implementing a fuel cell in an electric vehicle.



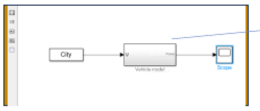

Fuel cell unit

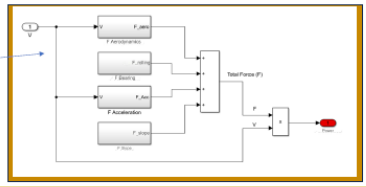
A fuel cell is a potentially clean energy source because it only produces water and consumes hydrogen gas ($H_2$). However, whether the system is considered clean depends on how the hydrogen is produced. The production process is very expensive due to the large quantities of platinum required and the complexities of its synthesis. Additionally, hydrogen must be compressed into gas cylinders at pressures between 350 and 700 bars, liquefied, or chemically produced onboard from methanol or methane.

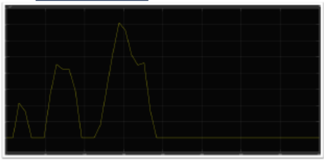
## Characteristic of electric vehicle

F = F_aerodynamic + F_rolling + F_acceleration + F_slope $=( 0,5.\rho.s.Cx.V^2 ) + ( m_v.g.\mu ) + ( m_v.a ) + m_v.g.\sin\alpha$

P=FxV







Vehicle Power

## Modelling of fuel cell

**1) Current of fuel cell [A]:**

$I_{fc} = \frac{P_{fc}}{Vfc}$

**2) Voltage of fuel cell [V]:**

Vc (voltage of cells) $=1.031-2.45\times10^{-4}\times j - 0.03 \ln (j+3)-2.11\times10^{-5}e^{(8\times10-3j)}$

J (current density mA/cm²) $= \frac{I_{fc}}{S_{fc}}$;

$S_{fc}$ (surface of cell = 480cm²)

$n_c$ (number of cells = 180)

$V_{fc} = V_c \times n_c$

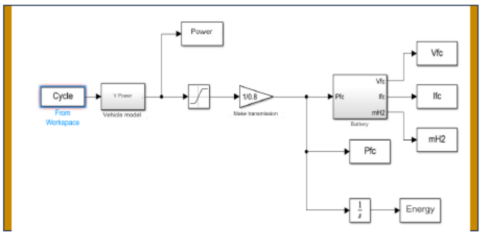
**3) Mass of $H_2$ [kg]**

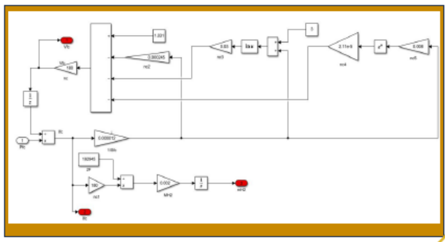
$m_{H2} = \int n_{H2} * MH_2 \, dt$

$M_{H2}$= molar mass of dihydrogen=2*10⁻³[kg/mol]

$n_{H2}$= molar flow rate[mol/s]

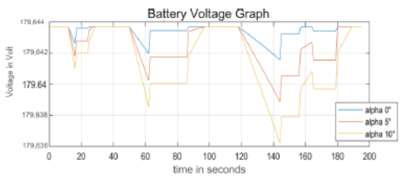
**Model of fuel cell in MATLAB Simulink**

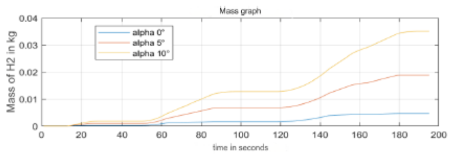


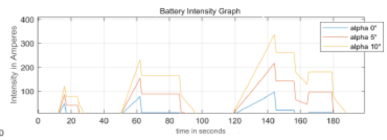



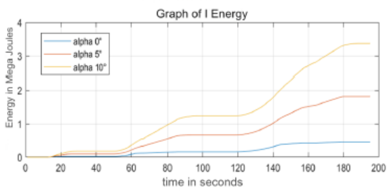
## Results of simulation

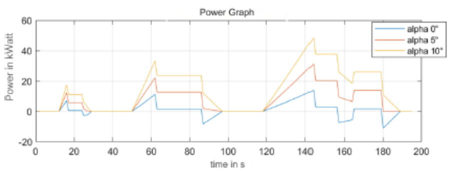
We simulate the following parameters at different angles alpha 0°, 5°, 10°

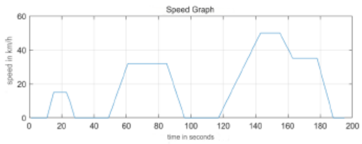



## Conclusion

**The simulation shows that the voltage of the fuel cell decreases with time for different $\alpha$ values and provides valuable insights into system performance and management under various configurations. The consumption of $H_2$ during one cycle is 0.036 kg for $\alpha = 10°$ and its deceases when $\alpha$ decreases. The fuel cell solution seems to be an excellent solution because consumption is not very high, however, it is necessary to compress the dihydrogen to store it.**

***@AECENAR/August 2024 Razan Youssef Kaddour***

## 2.2. Ammonia production project

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**Laboratory name:** AECENAR
**Laboratory website:** www.aecenar.com
**Location:** Ras Masqat/Tripoli

**Hydrogen Storage device**
**ICPT-AP**

**Supervisor:** - Dr. Berna Hamad
- Dr. Samir Mourad
**Presented by:** Ghayth Ali
**Department of Petroleum Chemistry**

### Title: Ammonia production System Using Solid Electrolyze

#### Introduction:

Solid electrolytes are materials that allow ionic conduction but not electronic conduction. They are characterized by the type of conducting ion (eg: proton (H+), oxygen (O2-)).They have potential applications in gas separation, chemical sensing, fuel cells, batteries, ammonia synthesis and decomposition.

#### Principle:

Electrolysis is a method that allows chemical reactions to be carried out using an electric current. It consists of passing a direct current through an electrolytic cell, composed of two electrodes in the sides of the electrolyte (Dielectric material).

- The formation of Ammonia requires a reaction between Hydrogen ($H_2$) and Nitrogen ($N_2$) which have the following Chemical equation:

Anode: $3H_2 \longrightarrow 6H^+ + 6e^-$
Cathode: $N_2 + 6H^+ + 6e^- \longrightarrow 2NH_3$

Overall : $3H_2(g) + N_2(g) \longleftrightarrow 2NH_3(l) + \Delta H \quad (\Delta H < 0)$

- The double arrow ($\leftrightarrow$) indicates that this reaction is reversible. Which means that the ammonia produced can decompose back into nitrogen and hydrogen.
- The symbol $\Delta H < 0$ indicates that the reaction is exothermic (releases heat).

Figure 1 shows a schematic of electrolyze, that the unite responsible for the ammonia reaction. It contains an ion exchange membrane which allows the passage of protons to react with $N_2$.

Factors influencing electrolysis:
- The electrolyte material
- The Electrode material
- Temperature during the process

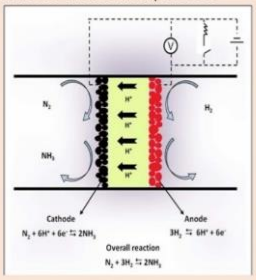


Figure 1

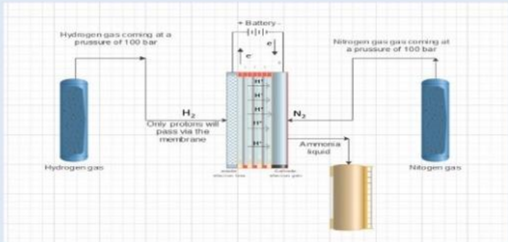


Figure 2

#### Material properties to be considered:

**- Electrolyte properties:**
- A material of high proton conductivity as polymers.
- Polymer electrolytes allow the synthesis of ammonia at low temperature and atmospheric pressure.
- They have advantages over high temperature electrolytes (HTPC) in avoiding ammonia decomposition.
- Reducing thickness of the electrolyte decrease operating temperature, manufacturing cost while increasing its life span.

The table below shows types of polymer electrolytes with there proton conductivity at a specific temperature in ($C^0$)

| Proton Conductor | Electrolytic Cell | Temperature (°C) | $NH_3$ Formation rate (mol $s^{-1}$ $cm^{-2}$) |
|---|---|---|---|
| Nafion | $H_2O$, Pt \|Nafion\| Ru, $N_2$, $NH_3$ | 90 | $2.12\times10^{-11}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SFCN, $N_2$, $NH_3$ | 80 | $1.13\times10^{-8}$ |
| SPSF | $H_2$, Ni-SDC \|Nafion\| SSCO, $N_2$, $NH_3$ | 80 | $6.5\times10^{-9}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SSN, $N_2$, $NH_3$ | 80 | $1.05\times10^{-8}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SSC, $N_2$, $NH_3$ | 80 | $0.98\times10^{-8}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SSF, $N_2$, $NH_3$ | 80 | $0.92\times10^{-8}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SSN, $N_2$, $NH_3$ | 80 | $1.05\times10^{-8}$ |
| SPSF | $H_2$, Ni-SDC \| SPSF \| SSN, $N_2$, $NH_3$ | 80 | $1.03\times10^{-8}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SBCF, $N_2$, $NH_3$ | 80 | $7.0\times10^{-9}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SBCC, $N_2$, $NH_3$ | 80 | $7.5\times10^{-9}$ |
| Nafion | $H_2$, Ni-SDC \|Nafion\| SBCN, $N_2$, $NH_3$ | 80 | $8.7\times10^{-9}$ |

Figure 3

**- Electrode properties:**
- Depending on the type of electrode, the rate of ammonia production can be increased.
- Both electrodes must be stable at the operating temperature and have suitable porosity and pore size to improve the catalyst surface area and enhance the catalytic activity.
- Certain electrodes can act as catalysts, accelerating $NH_3$ reactions occurring on their surface.
- The electrodes must not react with H' or $NH_3$.

**- Potential difference across the electrodes:**
- Minimum voltage difference: There is a voltage limit below which ammonia production is impossible.
- ***$\Delta G_R^0 = -nFE^0$***
  equation used to calculate the minimum voltage used to produce $NH_3$.
  $\Delta G°r$: Change in Gibbs free energy for the reaction
  F: Faraday constant
  n: Number of electrons
  $E^0$: Standard electromotive force
- Effect of applied potential: Increasing the potential to a certain point increases the rate of ammonia production.

Figures 4 and 5 shows the 3D design of the Solid electrolyze using FreeCAD program.

The Voltage of the battery is equal to 2V.
And the current density = 5.97 mA

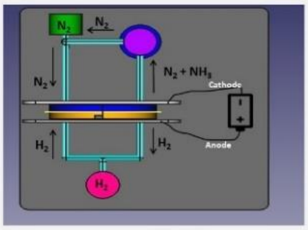


Figure 4

The Area of electrodes = 132.73 $cm^2$
The solid electrolyte is Nafion.
The operating temperature of the system is 80 °C.

Cathode used $SmFe_{0.7}Cu_{0.1}Ni_{0.2}$
Anode used is $NiCe_{0.8}Sm_{0.2}$

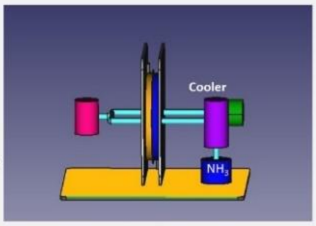


Figure 5

@AECENAR/ June 2024

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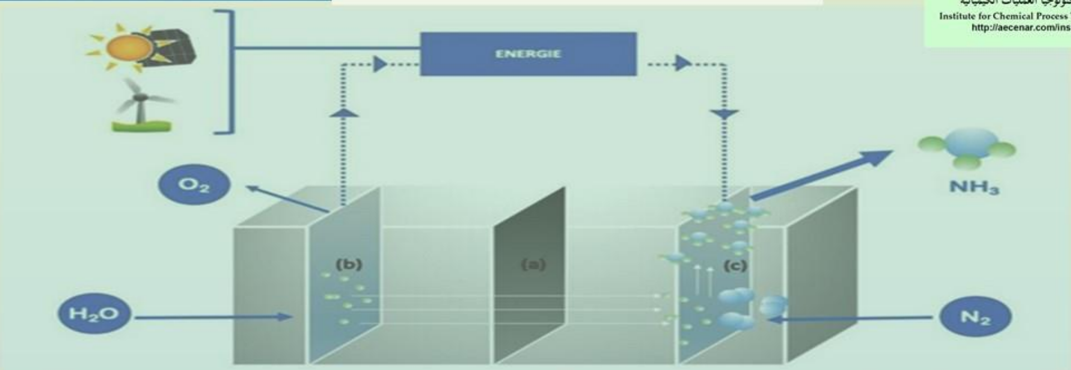



Figure : Alternative ammonia production at low T° and pressure in an electrolysis unit powered by renewable energy. (a) = separation membrane; (b) = anode; (c) = cathode. The dotted arrows indicate the path of the electrons within the device.

## Anode Preparation

**Chemical Formula:** Ni-Ce0.8Sm0.2
**Volume of the anode (disc shape):**
**Radius** = 6.5 cm **Height** = 0.1 cm or more
V = π r²h = π*6.52*0.1 = 13.273 cm3 = 13273 mm3
Total volume for 100g mass of this alloy = 13.53 cm3
ρ = 100/13,53 = 7.391 g/cm3
**M1** = ρ V = 7.391*13.273 = 98.100743 g

| Metal | Melting point (°C) | Density (g/cm^3) |
|---|---|---|
| Nickel | 1455 | 8.902 |
| Cerium | 795 | 6.76 |
| Samarium | 1072 | 7.52 |

| Metal | Mass (g) | %W | N° of moles | Xi |
|---|---|---|---|---|
| Nickel | 286 | 30.33 | 4.873 | 0.5134 |
| Cerium | 510 | 54.08 | 3.640 | 0.3835 |
| Samarium | 147 | 15.59 | 0.978 | 0.1030 |
| Alloy | 943 | 100 | 9.491 | 1 |

**Ni-Ce0.8Sm0.2**

**Nickel (58.5g)**

**Cerium (510g)**

**Samarium (147g)**

## Cathode Preparation

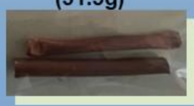
**Chemical Formula:** SmFe0.7Cu0.1Ni0.2
**Volume of the anode (disc shape):**
**Radius** = 6.5 cm **Height** = 0.1 cm or more
V = π r2h = π*6.52*0.1 = 13.273 cm3 = 13273 mm3
Total volume for 100g mass of this alloy = 13.01 cm3
ρ = 100/13.01 = 7.69 g/cm3
**M2** = ρ V = 7.69*13.273 = 102.06937 g

| Metal | Melting point (°C) | Density (g/cm^3) |
|---|---|---|
| Samarium | 1072 | 7.52 |
| Iron | 1538 | 7.874 |
| Copper | 1538 | 8.96 |
| Nickel | 1455 | 8.902 |

| Metal | Mass (g) | %W | N° of moles | Xi |
|---|---|---|---|---|
| Samarium | 147 | 15.59 | 0.978 | 0.1030 |
| Iron | 192 | 18.78 | 3.4381 | 0.35 |
| Copper | 31.5 | 3.08 | 0.5 | 0.05 |
| Nickel | 286 | 30.33 | 4.873 | 0.5134 |
| Alloy | 1022.29 | 100 | 9.8537 | 1 |

**Samarium (740g)**

**Copper (31.5g)**

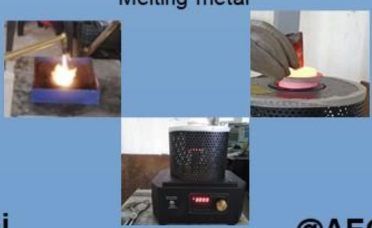


**Nickel(286g)**

## Alloy producing stages :

1)Melting nickel with a torch
2)After dissolving the nickel well, add the remaining iron to the melted nickel to incorporate it.

Melting metal



Pouring molten metal

Alloy

**Oussama Mostapha Al Dahabi**

**@AECENAR_ICPT_AP 20/Aug/2024**

# 3 Project 1: Fuel Cell project (ICPT - FC)

## 3.1 Position of Project

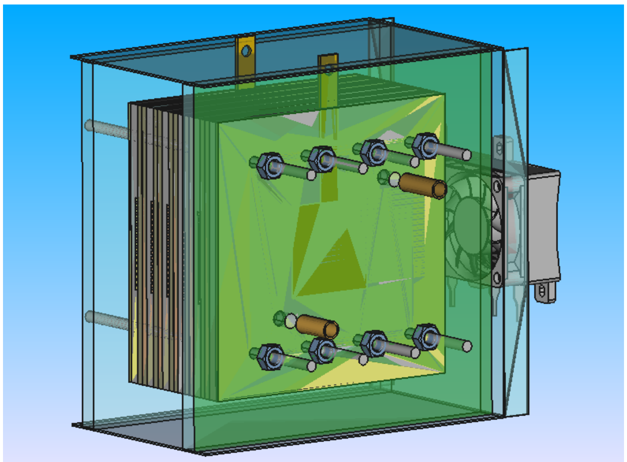
Work on this project will begin this year, as a simulation of the fuel cell project was conducted, and a small pilot project for the project was designed and implemented, with the project to be expanded and used as a source of stored energy instead of the traditional battery in the coming years.

## 3.2 Mechanical design

In this paragraph, we will present the mechanical design of Fuel Cell

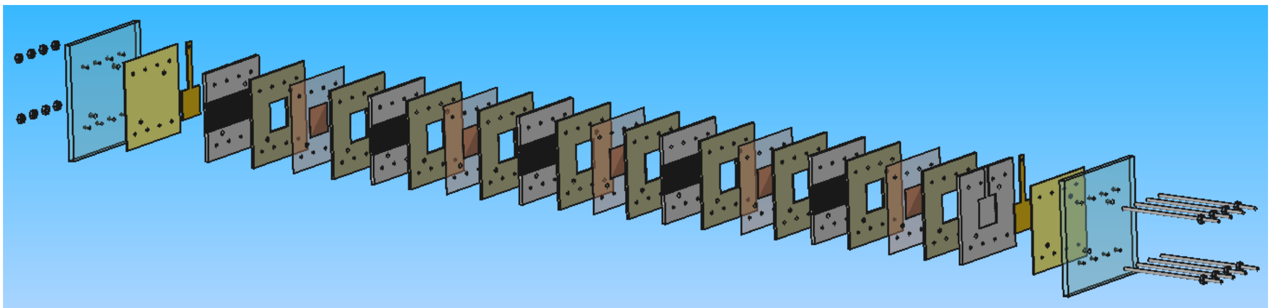
### 3.2.1 Overview of stack

22042024_Fuel cell - full design.FCStd



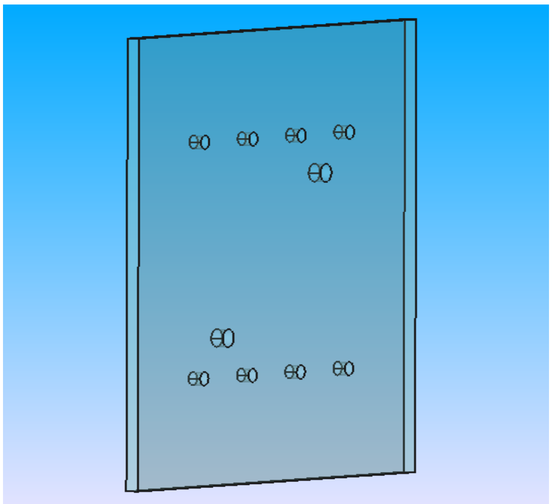
### 3.2.2 Fuel Cell exploded design

29052024_Fuel cell - Exploded.FCStd



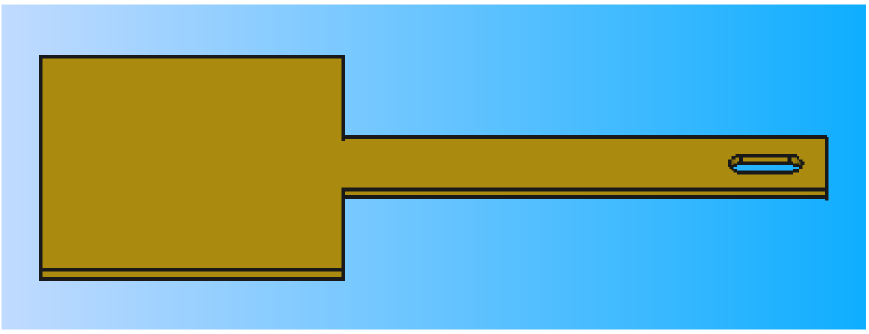
#### 3.2.2.1 End plate of FC stack

22042024_End plate redesign.FCStd



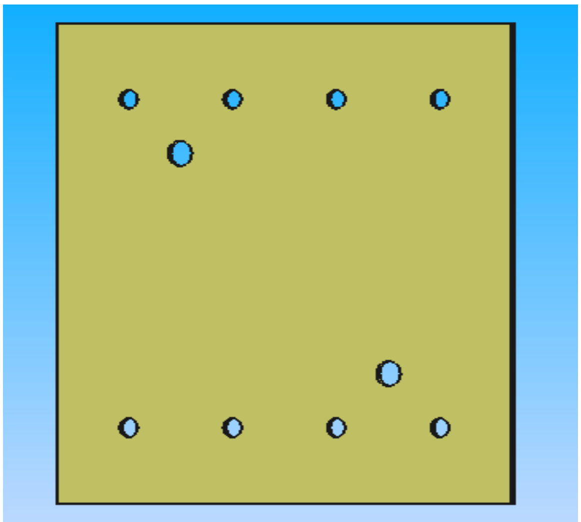
#### 3.2.2.2 Current plate of FC stack

29052024_Current plate.FCStd



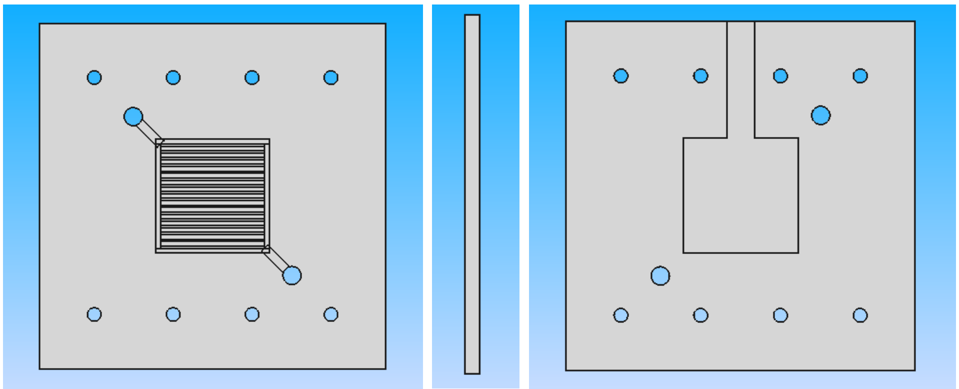
#### 3.2.2.3 Gasket behind the current plate of FC stack

22042024_Gasket behind Current plat



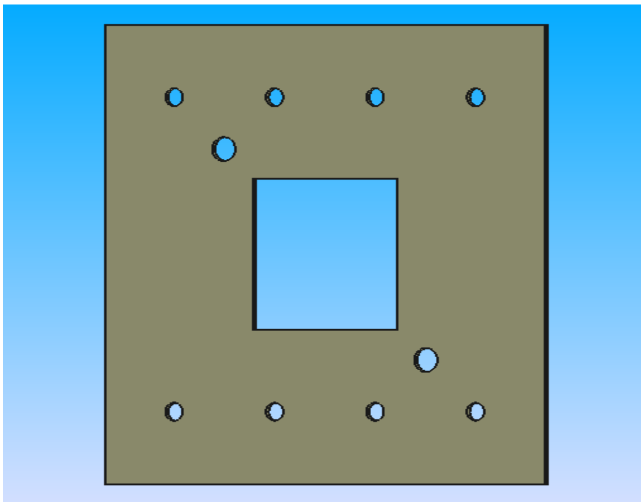
#### 3.2.2.4 $H_2$ graphite plate of FC stack

18042024_Graphite plate of H2.FCStd



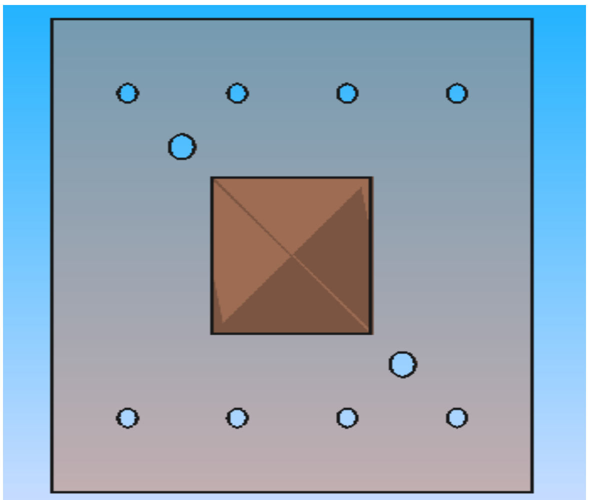
#### 3.2.2.5 Gasket of FC stack

19042024_Gasket redesign.FCStd

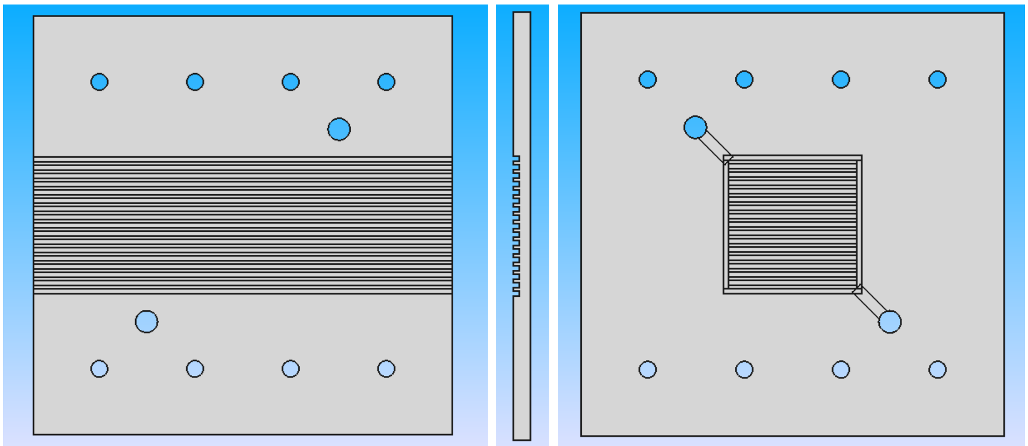


#### 3.2.2.6 Membrane of FC stack

19042024_MEA Redesign.FCStd

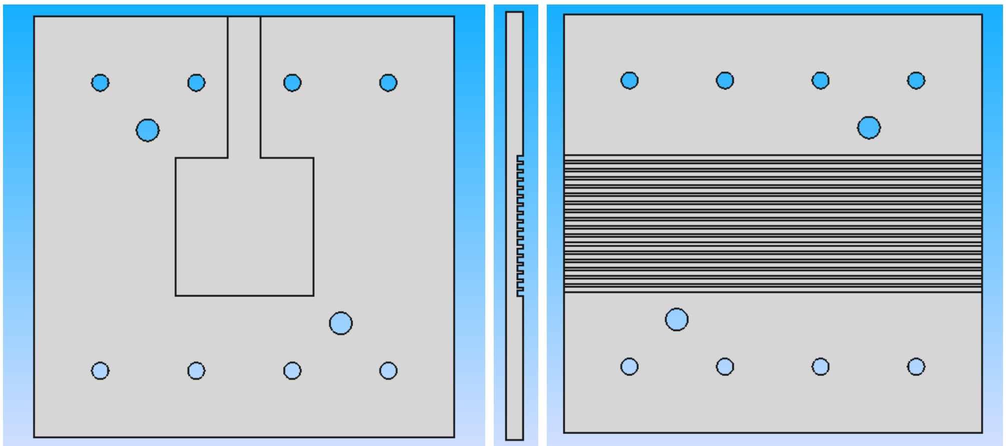


#### 3.2.2.7 BBP graphite plate of FC stack



18042024_BBP redesign.FCStd

#### 3.2.2.8 Air graphite plate of FC stack



18042024_Graphite plate of Air or O2.FC

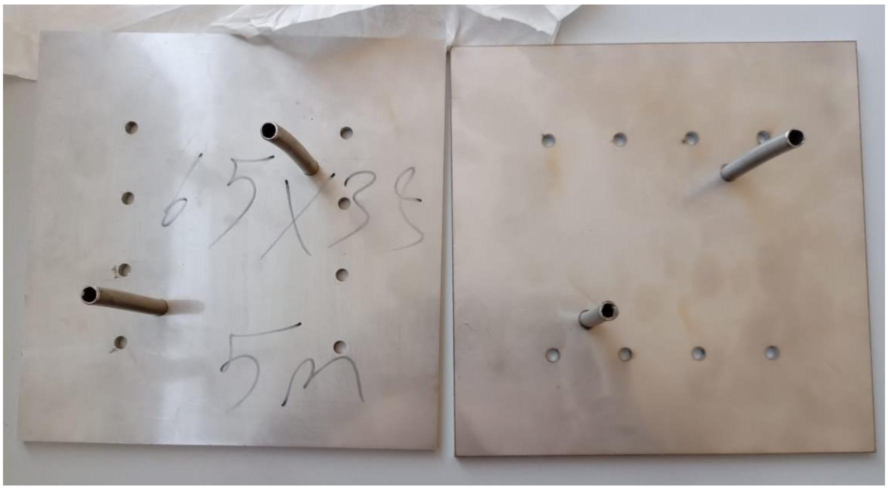
### 3.2.3 Sizing of FC design

This file contains all proposals and the suggested measurements for a pilot project application

13052024_Fuel cell Sizing details.pptx

## 3.3 Materials of FC stack

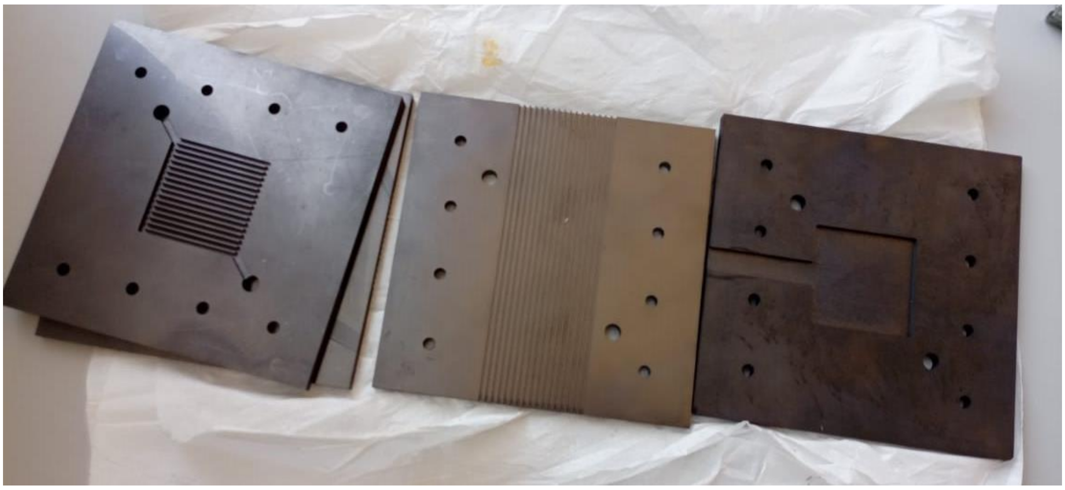
### 3.3.1 End plates



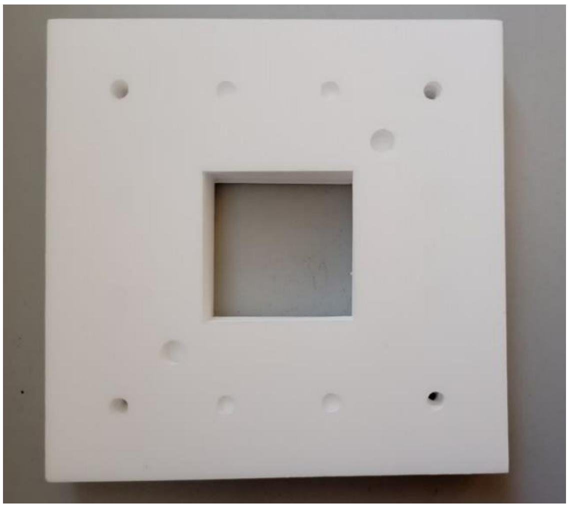

### 3.3.2 Current plates

### 3.3.3 Gasket behind the current plate

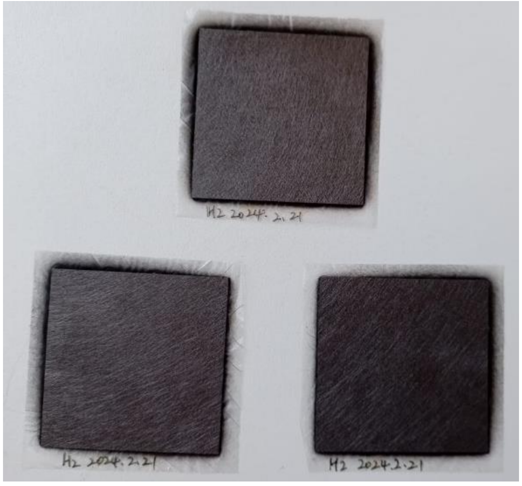
### 3.3.4 $H_2$,BPP, and Air graphite plate



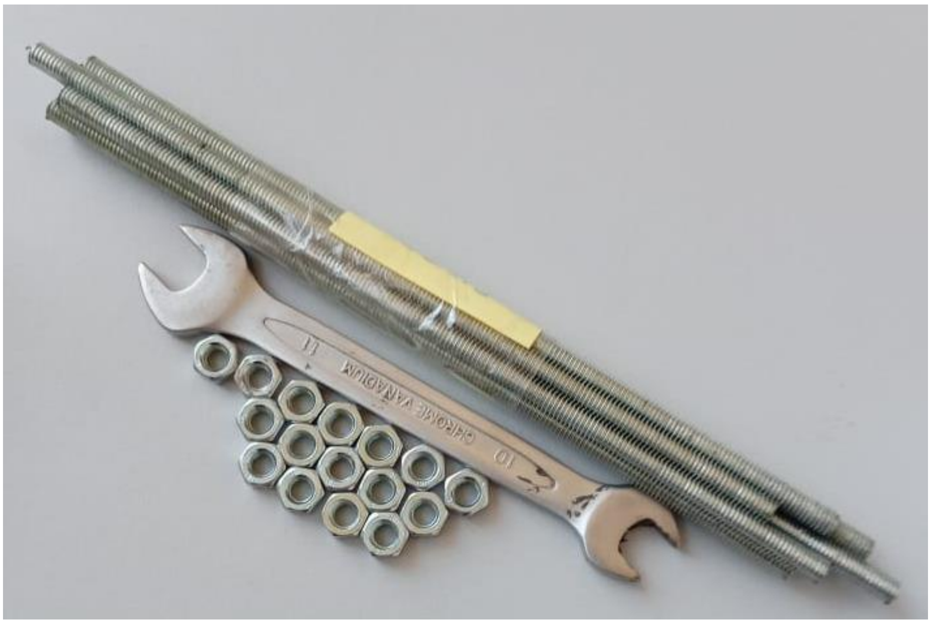
### 3.3.5 Gasket plate



### 3.3.6 Membrane plate (MEA)



### 3.3.7 Bolts & nuts



## 3.4 Characterization, modeling, and development of an innovative Fuel Cell[1]

MEMORY

In order to obtain the

PROFESSIONAL MASTER

In

Energy Physics

Presented and Supported by:

Razan Youssef Kaddour

Thursday, October 3, 2024

Title

Characterization, modeling and development of an innovative fuel cell

Supervisor

Dr. Moemen Mostafa Daboussy

Readers

Dr. Hamed Mounir Al-Khatib

Dr. Ahmad Khaled Othman

Pdf file of Master Thesis:

https://aecenar.com/index.php/downloads/send/18-icpt-intitute/1790-memory-razan-kaddour

1 From: Razan Abdulkader, Master Thesis, 2024, Lebanese University, Energetic Physics, work was done at AECENAR, supervisor: Dr. Moemen Dabbousy (Lebanese Univ. (LU))

### 3.4.1 Presentation on 3.10.24 at LaSeR facility

**Characterization, modeling and development of an innovative fuel cell**

**Presented and Supported by:**

**Razan Youssef Kaddour**
**Thursday, October 3, 2024**

**Supervisor**

**Dr. Moemen Mostafa Daboussy**

**Readers**

**Dr. Hamed Mounir Al-Khatib**

**Dr. Ahmad Khaled Othman**

1

## Presentation Plan

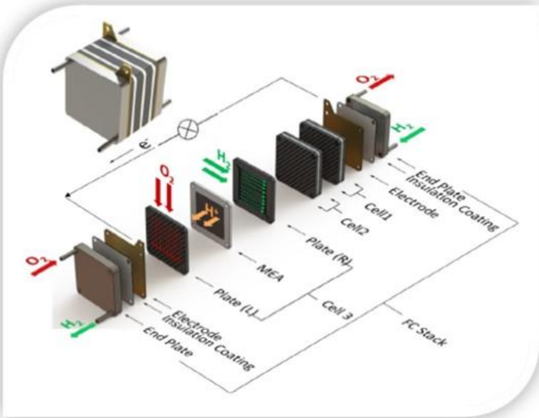
1. Introduction.
2. Characterization and operation of a fuel cell.
3. Installation of a fuel cell system at the AECENAR center.
4. Mathematical modeling of fuel cell.
5. Simulation results of the model on MATLAB.
6. Comparison between the model and experimental data.
7. Application of PEMFC in an electric vehicle.
8. Simulation results of the PEMFC model on MATLAB.
9. Conclusions and perspectives.

2

# 1. Introduction

A fuel cell is a device that produces electricity from the chemical reaction between a fuel and an oxidant.

In a fuel cell, the fuel, often hydrogen, and the oxidant, usually oxygen from the air, are fed into the cell, where they react to generate water, heat, and electricity.



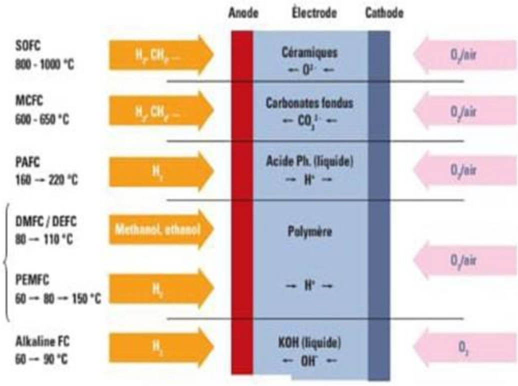

3

# 2. Characterization and operation of fuel cell

- **Fuel cell type:**

There are six main types of fuel cells, which are distinguished by the nature of their electrolyte (solid, acid, etc.)

- the proton exchange membrane fuel cell (PEMFC).
- methanol fuel cell (DMFC).
- the alkaline fuel cell (AFC).
- the phosphoric acid fuel cell (PAFC).
- the molten carbonate fuel cell (MCFC).
- the solid-state fuel cell (SOFC).

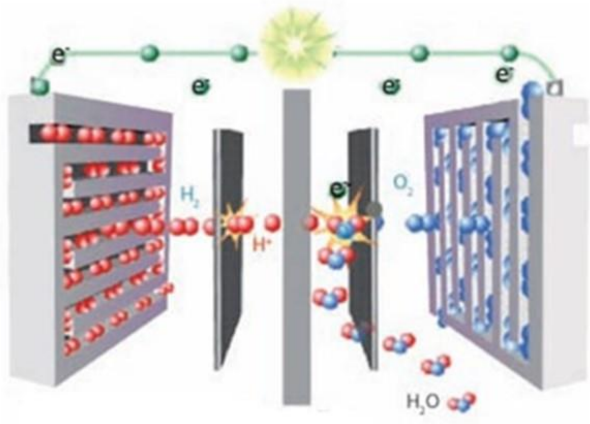



4

## 2. Characterization and operation of fuel cell

- **How a PEM fuel cell works**

  - The H2 molecule splits into 2 H+ ions and 2 electrons upon contact with the catalyst.
  - Electrons flow through the anode.
  - They travel through the external circuit and return to the cathode.

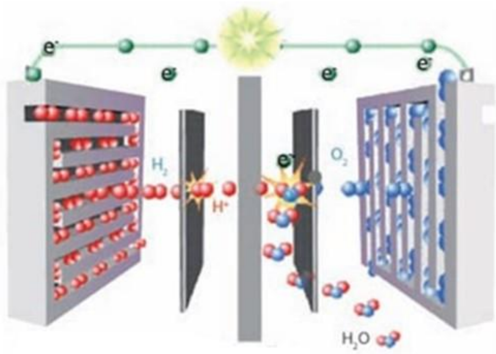



5

## 2. Fuel cell characterization

- **How a PEM fuel cell works**

  - Two oxygen atoms, each negatively charged , are formed.
  - These charges attract H+ ions across the membrane.
  - H+ ions combine with oxygen and electrons to form water (H2O ) .




$$H_{2}(g) + \frac{1}{2}O_{2}(g) \rightarrow H2O \text{ ( liquid ) } + \text{Electricity} + \text{Heat}$$

6

## 3. Installation of a fuel cell system at the AECENAR center

### ❖Fuel cell system design(free cad)

**PAC components:**

a) Terminal plate

b) Joint behind the end plate

c) Current plate

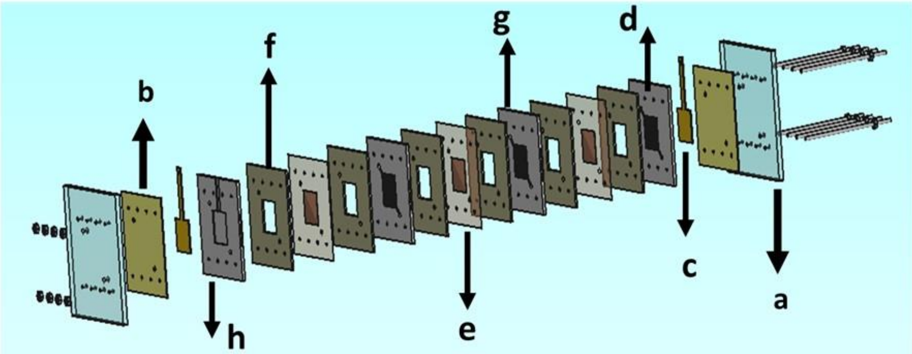
d) Graphite plate for H2

e) MEA

f) Joint

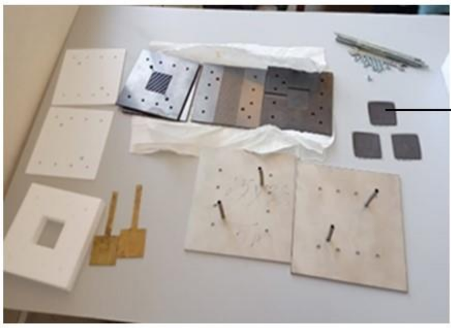
g) Graphite Bipolar Plate

h) Graphite plate for O2

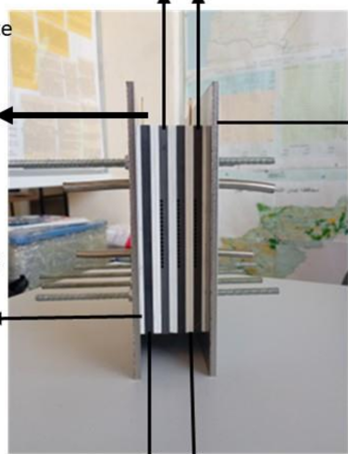



7

## 3. Installation of a fuel cell system at the AECENAR center




The image shows the components needed to assemble a fuel cell, including plates with etched patterns to manage gas flow, as well as separators for the electrodes.




8

# 4. Mathematical modeling of a fuel cell

- This section presents an electrochemical model to predict the dynamic behavior of polymer membrane hydrogen fuel cells (PEMFCs). The output voltage of a single cell, PAC, can be defined as:

$$V_{PAC} = N \times (E_{Nernst} - V_{act} - V_{ohmic} - V_{con})$$

-N is the number of elementary cells in the stack.

-$E_{nernst}$ is the Nernst voltage(V).

-$V_{act}$ is the activation polarization (V).

-$V_{ohmic}$ is the resistance bias (V).

-$V_{conc}$ is the concentration polarization (V).

9

# 4. Mathematical modeling of a fuel cell

- **Nernst tension:**

$$E_{Nernst} = 1.229 - 0.85 \times 10\text{^}{-3} \times (T - 298.15) + 4.31 \times 10\text{^}{-5} \times T \times [\ln(PH2) + \frac{1}{2}\ln(P_{O2})]$$

$P_{H2}$ partial pressures (atm) of hydrogen, PO2 partial pressures (atm) of oxygen. T is the operating temperature of the PEM (K).

- **Activation overvoltage:**

$$Vact = -[\xi_1 + \xi_2 \times T + \xi_3 \times T \times \ln(C_{O2}) + \xi_4 \times T \times \ln(ifc)]$$

$$CO2 = \frac{PO2}{5.08 \times 10\text{^}6 \times e^{-(\frac{498}{T})}}$$

With: $\xi 1$, $\xi 2$ , $\xi 3$, $\xi 4$ are the parametric coefficients appropriate to each physical model of the PEM. $C_{O2}$ is the oxygen concentration on the catalyst zone ($mol/cm3$ ).

Ifc is the PEM current (A).

10

# 4. Mathematical modeling of a fuel cell

- **Ohmic overvoltage:**

$V_{ohm} = ifc \times (R_m + R_c)$

$R_m = ƒ_m \times \frac{l}{A}$

$$ƒ_m = \frac{181.6 \times [1+0.03 \times (ifc/A) + 0.062 \times (T/303)^2 \times (ifc/A)^{2.5}]}{[\Psi - 0.634 - 3 \times (ifc/A) \times e^{(4.18 \times (\frac{T-303}{T}))}]}$$

$R$ is the contact resistance equivalent to the conduction of electrons ( Ω).

$R$ m is the equivalent resistance of the membrane to proton conduction ( Ω).

$l$ is the membrane thickness (μ$m$), A is the active area of the PEM ($cm$),

ƒm is the qualitative resistivity of the membrane ( Ω. $cm$). Ψ is the parametric coefficient .

11

# 4. Mathematical modeling of a fuel cell

- **Concentration surge**

$$V_{con} = -B \times \ln (1 - \frac{J}{Jmax})$$

$J$: current density ($A$ /$cm$^2 ). $Jmax$: maximum density ($A$/cm^2 ). B is the electrochemical constant (dependent on cell type [V]).

- **Molar flow rate of hydrogen ($H_2$)**

$$n_{h2} = \frac{(ifc \times N)}{(2 \times F)}$$

F is the Faraday constant which is expressed as [C]

- **Mass of hydrogen ($H_2$)**

$$mh2 = \int nh2 \times Mh2 \, dt$$

Mh2 is the molar mass of h2 which is expressed in [kg/mol].

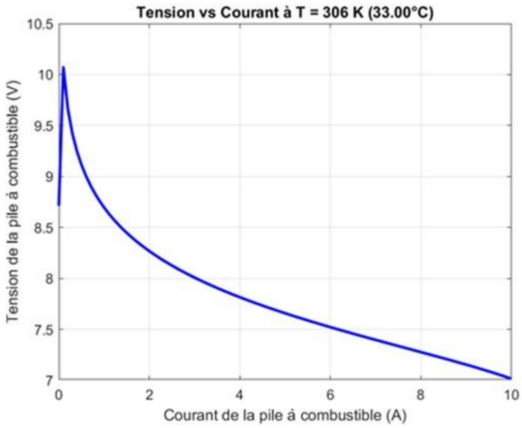
12

# 5. Model simulation results on MATLAB

The operating conditions of the mathematical model of the fuel cell are as follows :

1) Number of cells = 10 6) Partial pressure of oxygen $P_{O2}$ =0.2095[atm]
2) Partial pressure of hydrogen $P_{H2}$ =1[atm ] 7) Constant dependent on cell type B=0.016
3) Temperature = 33°C (306 Kelvin) 8) Contact resistance $R_c$ =0.0003 [Ohm]
4) Parametric coefficient Ψ(si )=23 9) Maximum current density $J_{max}$ =469*$10^{-3}$ [A/cm²]
5) Membrane thickness l= 27*$10^{-6}$ (m)

❖ **Voltage versus current curve:**

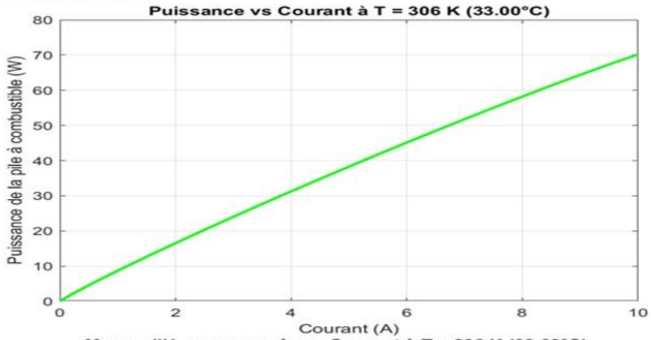



- The voltage peaks at 10.1 V upon initial activation.
- It drops quickly to 8.5 V because of the activation bias.
- The drop becomes gradual to 7 V at 10 A, due to ohmic and concentration losses.

13

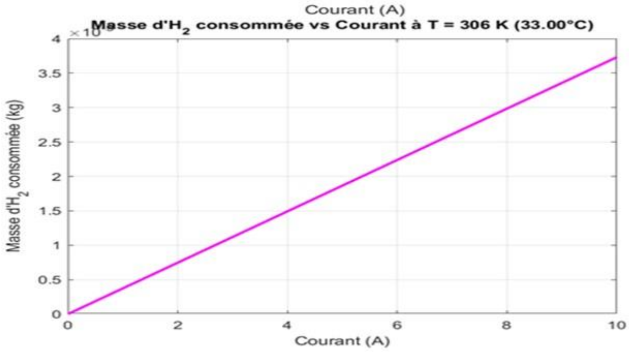
# 5. Model simulation results on MATLAB

❖ **Power curve as a function of current :**




- It reaches 70 W at 10 A.
- The linear relationship shows a proportional increase in power.
- This indicates stable operation of the battery within this current range.

❖ **H2 Mass Curve as a Function of Current:**



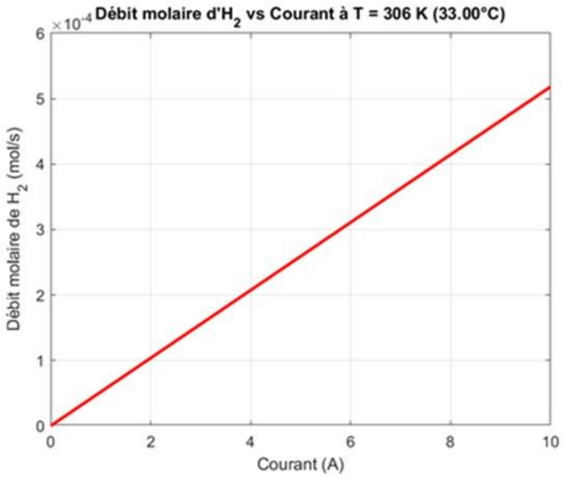

- At low current, consumption remains low.
- Growth is almost linear.

14

# 5. Model simulation results on MATLAB

❖ **H2 molar flow rate curve as a function of current:**

- At 10 A, the molar flow rate reaches about $5.1 \times 10^{-4}$ mol/s.
- This behavior follows Faraday's law, linking hydrogen consumption to electric current.




15

# 6. Comparison between the model and experimental data

In AECENAR center, we installed three PEM cells. However, due to the absence of the hydrogen bottle, it was not possible to test this system after installation. We took the real tests carried out at the Electrical Engineering Laboratory (LAGE) of the Scientific Research Center of Kasdi Merbah Ouargla University (Algeria).

**Operating conditions of the experimental part:**

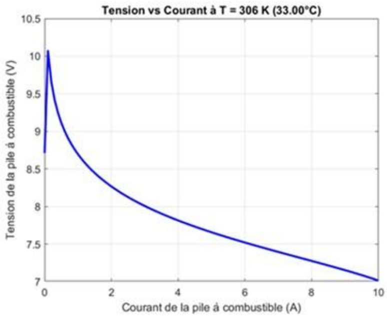
i. Number of cells = 10
ii. Membrane thickness 27 [µm]
iii. Nominal anode pressure [bar] 0.6 +/- 0.1
iv. I max=10A
v. Raw sectional cell 25 cm^2.

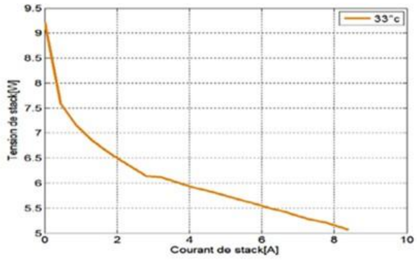
16

# 6. Comparison between the model and experimental data

❖ **Comparison of voltage-current curves**

Experimental curve



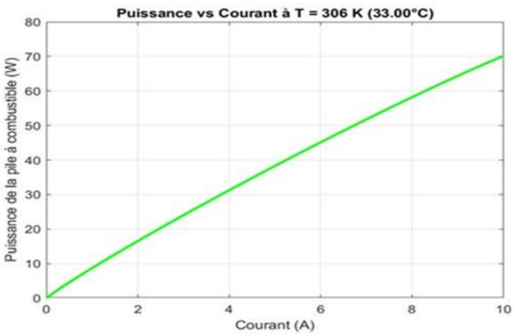

- The voltage drop after activation is more pronounced in the first figure.
- The second figure shows a more gradual decrease with a lower current limit.
- The first figure supports higher currents, while the second shows higher losses at high current.

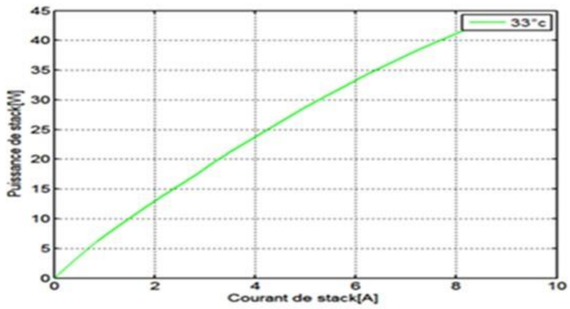
17

# 6. Comparison between the model and experimental data

❖ **Comparison of the Power-Current curves:**

Experimental curve



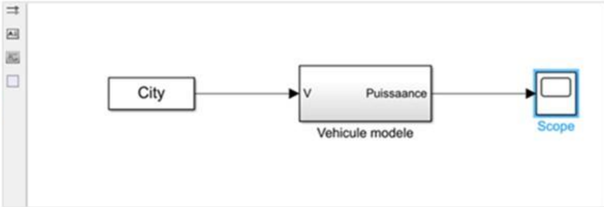

- No performance degradation is observed in the simulation.
- This suggests that real physical constraints are not taken into account in the simulation.
- The experimental curve indicates a decrease in P follows due to physical limitations (water accumulation, etc.).

18

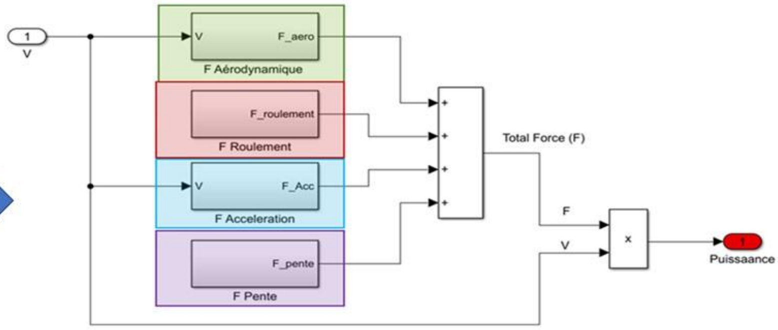
# 7.Application of PEMFC in electric vehicle.

- The forces acting on a vehicle include rolling resistance, slope resistance, aerodynamic force, acceleration force, and slope force .

**Vehicle model in Simulink**




F(N) = F _aérodynamique + F _roulement + F _accélération + F _pente




19

# 7.Application of PEMFC in electric vehicle.

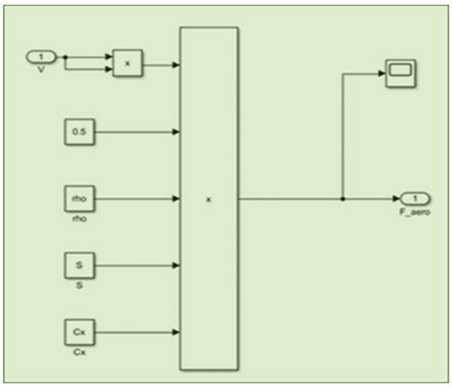
1. F _aerodynamic = 0.5 ×ρ ×S ×C $_x$ ×V $^2$

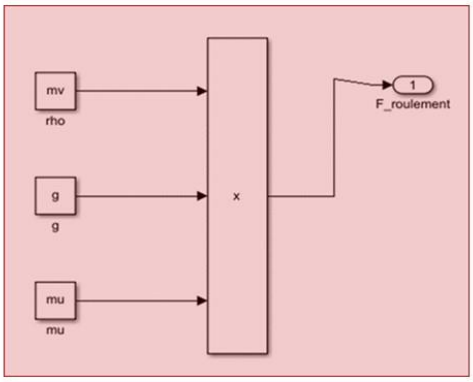
With :
V = vehicle speed [m/s]
ρ = air density (≈1.2 kg/m $^3$)
S = surface (frontal area) of the vehicle [m $^2$ ]
C $_x$ = drag coefficient.

2. F _rolling = m $_v$ ×g ×μ

With :
g = acceleration of gravity [9.81 m/s $^2$ ]
μ = coefficient of friction [≈0.01]
m $_v$ = mass of the vehicle.

**Model in Simulink**



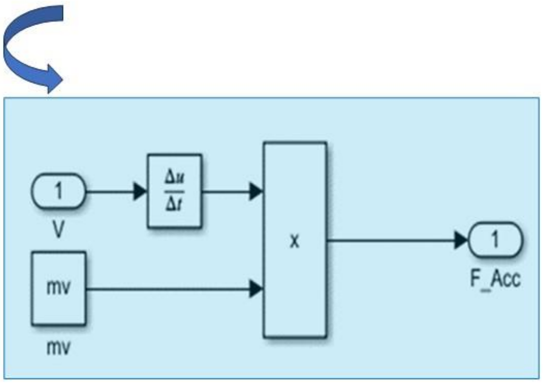

20

# 7.Application of PEMFC in electric vehicle.

3. F _acceleration =$m_v \times a$

With :

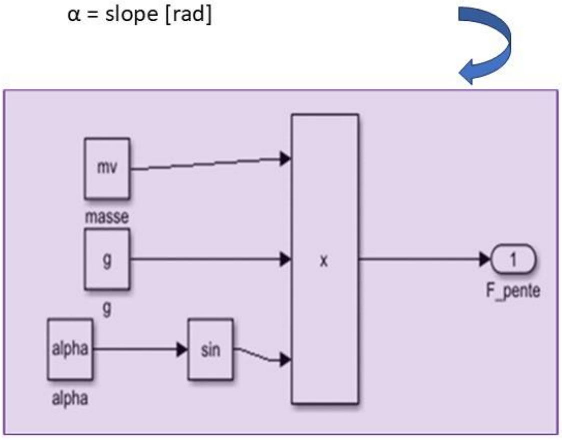
a = vehicle acceleration




4. F _ slope =$m_v \times g \times \sin \alpha$

With :

α = slope [rad]




21

# 7.Application of PEMFC in electric vehicle

## ❖ PAC Feature:

- **PAC current** $I_{fc} = \frac{P_{fc}}{V_{fc}}$;

$P_{fc}$ : PAC power[W]

$V_{fc}$ : PAC voltage [V ]

- **Molar flow rate**

$\dot{n}_{H2\text{-}stack} = \frac{I_{fc}}{2*F} \times n_c$

F: Farad constant

nc: number of cells in the stack

- **Hydrogen mass**

$m_{H2} = \int \dot{n}_{h2} \times M_{H2}\, dt$

$M_{h2} = 2 \times 10^{-3}$ Molar mass $H_2$ [kg/mol]

- **Cell voltage [V]**

i. $V_c = 1.031 - 2.45 \times 10^{-4} \times j - 0.03 \times \ln(d+3) - 2.11 \times 10^{-5} \times e^{(8\times10-3\times j)}$

j: Current density [mA/cm$^2$] ; $j = \frac{I_{fc}}{S_{fc}}$ With: $S_{fc}$ = 480 cm$^2$ : The surface area of a cell

ii. $V_{FC} = V_c \times n_c$ The total battery voltage [V].

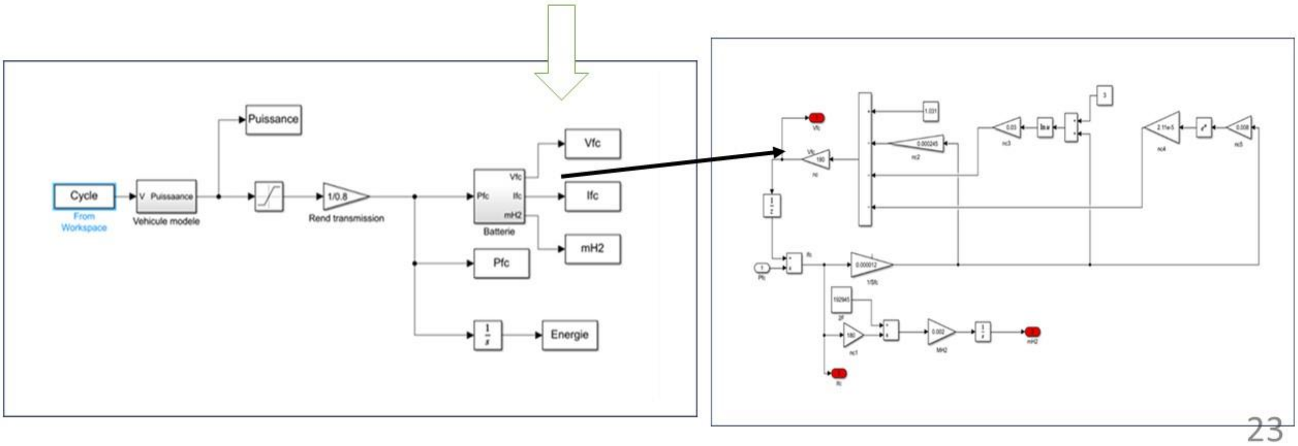
$V_c$ : The cell voltage [V]. $n_c$ the number of cells.

22

# 7.Application of PEMFC in electric vehicle

By integrating the vehicle's power as an input, the battery can be regulated in real time, thus optimizing energy management and system efficiency while responding to variations in energy needs.

**PEMFC model in MATLAB/SIMULINK**

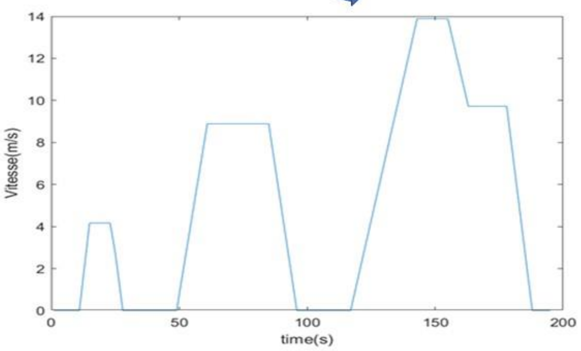



23

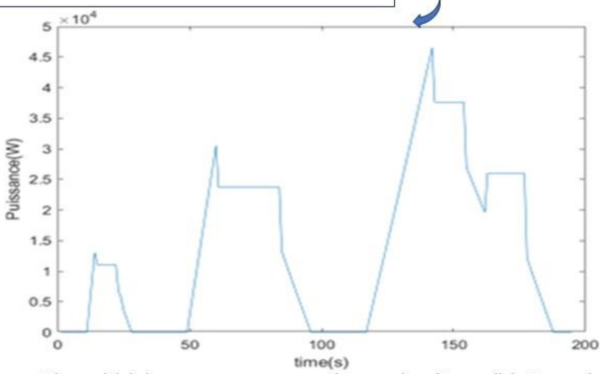
# 8. Results of the PEMFC model on MATLAB

**Electric vehicle characteristics:** ρ = air density rho=1.2(kg/m^3 ); S = vehicle surface area S=2.11(m2 ); Drag coefficient C x =0.28; Vehicle mass mv=1465(Kg); v. Gravity acceleration g=9.81 m/s2 ; vi. Friction coefficient μ =0.01; vi; alpha=10; time:0 to195s.

**Electric Vehicle Curves Results**




The electric vehicle speed curve simulated in MATLAB provides a detailed analysis of the vehicle's dynamic performance as a function of time.




The vehicle's power curve over time makes it possible to analyze the evolution of the energy delivered by the electric propulsion system .

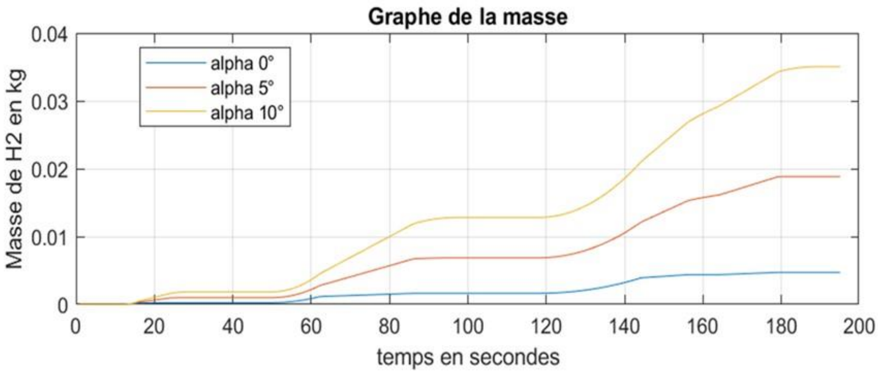
24

# 8.Result of PEMFC model on MATLAB

**PAC Feature:**

1) Nc =180 The number of cells in the stack 2) rtransmission =80 Transmission efficiency [%]
3) e = 1.602 *10^-19 Elementary electric charge [C] 4) Sfc =480 The surface area of a cell [cm^2 ]
5) N A : Avogadro's number = 6.022 * 10^23 mol^-1 6) t = 195 time [s]
7) MH2 = 2*10^-3 The molar mass of dihydrogen [kg/mol] 8) α =0°; α =5°; α =10°;

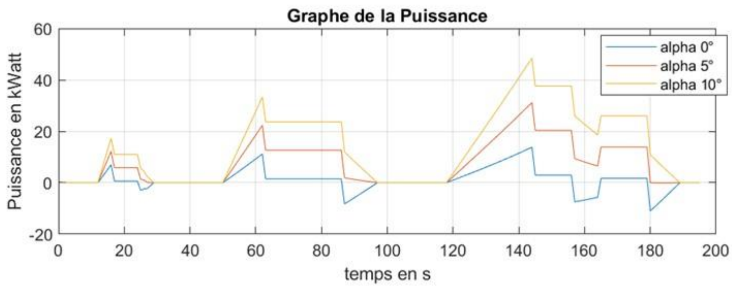
•**Mass** : Increase due to internal chemical reactions.



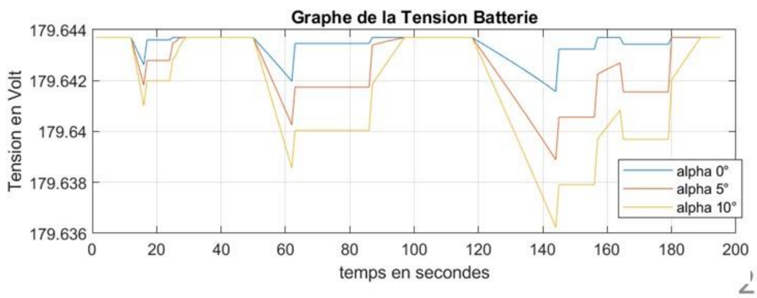

25

# 8.Result of PEMFC model on MATLAB

**Power** : Oscillations linked to the charge/discharge phases, varying according to the "alpha" slope.



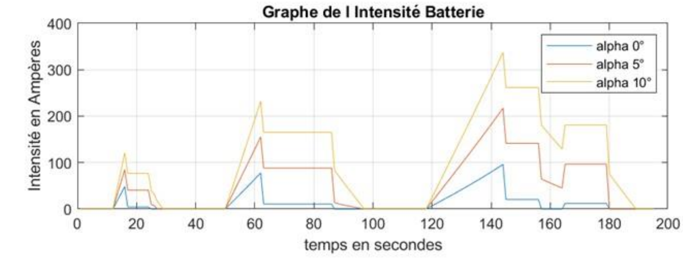

**Tension** : Gradual decrease, faster with high "alpha".



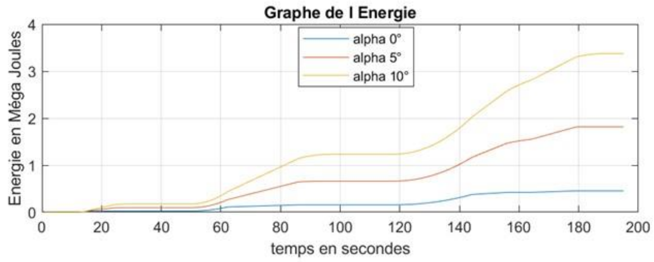

26

# 8.Result of PEMFC model on MATLAB

**Intensity** : Peaks similar to power, linked to the charge/discharge phases.




**Energy** : Charge/discharge cycles similar to those of power.




27

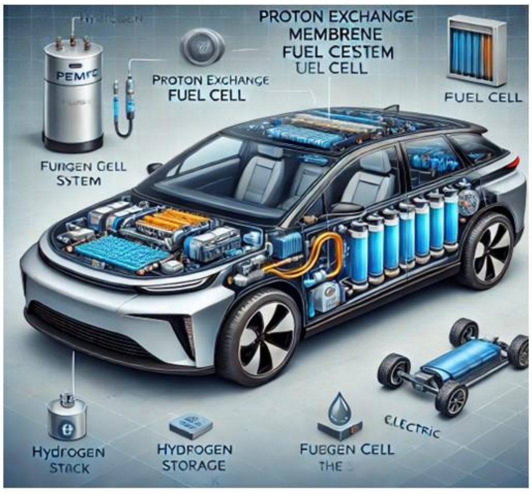
# 9. Conclusion and perspectives

- **Modeling and validation** of a PEM fuel cell system for electric vehicles.
- **Implementation in MATLAB/Simulink** to simulate dynamic stack behavior.
- **Successful comparison** of simulation results with experimental data.

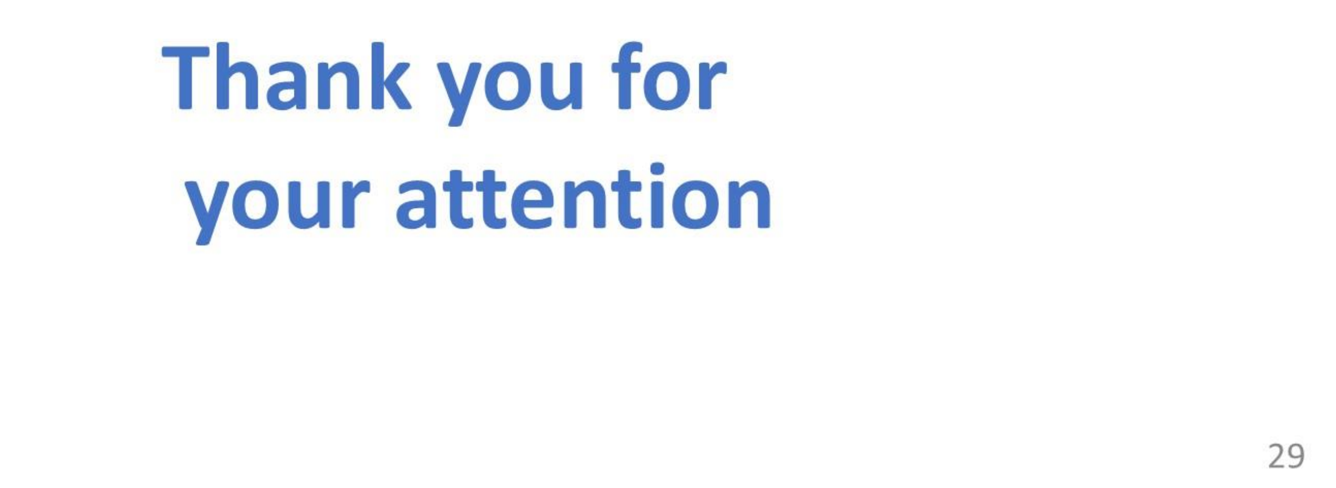
**Perspectives:**

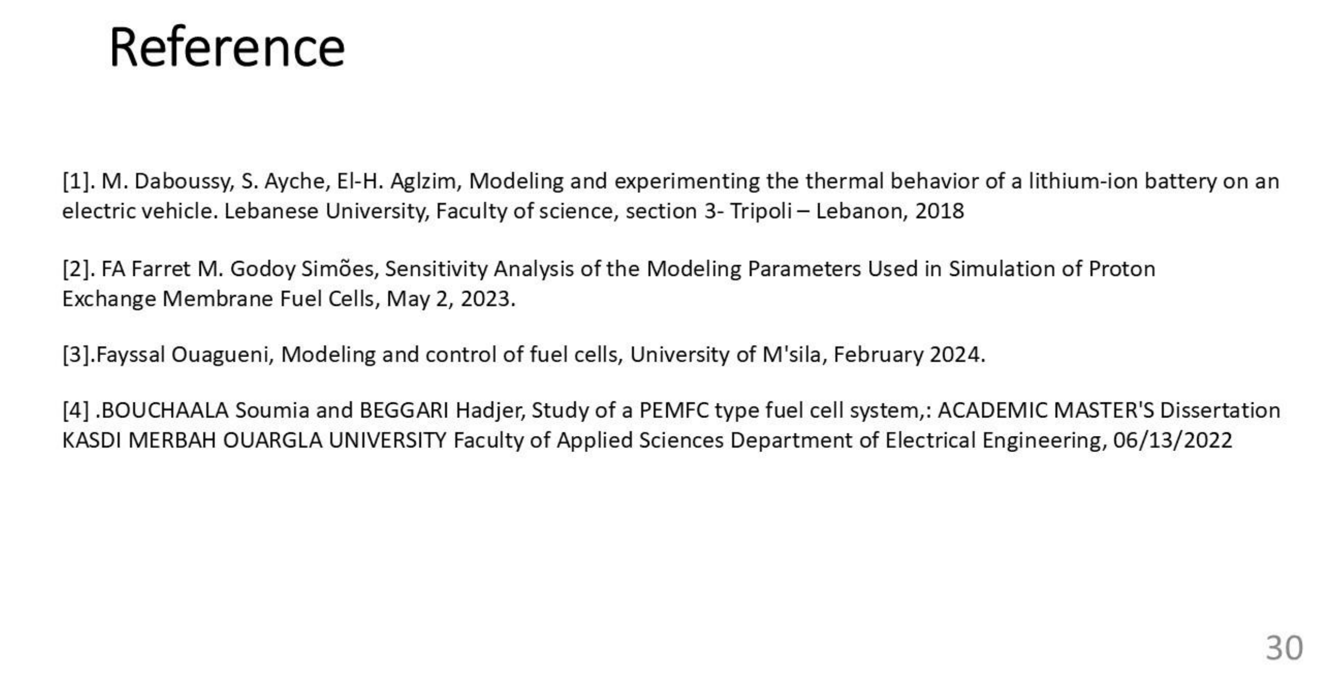
. Continue the installation of an experimental battery bench within the AECANAR center to collect experimental data.

- **Optimization of operating conditions** : hydration, temperature, pressure.
- **Study of hybrid systems** combining hydrogen fuel cells and batteries.
- **Improved modeling** for more accurate simulations.




28



[1]. M. Daboussy, S. Ayche, El-H. Aglzim, Modeling and experimenting the thermal behavior of a lithium-ion battery on an electric vehicle. Lebanese University, Faculty of science, section 3- Tripoli – Lebanon, 2018

[2]. FA Farret M. Godoy Simões, Sensitivity Analysis of the Modeling Parameters Used in Simulation of Proton Exchange Membrane Fuel Cells, May 2, 2023.

[3].Fayssal Ouagueni, Modeling and control of fuel cells, University of M'sila, February 2024.

[4] .BOUCHAALA Soumia and BEGGARI Hadjer, Study of a PEMFC type fuel cell system,: ACADEMIC MASTER'S Dissertation KASDI MERBAH OUARGLA UNIVERSITY Faculty of Applied Sciences Department of Electrical Engineering, 06/13/2022


### 3.4.2 Fuel Cell Modeling (Master Thesis Razan, Chapter 2)

#### 3.4.2.1 Introduction

The PEMFC fuel cell attracts the attention of researchers due to its many advantages. It generates electricity, water and heat, using the oxygen in the air and the hydrogen, which must be produced. Its production is a key issue for the adoption of these cells. This chapter presents the mathematical modeling of the cell, the test bench and its performance, as well as the design and installation of the fuel cell system, the components and their operation.

#### 3.4.2.2 Mathematical modeling of fuel cell

The theoretical thermodynamic potential of a PEMFC is about 1.23 V at atmospheric pressure and a temperature of 25°C. However, when the fuel cell is connected to a load, the actual voltage decreases compared to the theoretical voltage due to polarization phenomena. There are three types of polarization: activation polarization, ohmic (resistance) polarization, and concentration polarization. The VPAC fuel cell voltage can be expressed as follows:

$$V_{PAC} = N \times ( E_{Nernst} - V_{act} - V_{ohmic} - V_{con} ) \quad [21] \qquad (\acute{E}q\ 2,1)$$

N is the number of elementary cells in the stack.

E *nernst* is the Nernst voltage (V).

V act is the activation bias (V).

V *ohm* is the resistance bias (V).

V *conc* is the concentration bias (V).

**Supply voltage**

The supply voltage is a reversible thermodynamic potential of each fuel cell. It represents the no-load voltage of the PEM. This voltage is expressed as follows:

$$E_{Nernst} = \frac{\Delta G}{2\times F} - \frac{\Delta S}{2*F} \times (T - T_{ref}) + \frac{R\times T}{2\times F} * [\ln (P_{H2}) + \frac{1}{2} \ln (P_{O2})] \qquad [21]$$

Where $\Delta G$ is the free energy change (J/k.mol),

$\Delta s$ is the entropy change (J/k.mol),

F is the Faraday constant (C/k.mol),

T is the PEM operating temperature (k),

$Tref$ is the reference temperature (k), and

R is the universal gas constant (J/k.mol).

PH2 partial pressures (atm) of hydrogen, and PO2 partial pressures (atm) of oxygen.

When we substitute the standard value temperature and pressure, the equation becomes simplified as follows [21]:

$$E_{Nernst} = 1.229 - 0.85\times10^{-3} \times (T - 298.15) + 4.31\times10^{-5} \times T \times [\ln (P_{H2}) + \frac{1}{2} \ln (P_{O2})] \quad (\acute{E}q\ 2,3)$$

**Activation overvoltage**

At low current densities, due to the activation energy required to initiate the reaction between gases, especially oxygen at the cathode, the relationship between activation losses and current density is expressed as follows:

$$V_{act} = -[\xi_1 + \xi_2 \times T + \xi_3 \times T \times \ln(C_{O2}) + \xi_4 \times T \times \ln(i_{fc})] \ ; \qquad (\acute{E}q\ 2,4)$$

$$C_{O2}=\frac{PO2}{5.08\times106\times e^{-(\frac{498}{T})}} \quad (Éq\ 2,5)$$

$\xi_1, \xi_2, \xi_3, \xi_4$ are the parametric coefficients appropriate to each physical model of the PEM. C O2 is the oxygen concentration on the catalyst zone ($mol/cm3$ ).

$I_{fc}$ is the operating current of the PEM (A). [21]

### Ohmic Overvoltage

For average current densities, ohmic losses result from the electrical resistance of the various components of the proton exchange membrane (PEM) fuel cell, such as the electrolyte and electrodes. These losses can be expressed using Ohm's law, according to the following equation:

$$V_{ohm}=i_{fc}\times(R_M+R_c) \quad (Éq\ 2,5)$$

$$R_m=ʄ_m\times l/A \quad (Éq\ 2,6)$$

$$ʄ_m=\frac{181.6\times[1+0.03\times\left(\frac{ifc}{A}\right)+0.062\times\left(\frac{T}{303}\right)^2\times\left(\frac{ifc}{A}\right)^{2.5}}{[\Psi-0.634-3\times\left(\frac{ifc}{A}\right)\times\exp\left[4.18\times\left(\frac{T-303}{T}\right)\right]} \quad (Éq\ 2,7)$$

R is the contact resistance equivalent to electron conduction (Ω).

Rm is the equivalent resistance of the membrane to proton conduction (Ω).

l is the membrane thickness (µ$m$),

A is the active area of the PEM ($cm$),

ʄm is the qualitative resistivity of the membrane (Ω. $cm$).

Ψ is the parametric coefficient. [21]

### Concentration overvoltage

Concentration overvoltage is also called concentration polarization, it occurs at high current densities and is caused by the variation of the concentration of reactants (hydrogen or oxygen) at the electrodes, especially at the cathode. The following relation can describe these losses:

$$V_{con}=-B\times\ln\left(1-\frac{J}{Jmax}\right) \quad (Éq\ 2,8)$$

J is the current density ($A/cm2$ ). $Jmax$ is the largest current density ($A/ cm2$ ).

B is the electrochemical constant (dependent on cell type [V]). [21]

### Molar flow rate of hydrogen ($H_2$) in a PEM fuel cell

The molar flow rate represents the amount of moles of hydrogen consumed per unit time in the cell, usually expressed in moles per second (mol/s). This flow rate is crucial in a proton exchange membrane (PEM) fuel cell to power the electrochemical reaction. The following relationship:

$$n_{h2}=\frac{(ifc\times N)}{(2\times F)} \quad (Éq\ 2,9)$$

F is the Faraday constant which is expressed in [C].

### Hydrogen ($H_2$) mass in a PEM cell:

Together with the molar flow rate, it plays a key role in the autonomy of the cell, determining how long it can operate before the hydrogen tank needs to be refilled. In a PEM cell, a small mass of hydrogen is required to produce a significant amount of energy, making it a very efficient fuel source. According to the following relationship:

$$m_{h2} = \int nh2 \times Mh2 \, dt \qquad (\acute{E}q\ 2{,}10)$$

Mh2 is the molar mass of h2 expressed in [kg/mol].

In this study, several critical parameters were defined to model the behavior of the proton exchange membrane (PEM) fuel cell in MATLAB/Simulink. These parameters directly influence the simulation performance and results. A thorough understanding of these parameters is essential to optimize the system design.

Detailed calculations on MATLAB can be found in Appendix 1.[2]

---

[2] Appendix 1: **PAC parameter in MATLAB**

```
clear all ;
close all ;
clc;
n = 10; % Number of cells used in the stack
A = 25; % Active cell surface area of a cell [cm²]
l = 27e-6; % Membrane thickness [m]
T_K = 306; % Cell operating temperature [K]
T_C = T_K - 273.15; % Temperature in degrees Celsius
Po2 = 0.2095; % Partial pressure of oxygen [atm]
Ph2 = 1; % Partial pressure of hydrogen [atm]
Rc = 0.0003; % Contact resistance [Ohm]
B = 0.016; % Cell type dependent constant [V]
zeta11 = -0.853; % Parametric coefficient (fixed to a single value)
zeta3 = 7.6e-5; % Parametric coefficient
zeta4 = -1.93e-4; % Parametric coefficient
if = 23; % Parametric coefficient
Jn = 3e-3; % No-load current density [A/cm²]
Jmax = 469e-3; % Maximum current density [A/cm²]
F = 96485; % Faraday constant [C/mol]
Mh2 = 0.002; % Molar mass of H2 [kg/mol]
% Current range definition
current_range = 0:0.1:30; % Current from 0 to 30 A with a step of 0.1 A
num_current = length(current_range);
% Operation time (eg 1 hour)
t_op = 3600; % Time in seconds
```

```
for i = 1:num_current
ifc = current_range(i);
% Thermodynamic potential of each unit cell
E_N = 1.229 - (0.85*10^-3)*(T_K - 298.15) + (4.31*10^-5)*T_K*(log(Ph2) + 0.5*log(Po2));
% CO2 calculation
co2 = Po2 / (5.08*10^6 * exp(-498 / T_K));
zeta2 = 0.00286 + 0.0002*log(A) + (4.3*10^-5)*log(co2);
if ifc == 0
Vact = -(zeta11 + zeta2*T_K + zeta3*T_K*log(co2));
else
Vact = -(zeta11 + zeta2*T_K + zeta3*T_K*log(co2) + zeta4*T_K*log(ifc));
end
rom=181.6*(1+0.03*(ifc/A)+0.062*(T_K/303)^2*(ifc/A)^2.5)/((si-0.634-3*(ifc/A))*exp (4.18*((T_K-303)/T_K)));
Rm = rom * l / A;
Vohmic = ifc * (Rm + Rc);
if ifc == 0
J = Jn; 67

else
J = ifc / A; % [A/cm²]
end
Vcon = -B * log(1 - (J / Jmax));
Vfc = n * abs(E_N - Vact - Vohmic - Vcon);
Vfc_total(i) = Vfc;
Pfc = ifc * Vfc;
Pfc_total(i) = Pfc;
nh2 = (ifc * n) / (2 * F); % [mol/s]
nh2_total(i) = nh2 ;
mh2 = nh2 * Mh2 * t_op; % [kg]
mh2_total(i) = mh2;
end
color_voltage = 'b' ; % Blue
color_power = 'r' ; % Red
color_flow = 'g' ; % Green
color_mass = 'm' ; % Magenta
figure(1);
plot(current_range, Vfc_total, 'b-' , 'LineWidth' , 2);
xlabel( 'Fuel cell current (A)' );
ylabel( 'Fuel cell voltage (V)' );
title([ 'Voltage vs Current at T = ' num2str(T_K) ' K (' num2str(T_C, '%.2f' ) '°C)' ]);
grid on ;
%2. Power vs Current
figure(2);
```

#### 3.4.2.3 Fuel cell design (Free cad)

A fuel cell consists of graphite catalytic electrodes, a proton exchange membrane for the passage of ions, and bipolar plates to ensure uniform gas distribution and efficient water evacuation, all designed to maximize electrochemical efficiency and optimize thermal management.

- Fuel cell components:

a) Terminal plate

b) Gasket behind the terminal plate

c) Current plate

d) Graphite plate for H2

e) MEA

f) Gasket

g) Graphite bipolar plate

h) Graphite plate for O2

---

```
plot(current_range, Pfc_total, 'r-' , 'LineWidth' , 2);
xlabel( 'Current (A)' );
ylabel( 'Fuel cell power (W)' );
title([ 'Power vs Current at T = ' num2str(T_K) ' K (' num2str(T_C, '%.2f' ) '°C)' ]);
grid on ;
figure(3);
plot(current_range, nh2_total, 'g-' , 'LineWidth' , 2);
xlabel( 'Current (A)' );
ylabel( 'Molar flow rate of H_2 (mol/s)' );
title([ 'Molar flow rate of H_2 vs Current at T = ' num2str(T_K) ' K (' num2str(T_C, '%.2f' ) '°C)' ]);
grid on ;
figure(4);
plot(current_range, mh2_total, 'm-' , 'LineWidth' , 2);
xlabel( 'Current (A)' );
ylabel( 'Mass of H_2 consumed (kg)' );
title([ 'Mass of H_2 consumed vs Current at T = ' num2str(T_K) ' K (' num2str(T_C, '%.2f' ) '°C)' ]);
grid on ;
```

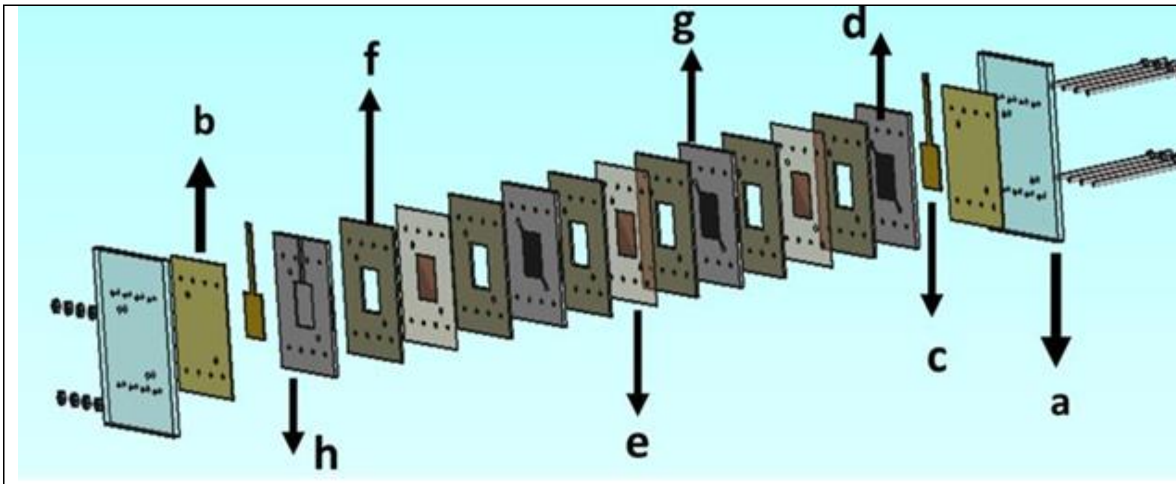



*Figure 2.27: Exploded 3-cell fuel cell (Free cad)*

Here is a more concise version of the description of the components of the PAC design (3-cell fuel cell)

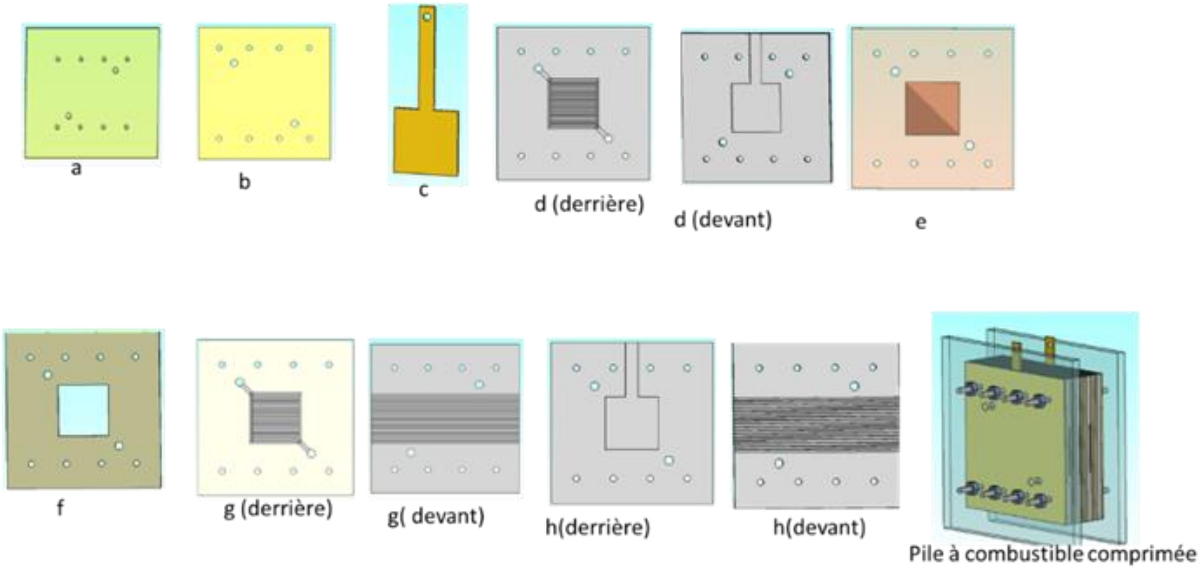



*Figure 2.28: Design of each cell (FreeCAD)*

*Table 3: Components of the 3 cells*

| | |
|---|---|
| 2 End plates | 2 Gaskets behind the end plates |
| 2 Current plates | 1 graphite plate for $H_2$ (Anode) |
| 3 MEA (Membrane Electrode Assembly) | 6 Gaskets |
| 2 Bipolar plates (BBP) | 2 Graphite plates for $O_2$ (Cathode) |

### 3.4.2.4 Fuel Cell System Installation

In the NLAP lab, we have been installing the fuel cell-cell plates. The installation of these plates is essential for the assembly and overall efficiency of the fuel cell system.

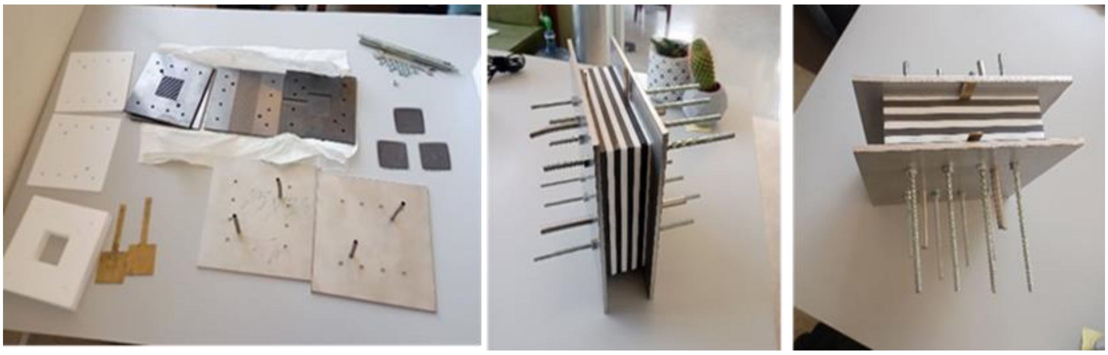


*Figure 2.29: Fuel cell system*

In the laboratory, we installed three PEM cells. However, due to the absence of the hydrogen bottle, it was not possible to test this system after installation.

We decided to adjust the number of cells in the simulation to test different configurations. This approach will allow us to analyze the performance of the system by changing the number of cells and comparing them with the expected results of the experimental part. We took the real tests carried out at the Electrical Engineering Laboratory (LAGE) of the Scientific Research Center of Kasdi Merbah Ouargla University (Algeria) [20].

Finally, comparing the simulated results with the experimental data will validate the reliability and accuracy of the model, ensuring that it faithfully reproduces the behavior of the real system.

#### 3.4.2.5 Experimental Data Analysis (LAGE)

The experimental fuel cell system (26 cells) stands out for its advanced technical features and its ability to simulate real operating conditions. Thanks to its modular and flexible design, this system allows experimenting with various configurations, facilitating the detailed study of PEM cell performance under different conditions. It integrates an intuitive user interface that simplifies the control and monitoring of critical parameters such as temperature, voltage, and current.

The system contains:

- 50 W PEM fuel cells (air-cooled, open cathode).
- USB interface.
- Displays to view all quantities.
- Intuitive and educational software.
- Automatic mode for recording.
- Instantaneous values and display of curves.
- Manual mode for point-by-point recording.
- Complete educational materials.

The system presented in Figure (2.34) is a system designed to produce electrical energy using a 50 W PEMFC fuel cell. The latter is powered by solar hydrogen [20].

Acquisition System: The software is designed to facilitate system control, data acquisition and graphical representation of the collected data.

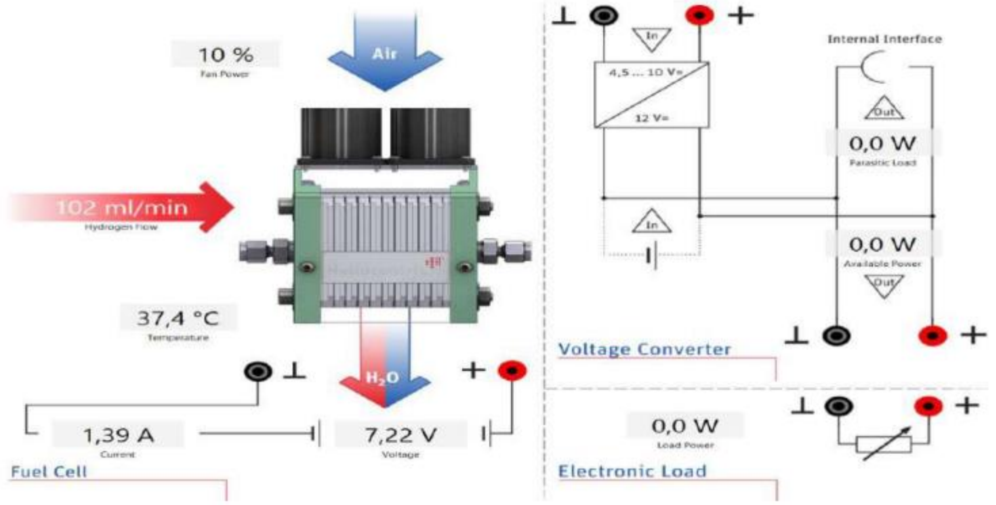
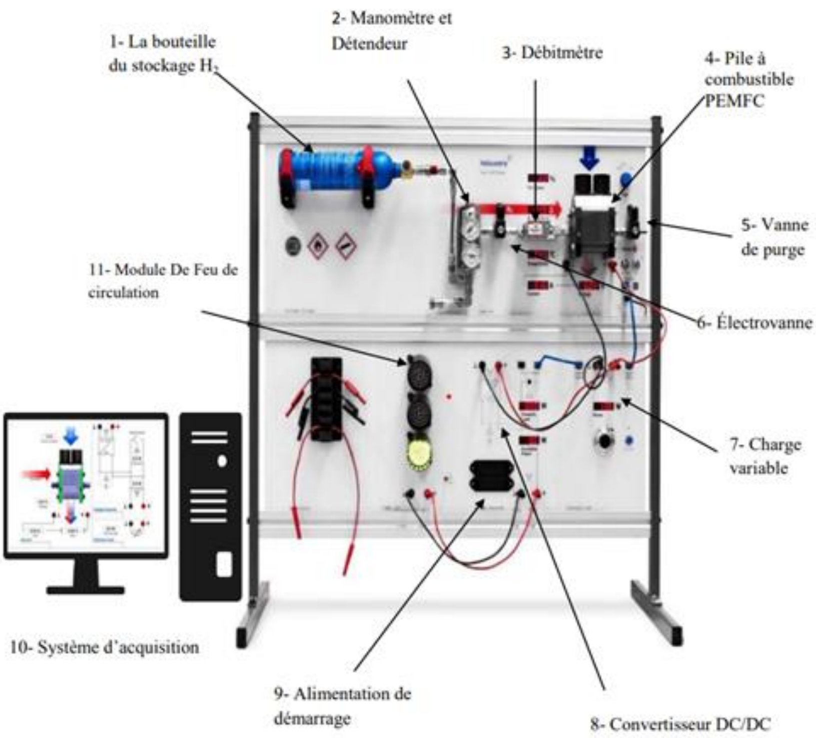



*Figure 2.31: Fuel cell software interface*

Comparing the results of the fuel cell (FC) model in MATLAB with the experimental data is essential to validate the accuracy of the model in the previous chapter. This step allows to verify whether the model correctly simulates the real performances of the cell, in particular in terms of voltage, current, power and hydrogen consumption. In case of significant deviations, adjustments can be made to the model to refine its predictions. When the simulated and experimental results are sufficiently close, the model is considered reliable and can be used to predict the performances under different conditions, thus reducing the need for repeated physical experiments.



#### 3.4.2.6 Application of PEMFC in Electric Vehicle

**Problem**

The limitation of natural resources and climate change, aggravated by polluting vehicles that emit large amounts of $CO_2$, require an urgent change in individual transportation modes. The automotive industry, in particular, contributes significantly to these environmental and energy problems. In response to this, hybrid electric vehicle technologies are increasingly perceived as one of the most promising solutions.

These vehicles, which combine an internal combustion engine with an electric motor, not only reduce greenhouse gas emissions but also improve energy efficiency by reducing fuel consumption. Moreover, by using renewable energy sources for electricity, these technologies contribute to decreasing dependence on fossil fuels, making the transportation system more sustainable in the long term. Thus, the adoption of hybrid vehicles could be a key element in addressing the environmental and energy challenges posed by the current automotive industry.

**Electric Vehicle Characteristic**

The forces acting on a vehicle include rolling resistance, grade resistance, aerodynamic force, acceleration force, and grade force. Rolling resistance comes from the friction between the tires and the road, while grade resistance and gravitational force influence the vehicle's movement on a slope.

Aerodynamic force opposes the movement due to friction with the air. Acceleration force occurs when the vehicle changes speed.

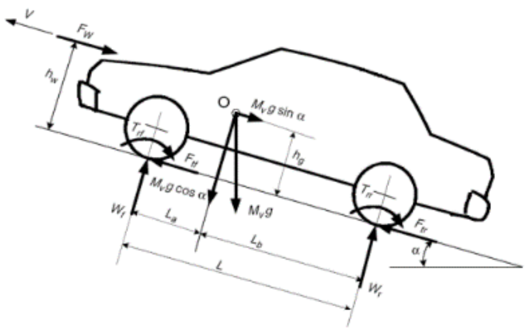


*Figure 2.32: Forces acting on the car*

$F(N) = F_{aerodynamic} + F_{rolling} + F_{acceleration} + F_{slope}$ (Eq *2,11)*

*Aerodynamic force*

Aerodynamic force, also called aerodynamic drag, is the resistance force exerted by the air on a moving object. It opposes the direction of movement of the object and is due to the interaction between the air and the surface of the object. This force increases proportionally to the speed of the object, making high-speed movements more energy-intensive, and is expressed as follows:

$F_{aerodynamic} = 0,5 \times \varrho \times S \times C_x \times V^2$ (Eq 2.12)

With:

V = vehicle speed [m/s]

$\varrho$ = air density (≈1.2 kg/$m^3$)

S = vehicle frontal area [$m^2$]

$C_x$ = drag coefficient

*Rolling force*

Rolling force (or rolling resistance) is the force that opposes the movement of a vehicle due to the contact between the wheels and the road surface. This force results from the deformation of the tires and the road surface, as well as the energy losses related to this phenomenon. It is expressed as follows:

$F_{rolling} = m_v \times g \times \mu$ (Eq 2.13)

With:

g = acceleration of gravity [9.81 m/$s^2$ ]

$\mu$ = coefficient of friction [≈0.01]

$m_v$ = mass of the vehicle

*Acceleration force*

The acceleration force is the force applied to increase the speed of a vehicle. It is expressed as follows:

F _acceleration =mv×a (Eq 2.14)

With:

a = acceleration of the vehicle

*Slope force*

The slope force (or gravitational force on a slope) is the component of the gravity force that acts on a vehicle when it moves on an inclined surface (uphill or downhill). According to the following relationship:

$F_{slope} = mv \times g \times \sin\alpha$ (Eq 2.15)

With:

$\alpha$ = slope [rad]

And we must calculate the vehicle power:

P=F×V (Eq 2.16)

V: Vehicle speed. F: Forces applied to the vehicle

#### 3.4.2.7 Vehicle Parameters in MATLAB

The purpose of the time and speed variables in MATLAB is to plot the curve of variation of the vehicle speed as a function of time. The results obtained will be presented in the previous chapter.

The vehicle parameters are:

i. $\varrho$ = air density rho=1.2(kg/$m^3$);

ii. S = surface (frontal area) of the vehicle S =2.11($m^2$);

iii. Drag coefficient $C_x$=0.28;

iv. Mass of the vehicle $m_v$=1465(Kg);

v. Gravity acceleration g=9.81 m/$s^2$;

vi. Friction coefficient μ =0.01;

vii. alpha=10°;

viii. Time from 0 to 195 seconds;

**The calculation is detailed in Appendix 2[3]**

[33] Appendix 2: Vehicle Parameter in MATLAB

```
rho=1.2;
S=2.11;
Cx=0.28;
mv=1465;
g=9.81;
mu=0.01;
alpha=10;
City =[
1.0000 0
2.0000 0
3.0000 0
4.0000 0
5.0000 0
:
:
195.0000 0
];
t=City(:,1) %time [s]
V=City(:,2) %speed [m/s]
simtemps = length(t);
% Calculate forces
F_Aerodynamic = 0.5 * rho * S * Cx * V.^2; % Aerodynamic force
F_rolling = mv * g*mu; % Rolling force
F_Slope = mv * g * sin(deg2rad(alpha))*ones(size(V)); % Slope force
% Calculate acceleration
a = [diff(V) ./ diff(t); 0]; % Acceleration (m/s^2)
F_Acceleration = mv * a; % Acceleration force
% Calculation of total forces
F = F_Aerodynamic + F_rolling + F_Acceleration + F_Slope;
P = F .* V; % Power (W)
plot(t, V);
```

#### 3.4.2.8 Vehicle model in Simulink

The vehicle model used in this study includes the following characteristics: a total weight of 1465 kg, an aerodynamic drag coefficient of 0.28, and a frontal area of 2.11 m². This model is simulated in MATLAB/Simulink to analyze the vehicle dynamics as a function of speed, acceleration, and acting forces such as rolling resistance, aerodynamic drag, and gravitational force. The results of this simulation provide a better understanding of the energy efficiency of the vehicle equipped with a fuel cell system.

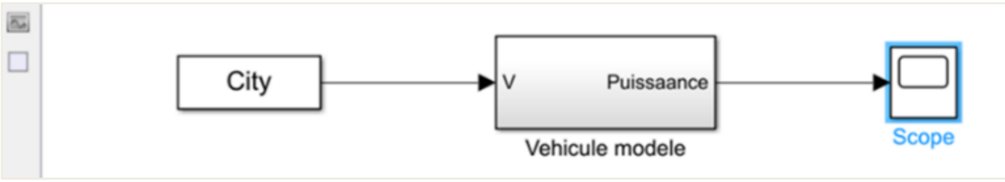



*Figure 2.33: Entering and exiting a vehicle*

In this Simulink model, the "Vehicle Model" block (which is a subsystem), representing the forces acting on the vehicle.

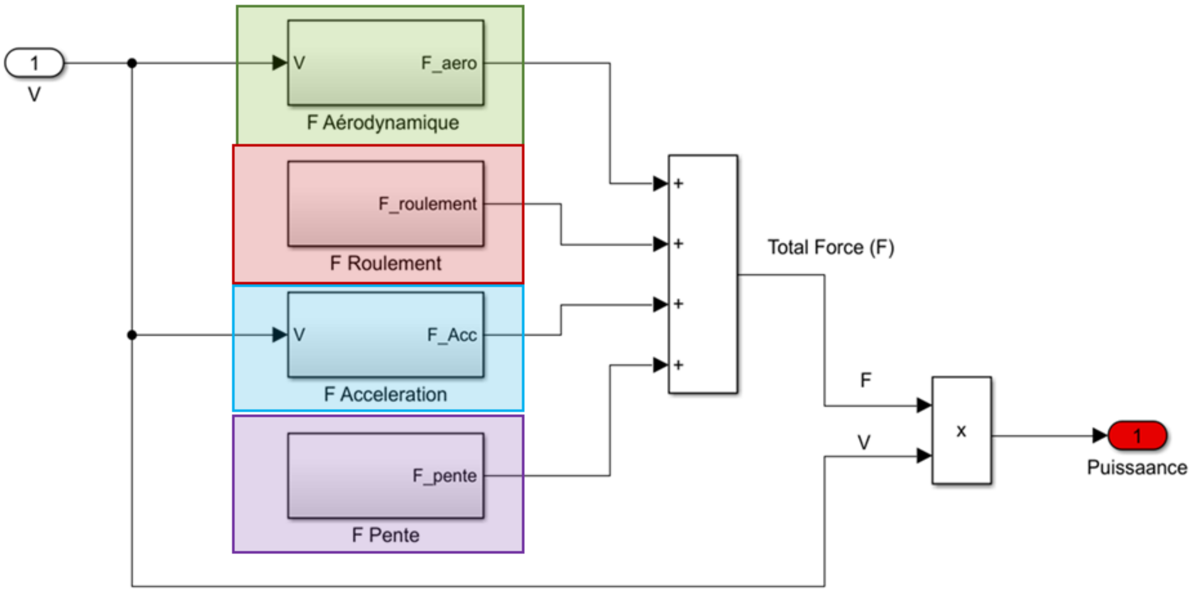



*Figure 2.34: Forces acting on vehicle*

Here is a picture of the aerodynamic, rolling, acceleration and slope forces blocks (which is a subsystem) in the Simulink model.

---

```
xlabel( 'time(s)' );
ylabel( 'Speed(m/s)' );
figure;
plot(t, P);
xlabel( 'time(s)' );
ylabel( 'Power(W)' );
```

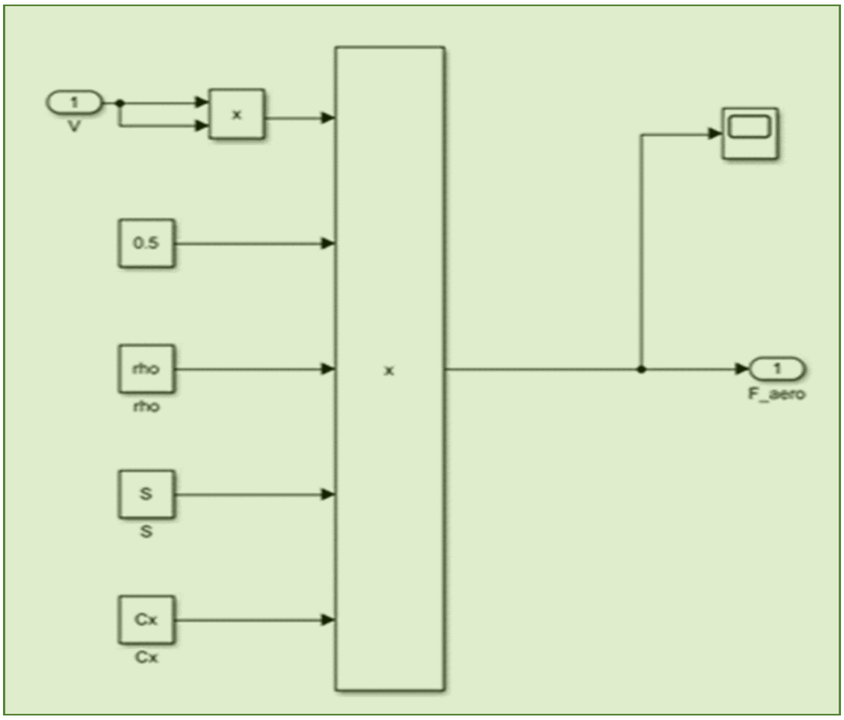



*Figure 2.35: Aerodynamic force block*

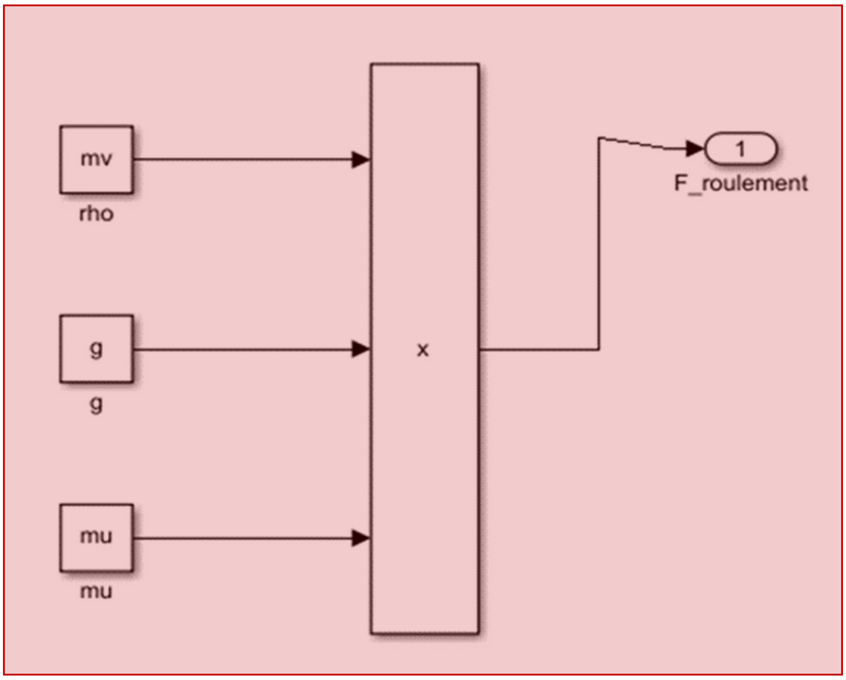



*Figure 2, 36: Rolling force block*

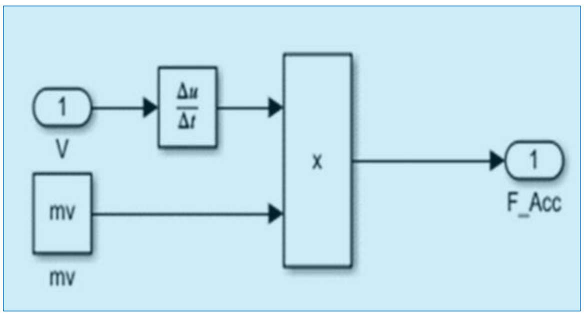



*Figure 2.38: Acceleration Force block*

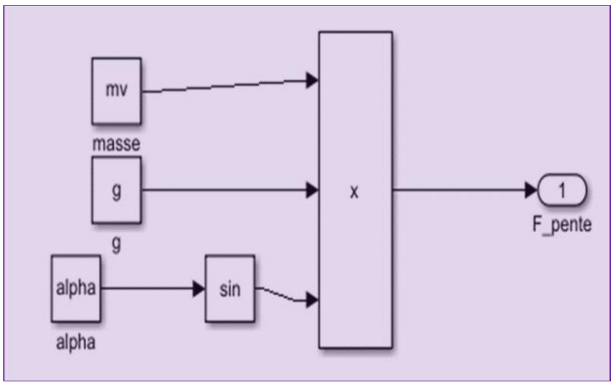



*Figure 2, 1: Slope Force block*

#### 3.4.2.9 Fuel Cell (PAC) Model

The simulation of proton exchange membrane fuel cells (PEMFC) is a valuable tool for the development and large-scale testing of new alternative energy sources. In order to develop a relevant PEMFC model, capable of analyzing fuel cell-based power generation systems, it is essential to accurately determine a set of specific modeling parameters.

**Fuel cell characteristics**

*Fuel cell current*

The current of a fuel cell is the flow of electrical charge resulting from the electrochemical reactions in the cell. It transforms the chemical energy of the fuel, such as hydrogen, into electrical energy, thus powering devices such as electric motors. According to the following equation:

$I\_fc = \frac{Pfc}{Vfc}$ (Eq *2,17)*

With $P_{fc}$ : power of FC [W], and $V_{fc}$ : voltage of FC [V]

*Molar flow rate*

The molar flow rate of hydrogen ($H_2$) in a fuel cell represents the amount of hydrogen consumed per unit of time, generally expressed in moles per second (mol/s).

The molar flow rate of dihydrogen [mol/s] in the stack;

$\dot{n}_{H2\text{-}stack} = \frac{Ifc}{2*F} \times n_c$ (Éq *2,18)*

With:

F: Faraday constant(C)

$n_c$: number of cells in the stack

*Hydrogen Mass*

The mass of hydrogen ($H_2$) in a fuel cell refers to the total amount of hydrogen used or available for electrochemical reactions within the cell.

The mass of H2 [kg];

$m_{H2} = \int \dot{n}_{h2} \times M_{H2}\, dt$ ( Éq *2,19)*

With:

$M_{H2}$ = 2 × 10-3 kg/mol The molar mass of dihydrogen [kg/mol]

*Fuel Cell voltage*

The fuel cell voltage corresponds to the difference in electrical potential between its electrodes, measured during its operation. It is an essential indicator of the performance and energy efficiency of the system. Optimizing this voltage is fundamental to maximizing electricity production [22].

The cell voltage [V] ;

$V_c$=1,031-2,45× $10^{-4}$×j- 0,03×ln (j+3 )-2,11×$10^{-5}$ ×exp(8 ×10-3×j )     ( Eq *2,20)*

With:

j : Current density [mA/cm2];

$j = \frac{Ifc}{Sfc}$     ( Eq 2,21)

$S_{fc}$ = 480 $cm^2$: The surface area of a cell [$cm^2$]

$V_{FC} = V_c \times n_c$     (Eq 2.22)

With

$V_c$: Cell voltage [V]

$V_{FC}$: Total battery voltage [V]

$n_c$ : the number of cells

△ **In this fuel cell model, it is essential to use the power demanded by the vehicle as the main input. This power determines the energy demand, directly influencing the electricity production of the fuel cell.**

By integrating the vehicle power as an input parameter, it becomes possible to regulate the operation of the stack in real time, thus ensuring optimal energy management and maximum system efficiency, while responding to variations in the vehicle's energy needs.

Among the following operating conditions:

i. $N_A$ = 6.022*10^23 Avogadro's number [mol^-1]

ii. e = 1.602 *10^-19 Elementary electric charge [C]

iii. t =195 time[s]

iv. $M_{H2}$ = 2*10^-3 Molar mass of dihydrogen [kg/mol]

v. $N_c$ =180 Number of cells in the stack

vi. $S_{fc}$ = 480 Surface area of a cell [$cm^2$]

vii. $r_{transmission}$ = 80 Transmission efficiency [%]

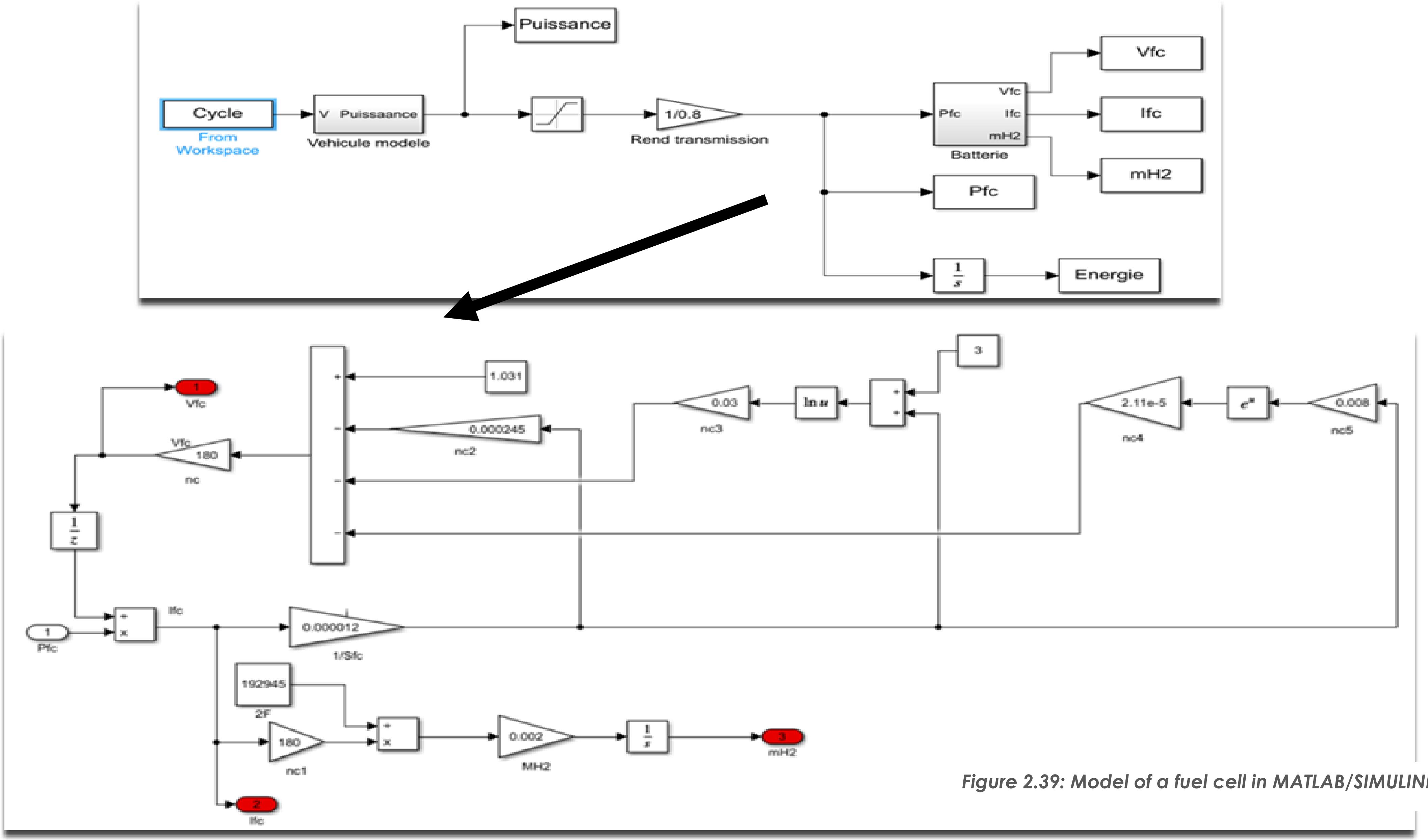



*Figure 2.39: Model of a fuel cell in MATLAB/SIMULINK*

#### 3.4.2.10 Conclusion

This chapter has outlined the key steps in the development of a fuel cell (FC) system for electric vehicles. Mathematical modeling has established fundamental relationships between the main FC parameters, such as voltage, current, power, and hydrogen consumption.

The implementation of this model in MATLAB/Simulink has allowed simulating the dynamic behavior of the fuel cell under different operating conditions, providing essential simulation results for performance analysis.

This approach has not only highlighted the ability of fuel cells to meet the energy requirements of electric vehicles, but also paved the way for future optimizations. Thus, this chapter demonstrates the promising application of fuel cells in electric vehicles, highlighting their potential as a key solution for clean and sustainable mobility, while contributing to the transition to greener transportation systems.

### 3.4.3 Results and Discussion (Master Thesis Razan, Chapter 3)

#### 3.4.3.1 Introduction

Once the model is validated, it is integrated into the Simulink simulation environment, which facilitates dynamic analysis and optimization of PAC performance in real conditions, particularly in the context of automotive applications.

In this chapter, we present the results of mathematical modelling characteristic curves in MATLAB and compare them with the experimental part.

In addition, the results from simulations performed with MATLAB/SIMULINK to evaluate the performance of the fuel cell (FC) in electric vehicles.

These electric vehicle simulations allow to generate the speed curve as a function of time and the power that must be used as input into PAC. In addition to the PAC simulation, the voltage, current, power, hydrogen molar flow ($H_2$) and the mass of $H_2$ consumed curves are all calculated at multiple alpha values.

#### 3.4.3.2 Fuel cell (PAC) characteristic curve in MATLAB

The operating conditions of the mathematical model of the fuel cell are as follows:

- Number of cells = 10
- Temperature = 33°C (306 Kelvin)
- Cell surface A= 25 (cm2)
- Membrane thickness l= 27*10-6(m)
- Cell type dependent constant B=0.016
- Oxygen partial pressure PO2 =0.2095[atm]
- Hydrogen partial pressure PH2=1[atm]
- Contact resistance Rc=0.0003 [Ohm]
- Parametric coefficient Ψ(si)=23
- No-load current density Jn=3*10-3 [A/cm²]
- Maximum current density Jmax=469*10-3[A/cm²]
- Faraday constant F=96485[C/mol]
- Molar mass of H2 Mh2=0.002 [kg/mol]

**Voltage-current characteristic curve**

Figure (2.27) shows the result of the simulation of voltage as a function of current.

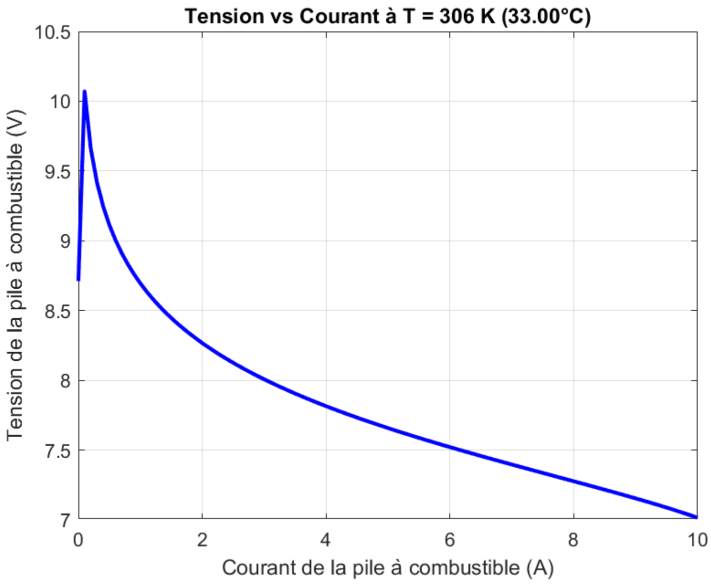



Figure 3.40: Voltage versus current curve

It presents an open circuit voltage (i=0) experiences a slight sudden increase, reaching a peak around 10.1 V. This phase corresponds to the activation zone of the fuel cell, marking the beginning of the electrochemical reaction.

After the initial peak, the voltage decreases rapidly with increasing current, it drops to about 8.5 V.

This decrease is due to the activation polarization, which corresponds to the loss of energy necessary to overcome the activation barriers of the reactions.

From this point, the curve shows a more gradual decrease in voltage as the current increases, going down to about 7 V at a current of 10 A.

This part represents the ohmic losses and the concentration losses, where the internal resistance of the cell and the limited availability of reactants cause a more linear decrease in voltage.

### Power-current characteristic curve

The results of the curve represent power as a function of current.

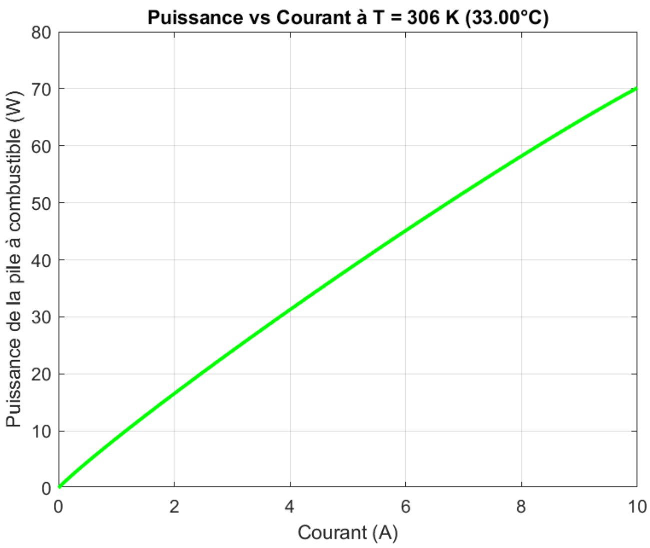



*Figure 3.41: Power curve as a function of current*

We notice that the power of a fuel cell increases progressively with increasing current, reaching 70 W at a current of 10 A. This linear relationship shows that the fuel cell provides increasing power as a function of current, without saturation or noticeable decrease over the interval shown. This means that for each increase in current, there is a proportional increase in power, suggesting a stable and efficient operation of the fuel cell in this current range.

**Flow rate and mass H2-current characteristic curve**

We then show the simulation results representing the molar flow rate H2 and the mass H2 as a function of the current.

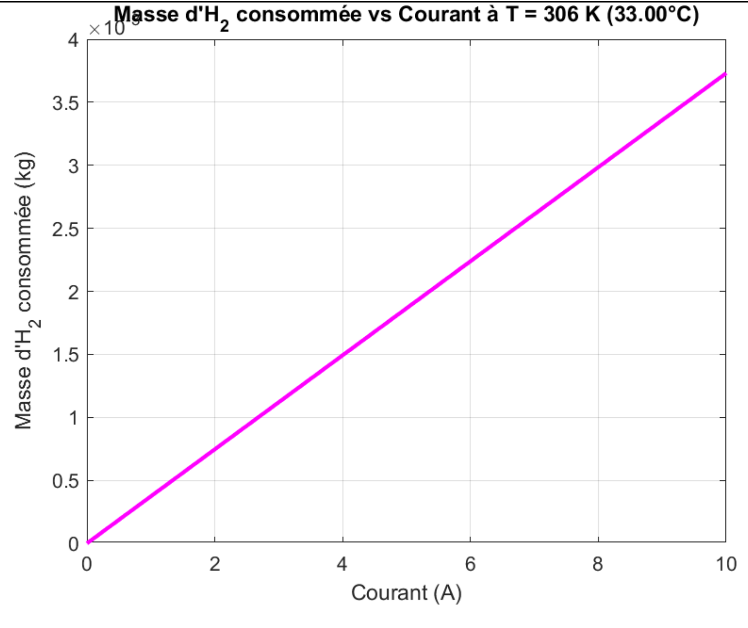



*Figure 3.42: $H_2$ mass curve as a function of current*

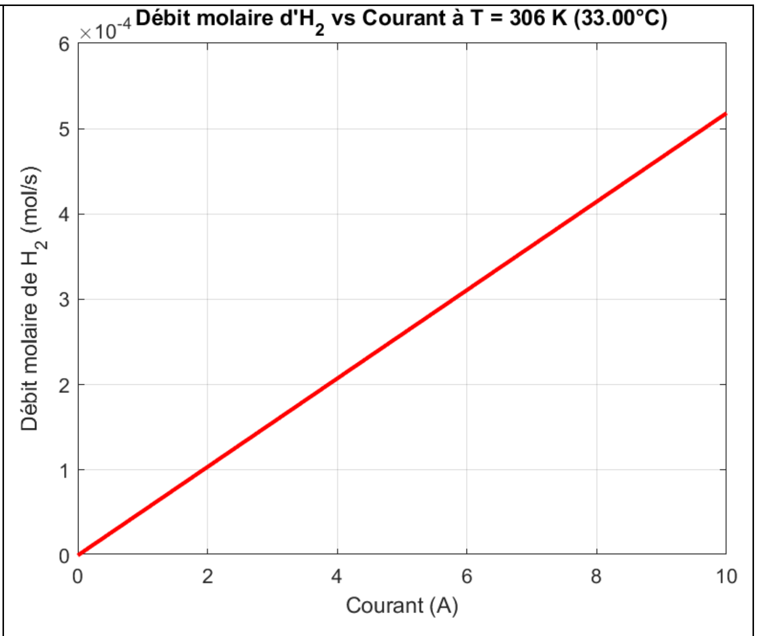



*Figure 3.43: H2 flow rate curve as a function of current*

The curve in Figure (3.42) showing the mass of hydrogen consumed by the fuel cell shows a steady increase as the current increases. As the current increases, the cell requires more hydrogen to power the electrochemical reactions.

For low currents, the mass of hydrogen consumed remains relatively low. As the current increases, the mass of hydrogen follows an almost linear growth. When the current reaches a higher value, the mass of hydrogen consumed reaches about 3.7×10-3 Kg.

Figure (3.43) of the molar flow rate of hydrogen shows a steady increase as the current generated by the fuel cell increases.

Initially, for low currents, the molar flow rate is relatively low, but it increases almost linearly with increasing current. When the current reaches higher values (10A), the molar flow rate reaches about 5.1× 10⁻4 mol/s. This behavior illustrates the direct relationship between the cell current and the amount of hydrogen consumed, in accordance with Faraday's law which relates the amount of reactants used to the electric current.

#### 3.4.3.3 Operating conditions of the experimental part

i. Temperature=33°C

ii. Number of cells =10

iii. Membrane thickness 27 [µm]

iv. Nominal anode pressure [bar] 0.6 +/- 0.1

v. I max=10A

vi. Gross sectional cell 25 cm2

vii. Maximum power 50 [W]

**Voltage-current characteristic curve**

Using the data stored in the acquisition system, the voltage-current characteristics (V-I) of the fuel cell were plotted as shown in:

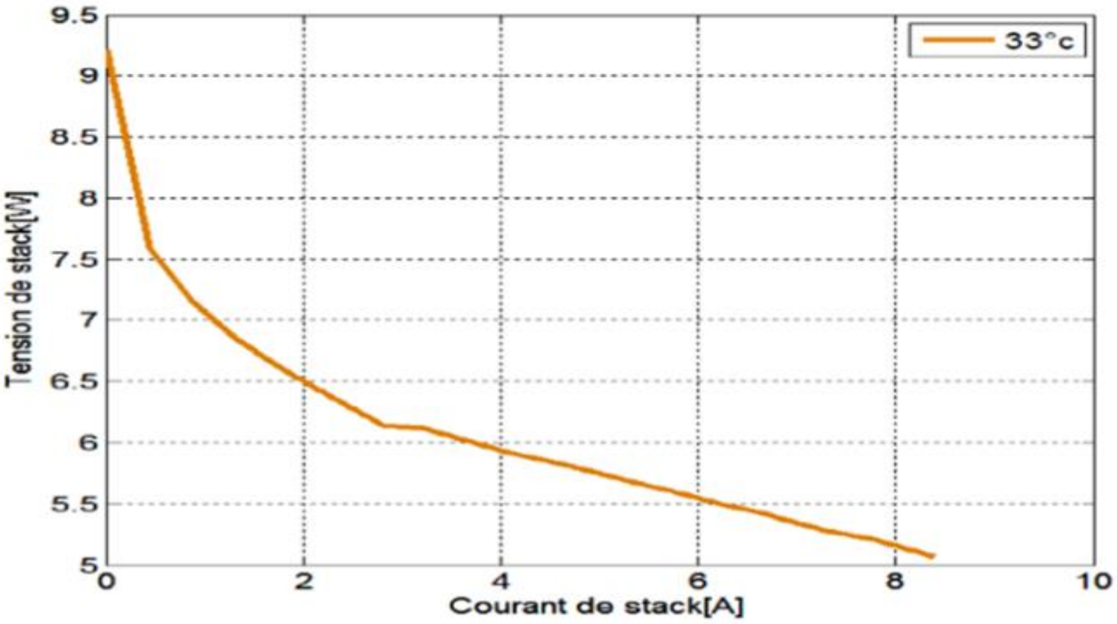



*Figure 3.44: Voltage curve as a function of current (from the experimental part)*

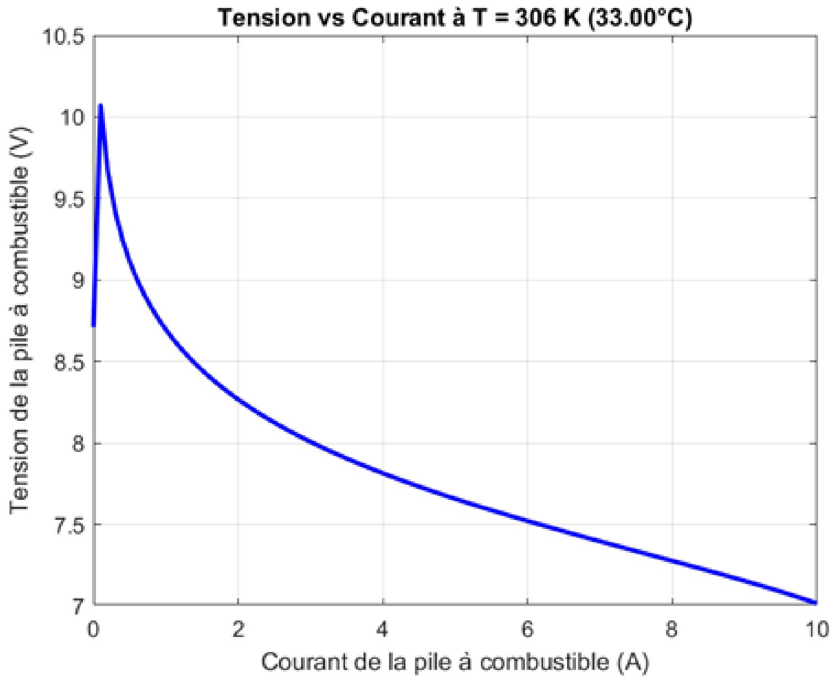
Figure (3.44) shows an open circuit voltage of about 9.21 V. It is observed that the cell voltage decreases inversely proportional to the current due to internal losses. The characteristic curve of the PEMFC cell highlights three distinct polarization zones:

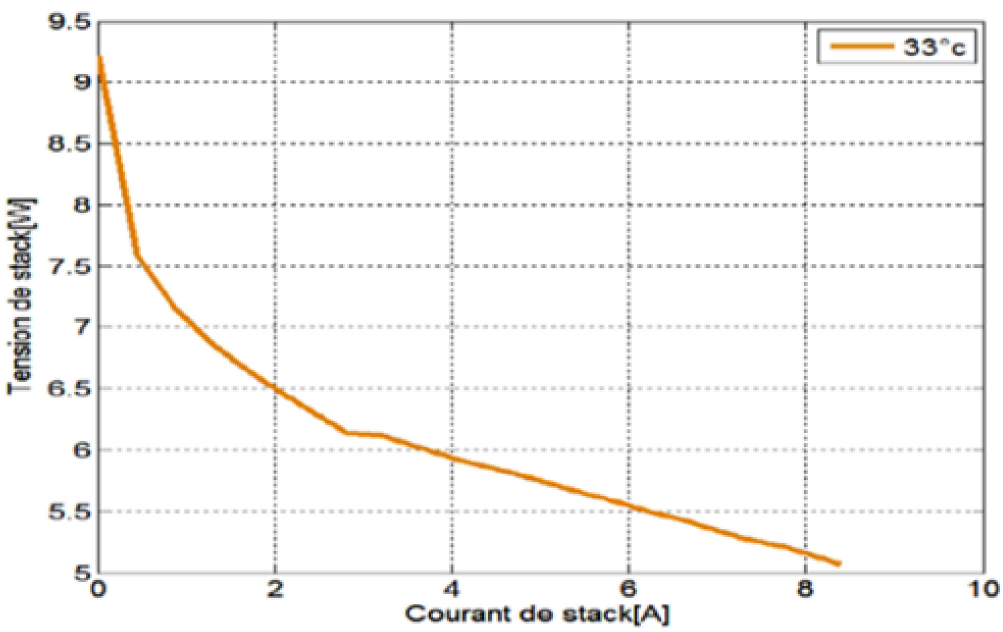
• From 0 to 0.44 A, there is the activation polarization zone, caused by the transfer of charges at the electrode/electrolyte interface, linked to the slowness of the chemical reaction on the surface of the electrode.

• From 0.44 to 2.81 A, we identify the resistance polarization zone, which results from the electrical resistance of the various components of the cell, in particular the electrolyte.

• From 2.81 to 8.39 A, we enter the diffusion polarization zone, influenced by the concentration of the electrolyte around the electrodes.

 **Comparison of voltage-current curves from the theoretical part with the experimental part :**




The open circuit voltage in the first figure is higher than the second figure, which could reflect differences in the materials used or the experimental conditions. In both figures, a decrease in voltage is observed after the activation phase, but this drop is more pronounced in the first figure, while the second figure shows a more gradual decrease with a lower current limit.

The second figure describes in more detail the different polarization zones, while the first shows a more regular decrease, related to ohmic and concentration losses.

In addition, the first figure shows a higher current limit, suggesting that the cell can support higher currents, unlike the second figure which shows a lower current limit, reflecting higher losses at higher currents.

**Power-current characteristic curve**

Using the data stored in the acquisition system, the power-current (P-I) characteristics of the fuel cell were plotted as shown in the figure:

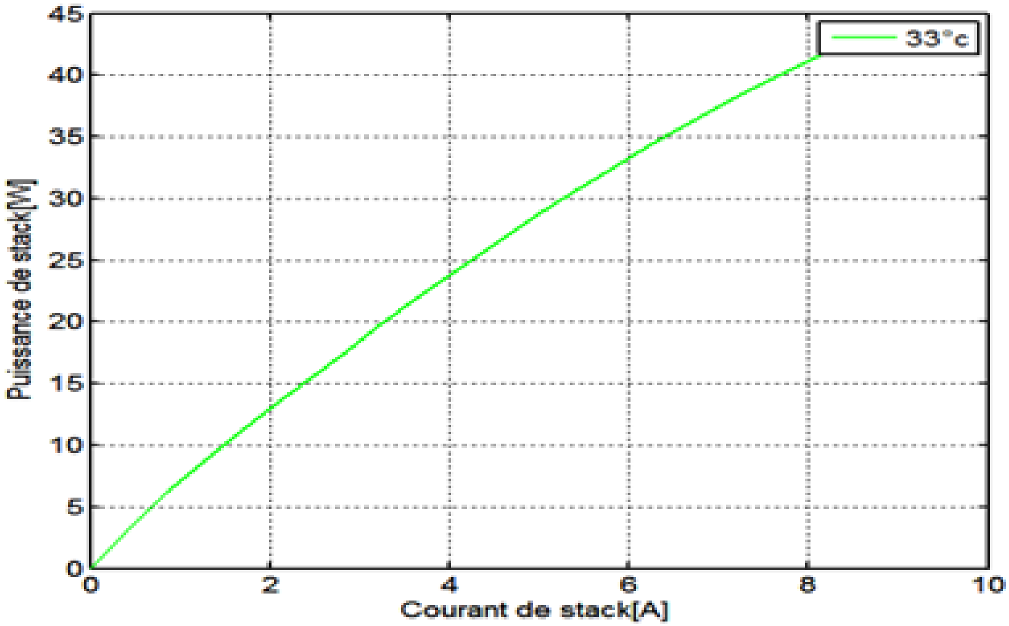
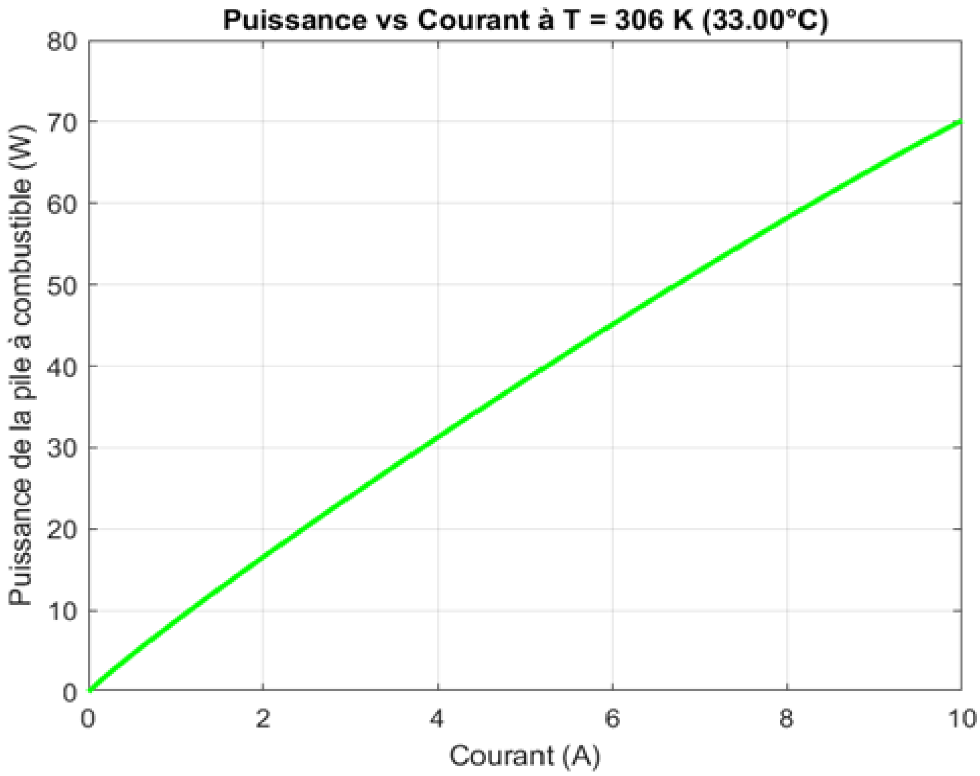



*Figure 3.45: Power curve as a function of current (from the experimental part)*

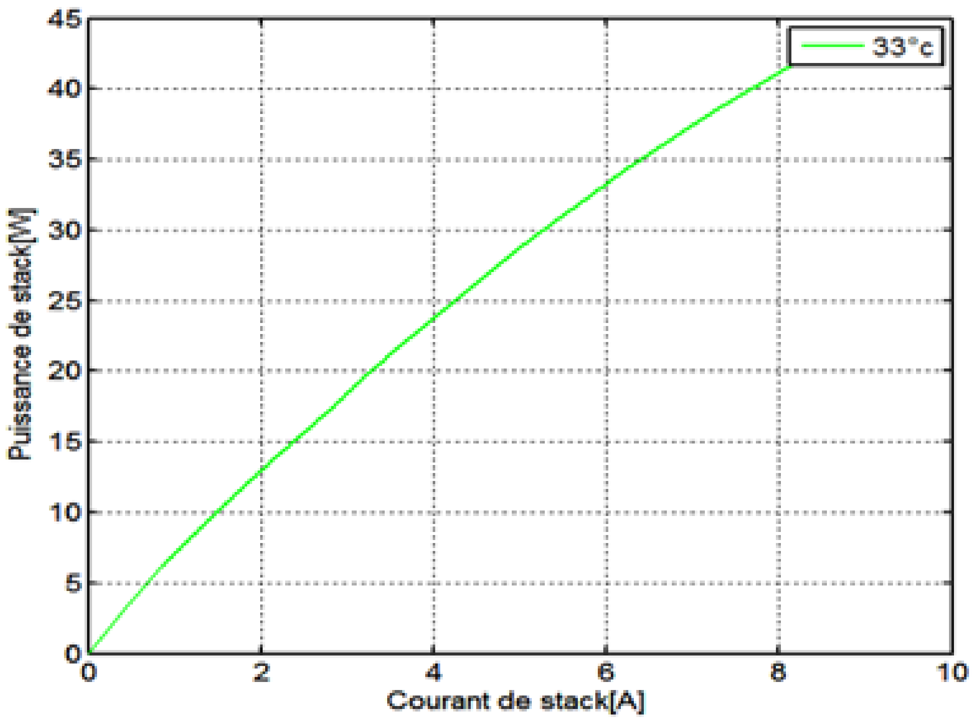
We observe that the power of a fuel cell increases gradually, reaching a maximum at a certain point, but then decreases. At a current of 8.39 A, the cell produces about 42 W. However, this maximum power point does not correspond to the optimal operating point of the cell. Indeed, it becomes difficult to maintain the cell at its maximum power due to the low efficiency of the cell, the accumulation of water and the increase in temperature, which complicates the control of the cell under these conditions.

- **Comparison of the power-current curves of the theoretical part with the experimental part:**

The comparison of the curves from the mathematical modeling and the experimental part reveals a good overall correspondence, at the same temperature (33°C). This consistency validates the modeling method used in Matlab, by demonstrating that the model results are in agreement with the experimental data, even under varied operating conditions.




*Mathematical modeling results*




*Experimental part*

The mathematical result figure shows a linear increase in power up to 70 W at 10 A, without performance degradation, suggesting a simulation without considering real physical constraints, while the experimental part curve reaches a peak of 42 W at 8.39 A, followed by a power drop due to physical limitations of the cell (water accumulation, thermal management, efficiency loss).

## 3.5 FC test specification

### 3.5.1 Test objectives:

Voltage

Current

Hydrogen ($H_2$) flow rate

### 3.5.2 Test Devices

Stack (Fuel Cell)

Voltmeter

Amperemeter

Hydrogen ($H_2$) tank

Connection wires

Resistor

Fan

#### 3.5.2.1 Installation of Fuel Cell

Components:

a) End plat
b) Gasket behind the end plate
c) Current plate
d) Graphite plate for $H_2$
e) MEA (Membrane Electrode Assembly)
f) Gasket
g) Graphite Bipolar Plate
h) Graphite plate for $O_2$

### 3.5.3 Pre-test: Hydrogen preparation for use in a fuel cell system:

First, an exothermic reaction is initiated, where hydrochloric acid (HCl) reacts with aluminum to produce hydrogen.

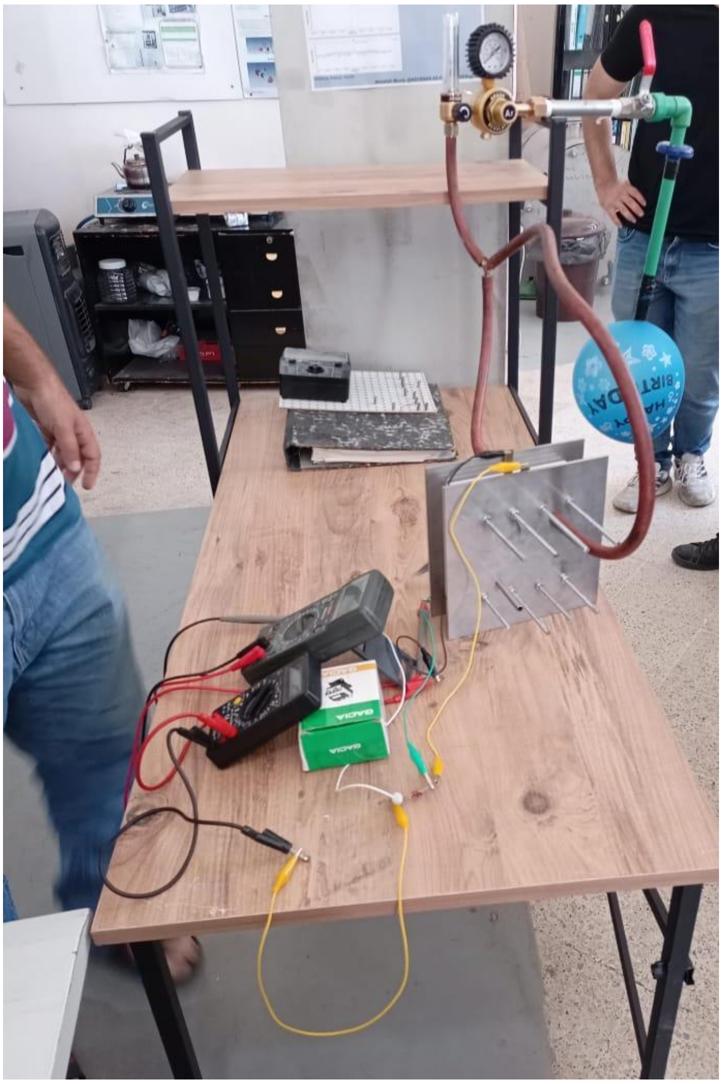
Next, the chemistry lab was set up following all appropriate safety standards.

The equipment used includes a water bottle connected to an Erlenmeyer flask via a tube. A small faucet is attached to the tube, with an uninflated balloon fixed to the end of the faucet.

A measured amount of acid was poured into the Erlenmeyer, followed by the addition of aluminum pieces. The reaction quickly accelerated, causing the balloon to inflate as it filled with hydrogen.

### 3.5.4 Specification for Fuel Cell System Test

| Step | Step Description | Expected Result |
|---|---|---|
| Precondition | -System is off<br>-The connection wires are connected<br>-the voltmeter as well as the amperemeter are prepared.<br>-Three resistors were used in place of a fuel cell stack, and the resistance (in ohms) was measured<br>-Additionally, a fan was installed on the fuel cell system to use oxygen | |
| Open the Valve | Open the valve | The valve is open and allows the hydrogen gas to pass through. |
| Switch ON the system | Turn Off the global Hydrogen valve<br>Turn On the system from the GUI | The system in general, produces water, heat, and electricity |



## 3.6 Fuel Cell System Test

### 3.6.1 Test result and failure analysis

The FC did not perform as expected. It did not produce as much electricity as expected. This may be due to the need to compress the hydrogen before it is introduced into the fuel cell.

## 3.7 What's Next

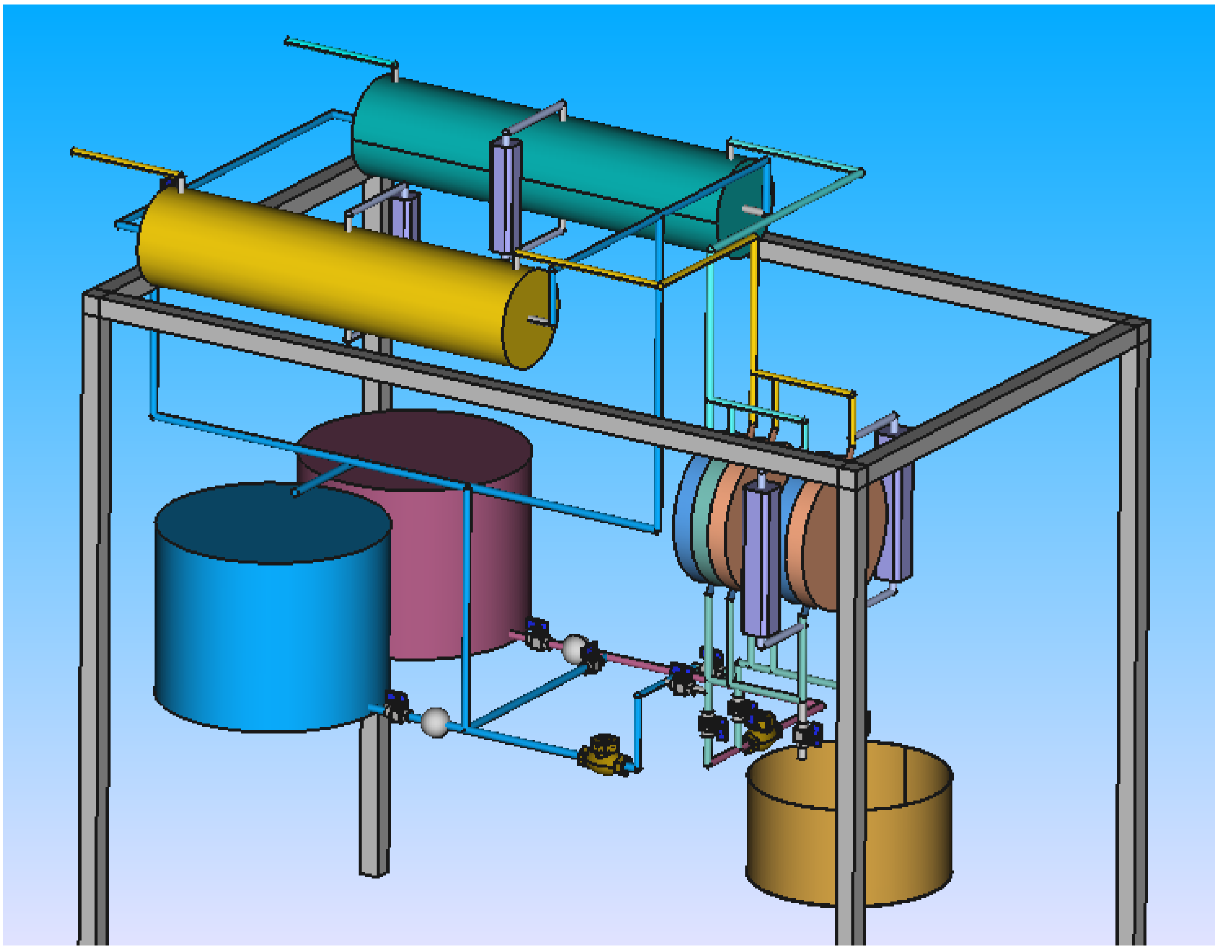
After completing the theoretical and design part of the first part of the project, work must be done in the future to secure pure and compressed hydrogen gas to operate the fuel cell model.

# 4 Project 2: Water electrolysis (ICPT - WE)

## 4.1 Position of ICPT-WE

The electrolysis project underwent an upgrade in 2023/2024 with the redesign and installation of new mechanical connections. The project also subsequently underwent testing of the Nafion membrane inside the electrolytic cell.

## 4.2 Re-design of electrolysis



FreeCAD file of Electrolysis re-design:

17042024_ELectroly
sis - pipes redesign.

## 4.3 Electrolyze System Requirements[4]

**System requirement**

- The system shall be able to produce hydrogen and oxygen, separately.

[4] from NLAP-WEDC Report 2023, Chapter 5

**Physical requirements**

- The electrodes shall be able to withstand the electrolysis temperature.

- The pipe system shall be able to withstand a temperature up to 100°C.

- The valves shall be able to resist the temperature and the pressure.

- The condensers shall be able to condense the vapor leaving the cell, with water.

**Chemical requirements**

- The electrodes shall be able to withstand the corrosion with KOH.

- The membrane shall be able to allows the ions to pass through so that electrolysis takes place when the current is connected.

- The membrane shall be able to insulate the two half-cells, chemically.

- The membrane shall be made of Nafion.

- The pipe system used shall be able to withstand the corrosion with KOH.

- The valves shall be able to withstand the corrosion with KOH.

- The metal of condenser used shall be able to withstand the corrosion with KOH.

**Mechanical requirements**

- The electrodes shall be thick enough to withstand the pressing (the pressing of the screw rods).

- The electrodes shall be thick enough to press the gaskets so that no gas can exit.

- The gaskets shall be able to prevent the leakage of gases and liquids from the cells.

- The gaskets shall be made of thermal caoutchouc.

- The pipes connections shall be able to resist the gas pressure without let gas exit through.

- The pressure of the pump shall be sufficient to fill the cells and not too high for the pipes system.

- The valves shall be able to close completely.

- The valves shall be able to open or close with independent pressure.

**Electrical requirements**

- For power supply, DC the current that pass through one cell shall be about 140 A DC and we have to test how much voltage shall be needed to make that.

- The power supply shall be able to let the electrolyze generates enough hydrogen so that we can burn it.

- The valves shall be able to be controlled from the GUI.

**Safety requirement**

- The hydrogen burner shall be able to burn the produced hydrogen gas to avoid the risk of its explosion.

## 4.4 Electrolyser System Test Specification[5]

**WE_Automation_Process**

Step 1: Camera connections

1- Connect the camera Adapter

2- Connect the camera with PC

On PC, open “Internet explorer”, then enter the IP address “192.168.1.64“(written on the camera box), password: a1111111

Step 2: PLC

1- Connect wire of PLC.

2- Turn UP (Turn On) the PLC breaker.

[5] from NLAP-WEDC Report 2023, Chapter 5

**GUI_Operation**

1- Open file named "***Electrolysis GUI***" placed on the desktop of "*Mediston Laptop".*

2- Through the GUI, we enter the solution.

3- When all valves are closed, turn on the power supply until burner is on.

If we find the voltage is up to 16V, the voltage must be reduced. *(Working on updates)*

---

### 4.4.1 System_test_cases

**00001: The lack shall be detected when it exists**

| Step | Step Description | Expected Result |
|---|---|---|
| **Precondition** | System is off | |
| **Switch ON the system** | Turn on the air compressor manually | Air enters to the whole system |
| **Lack is detected** | Air exit from the pie system | Lack position shall be detected with a marker |
| **Switch OFF the system** | Turn off the air compressor manually | The air stops enter to the pipe system |
| **Postcondition** | System is OFF | |

**00002: WHOLE SYSTEM TEST**

| Step | Step Description | Expected Result |
|---|---|---|
| **Precondition** | System is off | |

| | | |
|---|---|---|
| **Open the valves $V_1$ and $V_2$** | Open the valves $V_1$ and $V_2$ from the GUI | The valve $V_1$ and $V_2$ are open and enable to let the nitrogen gas pass |
| **WASH THE SYSTEM WITH NITROGEN** | Wash the system with Nitrogen for few minutes BY TURNING ON THE GLOBLE VALVE on the nitrogen tank | One can see that there is nitrogen exit from the gas outlets |
| **Switch ON the system** | Turn Off the globle nitrogen valve<br>Turn Up (Turn On) the breaker (behind the Kelvinator refrigerator)<br>Turn Up (Turn On) the two breakers (red & blue breakers in PLC box)<br>Turn ON the system from the GUI | THE SYSTEM IS GENERATING hydrogen and oxygen |
| **Burn the hydrogen** | Turn On the transformator | The Hydrogen is burning |
| **Switch Off the system** | Switch Off the system from the GUI<br>Switch Off the transformator | The system goes down |
| **WASH THE SYSTEM WITH NITROGEN** | Wash the system with Nitrogen for few minutes BY TURNING ON THE VALVE on the nitrogen tank | All the hydrogen existing in the pipe system exit |
| **Postcondition** | Turn off the system | System is off |

**00003: KOH pipe system test**

**The lack have to be marked with a marker and fixed**

| Step | Step Description | Expected Result |
|---|---|---|
| **Precondition** | System is off (No LIN signal) | |
| **Switch on the KOH system** | Open the KOH valves<br>Turn on the KOH pump | The water passes through the KOH pump to the cell |
| **Lack is detected** | Look at the KOH pump system and look if there is exiting of water from the system | There is entering of water from the pipe system |
| **Switch off the system.** | Switch off the the pump and then the 2 KOH vlves | The system goes down. |
| **Postcondition** | System is off | |

**00004: WHOLE SYSTEM TEST WITH ANOTHER POWER SUPPLY**

| Step | Step Description | Expected Result |
|---|---|---|
| **Precondition** | System is off | |
| **THE CHANGING F THE POWER SUPPLY WIT A POWER SUPPLY OF HIGHER VOLTAGE** | Replacing the power supply with the welding machine | More hydrogen is generated |
| **Open the valves $V_1$ and $V_2$** | **Open the valves $V_1$ and $V_2$ from the GUI** | The valve $V_1$ and $V_2$ are open and enable to let the nitrogen gas pass |
| **WASH THE SYSTEM WITH NITROGENE** | Wash the system with Nitrogen for few minutes BY TURNING ON THE VALVE on the nitrogen tank | One can see that there is nitrogen exit from the gas outlets |

| | | |
|---|---|---|
| **Switch on the system** | Turn off the nitrogen<br>Turn on the system from the GUI | THE SYSTEM IS GENERATING hydrogen and oxygen |
| **Burn the hydrogen** | Turn on the transformator | The Hydrogen is burning |
| **Switch off the system.** | Switch off the system from the GUI<br>Switch off the transformator | The system goes down. |
| **WASH THE SYSTEM WITH NITROGENE** | Wash the system with Nitrogen for few minutes BY TURNING ON THE VALVE on the nitrogen tank | All the hydrogen existing in the pipe system exit |
| **Postcondition** | Turn off the system | System is off |

**00005: WHOLE SYSTEM TEST WITH ONLY ONE CELL CONNECTED**

| **Step** | **Step Description** | **Expected Result** |
|---|---|---|
| **Precondition** | System is off | |
| **CONNECTING THE COMPLETE VOLTAGE TO ONLY ONE CELL** | DISCONNECT THE POWER SUPPLY FROM TWO CELLS AND CONNECT IT TO ONLY ONE CELL. | MORE CURRENT WILL DRIVE THROUGH THE CELL |
| **Open the valves $V_1$ and $V_2$** | **Open the valves $V_1$ and $V_2$ from the GUI** | The valve $V_1$ and $V_2$ are open and enable to let the nitrogen gas pass |
| **WASH THE SYSTEM WITH NITROGEN** | Wash the system with Nitrogen for few minutes BY TURNING ON THE VALVE on the nitrogen tank | One can see that there is nitrogen exit from the gas outlets |
| **Switch on the system** | Turn off the nitrogen<br>Turn on the system from the GUI | THE SYSTEM IS GENERATING hydrogen and oxygen |

| | | |
|---|---|---|
| **Burn the hydrogen** | Turn on the transformator | The Hydrogen is burning |
| **Switch off the system** | Switch off the system from the GUI<br>Switch off the transformator | The system goes down. |
| **WASH THE SYSTEM WITH NITROGEN** | Wash the system with Nitrogen for few minutes BY TURNING ON THE VALVE on the nitrogen tank | All the hydrogen existing in the pipe system exit |
| **Postcondition** | Turn off the system | System is off |

**00006: WHOLE SYSTEM TEST after increasing of the KOH concentration**

| Step | Step Description | Expected Result |
|---|---|---|
| **Precondition** | System is off | |
| **Emptying the cells** | Placing a container under the two emptying valves and open the two emptying valves so that the containers are filled with the solution of the cells. | The solution flows into the containers. |
| **Closing of the emptying valves.** | closing the emptying valves after the whole solution flowed from the cells into the containers. | The emptying valves are closed |
| **Increase the KOH concentration.** | For the solution from the cells into the KOH tank and increase the KOH concentration, by adding new KOH. | The KOH concentration increase |
| **Open the valves $V_1$ and $V_2$** | Open the valves $V_1$ and $V_2$ from the GUI | The valve $V_1$ and $V_2$ are open and enable to let the nitrogen gas pass |
| **WASH THE SYSTEM WITH NITROGEN** | Wash the system with Nitrogen for few minutes BY TURNING ON THE VALVE on the nitrogen tank | One can see that there is nitrogen exit from the gas outlets |

| | | |
|---|---|---|
| **Switch on the system** | Turn off the nitrogen<br>Turn on the system from the GUI | THE SYSTEM IS GENERATING hydrogen and oxygen |
| **Burn the hydrogen** | Turn on the transformator | The Hydrogen is burning |
| **Switch off the system.** | Switch off the system from the GUI<br>Switch off the transformator | The system goes down. |
| **WASH THE SYSTEM WITH NITROGEN** | Wash the system with Nitrogen for few minutes BY TURNING ON THE VALVE on the nitrogen tank | All the hydrogen existing in the pipe system exit |
| **Postcondition** | Turn off the system | System is off |

**00007: Test whether the membrane is ruptured**

**If there are air bubbles from the hydrogen half cells set the membrane have to be changed.**

| Step | Step Description | Expected Result |
|---|---|---|
| **Precondition** | System is off | |
| **Emptying the cells** | Placing a container under the two emptying valves and open the two emptying valves so that the containers are filled with the solution of the cells . | The solution flows into the containers. |
| **Closing of the emptying valves.** | Closing the emptying valves after the whole solution flowed from the cells into the containers. | The emptying valves are closed |
| **Let the air enter to the half-cell set of oxygen.** | Connect the air compressor to one set of the half cell sets and tur on the compressor. | Air bubbles are seen only in the one set on which the air bubbles are connected |
| **Stop the air** | Turn off the compressor | The compressor is off |

| | | |
|---|---|---|
| **Postcondition** | Turn off the system | System is off |

**00008: A simple test of an Electrolysis system -Case add water manually-**

| **Steps** | **Steps description** | **Excepted result** |
|---|---|---|
| **Precondition** | System is Off | |
| | The cells are partially filled with NaOH solution | |
| **Run pump to fill the cells with the NaOH solution** | Open the valves ($V_3$) & ($V_4$) from the GUI | ($V_3$) & ($V_4$) are opened and enable to let the electrolyte solution pass |
| | Click "Start" on the Electrolyte bottom from the GUI | The cells enable to filled with electrolyte solution |
| | Wait 5 seconds, the pump ($P_1$) run automatically | The pump ($P_1$) is turned On |
| **Turn Off the pump when the cells are filled with NaOH solution** | When ($L_3$) & ($L_4$) go from "Low" to "High", turn Off the pump from the GUI | The cells filled with electrolyte solution |
| | | Pump ($P_1$) turned Off |
| **Close the valves ($V_3$) & ($V_4$)** | Turn Off the valves ($V_3$) & ($V_4$) from the GUI | The valves ($V_3$) & ($V_4$) are closed |
| | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass |

| | | |
|---|---|---|
| **Wash the system with Nitrogen gas** | Close the blue ball valve of the water tank manually | The blue ball valve is closed |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system |
| | | The air bubbles appear (generate) in the Gas AutoSafety |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| **Turn ON the burner to burn the gas** | Click "Start" on Fuel Burner from the GUI | The transformer is turned On |
| | | The burner is turned On |
| | | Redness of the metal strip of the burner |
| **Connect the Power Supply on the system** | Ensure that the pump ($P_1$) is turned Off | Pump ($P_1$) is closed |
| | Click "Start" on the Power Supply bottom from the GUI | The Power Supply is On |
| | | The system is generating Hydrogen and Oxygen |

| | | |
|---|---|---|
| | | 5 minutes after turning On the burner, a flame appears |
| **Add water to the system** | Click "Start" on Water from the GUI | |
| | Turn On the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the water pass through the cells |
| | Turn On the pump ($P_2$) | Pump ($P_2$) is turned On |
| | After few minutes, Click "Stop" on the valves ($V_1$) & ($V_2$) with the Command OFF "CMD OFF" from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| | When ($L_3$) & ($L_4$) go from "Low" to "High", turn Off the pump ($P_2$) from the GUI | The pump ($P_2$) is turned Off |
| | When ($L_3$) & ($L_4$) go from "Low" to "High", Turn Off the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| **Disconnect the Power Supply on the system** | Click "Stop" on Power Supply bottom from the GUI | The electricity is turned Off from the system |
| | | The generation of Hydrogen and Oxygen are stopped |
| **Turn Off the fuel burner** | Click "Stop" on the Fuel Burner bottom from the GUI | Burner (Transformer) is Off |
| | | The valves ($V_1$) & ($V_2$) are closed |

| | | |
|---|---|---|
| | Click "Stop" on the valves ($V_1$) & ($V_2$) from the GUI | Flame disappears (is Off) |
| **Re-wash the system with Nitrogen gas** | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system |
| | | The air bubbles appear (generate) in the Gas AutoSafety |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| **Post condition** | Turn Off the system | System is Off |
| | The cells are partially filled with NaOH solution | |
| | The cells are filled totally with NaOH solution | |

**00009: A simple test of an Electrolysis system -Case add water automatically-**

| Steps | Steps description | Excepted result |
|---|---|---|
| **Precondition** | System is Off | |
| | The cells are partially filled with NaOH solution | |
| **Run pump to fill the cells with the NaOH solution** | Open the valves ($V_3$) & ($V_4$) from the GUI | ($V_3$) & ($V_4$) are opened and enable to let the electrolyte solution pass |
| | Click "Start" on the Electrolyte bottom from the GUI | The cells enable to filled with electrolyte solution |
| | Wait 5 seconds, the pump ($P_1$) run automatically | The pump ($P_1$) is turned On |
| **Turn Off the pump when the cells are filled with NaOH solution** | When ($L_3$) & ($L_4$) go from "Low" to "High", turn Off the pump from the GUI | The cells filled with electrolyte solution |
| | | Pump ($P_1$) turned Off |
| **Close the valves ($V_3$) & ($V_4$)** | Turn Off the valves ($V_3$) & ($V_4$) from the GUI | The valves ($V_3$) & ($V_4$) are closed |
| **Wash the system with Nitrogen gas** | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system |

| | | |
|---|---|---|
| | | The air bubbles appear (generate) in the Gas AutoSafety |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| **Turn ON the burner to burn the gas** | Click "Start" on Fuel Burner from the GUI | The transformer is turned On |
| | | The burner is turned On |
| | | Redness of the metal strip of the burner |
| **Connect the Power Supply on the system** | Ensure that the pump ($P_1$) is turned Off | Pump ($P_1$) is closed |
| | Click "Start" on the Power Supply bottom from the GUI | The Power Supply is On |
| | | The system is generating Hydrogen and Oxygen |
| | | 5 minutes after turning On the burner, a flame appears |
| | Click "Start" on Water from the GUI | |

| | | |
|---|---|---|
| | Turn On the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the water pass through the cells |
| | Turn On the pump ($P_2$) | Pump ($P_2$) is turned On |
| **Add water to the system** | When ($L_3$) & ($L_4$) go from "Low" to "High", the pump ($P_2$) is turned Off automatically from the GUI | Pump ($P_2$) is turned Off |
| | When ($L_3$) & ($L_4$) go from "Low" to "High", the valves ($V_1$) & ($V_2$) are turned Off automatically from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| | Click "Stop" on Water from the GUI | |
| **Disconnect the Power Supply on the system** | Click "Stop" on Power Supply bottom from the GUI | The electricity is turned Off from the system |
| | | The generation of Hydrogen and Oxygen are stopped |
| **Turn Off the fuel burner** | Click "Stop" on the Fuel Burner bottom from the GUI | Burner (Transformer) is Off |
| | Click "Stop" on the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| | | Flame disappears (is Off) |
| | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass |

| | | |
|---|---|---|
| Re-wash the system with Nitrogen gas | Close the blue ball valve of the water tank manually | The blue ball valve is closed |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system |
| | | The air bubbles appear (generate) in the Gas AutoSafety |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| Post condition | Turn Off the system | System is Off |
| | The cells are partially filled with NaOH solution | |
| | The cells are filled totally with NaOH solution | |

**00010: A simple test of an Electrolysis system -Case without add water-**

| Steps | Steps description | Excepted result |
|---|---|---|
| Precondition | System is Off | |

| | | |
|---|---|---|
| | The cells are partially filled with NaOH solution | |
| **Run pump to fill the cells with the NaOH solution** | Open the valves ($V_3$) & ($V_4$) from the GUI | ($V_3$) & ($V_4$) are opened and enable to let the electrolyte solution pass |
| | Click "Start" on the Electrolyte bottom from the GUI | The cells enable to filled with electrolyte solution |
| | Wait 5 seconds, the pump ($P_1$) run automatically | The pump ($P_1$) is turned On |
| **Turn Off the pump when the cells are filled with NaOH solution** | When ($L_3$) & ($L_4$) go from "Low" to "High", turn Off the pump from the GUI | The cells filled with electrolyte solution |
| | | Pump ($P_1$) turned Off |
| **Close the valves ($V_3$) & ($V_4$)** | Turn Off the valves ($V_3$) & ($V_4$) from the GUI | The valves ($V_3$) & ($V_4$) are closed |
| **Wash the system with Nitrogen gas** | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system |
| | | The air bubbles appear (generate) in the Gas AutoSafety |
| | | The Nitrogen bottle is closed |

| | | |
|---|---|---|
| | Turn Off the Nitrogen bottle by its gate valve manually | The air bubbles disappear (doesn't generate) in the Gas AutoSafety |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| **Turn ON the burner to burn the gas** | Click "Start" on Fuel Burner from the GUI | The transformer is turned On |
| | | The burner is turned On |
| | | Redness of the metal strip of the burner |
| **Connect the Power Supply on the system** | Ensure that the pump ($P_1$) is turned Off | Pump ($P_1$) is closed |
| | Click "Start" on the Power Supply bottom from the GUI | The Power Supply is On |
| | | The system is generating Hydrogen and Oxygen |
| | | 5 minutes after turning On the burner, a flame appears |
| **Disconnect the Power Supply on the system** | Click "Stop" on Power Supply bottom from the GUI | The electricity is turned Off from the system |
| | | The generation of Hydrogen and Oxygen are stopped |
| **Turn Off the fuel burner** | Click "Stop" on the Fuel Burner bottom from the GUI | Burner (Transformer) is Off |

| | | |
|---|---|---|
| | Click "Stop" on the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| | | Flame disappears (is Off) |
| **Re-wash the system with Nitrogen gas** | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system |
| | | The air bubbles appear (generate) in the Gas AutoSafety |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed |
| **Post condition** | Turn Off the system | System is Off |
| | The cells are partially filled with NaOH solution | |
| | The cells are filled totally with NaOH solution | |

## 4.5 Electrolyzer System tests

### 4.5.1 Electrolyzer test (Test whether the pressure is equilibrium) 5.5.2023 [6]

If the water level sensors are in the parallel level throughout the test period, we have come to a solution to the problem of pressure difference within a single cell. Now we can replace the membrane with Nafion.

But if the water level sensors aren't in the parallel level throughout the test period, this means that there is a problem with suffocation (closed) in one of the condenser tubes.

**Goal:**

In the previous test, we had a problem with the pressure balance between the two half-cells, and to resolve this problem, we suggested placing flashback arrestor at the oxygen gas outlet. The aim of this test is to ensure the correctness of the pressure balance between the two half-cells.

**Expected result:**

In case of equilibrium between the two half-cells, the level sensor pointer for each half-cell (water level parallels between the cathodic half-cell and the anodic half-cell).

If there is a pressure difference between the two-level sensors, we should notice a difference in the level of the solution at the two sensors.

**Operation Steps:**

**00008: A simple test of an Electrolysis system -Case add water manually-**

| Steps | Steps description | Excepted result | Result |
|---|---|---|---|
| **Precondition** | System is Off | | ✔ |
| | The cells are partially filled with NaOH solution | | ✔ |
| **Run pump to fill the cells** | Open the valves ($V_3$) & ($V_4$) from the GUI | ($V_3$) & ($V_4$) are opened and enable to let the electrolyte solution pass | ✔ |

[6] from NLAP-WEDC Report 2023, Chapter 5

| | | | |
|---|---|---|---|
| **with the NaOH solution** | Click "Start" on the Electrolyte bottom from the GUI | The cells enable to filled with electrolyte solution | ✔ |
| | Wait 5 seconds, the pump $(P_1)$ run automatically | The pump $(P_1)$ is turned On | ✔ |
| **Turn Off the pump when the cells are filled with NaOH solution** | When $(L_3)$ & $(L_4)$ go from "Low" to "High", turn Off the pump from the GUI | The cells filled with electrolyte solution | ✔ |
| | | Pump $(P_1)$ turned Off | ✔ |
| **Close the valves $(V_3)$ & $(V_4)$** | Turn Off the valves $(V_3)$ & $(V_4)$ from the GUI | The valves $(V_3)$ & $(V_4)$ are closed | ✔ |
| **Wash the system with Nitrogen gas** | Open the valves $(V_1)$ & $(V_2)$ from the GUI | The valves $(V_1)$ & $(V_2)$ are open and enable to let the nitrogen gas pass | ✔ |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed | ✔ |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system | ✔ |
| | | The air bubbles appear (generate) in the Gas AutoSafety | ✔ |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed | ✔ |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety | ✔ |

| | | | |
|---|---|---|---|
| | Open the blue ball valve of water tank manually | The blue ball valve is opened | ✓ |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✓ |
| **Turn ON the burner to burn the gas** | Click "Start" on Fuel Burner from the GUI | The transformer is turned On | ✓ |
| | | The burner is turned On | ✓ |
| | | Redness of the metal strip of the burner | ✓ |
| **Connect the Power Supply on the system** | Ensure that the pump ($P_1$) is turned Off | Pump ($P_1$) is closed | ✓ |
| | Click "Start" on the Power Supply bottom from the GUI | The Power Supply is On | ✓ |
| | | The system is generating Hydrogen and Oxygen | ✓ |
| | | 5 minutes after turning On the burner, a flame appears | ✓ |
| **Add water to the system** | Click "Start" on Water from the GUI | | ✓ |
| | Turn On the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the water pass through the cells | ✓ |
| | Turn On the pump ($P_2$) | Pump ($P_2$) is turned On | ✓ |

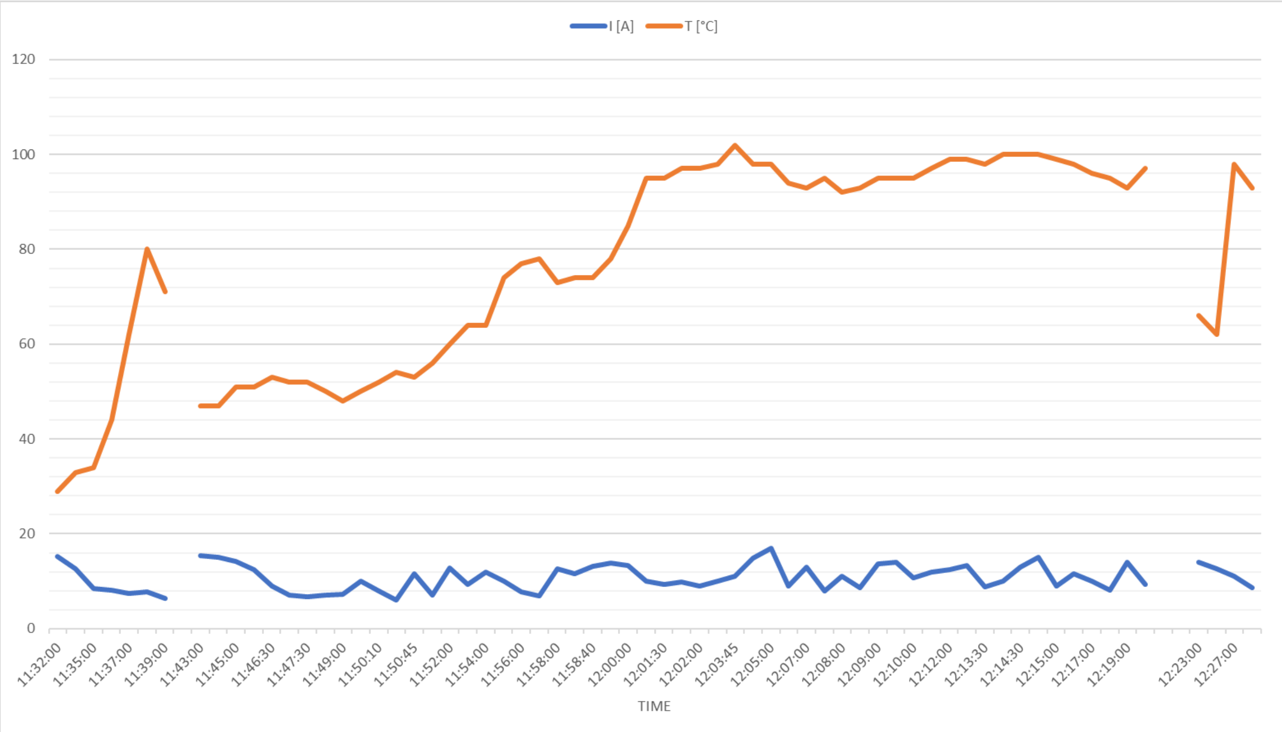
| | | | |
|---|---|---|---|
| | After few minutes, Click "Stop" on the valves ($V_1$) & ($V_2$) with the Command OFF "CMD OFF" from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✓ |
| | When ($L_3$) & ($L_4$) go from "Low" to "High", turn Off the pump ($P_2$) from the GUI | The pump ($P_2$) is turned Off | ✗ |
| | When ($L_3$) & ($L_4$) go from "Low" to "High", Turn Off the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✗ |
| **Disconnect the Power Supply on the system** | Click "Stop" on Power Supply bottom from the GUI | The electricity is turned Off from the system | ✓ |
| | | The generation of Hydrogen and Oxygen are stopped | ✓ |
| **Turn Off the fuel burner** | Click "Stop" on the Fuel Burner bottom from the GUI | Burner (Transformer) is Off | ✓ |
| | Click "Stop" on the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✓ |
| | | Flame disappears (is Off) | ✓ |
| **Re-wash the system with Nitrogen gas** | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass | ✓ |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed | ✓ |

| | | | |
|---|---|---|---|
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system | ✓ |
| | | The air bubbles appear (generate) in the Gas AutoSafety | ✓ |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed | ✓ |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety | ✓ |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened | ✓ |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✓ |
| **Post condition** | Turn Off the system | System is Off | ✓ |
| | The cells are partially filled with NaOH solution | | ✓ |
| | The cells are filled totally with NaOH solution | | ✗ |

## Data collected during test:

| Electrolysis test 05.05.2023 | | | | |
|---|---|---|---|---|
| Time | U [V] | I [A] | T [°C] | Notes |
| 11:32:00 | 8.58 | 15.3 | 29 | |
| 11:34:00 | 8.97 | 12.6 | 33 | |
| 11:35:00 | 9 | 8.4 | 34 | |
| 11:36:00 | 9 | 8.2 | 44 | |
| 11:37:00 | 9 | 7.4 | 62 | |
| 11:38:00 | 11.8 | 7.7 | 80 | |
| 11:39:00 | 11.9 | 6.3 | 71 | |
| | | | | BREAK |
| 11:43:00 | 9 | 15.4 | 47 | |
| 11:44:00 | 11.8 | 15 | 47 | |
| 11:45:00 | 11.9 | 14.2 | 51 | |
| 11:46:00 | 11.9 | 12.5 | 51 | |
| 11:46:30 | 11.9 | 9 | 53 | |
| 11:47:00 | 11.9 | 7.1 | 52 | |
| 11:47:30 | 11.9 | 6.8 | 52 | |
| 11:48:00 | 11.9 | 7.1 | 50 | |
| 11:49:00 | 11.9 | 7.3 | 48 | |
| 11:50:00 | 11.9 | 10 | 50 | |
| 11:50:10 | 11.9 | 8 | 52 | |
| 11:50:30 | 11.9 | 6 | 54 | |
| 11:50:45 | 11.9 | 11.6 | 53 | |
| 11:51:40 | 11.9 | 7 | 56 | |
| 11:52:00 | 11.9 | 12.8 | 60 | |
| 11:53:00 | 11.9 | 9.3 | 64 | Add water |
| 11:54:00 | 9 | 12 | 64 | |
| 11:55:00 | 9 | 10 | 74 | |
| 11:56:00 | 11.9 | 7.8 | 77 | Stable and steady flame |
| 11:57:00 | 11.9 | 6.9 | 78 | |
| 11:58:00 | 11.9 | 12.7 | 73 | |
| 11:58:20 | 11.9 | 11.6 | 74 | |
| 11:58:40 | 11.9 | 13.2 | 74 | |
| 11:59:00 | 11.9 | 13.9 | 78 | |
| 12:00:00 | 11.9 | 13.3 | 85 | |
| 12:01:00 | 11.9 | 10 | 95 | |
| 12:01:30 | 11.9 | 9.4 | 95 | |
| 12:02:00 | 11.9 | 9.8 | 97 | |
| 12:02:00 | 11.9 | 9 | 97 | |
| 12:03:00 | 11.9 | 10 | 98 | |

| | | | | |
|---|---|---|---|---|
| 12:03:45 | 11.9 | 11 | 102 | |
| 12:04:00 | 11.9 | 14.9 | 98 | |
| 12:05:00 | 11 | 17 | 98 | |
| 12:06:00 | 11 | 9 | 94 | |
| 12:07:00 | 11 | 13 | 93 | |
| 12:07:30 | 11.9 | 8 | 95 | |
| 12:08:00 | 11.9 | 11 | 92 | |
| 12:08:45 | 11.9 | 8.7 | 93 | |
| 12:09:00 | 11.9 | 13.6 | 95 | |
| 12:09:30 | 11.9 | 14 | 95 | |
| 12:10:00 | 11.9 | 10.8 | 95 | |
| 12:11:00 | 11.9 | 12 | 97 | |
| 12:12:00 | 11.9 | 12.5 | 99 | |
| 12:13:00 | 11.9 | 13.3 | 99 | |
| 12:13:30 | 11.9 | 8.8 | 98 | |
| 12:14:00 | 11.9 | 10 | 100 | |
| 12:14:30 | 11.9 | 13 | 100 | |
| 12:14:40 | 11.9 | 15 | 100 | |
| 12:15:00 | 11.9 | 9 | 99 | |
| 12:16:00 | 11.9 | 11.5 | 98 | |
| 12:17:00 | 11.9 | 10.1 | 96 | |
| 12:18:00 | 11.9 | 8.1 | 95 | |
| 12:19:00 | 11.9 | 14 | 93 | |
| 12:19:30 | 11.9 | 9.3 | 97 | |
| | | | | BREAK |
| | | | | O2 condenser is more warm than H2 condenser |
| 12:23:00 | 9.93 | 14 | 66 | |
| 12:25:00 | 9.93 | 12.7 | 62 | |
| 12:27:00 | 9.93 | 11 | 98 | |
| 12:29:00 | 9.93 | 8.7 | 93 | |




⚠ **Note:**

1. he intensity (I) measures the AC, while the voltage (V) measures the DC.

2. The inlet of $O_2$ condenser is too warm than inlet of $H_2$ condenser.

**Result view:**

Level sensors: on the left side, the level sensor placed on the anodic half-cell. On the right side, the level sensor placed on cathodic half-cell.

**Conclusion:**

At the end of the test, we found that the water level in the sensor was almost identical. Which means that the pressure differential problem has been preliminarily resolved.

#### 4.5.2 Electrolyzer test 28.06.2023[7]

For the purpose of measuring the DC intensity of the cells system, an intensity sensor (Ammeter) with a capacity of 200 A has been installed.

**Goal:**

This test aims to collect the DC intensity data of the system cells during operation, in order to know the amount of hydrogen and oxygen gas generated.

**Expected result:**

Obtaining the required DC intensity data to balance it with the amount of Hydrogen and Oxygen gas generated.

If this is achieved, we can estimate the amount of hydrogen produced and thus select a suitable flowmeter for the hydrogen gas emitted

**Test specifications:**

**00010: A simple test of an Electrolysis system -Case without add water-**

| Steps | Steps description | Excepted result | Result |
|---|---|---|---|
| Precondition | System is Off | | ✔ |
| | The cells are partially filled with NaOH solution | | ✔ |

[7] from NLAP-WEDC Report 2023, Chapter 5

| | | | |
|---|---|---|---|
| **Run pump to fill the cells with the NaOH solution** | Open the valves ($V_3$) & ($V_4$) from the GUI | ($V_3$) & ($V_4$) are opened and enable to let the electrolyte solution pass | ✓ |
| | Click "Start" on the Electrolyte bottom from the GUI | The cells enable to filled with electrolyte solution | ✓ |
| | Wait 5 seconds, the pump ($P_1$) run automatically | The pump ($P_1$) is turned On | ✓ |
| **Turn Off the pump when the cells are filled with NaOH solution** | When ($L_3$) & ($L_4$) go from "Low" to "High", turn Off the pump from the GUI | The cells filled with electrolyte solution | ✓ |
| | | Pump ($P_1$) turned Off | ✓ |
| **Close the valves ($V_3$) & ($V_4$)** | Turn Off the valves ($V_3$) & ($V_4$) from the GUI | The valves ($V_3$) & ($V_4$) are closed | ✓ |
| **Wash the system with Nitrogen gas** | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass | ✓ |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed | ✓ |

| | | | |
|---|---|---|---|
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system | ✓ |
| | | The air bubbles appear (generate) in the Gas AutoSafety | ✓ |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed | ✓ |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety | ✓ |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened | ✓ |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✓ |
| **Turn ON the burner to burn the gas** | Click "Start" on Fuel Burner from the GUI | The transformer is turned On | ✓ |
| | | The burner is turned On | ✓ |
| | | Redness of the metal strip of the burner | ✓ |

| | | | |
|---|---|---|---|
| **Connect the Power Supply on the system** | Ensure that the pump ($P_1$) is turned Off | Pump ($P_1$) is closed | ✔ |
| | Click "Start" on the Power Supply bottom from the GUI | The Power Supply is On | ✔ |
| | | The system is generating Hydrogen and Oxygen | ✔ |
| | | 5 minutes after turning On the burner, a flame appears | ✔ |
| **Disconnect the Power Supply on the system** | Click "Stop" on Power Supply bottom from the GUI | The electricity is turned Off from the system | ✔ |
| | | The generation of Hydrogen and Oxygen are stopped | ✔ |
| **Turn Off the fuel burner** | Click "Stop" on the Fuel Burner bottom from the GUI | Burner (Transformer) is Off | ✔ |
| | Click "Stop" on the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✔ |
| | | Flame disappears (is Off) | ✔ |

| | | | |
|---|---|---|---|
| **Re-wash the system with Nitrogen gas** | Open the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are open and enable to let the nitrogen gas pass | ✓ |
| | Close the blue ball valve of the water tank manually | The blue ball valve is closed | ✓ |
| | Open the bottle of Nitrogen gas 5 minutes @ 4 bars | The Nitrogen gas pass through the system | ✓ |
| | | The air bubbles appear (generate) in the Gas AutoSafety | ✓ |
| | Turn Off the Nitrogen bottle by its gate valve manually | The Nitrogen bottle is closed | ✓ |
| | | The air bubbles disappear (doesn't generate) in the Gas AutoSafety | ✓ |
| | Open the blue ball valve of water tank manually | The blue ball valve is opened | ✓ |
| | Close the valves ($V_1$) & ($V_2$) from the GUI | The valves ($V_1$) & ($V_2$) are closed | ✓ |
| | Turn Off the system | System is Off | ✓ |

| | | |
|---|---|---|
| **Post condition** | The cells are partially filled with NaOH solution | ✔ |
| | The cells are filled totally with NaOH solution | ✘ |

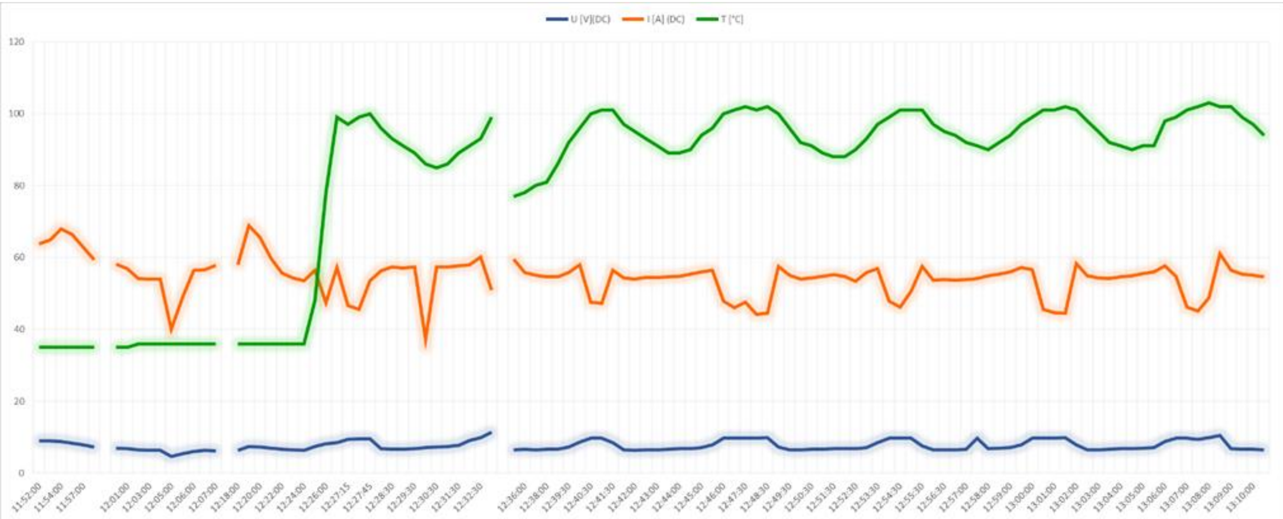
**Data collected during test:**

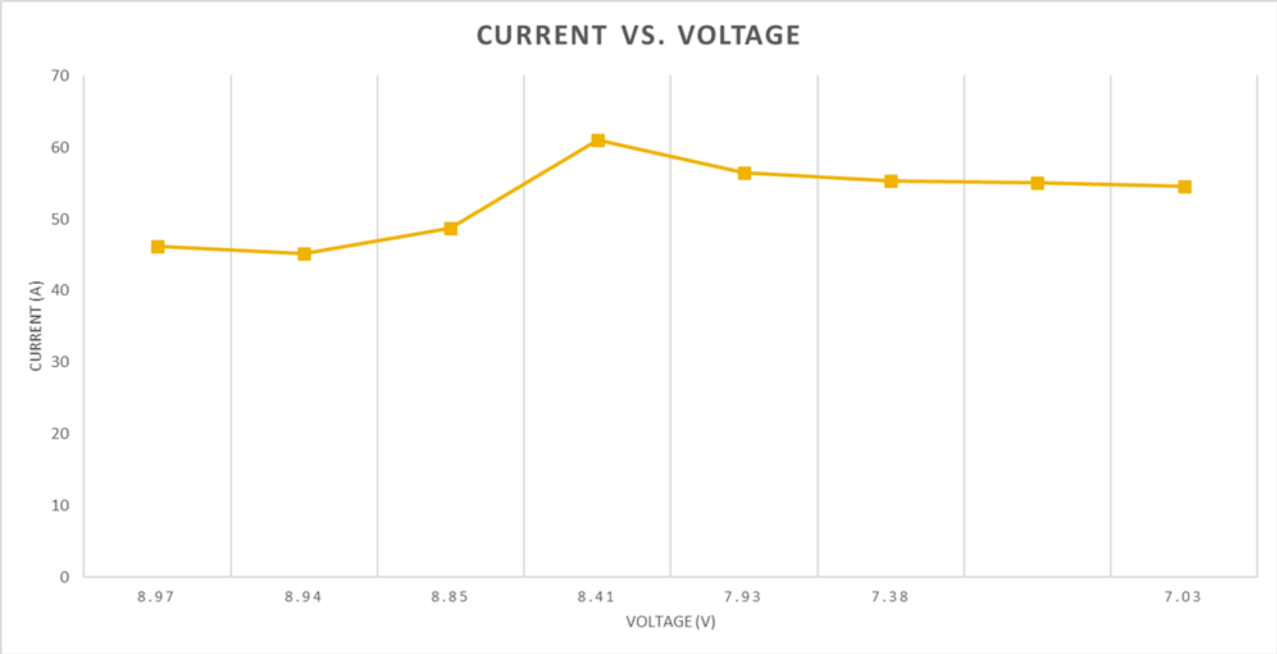
| Time | U [V](DC) | I [A] (DC) | T [°C] | Notes |
|---|---|---|---|---|
| 11:52:00 | 8.97 | 63.78 | 35 | |
| 11:53:00 | 8.94 | 64.8 | 35 | |
| 11:54:00 | 8.85 | 68 | 35 | |
| 11:56:00 | 8.41 | 66.47 | 35 | |
| 11:57:00 | 7.93 | 62.86 | 35 | |
| 11:58:00 | 7.38 | 59.43 | 35 | |
| | | | | BREAK ON/OFF |
| 12:00:00 | 7.03 | 58.21 | 35 | |
| 12:01:00 | 6.8 | 56.89 | 35 | |
| 12:02:00 | 6.55 | 54.1 | 36 | Appearance of Hydrogen gas |
| 12:03:00 | 6.45 | 54.01 | 36 | |
| 12:04:00 | 6.32 | 54.08 | 36 | |
| 12:05:00 | 4.7 | 40.07 | 36 | |
| 12:05:30 | 5.44 | 49.15 | 36 | |
| 12:06:00 | 6.13 | 56.51 | 36 | |
| 12:06:30 | 6.36 | 56.6 | 36 | |
| 12:07:00 | 6.24 | 57.8 | 36 | |
| | | | | BREAK ON/OFF |

| | | | | |
|---|---|---|---|---|
| 12:18:00 | 6.41 | 58 | 36 | |
| 12:19:00 | 7.43 | 68.78 | 36 | |
| 12:20:00 | 7.36 | 65.57 | 36 | |
| 12:21:00 | 7.03 | 59.85 | 36 | |
| 12:22:00 | 6.7 | 55.74 | 36 | |
| 12:23:00 | 6.54 | 54.35 | 36 | |
| 12:24:00 | 6.39 | 53.53 | 36 | |
| 12:25:00 | 7.39 | 56.48 | 48 | Stable and steady flame |
| 12:26:00 | 8.19 | 47.44 | 78 | |
| 12:27:00 | 8.54 | 57.23 | 99 | |
| 12:27:15 | 9.51 | 46.7 | 97 | |
| 12:27:30 | 9.63 | 45.6 | 99 | |
| 12:27:45 | 9.55 | 53.55 | 100 | |
| 12:28:00 | 6.82 | 56.28 | 96 | |
| 12:28:30 | 6.7 | 57.35 | 93 | |
| 12:29:00 | 6.74 | 57 | 91 | |
| 12:29:30 | 6.9 | 57.35 | 89 | |
| 12:30:00 | 7.11 | 37.29 | 86 | |
| 12:30:30 | 7.23 | 57.42 | 85 | |
| 12:31:00 | 7.39 | 57.36 | 86 | |
| 12:31:30 | 7.81 | 57.67 | 89 | |
| 12:32:00 | 9.14 | 58 | 91 | |
| 12:32:30 | 9.95 | 60.06 | 93 | |
| 12:32:45 | 11.43 | 51 | 99 | |
| | | | | BREAK ON/OFF |

| | | | | |
|---|---|---|---|---|
| 12:35:00 | 6.5 | 59.56 | 77 | |
| 12:36:00 | 6.63 | 55.78 | 78 | |
| 12:37:00 | 6.6 | 55.08 | 80 | |
| 12:38:00 | 6.63 | 54.6 | 81 | |
| 12:39:00 | 6.73 | 54.6 | 86 | |
| 12:39:30 | 7.28 | 55.78 | 92 | |
| 12:40:00 | 8.62 | 58.01 | 96 | |
| 12:40:30 | 9.71 | 47.61 | 100 | |
| 12:41:00 | 9.77 | 47.22 | 101 | |
| 12:41:30 | 8.55 | 56.48 | 101 | |
| 12:41:45 | 6.53 | 54.3 | 97 | |
| 12:42:00 | 6.4 | 54.04 | 95 | |
| 12:42:30 | 6.49 | 54.41 | 93 | |
| 12:43:00 | 6.57 | 54.4 | 91 | |
| 12:43:30 | 6.67 | 54.57 | 89 | |
| 12:44:00 | 6.81 | 54.79 | 89 | |
| 12:44:30 | 6.91 | 55.37 | 90 | |
| 12:45:00 | 7.16 | 55.95 | 94 | |
| 12:45:30 | 7.94 | 56.53 | 96 | |
| 12:46:00 | 9.76 | 47.9 | 100 | |
| 12:47:00 | 9.8 | 46 | 101 | |
| 12:47:30 | 9.78 | 47.6 | 102 | |
| 12:48:00 | 9.82 | 44.23 | 101 | |
| 12:48:30 | 9.86 | 44.46 | 102 | |
| 12:49:00 | 7.23 | 57.55 | 100 | |
| 12:49:30 | 6.57 | 55.04 | 96 | |
| 12:50:00 | 6.6 | 54.04 | 92 | |
| 12:50:30 | 6.72 | 54.37 | 91 | |
| 12:51:00 | 6.73 | 54.81 | 89 | |
| 12:51:30 | 6.9 | 55.2 | 88 | |
| 12:52:00 | 6.83 | 54.71 | 88 | flame |
| 12:52:30 | 6.91 | 53.32 | 90 | flame |
| 12:53:00 | 7.17 | 55.77 | 93 | flame |
| 12:53:30 | 8.5 | 56.94 | 97 | |
| 12:54:00 | 9.72 | 47.87 | 99 | |
| 12:54:30 | 9.78 | 46.13 | 101 | |
| 12:55:00 | 9.81 | 50.7 | 101 | |
| 12:55:30 | 7.6 | 57.48 | 101 | |
| 12:56:00 | 6.5 | 53.63 | 97 | |
| 12:56:30 | 6.48 | 53.82 | 95 | |
| 12:56:45 | 6.5 | 53.74 | 94 | |
| 12:57:00 | 6.64 | 53.85 | 92 | |
| 12:57:30 | 9.75 | 54.2 | 91 | |
| 12:58:00 | 6.83 | 54.86 | 90 | |
| 12:58:30 | 7.02 | 55.45 | 92 | |

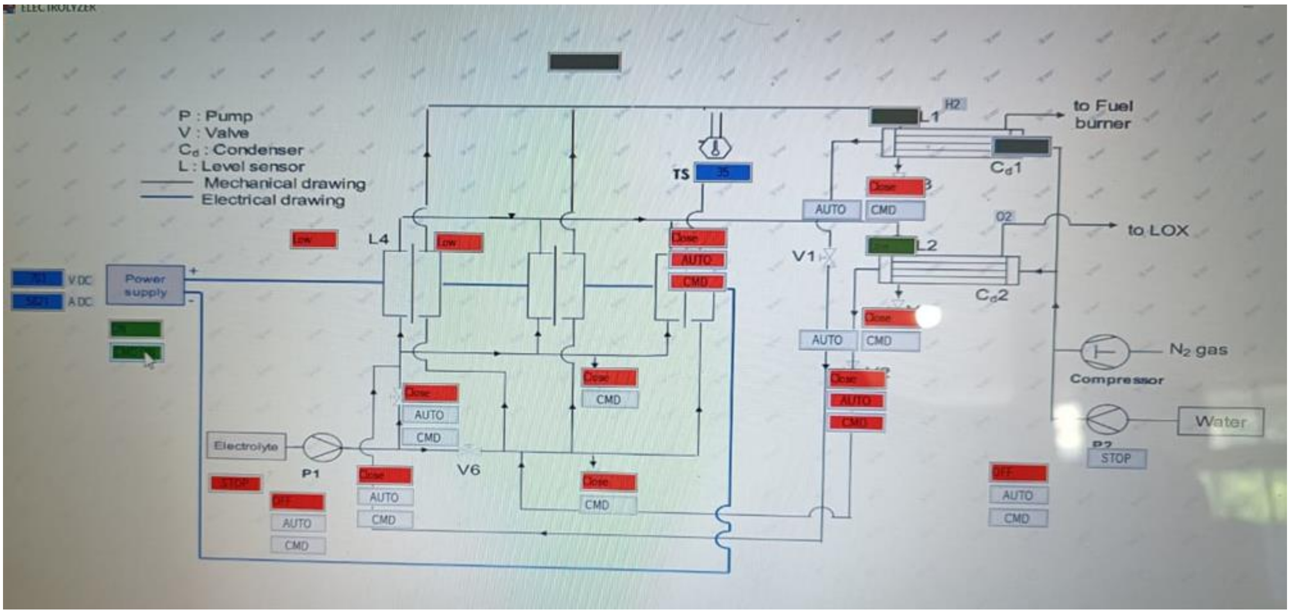
| | | | | |
|---|---|---|---|---|
| 12:59:00 | 7.15 | 56.04 | 94 | |
| 12:59:30 | 7.87 | 57.25 | 97 | Flame |
| 13:00:00 | 9.76 | 56.6 | 99 | |
| 13:00:30 | 9.83 | 45.59 | 101 | |
| 13:01:00 | 9.83 | 44.68 | 101 | |
| 13:01:30 | 9.85 | 44.51 | 102 | |
| 13:02:00 | 7.92 | 58.23 | 101 | |
| 13:02:30 | 6.55 | 54.89 | 98 | |
| 13:03:00 | 6.59 | 54.24 | 95 | |
| 13:03:30 | 6.68 | 54.14 | 92 | Flame |
| 13:04:00 | 6.78 | 54.64 | 91 | Flame |
| 13:04:30 | 6.85 | 54.89 | 90 | Flame |
| 13:05:00 | 6.95 | 55.52 | 91 | Flame |
| 13:05:30 | 7.19 | 55.92 | 91 | Flame |
| 13:06:00 | 8.77 | 57.65 | 98 | Flame |
| 13:06:30 | 9.77 | 54.77 | 99 | Flame |
| 13:07:00 | 9.79 | 46.18 | 101 | |
| 13:07:30 | 9.48 | 45.12 | 102 | |
| 13:08:00 | 9.96 | 48.74 | 103 | |
| 13:08:30 | 10.59 | 61 | 102 | |
| 13:09:00 | 6.85 | 56.44 | 102 | |
| 13:09:30 | 6.64 | 55.39 | 99 | |
| 13:10:00 | 6.65 | 55.09 | 97 | |
| 13:10:30 | 6.61 | 54.59 | 94 | |




CURRENT VS. VOLTAGE
70
60
50
40
30
20
10
0
CURRENT (A)
8.97
8.94
8.85
8.41
7.93
7.38
7.03
VOLTAGE (V)

**Result view:**


Camera 01


**Conclusion:**

Test passed successfully. The next step is to install the produced hydrogen meter.

### 4.5.3 Membrane test

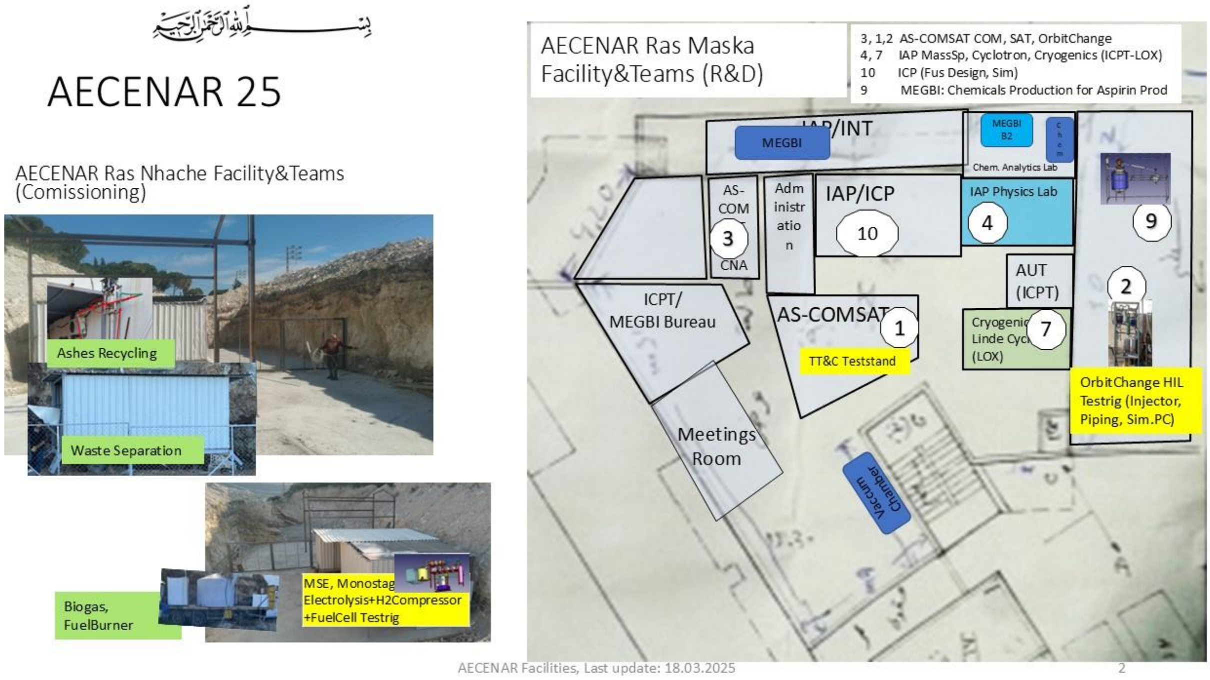
Following comprehensive modifications to the proposed connections, the existing membrane was replaced with a Nafion membrane. A subsequent electrolysis cell test revealed unsatisfactory performance. An investigation determined that the Nafion membrane, by its inherent nature, exhibits selective proton permeability while restricting anion passage. This characteristic rendered it unsuitable for our operational requirements. Consequently, the Nafion membrane must be replaced with an alternative, such as an Anion Exchange Membrane (AEM), which facilitates the passage of anions, thus enabling the desired electrochemical processes.

## 4.6 What's next

To complete the applied part of the electrolysis project, we have to change the Nafion membrane to another from the type AEM membrane, and then test it.

After the test's success, we had to do a long-term experiment, which showed us the model's endurance and the amount of hydrogen and oxygen produced over time. After completing this step, we will move to operating several cells simultaneously.

## 4.7 What's next




Commisioning at Ras Nhache

# 5 Project 3: Multistage electrolysis (ICPT - MSE)

## 5.1 Position of Multistage Electrolysis Project

The project's theoretical underpinnings were solidified in 2022, leading to the development of the initial design. Subsequent years, 2023 and 2024, were marked by the meticulous refinement of the design, encompassing detailed sizing calculations, strategic material selection, and efficient procurement. This culminated in the implementation of the pilot project model.

## 5.2 Requirements

### 5.2.1 Product requirements of the multistage electrolyse cell

The material of the electrolyze: stainless steel 304

The thickness of the electrodes: thick enough to withstand the pressing without change in shape

The dimensions of the electrodes: consider the current calculated

Taking into account the relation:

I = 0,4 x the surface that touches the solution=0,4 x A=0,4×3,14×$r^2$

The cell voltage is U = 2,4 Volt

The thickness of the gasket:

On the cathode side:  0,5 cm

On the anode side: 0,25 cm

The calculations must be done again taking into account the conductivity of the stainless steel 304

The resistivity of the stainless steel 304 is very small ($0,72*10^{-6}$ (ohm meter)$^{-1}$) so it can be neglect and the calculations above are correct.

The dimension of the endplates: a bit bigger in dimension then the electrodes and thin enough to withstand the stress of the screws

The dimension of the wholes for the screw in the endplates: asking a mechanist

The dimensions of the screws: asking a mechanist

The type of the membrane: search it in google available and to be searched which one is the best:

Nafion n117 price: 340USD/pcs for 30*30cm. or 136USD for 15*15cm.

Nafion n115 price: 136USD/pcs for 20*20cm.

NR212 price is 303USD/pcs, 61cm*30cm.

NR211 price is 114USD/pcs, 20*20cm

Nafion N115 price is 136USD/pcs for 20*20cm

All the named Nafion membranes are from Alibaba:

https://www.alibaba.com/product-detail/Ion-Exchange-Membrane-Manufacturer-In-China_1600326782762.html

The diameter of the wholes

Of the water inlet:

Of gas outlet:

The dimensions of the whole of the gasket based on the

The dimensions of the catalyzer of the upcoming water vapor based on the calculation of the temperature of the cells and the amount of the water vapor upcoming.

The current = I = 0,4 x the surface that touches the solution=0,4 x A=$0{,}4 \times 3{,}14 \times r^2$.

### 5.2.2 System requirements

- The system shall be able to produce essentially the HW.

- It shall also be able to produce hydrogen and oxygen separately as a by-product.

### 5.2.3 Mechanical requirements

- The electrodes shall be thick enough to withstand the pressing (the pressing of the screw rods).
- The electrodes shall be thick enough to press the gaskets so that no gas can exit.
- The gasket shall be able to prevent the leakage of gases and liquids from the stack (cell group).
- The gases ($H_2/O_2$) shall be able the pass separately through the holes of the gaskets, the electrodes, and the membranes in the stack.
- The membrane shall be able to separate two types of gas [$H_2/O_2$].
- The Endplate shall be thick enough to withstand the pressing of the stack.
- The pipe connections shall be able to resist the gas pressure without letting gas exit through.
- The pressure of the pump shall be sufficient to fill the cells and not too high for the pipes system.

- The water pipe shall be able to deliver water to the KOH tank, distillation tank, and burner rooms from the water tank.

- The condenser shall be able to condense the gas formed through the KOH solution.

- The gases formed shall be able to pass through the pipes of the condensers.

- The Nitrogen pipe shall be able to pass Nitrogen gas through the stacks, condensers, and filters.

- The distillation tank shall be able to distill water from the $K_2CO_3$ solution.

- The distilled tank shall be able to contain the HW.

- The Nitrogen gas tank shall be able to fill the stacks, the condensers, and the filers with Nitrogen gas.

- The water tank shall be able to fill the KOH tank and sufficient to cool the distillation tank and burners.

- The igniter shall be able to burn mixed gas with the presence of Oxygen gas.

- The water shall be able to condense the water vapor.

- The condensate water shall be returned to the KOH tank.

- The burner shall be able to collect the liquid inside it.

- The water pump shall be able to deliver water from the water tank to the components.

- The valves shall be able to close completely.

- The valves shall be able to open or close with independent pressure.

- The ball valve shall be able to pass the solution from one component to the other.

- The check valve shall be able to pass the solution in one direction (without return).

- The level sensor shall be able to show the liquid level in the component [or tank].

- The Flashback Arrestor shall be able to avoid the explosion of $H_2$ gas.

- The Flashback Arrestor shall be installed at the $H_2$ gas outlet.

- The stand shall be able to support the MSE components.

- The distillation tank shall be formed into two parts: upper and lower.

- The epoxy shall be able to join the stainless plate with the caoutchouc pipe.

### 5.2.4 Chemical requirements

- The electrodes shall be able to withstand the corrosion with KOH.

- The membrane shall be able to allow the ions to pass through so that electrolysis takes place when the current is connected.

- The membrane shall be able to insulate the two half-cells, chemically.
- The membrane shall be made of AEM (Anion Exchange Membrane).
- The pipe system used shall be able to withstand the corrosion with KOH.
- The valves shall be able to withstand the corrosion with KOH.
- The metal of the condenser used shall be able to withstand the corrosion with KOH.
- The pH sensor shall be able to measure the high concentration of the solution.
- The $O_2$ gas pipe shall be able to withstand the corrosion with $O_2$.
- The KOH tank shall be able to withstand the corrosion with KOH solution.
- The gas filter shall be able to withstand the corrosion of $O_2$ gas.
- The water shall be unable to limescale.
- The dry ice shall be able to react with KOH solution.
- The dry ice tank shall be able to withstand the corrosion of KOH and $K_2CO_3$ solutions.
- The distillation tank shall be able to withstand the corrosion of $K_2CO_3$ solution.
- The KOH pump shall be able to withstand the corrosion of the KOH solution.
- The sensors shall be able to withstand the corrosion of the KOH solution.
- The level sensor shall be able to withstand the corrosion of the KOH solution.
- The distillation tank shall be able (especially the lower part) to withstand the high concentration of $K_2CO_3$ solution.
- The pH meter shall be able to measure the pH of the distilled water produced, of the KOH solution entering and exiting into/from each stack, and of the $K_2CO_3$ solution.
- The end plate should be prohibited and isolated from any contact with the KOH solution.
- The thermoplastic silicone should be able to resist corrosion.
- The thermoplastic silicone should be able to resist reaction with chemicals, especially KOH solution.
- The epoxy shall be able to withstand the KOH solution (no reaction between epoxy glue and KOH solution).

#### 5.2.5 Electrical requirements

- The wires shall be connected in parallel.
- For power supply, DC the current that passes through one cell shall be about 26.6 A for each gram of Hydrogen gas produced and the voltage shall be 2V for each cell in the stack.

- The power supply shall be able to let the electrolyze generate enough hydrogen so that we can burn it.

- The GUI shall be able to control all electrical components: valves, sensors, and pumps.

- The igniter shall be connected to the electricity and shall be controlled by GUI.

- The system shall be connected with the earth by the Ground wire.

- The end plate should be electrically insulated.

- The thermoplastic silicone shall be able to insulate materials electrically.

- The epoxy shall be able to insulate materials electrically.

### 5.2.6 Physical requirements

- The electrodes shall be able to withstand the electrolysis temperature.
- The electrodes shall be made of Nickel.
- The endplate shall be made in Stainless [or Plexy].
- The gasket shall be made of Silicone (good chemical resistance to KOH).
- The membrane shall be made in AEM (Anion Exchange Membrane).
- The temperature sensor shall be able to measure the electrolyte temperature, gas amount temperature, and the KOH solution temperature pass in the condenser.
- The water pipes shall be made of PPR pipe [or PVDF/Plastic].
- The KOH solution pipe shall be made of PVDF.
- The KOH solution pipe shall be able to withstand the electrolysis temperature.
- The $O_2$ gas pipe shall be made in Stainless [PVDF / PPR/ Caoutchouc].
- The $H_2$ gas pipe shall be made of Stainless [PVDF / PPR/Caoutchouc].
- The $N_2$ pipe shall be made of Caoutchouc [or PPR].
- The KOH tank shall be made of Plastic [Stainless].
- The KOH tank shall be able to withstand the electrolysis temperature.
- The condenser shall be able to condense the gas formed by electrolysis.
- The condenser shall be made of Stainless.
- The gas filter shall be able to filter the gas ($O_2$/$H_2$).
- The Nitrogen pipe shall be made of Caoutchouc.
- The water shall be distilled.
- The water shall be unable to limescale (free of limescale).
- The dry ice shall be made in powder/finger.
- The dry ice tank shall be able to withstand the temperature of the reaction.

- The dry ice tank shall be made of stainless [or PTFE (Polytetrafluoroethylene)/ Polycarbonate/thermal glass].
- The distillation tank shall be able to condense the water vapor.
- The distillation tank shall be made of stainless.
- The distillation tank shall be thick enough (especially the lower part) to withstand the high concentration of $K_2CO_3$ solution
- The distilled tank shall be made of glass [or plastic/ stainless].
- The gas filter shall be made of Plastic [or Glass].
- The gas filter shall be able to withstand the temperature of the gas formed.
- The burner room shall be able to withstand the pressure of burn.
- The water shall be able to cool the burner room.
- The igniter shall be able to burn gas with the presence of the Oxygen gas.
- The burner shall be made of Glass (transparent material).
- The flashback arrestor shall be able to avoid the burn of gas ($H_2$ gas).
- The temperature sensor shall be able to measure the temperature.
- The pressure sensor shall be able to measure the pressure in the components.
- The liquid level reader shall be made of Transparent plastic to view the level of liquid.
- The pipe system shall withstand a temperature of up to 100°C.
- The valves shall be able to resist the temperature and the pressure.
- The condensers shall be able to condense the vapor leaving the cell, with KOH solution.
- The stove shall be with a variable temperature control.
- The water bath should be able to withstand heat (high temperature).
- The water bath shall be made in stainless/aluminum/iron/thermal glass.
- The thermoplastic silicone should be able to resist heat (temperature).
- The epoxy shall be able to withstand the high temperature (≤150℃).

### 5.2.7 Automation requirements

- All electrical parts of the system shall be controlled by GUI.
- All electrical valves of the system shall be controlled by GUI.
- All Sensors of the system shall be controlled by GUI.

### 5.2.8 Safety requirements

- The hydrogen burner shall be able to burn the produced hydrogen gas to avoid the risk of its explosion.
- The system shall be electrically isolated.
- The system shall be connected to Earth wire.
- The dry ice shall be thermally isolated with gloves.

- The dry ice tank shall be touched using thermally gloves only.
- The distillation tank shall be placed in a well-ventilated area.

#### 5.2.8.1 Safety of Hydrogen Storage

**Safety Tips for Hydrogen Storage**

## 5 نصائح لضمان سلامة مصنع الهيدروجين

### 1. اختيار خزانات تخزين الهيدروجين المضغوط المناسبة

يمكن تخزين الهيدروجين كغاز أو سائل. وتتطلب الطريقة الأولى خزانات عالية الضغط (100–1,000 بار أو 1,400–14,500 رطلاً/بوصة مربعة)، بينما تتطلب الطريقة الثانية درجات حرارة تبريدية. وفي هذه المقالة، نركز على غاز الهيدروجين المضغوط.

لضمان السلامة المثلى لمصنع الهيدروجين، من الضروري استخدام **الخزانات المصنعة بمواد مناسبة**.

**حسب الحجم والضغط**، يجب استخدام أحد **الأنواع الأربعة** من أوعية الضغط لتخزين الهيدروجين المضغوط .

- **النوع الأول**

إن هذه الخزانات المعدنية مصنوعة عادةً من الفولاذ أو الألومنيوم. ويمكنها تحمل أقصى ضغط مقدَّر يبلغ 175 بار (للألومنيوم) و200 بار (للفولاذ). تتميز الخزانات من النوع الأول بأنها رخيصة الإنتاج، لكنها ثقيلة جدًا كونها مصنوعة بالكامل من المعدن. تُستخدم لتخزين الهيدروجين في حالتيه السائلة والغازية .

- **النوع الثاني**

إن هذه الخزانات المعدنية مصنوعة من الألومنيوم، لكنها تتميز بلفائف خيوط حول الأسطوانة المعدنية. ويمكن أن تتكون من الألياف الزجاجية/الأراميد أو ألياف الكربون. وحسب المادة المستخدمة، يمكنها تحمل أقصى ضغط يصل إلى 299 بار.

خزانات النوع الثاني أقل في الوزن وأقوى، لكنها أغلى ثمنًا .

- **النوع الثالث**

تتكون هذه الخزانات من مواد مركبة مزودة ببطانة معدنية، ويمكنها تحمل ضغط أعلى. على سبيل المثال،

يمكن أن يتحمل خزان الألومنيوم/الأراميد ضغطًا يصل إلى 438 بار. ومن ناحية أخرى، فإن خزان الألومنيوم/الكربون المركب يمكن أن يتحمل الضغوط حتى 700 بار. ونتيجة لهذا فإنها أكثر تكلفة أيضًا .

- **النوع الرابع**

لا تحتوي هذه الخزانات على معادن، فهي مصنوعة بالكامل من ألياف الكربون مع بطانة من البوليمر. ويمكنها تحمل أقصى ضغط يبلغ 700 بار على الرغم من أن وزنها أقل من الأنواع الأخرى. والجانب السلبي هنا هو أن استخدام كميات كبيرة من ألياف الكربون يجعلها أكثر تكلفة أيضًا .

## 2. اختيار المواد المناسبة

إن للهيدروجين تأثيرًا ضارًا في الخصائص الميكانيكية لكل المواد. فعلى سبيل المثال، يمكن أن يسبب هشاشة المعادن. وهذا بدوره يمكن أن يؤدي إلى فقدان مقاومة الشد وقابلية الطرق والسحب ومتانة الكسر، ويؤدي إلى زيادة نمو تشققات الاجهاد.

تعتمد درجة هذا التدهور على المادة وضغط الهيدروجين ودرجة حرارته والحمل الميكانيكي. وهذا يعني أن بعض المواد أفضل من غيرها .

بشكل مثالي، يجب اختبار المواد لضمان أنها تعمل في ظروف التشغيل المتوقعة. إذا لم يكن ذلك ممكنًا، فإليك بعض المواد **المستخدمة بشكل شائع** :

- الفولاذ المقاوم للصدأ الأوستنيتي
- سبائك الألومنيوم
- فولاذ حديدي منخفض الخلائطية
- فولاذ حديدي من الكربون والمنجنيز
- سبائك النحاس

من ناحية أخرى، **ينبغي تجنب المواد الآتية** :

- الفولاذ الحديدي والمارتنسيتي عالي القوة
- حديد الزهر الرمادي والمطاوع واللدن
- سبائك النيكل
- سبائك التيتانيوم

## 3. اختيار الموقع الأمثل لإنشاء خزانات تخزين الهيدروجين

عندما يتعلق الأمر بسلامة مصنع الهيدروجين، من المهم اختيار وعاء التخزين المناسب وكذلك الموقع الأمثل لإنشائه .

على الرغم من **إمكانية تخزين أسطوانات الهيدروجين الصغيرة في الأماكن الداخلية**، فلا يوصى بذلك للكميات الكبيرة.

**التخزين الخارجي أكثر أمانًا بشكل عام، بل هو ضروري لتخزين كميات كبيرة من الهيدروجين** حيث يسمح بتبديد الغاز بسهولة في حال التسرب العرضي للهيدروجين.

فيما يأتي بعض خصائص الموقع المثالي لتخزين الهيدروجين المضغوط.

-التهوية الجيدة لمنع تراكم الهيدروجين

-الإنشاء على مسافة آمنة من الهياكل ومنافذ التهوية

-الحماية من حركة المركبات أو من الأجسام الساقطة

-تجنُّب التعرض لأشعة الشمس المباشرة، وألا تتجاوز درجة الحرارة المحيطة 52 درجة مئوية (126 درجة فهرنهايت تقريبًا)

-الحماية من الوصول غير المصرح به

## 4. منع تراكم غاز الهيدروجين في حاوية أو حيِّز مغلق

حسبما ذُكر أعلاه، فإن التهوية أمر بالغ الأهمية عند التعامل مع الهيدروجين. حيث تضمن تبديد الغاز بسرعة وعدم التمكُّن من تشكيل مزيج قابل للاشتعال مع الأكسجين الموجود في الهواء .

ولأن الهيدروجين خفيف للغاية، **من المؤكد أن هذا التراكم سيحدث بالقرب من سقف الغرفة أو الحاوية**. يجب مراعاة ذلك عند تصميم هذه المرافق.

يعني هذا أن هناك حاجة إلى وجود **تهوية مناسبة وأجهزة كشف وتدابير للسيطرة في المساحة العلوية** .

فضلاً عن ذلك، ولأنه لا يمكن استبعاد تسرب الهيدروجين تمامًا، من الضروري أيضًا **تركيب أجهزة كشف اللهب و/أو الغاز ونظام إخماد الحرائق** .

عند انطلاق غاز الهيدروجين في الهواء، سيصعد إلى الأعلى على الفور بسرعة 10 أمتار/ثانية، لذا فإنه ببساطة من الضروري **الكشف عن تركيز الهيدروجين عند أعلى نقطة في الغرفة** .وستحتاج أيضًا إلى **إعداد تهوية** الغرفة عند النقطة نفسها: يجب إخراج الهواء من أعلى نقطة. وإذا وضعت جهاز الكشف عند نقطة أدنى في الغرفة، فسيمتلئ أولاً الجزء من الغرفة أعلى جهاز الكشف بتركيز عالٍ جدًا من الهيدروجين، قبل الكشف عن الغاز. وينطبق الأمر نفسه على التهوية. إذا أدخلت الهواء من أعلى وأفرغته عند مستوى أقل، فلن تتخلص ببساطة من الهيدروجين. حيث يجب أن يكون تدفق التهوية من الأسفل إلى الأعلى.

خلال التشغيل العادي، يكون معدل التهوية منخفضًا نسبيًا، لكن عند الكشف عن الغاز في أعلى نقطة في الغرفة فقط، يجب عليك على الفور إخراج كمية هائلة من الهواء (الممزوج بالغاز). بالنسبة إلى المباني الجديدة المخصصة لتصنيع شاحنات الهيدروجين (التي تتم تعبئتها أيضًا داخل المبنى)، يمكن تركيب جهاز كشف الغاز بالقرب من السقف (على ارتفاع أكثر من 10 أمتار)، وعند الكشف عن الغاز، يُفتح السقف تلقائيًا.

## 5. منع تسرب الهيدروجين

تُعد حالات التسرب مشكلة رئيسية في العمليات التي تستخدم الهيدروجين حيث إن هذا عنصر صغير جدًا وهو مسؤول عن وقوع نسبة كبيرة من الحوادث .

تتمثل إحدى الطرق التي يمكن من خلالها منع حدوث التسرب في تركيب أجهزة كشف التسرب التي ينبغي صيانتها واختبارها بشكل دوري. وعلى أي حال، ينبغي إجراء اختبارات التسرب بشكل منتظم، بما في ذلك الفحوصات التشغيلية للصمامات .

هناك طريقتان شائعتان للاختبار وهما استخدام محلول فقاعات الصابون أو جهاز كشف الهيدروجين المحمول باليد. وبالإضافة إلى الاختبارات المنتظمة، يجب على مشغلي المصنع التحقق من وجود تسرب في كل مرة تتم فيها إعادة تجميع

الوصلات. وعلاوة على ذلك، لا بد من فحص وصلات النظام بحثًا عن علامات التآكل والبلى والتشقق والانبعاج والتقشر أو أي شكل آخر من أشكال التلف.

Hydrogen, a highly flammable and explosive gas, requires careful storage and handling to prevent accidents. Here are some essential safety tips:

- **Storage Location:**
  - Isolated Area: Store hydrogen cylinders in a well-ventilated, isolated area away from heat sources, sparks, and open flames.
  - Secure Fastening: Ensure cylinders are securely fastened to prevent them from falling or being knocked over.
  - Gas detector installation: It is installed at the highest point in the room (ceiling at a height of more than 10 meters) and when gas is detected, the ceiling will open automatically.
  - Installing leak detection devices that should be maintained and tested periodically.
  - Install leak tests regularly, including operational checks of valves.
- **Cylinder Handling**
  - Protective Gear: Wear appropriate protective gear, including safety glasses, gloves, and closed-toe shoes, when handling hydrogen cylinders.
  - Avoid Rough Handling: Handle cylinders gently to prevent damage to the valves or other components.
  - Leak Checks: Regularly inspect cylinders for leaks using soap bubble solution or handheld Hydrogen Detector.
  - Protection from vehicle movement and falling objects.
  - Avoid exposure to direct sunlight, and the ambient temperature should not exceed 52°C.
  - Protection from unauthorized access.
- **Ventilation**
  - Adequate Ventilation: Ensure proper ventilation in the storage area to prevent the accumulation of hydrogen gas.
  - Exhaust Fans: Consider installing exhaust fans to facilitate ventilation.

  ⚠ **Note: Air must be brought in from the bottom to the top to ventilate the place.**

- **Fire Safety**

- Fire Extinguishers: Keep fire extinguishers readily available and ensure personnel are trained properly.
- Emergency Plan: Develop and practice an emergency evacuation plan in case of a fire or other emergency.

➢ **Electrical Safety**

- Grounding: Ground all electrical equipment in the storage area to prevent static discharges.
- Avoid Sparks: Minimize electrical equipment near hydrogen cylinders to avoid creating sparks.

➢ **Signage**

Warning Signs: Mark the storage area with warning signs indicating the presence of hydrogen gas and the associated hazards.

➢ **Regular Inspections**

- Cylinder Inspections: Regularly inspect hydrogen cylinders for damage, leaks, or corrosion.
- Plant operators must check for leaks each time connections are reassembled.
- Inspect system connections for signs of wear, tear, cracking, denting, peeling, or any other form of damage.
- Safety Equipment: Ensure that safety equipment, such as fire extinguishers and emergency shutoff valves, are in good working condition.

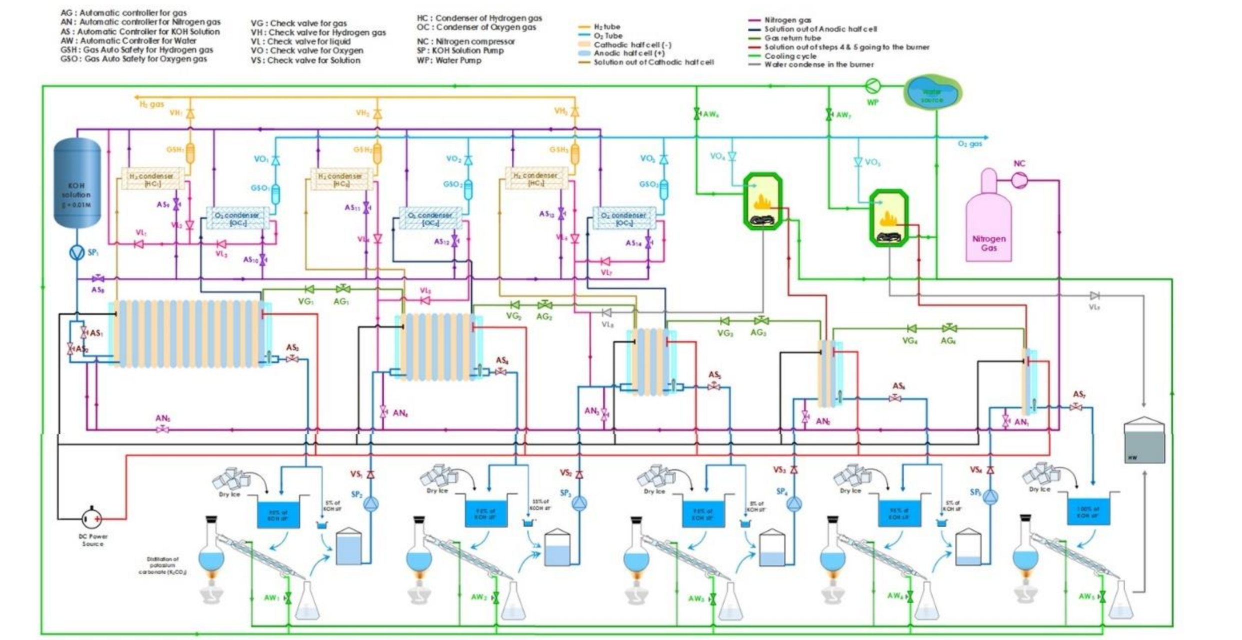
➢ **Training**

Personnel Training: Train all personnel in handling hydrogen gas on safety procedures, emergency response, and the proper use of equipment.

By following these safety tips, you can significantly reduce the risk of accidents associated with hydrogen storage and ensure a safe working environment.

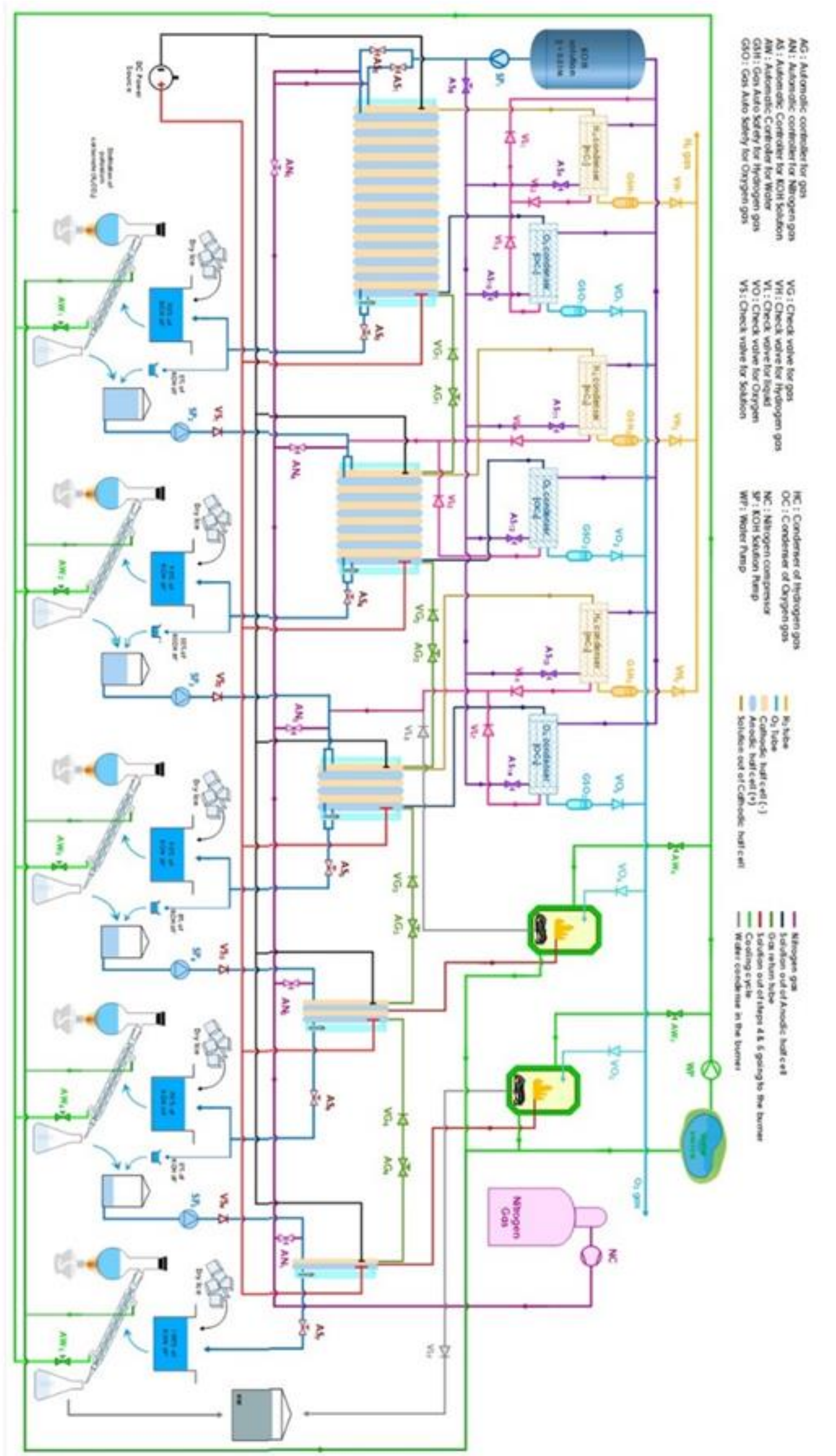
## 5.3 System Design and Mechanical design

### 5.3.1 Electrolysis multistage design overview




[Multistage design (27072023) _ Edraw file]

01082023_MSE flow chart - with electricity.


AG : Automatic controller for gas
AN : Automatic controller for Nitrogen gas
AS : Automatic Controller for KOH Solution
AW : Automatic Controller for Water
GSH : Gas Auto Safety for Hydrogen gas
GSO : Gas Auto Safety for Oxygen gas
VG : Check valve for gas
VH : Check valve for Hydrogen gas
VL : Check valve for liquid
VO : Check valve for Oxygen
VS : Check valve for Solution
HC : Condenser of Hydrogen gas
OC : Condenser of Oxygen gas
NC : Nitrogen compressor
SP : KOH Solution Pump
WP : Water Pump
$H_2$ tube
$O_2$ Tube
Cathodic half cell (-)
Anodic half cell (+)
Solution out of Cathodic half cell
Nitrogen gas
Solution out of Anodic half cell
Gas return tube
Solution out of steps 4 & 5 going to the burner
Cooling cycle
Water condense in the burner
Dry Ice
Nitrogen Gas
NC
WP

### 5.3.2 FlowChart of MSE design

In this paragraph, we will present the mechanical design of multistage electrolysis using a burner room for the two last stages.

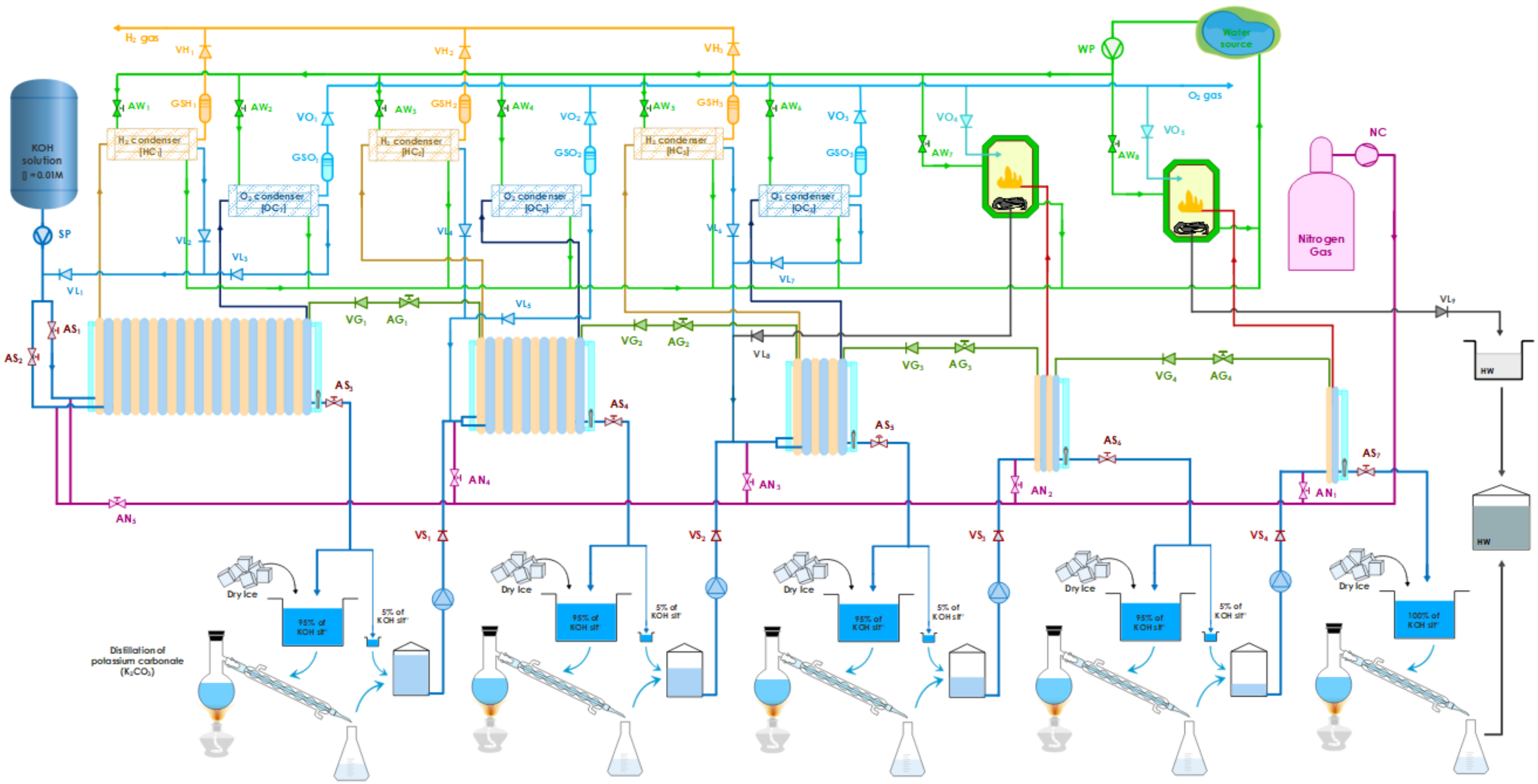


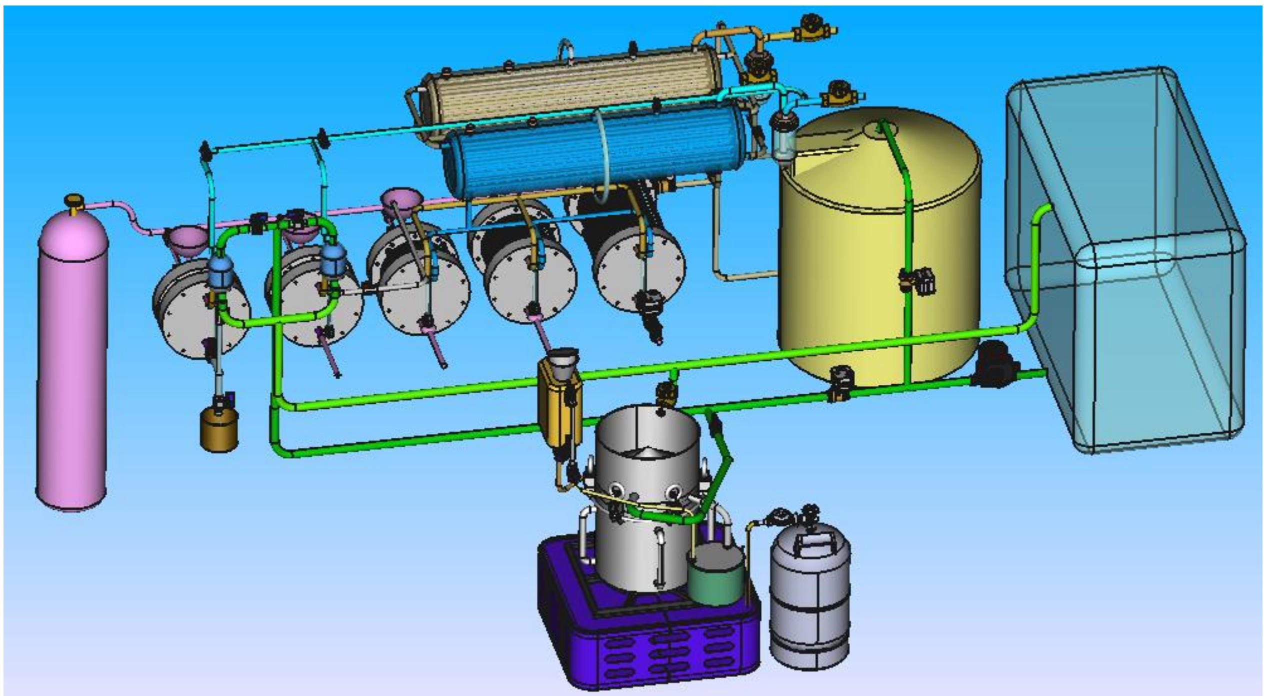

**Figure: MSE using the burner rooms**

The Edraw file contains the MSE details using burner rooms:

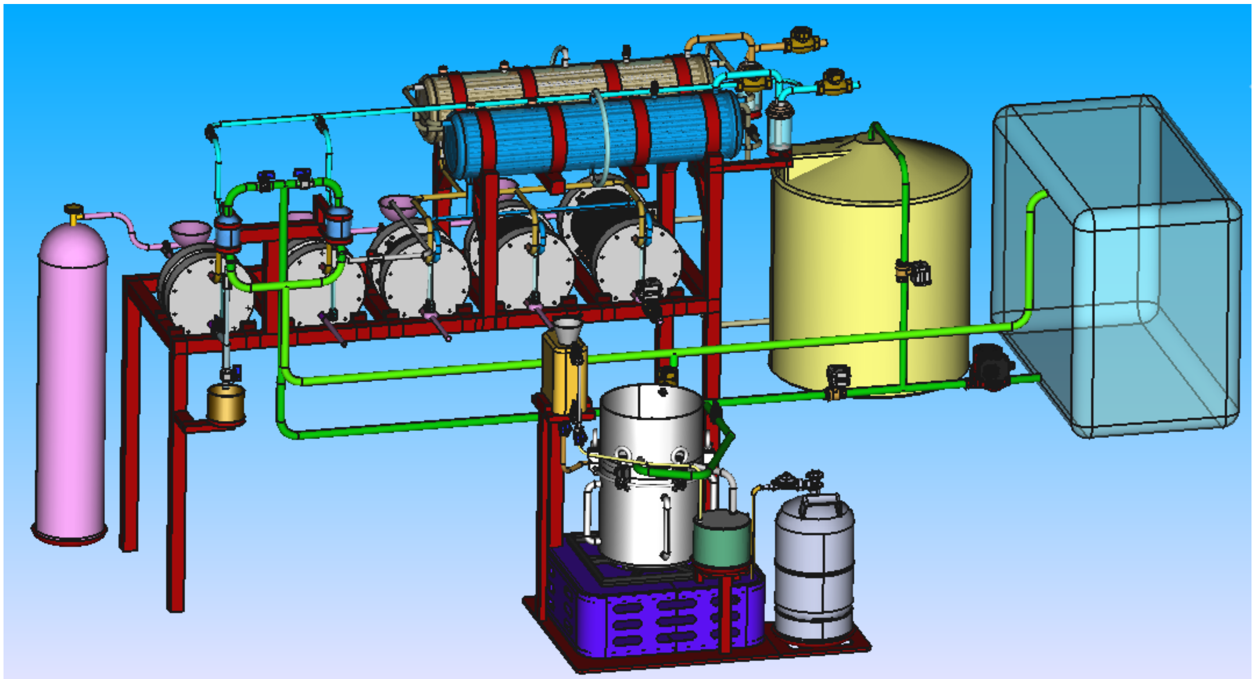
08052024_MSE flow
chart - with electrici

The FreeCAD file contains the MSE details using burner rooms:

10052024_MSE - All
components with pi



### 5.3.3 Design of the MSE with stand

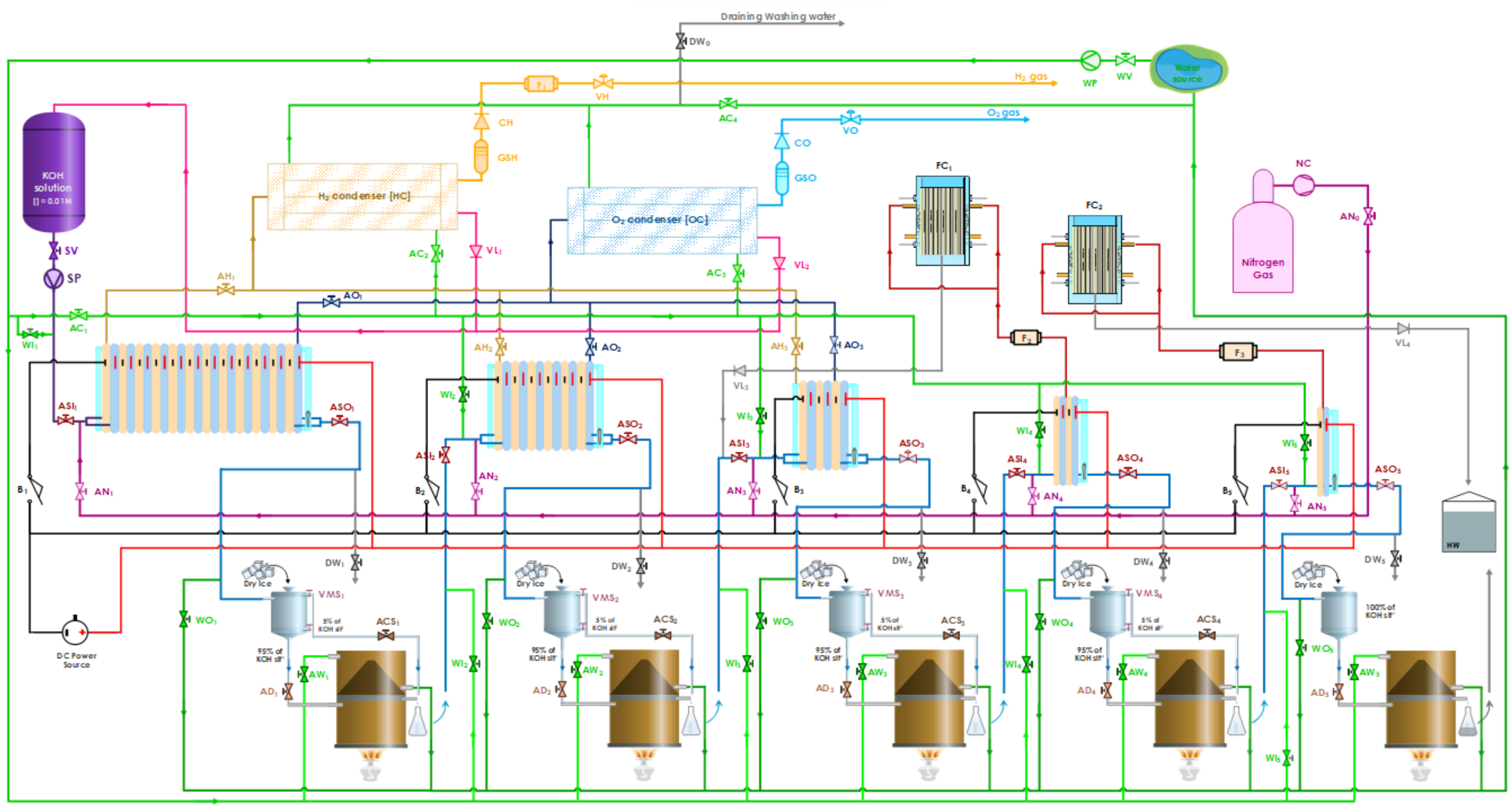


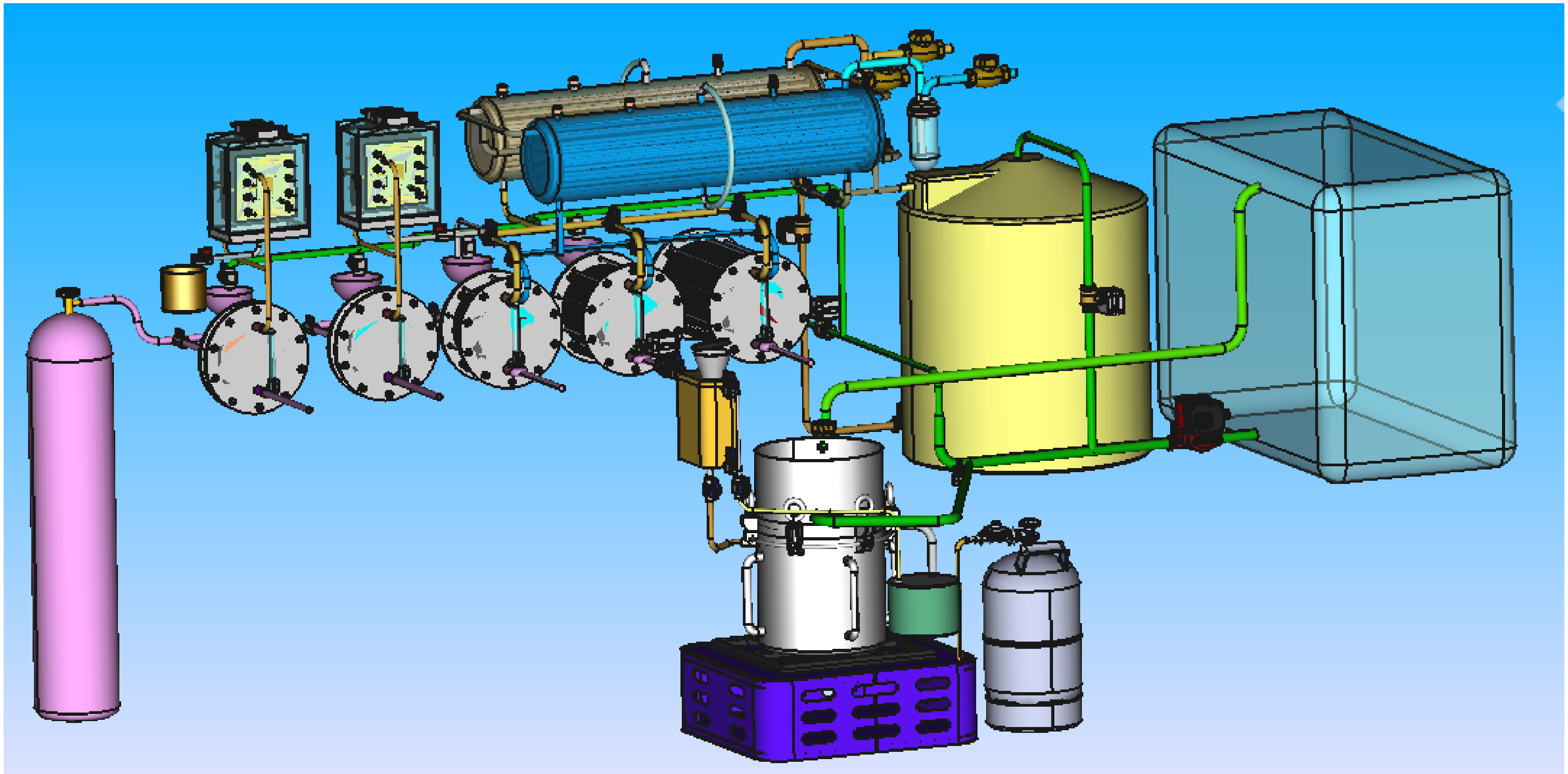
The FreeCAD file:

10052024_MSE - All components with pipes cnx.FCStd

### 5.3.4 Replacement of burners room by FuelCell

A to burn the gas mixture (consisting of hydrogen and oxygen gases) in a cold combustion manner by replacing the two combustion chambers with fuel cells (figure below) has been proposed, but this design is unrealistic and cannot be implemented. The main problem lies in the inherent selectivity of the membrane, which is specifically designed to facilitate the passage of hydrogen ions while strictly preventing the passage of oxygen molecules. This critical design constraint renders the proposed system inoperable. The presence of oxygen and deuterium within the fuel cell environment not only fails to contribute to the desired electrochemical reactions; but also poses a significant risk of blocking the membrane pores, impeding the flow of hydrogen ions and seriously compromising the fuel cell function.


Draining Washing water
DW0
H2 gas
O2 gas
WP
WV
Water source
KOH solution
SV
SP
H2 condenser [HC]
O2 condenser [OC]
CH
GSH
CO
GSO
VH
VO
AC1
AC2
AC3
AC4
AH1
AH2
AH3
AO1
AO2
AO3
VL1
VL2
VL3
VL4
FC1
FC2
F1
F2
F3
NC
AN0
Nitrogen Gas
WI1
WI2
WI3
WI4
WI5
ASI1
ASI2
ASI3
ASI4
ASI5
ASO1
ASO2
ASO3
ASO4
ASO5
AN1
AN2
AN3
AN4
AN5
B1
B2
B3
B4
B5
DW1
DW2
DW3
DW4
DW5
Dry Ice
VMS1
VMS2
VMS3
VMS4
ACS1
ACS2
ACS3
ACS4
WO1
WO2
WO3
WO4
WO5
AW1
AW2
AW3
AW4
AW5
AD1
AD2
AD3
AD4
AD5
DC Power Source
HW

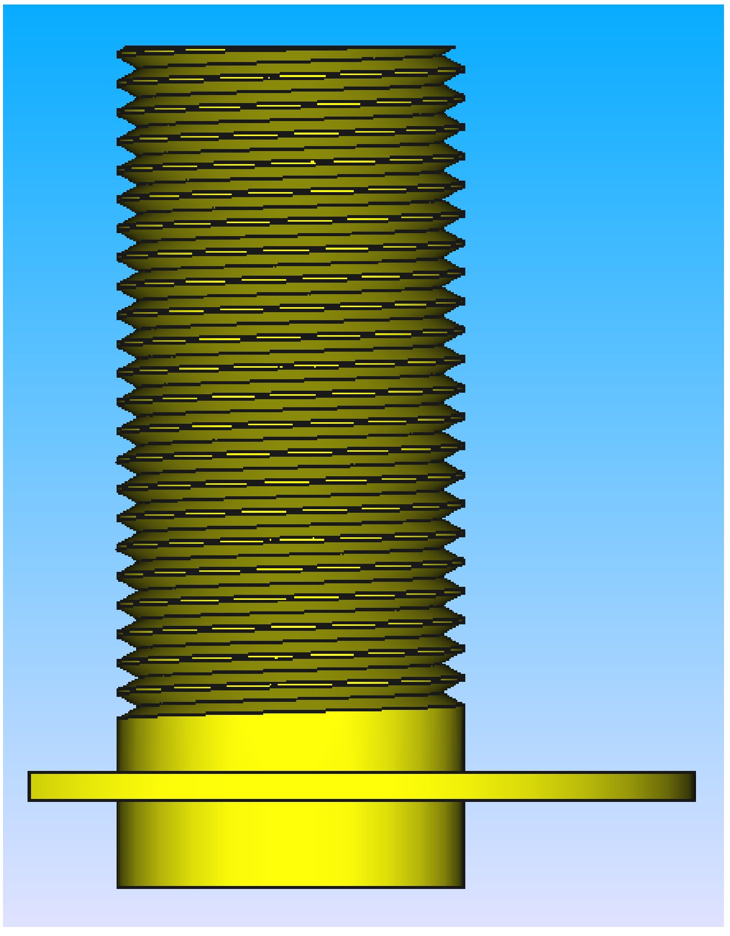


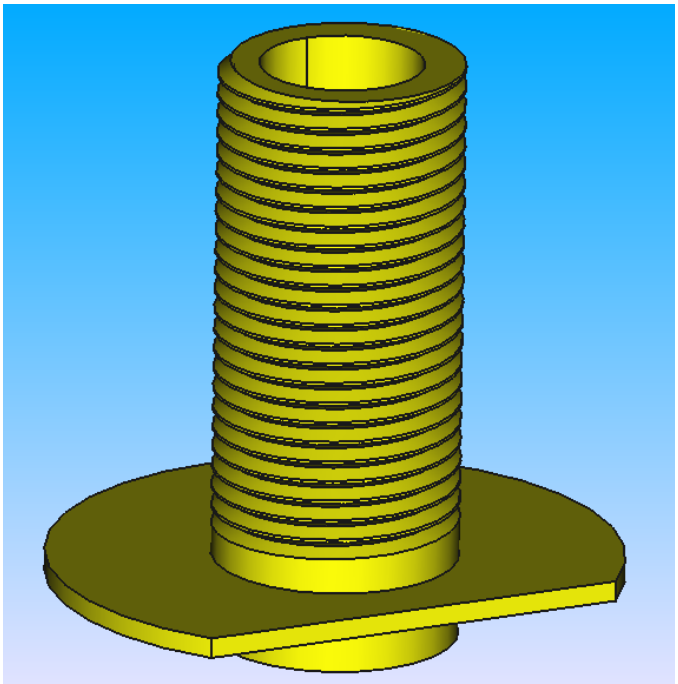
## 5.4 Concept for Stack Adapter (not realized yet)

### 5.4.1 Possible Realization Concept with PPR-metals interface

### 5.4.2 Design for 3D print

#### 5.4.2.1 Part 1

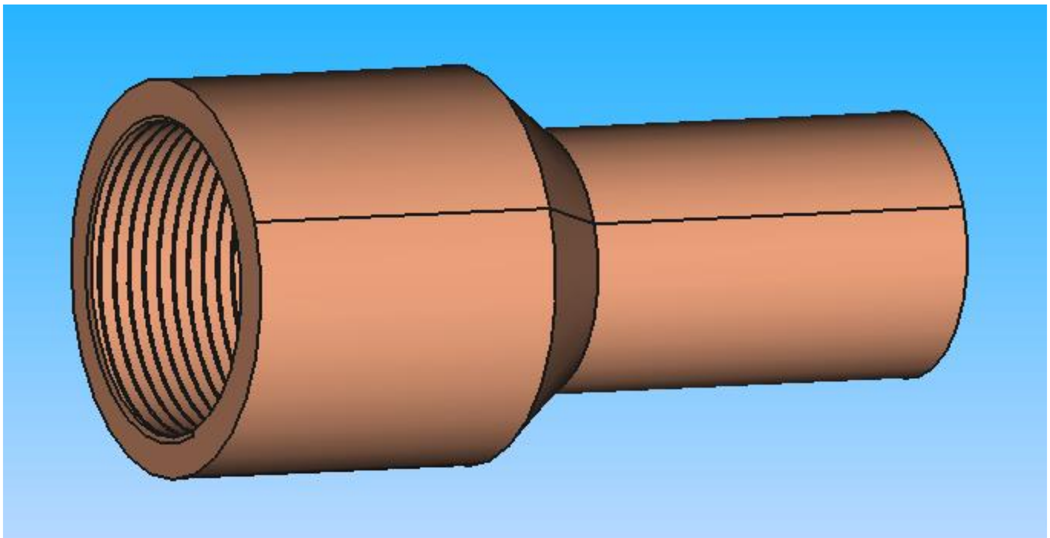


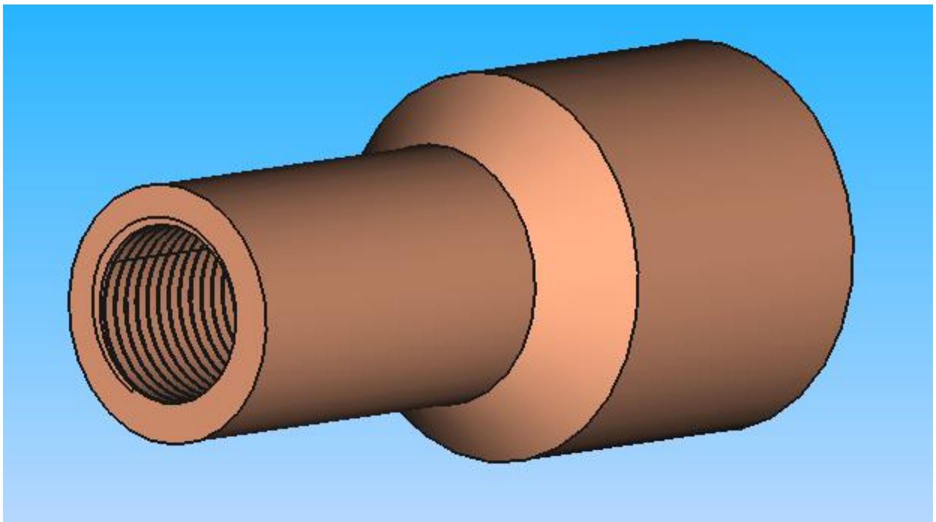


The FreeCAD file :

26122024_Design part 1.FCStd

#### 5.4.2.2 Part 2

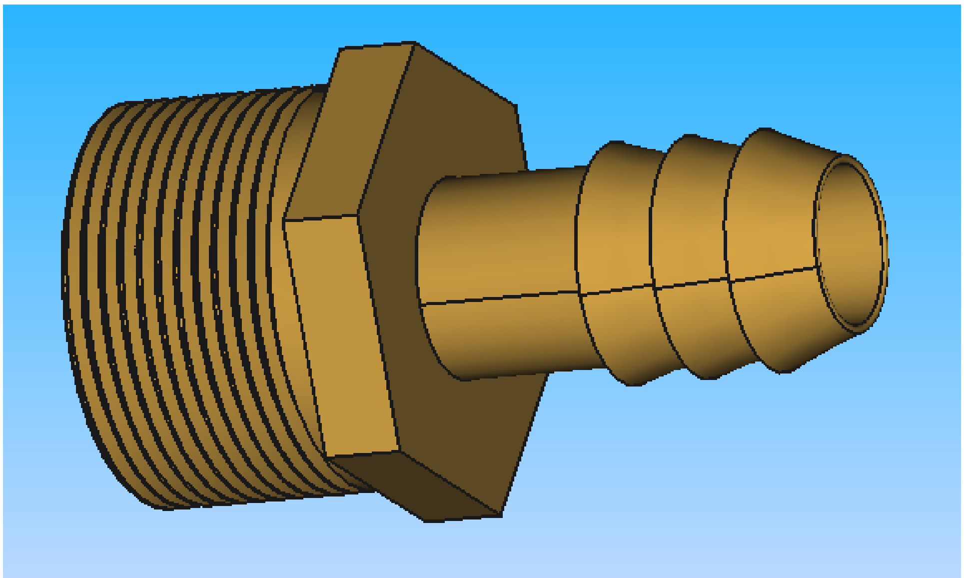




The FreeCAD file :

27122024_design
part 2 _.FCStd

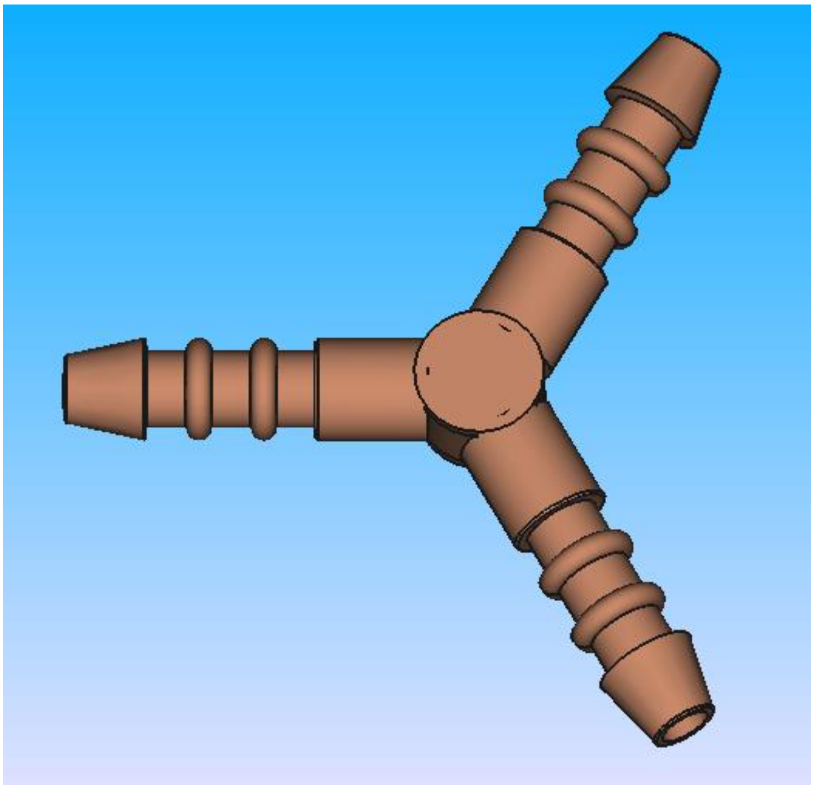
#### 5.4.2.3 Part 3



The FreeCAD file :

27122024_Design
part 3.FCStd

### 5.4.2.4 Part 4



The FreeCAD file :

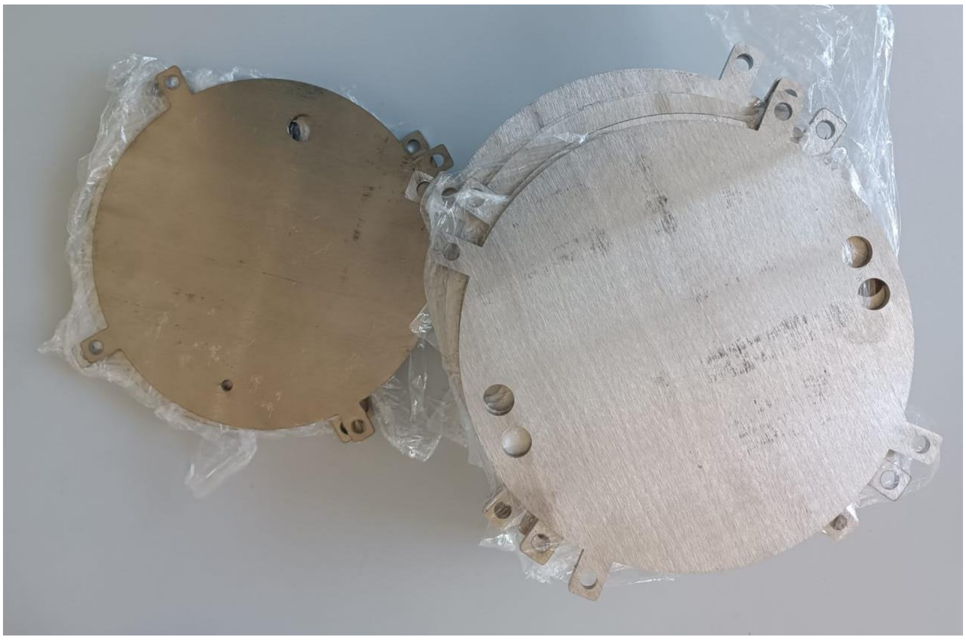
30122024_Design part 4.FCStd

## 5.5 Realization of the MSE

### 5.5.1 Materials of MSE electrolyze stack

#### 5.5.1.1 Stainless for end plates

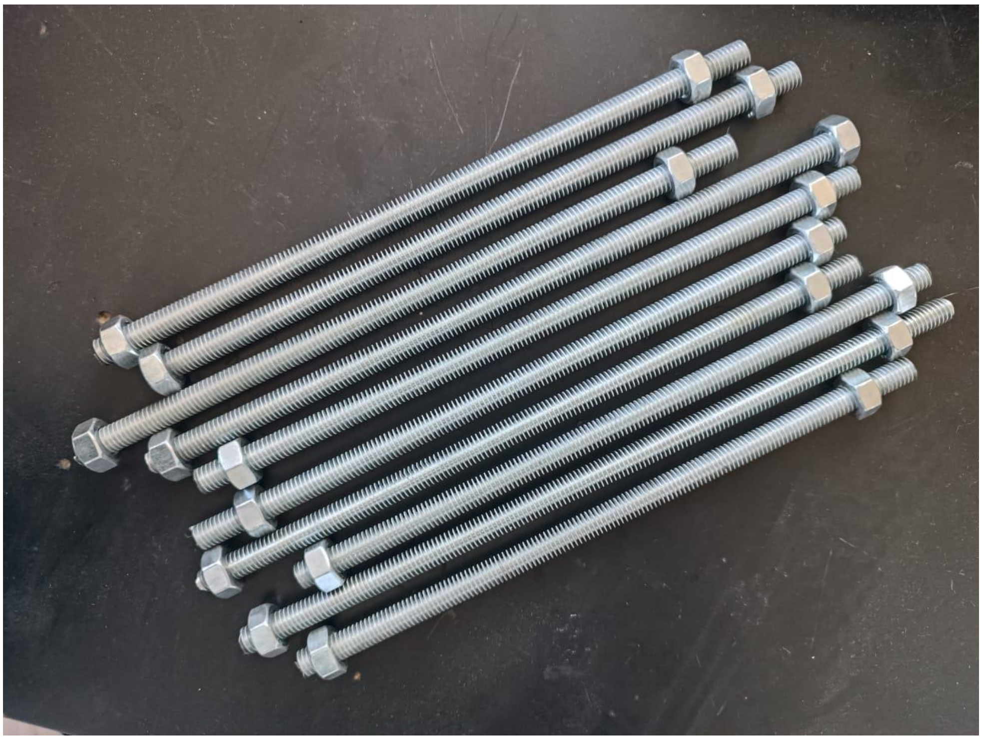
#### 5.5.1.2 Nickel for electrodes



#### 5.5.1.3 AEM for membrane exchange


#### 5.5.1.4 PTFE gasket for gasket between components

#### 5.5.1.5 Bolts & nuts



### 5.5.2 Material invoices

#### 5.5.2.1 MEA invoice

# Quotations

Suzhou Sinero Technology Co., LTD

Date: 17/07/2024 Receipt Num:SIN2024071704

From

Address: No. 337, Binhe Road, High tech Zone, Suzhou, Jiangsu

Zip code: 215000

Phone: 15190163610

| NO. | Description | Product model | Unit Price | Quantity | Amount |
|---|---|---|---|---|---|
| 1 | Anion exchange membrane | FAA-3-PK-130 20*20cm | $53.5 | 28 | $1498 |

Total amount of goods: $1498

Freight:$48

Total: $1546

Validity of Quotation: 30/7/2024

Bank Reference:

Bank Name: Industrial and Commercial Bank of China Suzhou Oriental Garden sub branch

Bank Address: No. 188, Suchun West Road, Suzhou Industrial Park, Suzhou city, China

Account No: 1102130919000071753

Authorized Signatures: Liu Xiuxiu

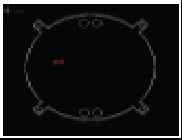
### 5.5.2.2 Nickel plates invoice

**Wuxi Oriental Denuo International Trading Co., Ltd.**
**无锡东方德诺国际贸易有限公司**
9#1519, Shenzhen-Hong Kong Asia-Pacific Center, No.299 Fangcheng Avenue,
Xinwu District, Wuxi City, Jiangsu Province
Name FreyaDuan Email: freya@dfdnmetal.com Tel : +86 18626079904 (whatsapp/ wechat)

**PROFORMA INVOICE**

To:

INVOICE NO:DN2024121515
DATE:2024-07-10

| ITEM NO. | DESCRIPTION GOODS | SPECIFICATION | Quantity (PCS) | PRICE USD/PC | AMOUNT |
|---|---|---|---|---|---|
| 1 | pure nickel Processing parts<br>3 mm thickness<br>Diameter: 200mm |  | 31 | $36.00 | $1,116.00 |
| 2 | pure nickel Processing parts<br>3 mm thickness<br>Diameter: 200mm |  | 5 | $36.00 | $180.00 |
| 3 | Transportation costs | by fedex | / | / | $350.00 |
| | | | | | $1,646.00 |

1.REQUIREMENTS
(1)Delivery time: 7 days after receving advance payment.
(2)The Proforma Invoice is valid for 5 days from the date of issuing
(3)Terms of Price: FOB Shangahi port.
(4)Terms of Payment: TT 30% as a deposit, 70% before delivery.
(6)Packing:Standard packing.
(7)Weight:Actual
(8)Country of :China
(9)After signing the PI, please complete the advance payment within three working days.
(10)After the seller prepares the goods, the buyer needs to pay off balance payment within 7 days, if the balance payment is not paid off, the contract becomes invalid and the deposit is not refundable.

2.BANK DETAILS

| | |
|---|---|
| Beneficiary: | Wuxi Oriental Denuo International Trading Co., Ltd. |
| Bank name: | DBS BANK (HONG KONG) LIMITED |
| Bank Address: | MILLENNIUM CITY 6 FLOOR 9 392 KWUN TONG ROAD |
| Bank A/C: | 799527527 |
| Swift Code: | DHBKHKHHXXX |

| Confirmed by Buyer: | Confirmed by Seller: |
|---|---|
| | For and on behalf of<br>Wuxi Oriental Denuo International Trading Co., Ltd.<br>无锡东方德诺国际贸易有限公司<br>Mr. Bin Xu.<br>Authorized Signature(s) |

无锡东方德诺国际贸易有限公司
Wuxi Oriental Denuo International Trade Co., Ltd.
中国・德诺
Denuo・China

# Wuxi Oriental Denuo International Trading Co., Ltd.
无锡东方德诺国际贸易有限公司

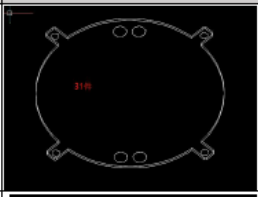
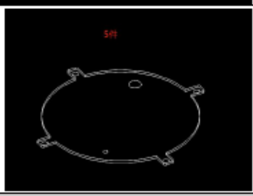
Tel: 0086- 18626079904 (whatsapp/ wechat) Fax: 0086-0510- 83853567

Miss Freya | www.dfdn.en.alibaba.com | Email: freya@dfdnmetal.com

Manager | 9#1519, Shenzhen-Hong Kong Asia-Pacific Center, No.299 Fangcheng Avenue, Xinwu District, Wuxi City, Jiangsu Province

## Quotation List

| | | |
|---|---|---|
| Buyer: | | No:DN2024151629 |
| Add.: | | Date:2024-06-28 |

| | Item name | Description | Quantity (PCS) | Unit Price (USD/PC) | Amount |
|---|---|---|---|---|---|
| 1 | pure nickel Processing parts<br>3 mm thickness<br>Diameter: 200mm |  | 31 | $5.00 | $155.00 |
| 2 | pure nickel Processing parts<br>3 mm thickness<br>Diameter: 200mm |  | 5 | $5.00 | $25.00 |
| **Total Amount** | | | **36** | | **$180.00** |

**Terms & Conditions**

1, Payment:TT 30% as deposit, the balance 70% before shipment.

2, Trade Term:DDP north lebanon.

3, Pack:Standard packing.

4, Delivery time: within 15 working days after receiving deposit.

5, The price is valid within 10 days.

6,Exchange rate: 1 USD = 7.2 RMB

For and on behalf of
Wuxi Oriental Denuo International Trading Co., Ltd.
无锡东方德诺国际贸易有限公司

Authorized Signature(s)

### 5.5.2.3 PTFE invoice

# INVOICE

Contract no:240719-1 Gemmy Heart Priceless Conscience Date:2024.7.19

The sellers:

Langfang gemmy sealing materials Co., Ltd.

Guang An town, DaCheng county LangFang city HeBei province china. + 8613722605656

gemmyheart@hotmail.com

The buyers:

Mariam R

Say total amount:249.6USD

| NO. | product | size | qty | price | total |
|---|---|---|---|---|---|
| 1 | ptfe gasket | inlet step 1 2 3 | 3 | 3 | 9 |
| 2 | 3mm thickness | step 12 3 | 56 | 1.6 | 89.6 |
| 3 | | outlet step 123 | 3 | 3 | 9 |
| 4 | | inlet step 4 5 | 2 | 3 | 6 |
| 5 | | step 4 5 | 3 | 2 | 6 |
| 6 | | outlet step 4 5 | 2 | 3 | 6 |
| 7 | | behind current plate | 2 | 2 | 4 |
| 8 | | redesign | 12 | 2 | 24 |
| | shipping cost | fedex | 1 | 96 | 96 |
| | Total: 249.6USD DAP | | | | |

lead time: 5days ready

total gross weight:12KG

Insurance:to be covered by buyers

Terms of payment:100%TT in advance

volume: 0.01m³

The sellers: The buyers:

Bank Account (:Hong Kong account, supports multiple currencie)

| | |
|---|---|
| Beneficiary Name | Langfang Gemmy Sealing Materials Co., Ltd. |
| Beneficiary account number | 393933763 |
| Country/Region | HongKong |
| Swift Code | CITIHKHX or CITIHKHXXXX |
| Beneficiary Address | Unit 06, 12/F., Emperor Group Centre, 288 Hennessy Road, Wan Chai, Hong Kong |
| Beneficiary Bank | CITIBANK, N.A., HONG KONG BRANCH citibank |
| Beneficiary Bank Address | CHAMPION TOWER, THREE GARDEN ROAD, CENTRAL, HONG KONG |
| Bank Code | 006 |
| Branch Code | 391 |

Supported Currencies :

USD EUR AUD GBP CAD HKD JPY SGD CNY

Langfang gemmy Sealing Materials Co., Ltd.

address:No. Guang'an town, Dacheng County, Langfang City, Hebei Province, China

alipay:hbxxmf@alibaba.com.cn 许东旭

# INVOICE

Contract no:240719-1 Gemmy Heart Priceless Conscience Date:2024.7.19

The sellers:

Langfang gemmy sealing materials Co., Ltd.

Guang An town, DaCheng county LangFang city HeBei province china. + 8613722605656

gemmyheart@hotmail.com

The buyers:

Mariam R

Say total amount:33.2USD

| NO. | product | size | qty | price | total |
|---|---|---|---|---|---|
| 1 | ptfe gasket | inlet step 1 2 3 | 3 | 0.4 | 1.2 |
| 2 | 3mm thickness | step 12 3 | 56 | 0.4 | 22.4 |
| 3 | | outlet step 123 | 3 | 0.4 | 1.2 |
| 4 | | inlet step 4 5 | 2 | 0.4 | 0.8 |
| 5 | | step 4 5 | 3 | 0.4 | 1.2 |
| 6 | | outlet step 4 5 | 2 | 0.4 | 0.8 |
| 7 | | behind current plate | 2 | 0.4 | 0.8 |
| 8 | | redesign | 12 | 0.4 | 4.8 |
| | Total: 33.2USD DAP | | | | |

lead time: 5days ready

total gross weight:12KG

Insurance:to be covered by buyers

Terms of payment:100%TT in advance

volume: 0.01m³

The sellers: The buyers:

Bank Account (:Hong Kong account, supports multiple currencie)

| | |
|---|---|
| Beneficiary Name | Langfang Gemmy Sealing Materials Co., Ltd. |
| Beneficiary account number | 393933763 |
| Country/Region | HongKong |
| Swift Code | CITIHKHX or CITIHKHXXXX |
| Beneficiary Address | Unit 06, 12/F., Emperor Group Centre, 288 Hennessy Road, Wan Chai, Hong Kong |
| Beneficiary Bank | CITIBANK, N.A., HONG KONG BRANCH citibank |
| Beneficiary Bank Address | CHAMPION TOWER, THREE GARDEN ROAD, CENTRAL, HONG KONG |
| Bank Code | 006 |
| Branch Code | 391 |

Supported Currencies :

USD EUR AUD GBP CAD HKD JPY SGD CNY

Langfang gemmy Sealing Materials Co., Ltd.

address:No. Guang'an town, Dacheng County, Langfang City, Hebei Province, China

alipay:hbxxmf@alibaba.com.cn 许东旭

# INVOICE

Contract no:240808-12 Gemmy Heart Priceless Conscience Date:2024.8.8

The sellers:

Langfang gemmy sealing materials Co.,Ltd.

Guang An town, DaCheng county LangFang city HeBei province china. + 8613722605656

gemmyheart@hotmail.com

The buyers:

Mariam R

Say total amount:47.6USD

| NO. | product | size | qty | price | total |
|---|---|---|---|---|---|
| 1 | ptfe gasket | step 12 3 | 6 | 1.6 | 9.6 |
| 2 | | step 4 5 | 4 | 2 | 8 |
| | shipping cost | fedex | 1 | 30 | 30 |
| | Total: 47.6USD DAP | | | | |

lead time: 5days ready

total gross weight:2KG

Insurance:to be covered by buyers

Terms of payment:100%TT in advance

volume: 0.01m³

The sellers: The buyers:

Bank Account (:Hong Kong account, supports multiple currencie)

| | |
|---|---|
| Beneficiary Name | Langfang Gemmy Sealing Materials Co., Ltd. |
| Beneficiary account number | 393933763 |
| Country/Region | HongKong |
| Swift Code | CITIHKHX or CITIHKHXXXX |
| Beneficiary Address | Unit 06, 12/F., Emperor Group Centre, 288 Hennessy Road, Wan Chai, Hong Kong |
| Beneficiary Bank | CITIBANK, N.A., HONG KONG BRANCH citibank |
| Beneficiary Bank Address | CHAMPION TOWER, THREE GARDEN ROAD, CENTRAL, HONG KONG |
| Bank Code | 006 |
| Branch Code | 391 |

Supported Currencies :

USD EUR AUD GBP CAD HKD JPY SGD CNY

Langfang gemmy Sealing Materials Co., Ltd.

address:No. Guang'an town, Dacheng County, Langfang City, Hebei Province, China

### 5.5.2.4 Stainless invoice

NAGGIAR SINCE 1860

Naggiar Trading s.a.l
Capital : L.L 2 760 000 000
C.R Beirut : 43320

ID VAT No. 168-601
www.naggiar.net

6 Hobeika Street,Saifi
Beirut 2029 6406
Lebanon

Phone +961 1 562652
Fax +961 1 448391

To : AECENAR

Beirut; 70/320273

/

NT NAHR NAGGIAR TRADING SAL

**Quotation No.** 931267 1 -0-73112

Date: June 14,2024 **SAV**

Mr/Mrs,
We thank you for your inquiry and we are pleased to quote the following:

| Item # | Secondary Qty | Unit | Description | Primary Qty About | Unit | Unit Price $ VAT Excluded | Amount |
|---|---|---|---|---|---|---|---|
| 12841 | 20.40 | KG | S.S. Sheets Aisi 304 Thickness 3.00 MM 850X1000; Mat | 20.40 | KG | 3.20 | 65.28 |
| 999922 | 0.15 | PC | LASER 1 | 0.15 | PC | 100.00 | 15.00 |

| | | | |
|---|---|---|---|
| **Subtotal** | : | **US** | **80.28** |
| **VAT sales tax 11 %** | : | **US** | **8.83** |
| **Total VAT included** | : | **US** | **89.11** |

Payment Terms : Cash by USD Banknotes
Delivery Place : NAGGIAR NAHR
Delivery Date : WITHIN 3 WORKING DAYS, FROM ORDER CONFIRMATION
Delivery Method : BY YOUR TRUCK
Validity : 3 DAYS SUBJECT UNSOLD
Special Conditions : VAT to be paid in USD

**N.B: In the event of any claim on the goods received, it should be notified to us within 24 hours after reception of your order, Any item left over after your pickup will be considered as scrap.**
**Please note that your order can be processed only in case all your previous invoices have been settled on basis of our agreement terms.**

We hope our offer is satisfactory and look forward to receive your confirmation to which we shall give our prompt and careful attention. Should you need any further information, please feel free to contact us.

Best regards,
**NAGGIAR TRADING S.A.L.**
SANDY MOUFARREJ

01-562652 ext. 225

14/06/2024 / 07:40:25 - Socrate release SP 07.34.0000 - PAGE: 1 / 1
new-nag/OMAA

NAGGIAR SINCE 1860

Naggiar Trading s.a.l
Capital : L.L 2 760 000 000
C.R Beirut : 43320

ID VAT No. 168-601
www.naggiar.net

6 Hobeika Street,Saifi
Beirut 2029 6406
Lebanon

Phone +961 1 562652
Fax +961 1 448391

To : AECENAR

Beirut; 70/320273

/

NT NAHR NAGGIAR TRADING SAL

Quotation No. 931268 1 -0-73113

Date: June 14,2024 **SAV**

Mr/Mrs,

We thank you for your inquiry and we are pleased to quote the following:

| Item # | Secondary Qty | Unit | Description | Primary Qty About | Unit | Unit Price $ VAT Excluded | Amount |
|---|---|---|---|---|---|---|---|
| 12846 | 34.00 | KG | S.S. Sheets Aisi 304 Thickness CR 5.00 MM 850X1000; Mat | 34.00 | KG | 3.20 | 108.80 |
| 999922 | 0.18 | PC | LASER 1 | 0.18 | PC | 100.00 | 18.00 |

| | | | |
|---|---|---|---|
| Subtotal | : | US | 126.80 |
| VAT sales tax 11 % | : | US | 13.95 |
| Total VAT included | : | US | 140.75 |

Payment Terms : Cash by USD Banknotes
Delivery Place : NAGGIAR NAHR
Delivery Date : WITHIN 3 WORKING DAYS, FROM ORDER CONFIRMATION
Delivery Method : BY YOUR TRUCK
Validity : 3 DAYS SUBJECT UNSOLD
Special Conditions : VAT to be paid in USD

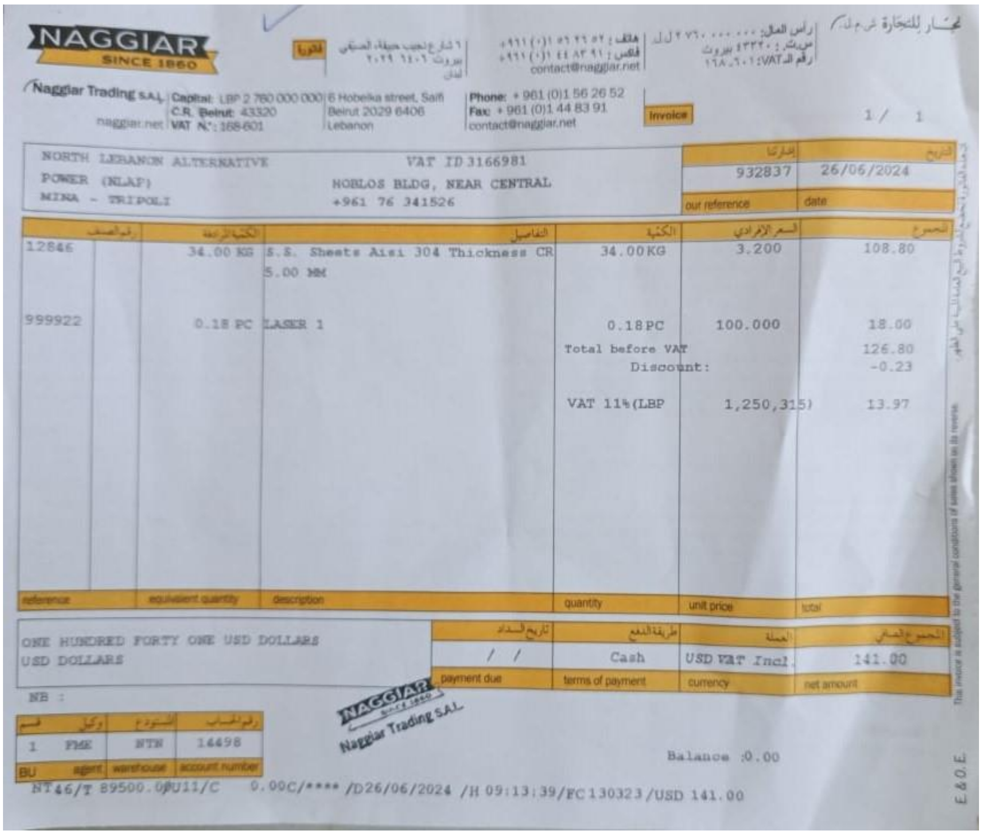
**N.B:** In the event of any claim on the goods received, it should be notified to us within 24 hours after reception of your order, Any item left over after your pickup will be considered as scrap.
Please note that your order can be processed only in case all your previous invoices have been settled on basis of our agreement terms.

We hope our offer is satisfactory and look forward to receive your confirmation to which we shall give our prompt and careful attention. Should you need any further information, please feel free to contact us.

Best regards,
**NAGGIAR TRADING S.A.L.**
SANDY MOUFARREJ

**01-562652 ext.** 225

14/06/2024 / 07:44:49 - Socrate release SP 07.34.0000 - PAGE: 1 / 1
new-nag/OMAA



NAGGIAR SINCE 1860

Naggiar Trading S.A.L. | Capital: LBP 2 760 000 000 | C.R. Beirut: 43320 | VAT N°: 168-601 | naggiar.net

6 Hobeika street, Saifi, Beirut 2029 6406, Lebanon

Phone: + 961 (0)1 56 26 52 | Fax: + 961 (0)1 44 83 91 | contact@naggiar.net

Invoice 1/ 1

NORTH LEBANON ALTERNATIVE POWER (NLAP) MINA - TRIPOLI
VAT ID 3166981
HOBLOS BLDG, NEAR CENTRAL
+961 76 341526

| our reference | date |
|---|---|
| 932837 | 26/06/2024 |

| reference | | equivalent quantity | description | quantity | unit price | total |
|---|---|---|---|---|---|---|
| 12846 | | 34.00 KG | S.S. Sheets Aisi 304 Thickness CR 5.00 MM | 34.00KG | 3.200 | 108.80 |
| 999922 | | 0.18 PC | LASER 1 | 0.18PC | 100.000 | 18.00 |
| | | | | Total before VAT | | 126.80 |
| | | | | Discount: | | -0.23 |
| | | | | VAT 11%(LBP | 1,250,315) | 13.97 |

ONE HUNDRED FORTY ONE USD DOLLARS
USD DOLLARS

| payment due | terms of payment | currency | net amount |
|---|---|---|---|
| / / | Cash | USD VAT Incl. | 141.00 |

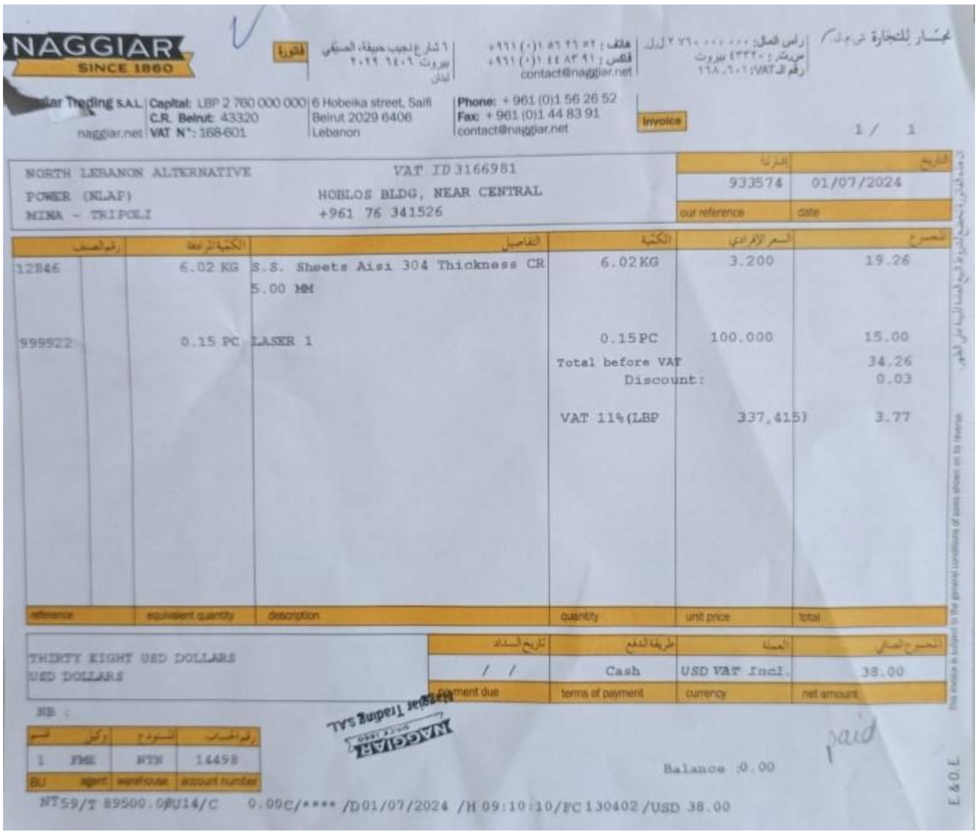
NB :

| BU | agent | warehouse | account number |
|---|---|---|---|
| 1 | FME | NTN | 14498 |

Balance :0.00

NT46/T 89500.0ØU11/C 0.00C/**** /D26/06/2024 /H 09:13:39/FC130323/USD 141.00

E.&O.E.



NAGGIAR SINCE 1860

Naggiar Trading S.A.L. | Capital: LBP 2 760 000 000 | C.R. Beirut: 43320 | VAT N°: 168-601 | naggiar.net

6 Hobeika street, Saifi, Beirut 2029 6406, Lebanon

Phone: + 961 (0)1 56 26 52 | Fax: + 961 (0)1 44 83 91 | contact@naggiar.net

Invoice 1/ 1

NORTH LEBANON ALTERNATIVE POWER (NLAP) MINA - TRIPOLI
VAT ID 3166981
HOBLOS BLDG, NEAR CENTRAL
+961 76 341526

| our reference | date |
|---|---|
| 933574 | 01/07/2024 |

| reference | | equivalent quantity | description | quantity | unit price | total |
|---|---|---|---|---|---|---|
| 12846 | | 6.02 KG | S.S. Sheets Aisi 304 Thickness CR 5.00 MM | 6.02KG | 3.200 | 19.26 |
| 999922 | | 0.15 PC | LASER 1 | 0.15PC | 100.000 | 15.00 |
| | | | | Total before VAT | | 34.26 |
| | | | | Discount: | | 0.03 |
| | | | | VAT 11%(LBP | 337,415) | 3.77 |

THIRTY EIGHT USD DOLLARS
USD DOLLARS

| payment due | terms of payment | currency | net amount |
|---|---|---|---|
| / / | Cash | USD VAT Incl. | 38.00 |

NB :

| BU | agent | warehouse | account number |
|---|---|---|---|
| 1 | FME | NTN | 14498 |

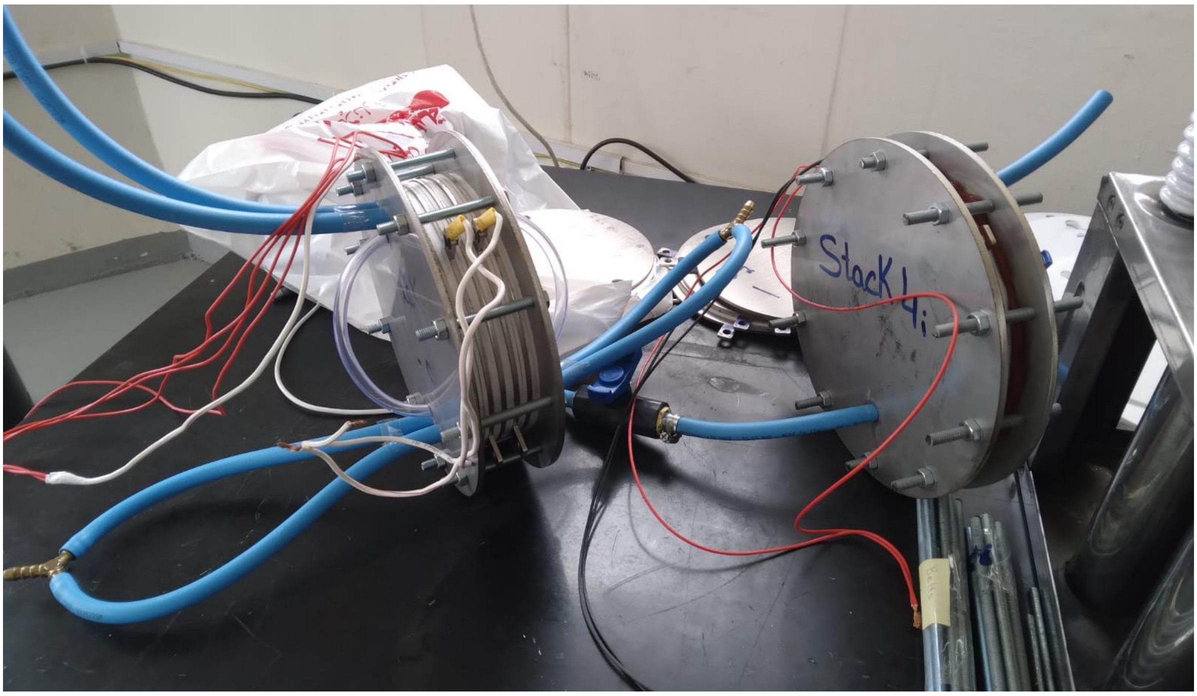
paid

Balance :0.00

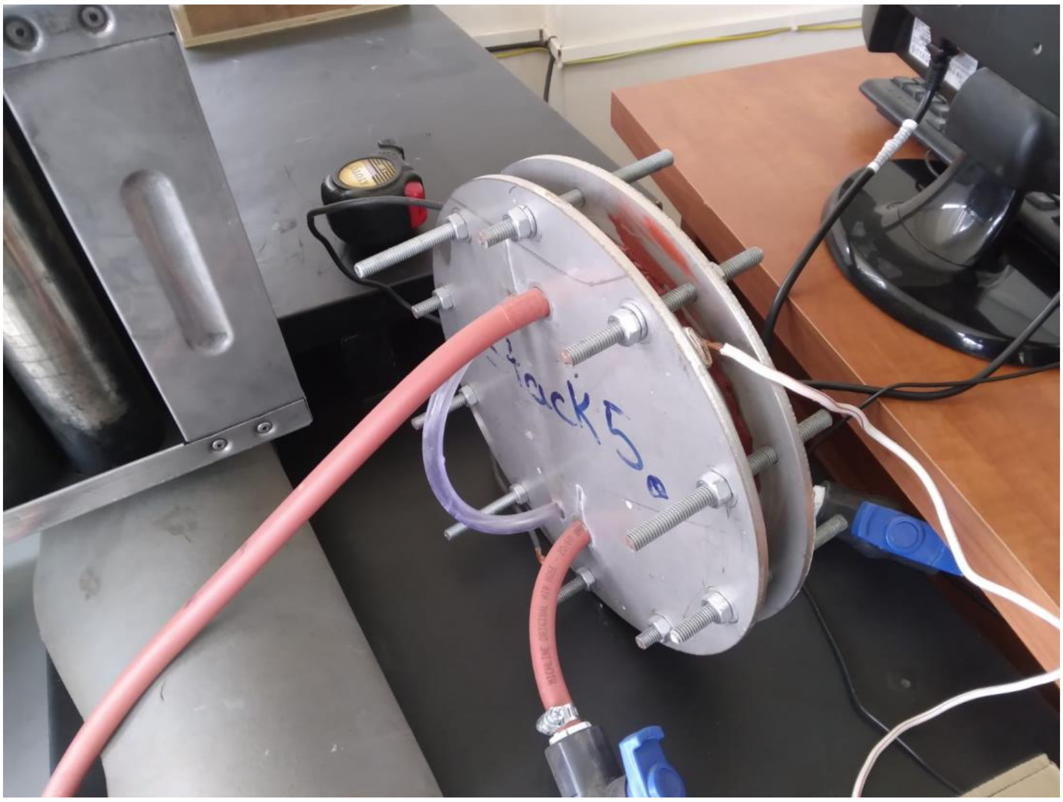
NT59/T 89500.0ØU14/C 0.00C/**** /D01/07/2024 /H 09:10:10/FC130402/USD 38.00

E.&O.E.

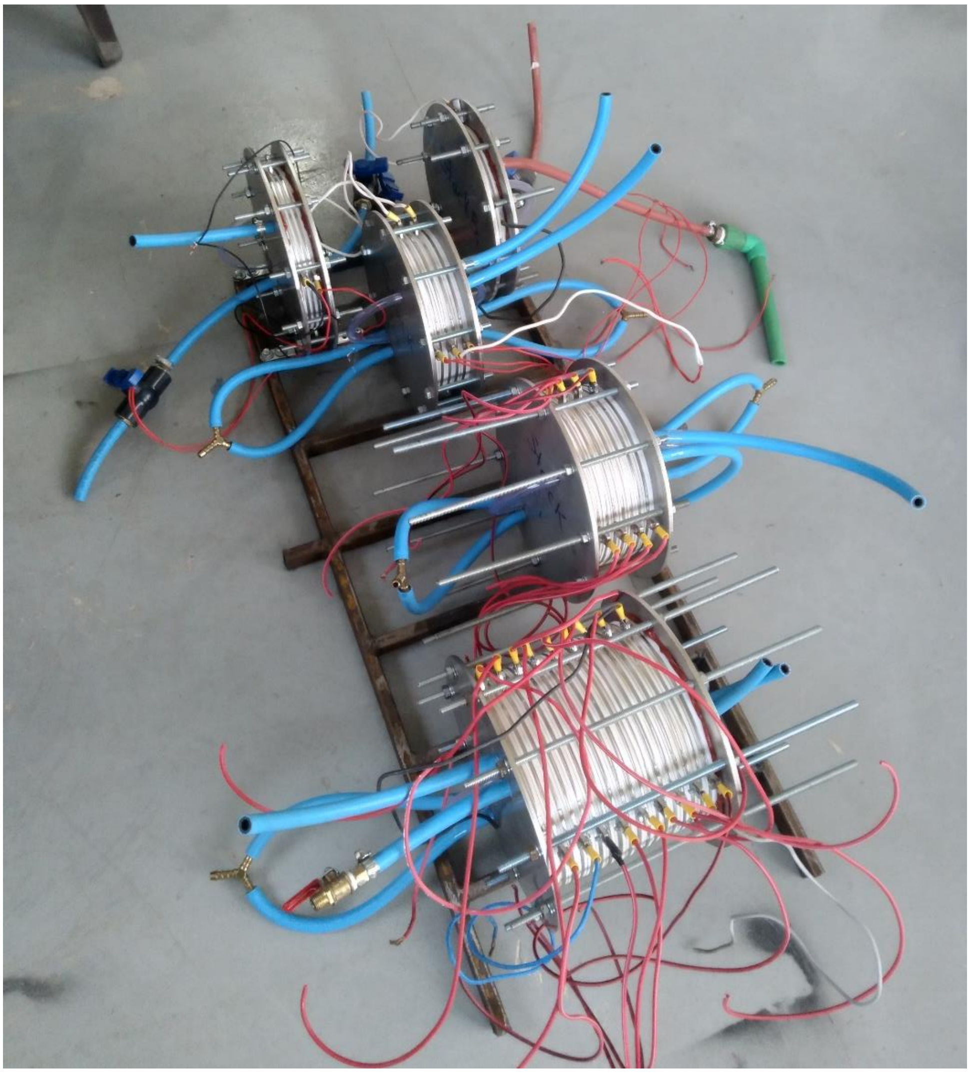
### 5.5.3 Realization of MSE stacks




*Picture above: Stack 3 (left) and Stack 4 (right)*




*Picture above: Stack 5*

*Pictures above: Stack 1 to 5*

## 5.6 Operation of the system

### 5.6.1 Preparation of KOH solution

To prepare this solution we need a:

- 50 L of distilled water
- 4 kg* of KOH crystals

* ⚠ N.B.: The lower the purity of the crystals, the more crystals we need

- Plastic or glass bowl
- Tank 60L of volume
- balance weight per gram
- Stick to mix solution
- pH meter
- Funnel
- Gloves

We weighed 1400 gr of the KOH crystals via a weighing balance. We put 50 L of distilled water in the tank, then added the KOH crystals and mixed the solution well. Based on the value (the pH shall be 13.6), we measured the pH of the solution and added water and/or crystals.

### 5.6.2 Pre-Operation

1- The Dry ice powder is available

2- The dry ice tank and distillation tank are connected properly

3- The butane gas bottle is full and connected properly to the stove

4- The distilled water tank is in the appropriate place to receive drops of distilled water coming out of the distillation tank

5- All mechanical connections are done

6- Close the ball manual valve of the water tank and fill it with distilled water

7- Close the ball manual valve of the KOH tank and fill it with the KOH solution prepared previously

8- Ensure that the pipes are connected correctly and repair leaks, if any

9- Fill the gas filters with water halfway

10- Ensure that all mechanical valves are working properly, opening and closing

11- Ensure that all electrical equipment (Electrical valves, pumps, sensors, …) is connected to the electrical current

12- Ensure that the system is controlled correctly through the GUI

13- Ensure the DC power is connected correctly to the cells of each stack

14- All breakers (**$B_1$**, **$B_2$**, **$B_3$**, **$B_4$**, and **$B_5$**) are opened

15- Wash the system with nitrogen gas

1) Open all inlet automatic controller valves of stacks
(Valve **$ASI_1$**, **$ASI_2$**, **$ASI_3$**, **$ASI_4$**, and **$ASI_5$**)

2) Close all outlet automatic controller valves of stacks
(Valve **$ASO_1$**, **$ASO_2$**, **$ASO_3$**, **$ASO_4$**, and **$ASO_5$**)

3) Open the automatic controller valves of hydrogen and oxygen gases
(Valves **$AH_1$**, **$AH_2$**, **$AH_3$**, **$AO_1$**, **$AO_2$**, and **$AO_3$**)

4) Open the ball valve of hydrogen gas **VH** and oxygen gas **VO**

5) Connect the nitrogen tank with the stacks by nitrogen valves
(valve **$AN_1$**, **$AN_2$**, **$AN_3$**, **$AN_4$**, and **$AN_5$**)

6) Open the nitrogen valves (Valve **$AN_1$**, **$AN_2$**, **$AN_3$**, **$AN_4$**, and **$AN_5$**)

7) Open the valve of Nitrogen tank for 5-10 minutes at 3 bars

8) Close the nitrogen tank **$VN_0$**, and nitrogen valves
(Valve **$VN_1$**, **$AN_2$**, **$AN_3$**, **$AN_4$**, and **$AN_5$**)

9) Close the Hydrogen valves (Valve **$AH_1$**, **$AH_2$**, and **$AH_3$**) & Oxygen valves
(Valve **$AO_1$**, **$AO_2$**, and **$AO_3$**)

10) Close the **VH** and **VO** valves

16- Connecting electricity to the fuel cells to withdraw the electricity generated from the fuel cells

17- Reclose all valves

### 5.6.3 Operation of the MSE system

1- Fill the Condensers with the previously prepared KOH solution using the following steps:

1) Open the KOH tank valve **SV**

2) Open the **$AC_1$**, **$AC_2$**, **$AC_3$** and **$AC_4$** to get solution into the condensers

3) Turn ON the KOH pump (**SP**)

2- Fill the Stack #1 with the previously prepared KOH solution using the following steps:

1) Open the **AH**$_1$ and **VH** valve

2) Open the **AO**$_1$ and **VO** valve

3) Open the **ASI**$_1$ valve; to enter the KOH solution into stack #1

4) When the KOH solution reaches the required level in Stack #1, close **ASI**$_1$ while keeping the **AC**$_1$**, AC**$_2$**, and AC**$_3$ valves opened

3- Turn ON the electricity (DC) on Stack #1 by closing breaker **B**$_1$

4- Monitoring the solution level in Stack #1, pH, electrical voltage with current, and temperature through sensors

⚠ **N.B.: If the temperature of the Stack increases, we disconnect the DC electricity for some time to reduce the temperature of the stack. We can also add more KOH solution to the stack to cool the stack if the solution level decreases.**

5- Transfer the remaining solution in Stack #1 to the dry ice tank in the following steps:

1) When the appropriate pH is reached (or the solution level drops to half or less if no solution is added), we disconnect the electrical current from the stack by opening breaker **B**$_1$

2) Close **AO**$_1$ valve

3) Open the **ASO**$_1$ valve to empty the solution from the stack

4) Open **VMS**$_1$ valve, with keeping the **AD**$_1$ valves closed

6- When the stack is empty, close **VMS**$_1$

7- Add the right amount of dry ice into the dry ice tank intermittently and in small quantities*

* ⚠ **N.B.: It is important to add dry ice intermittently and in small quantities to avoid boiling and/or freezing and to ensure the effective interaction of materials, as well as for personal safety.**

8- When the reaction of Dry ice with concentrated KOH solution is finished, Open the **$AD_1$** valve

9- Open the **WV** and the **$AW_1$** valves and Turn ON the water pump (**WP**)
10- Setting a fire under the distillation tank

11- When the distillation process is finished, open the **$ACS_1$** valve to add the rest of the KOH solution (5%) to the distilled water tank. Now the KOH solution is ready to be added to Stack #2

12- Turn OFF the water pump (**WP**) if there is no need for other systems, then close the **WV** valve

13- <u>To re-install stack #1</u>, close the **$ASO_1$** valve, and repeat the $2^{nd}$ step to the $12^{th}$ of operation steps

14- <u>Add the new KOH solution</u> (Final solution extracted from Stack #1) <u>to Stack #2</u>

1) Open the **$AH_2$** and **VH** valve

2) Open the **$AO_2$** and **VO** valve

3) Open the **$ASI_2$** valve; to enter the KOH solution into stack #2

4) When the KOH solution reaches the required level in Stack #2, close **$ASI_2$** while keeping the **$AC_1$, $AC_2$, and $AC_3$** valves opened

15- Turn ON the electricity (DC) on Stack #2 by closing breaker **$B_2$**

16- Monitoring the solution level in Stack #2, pH, electrical voltage with current, and temperature through sensors

17- <u>Transfer the remaining solution in Stack #2 to the dry ice tank</u> in the following steps:

1) When the appropriate pH is reached (or the solution level drops to half or less if no solution is added), we disconnect the electrical current from the stack by opening breaker **$B_2$**

2) Close **$AO_2$** valve

3) Open the **$ASO_2$** valve to empty the solution from the stack

4) Open **$VMS_2$** valve, with keeping the **$AD_2$** valves closed

18- When the stack is empty, close **VMS$_2$**

19- Add the right amount of dry ice into the dry ice tank intermittently and in small quantities

20- When the reaction of Dry ice with concentrated KOH solution is finished, Open the **AD$_2$** valve

21- Open **AW$_2$** - Open the **WV** valve if it is closed - and Turn ON the water pump (**WP**), if it isn't running

22- Setting a fire under the distillation tank

23- When the distillation process is finished, open the **ACS$_2$** valve to add the rest of the KOH solution (5%) to the distilled water tank. Now the KOH solution is ready to be added to Stack #3

24- <u>To re-install stack #2</u>, close the **ASO$_2$** valve, open the **ASI$_2$**, the **AH$_2$** valve, and the **AO$_2$** valve, and repeat the 14$^{th}$ step to 23$^{th}$ of operation steps

25- <u>Add the new KOH solution</u> (Final solution extracted from Stack #2) <u>to Stack #3</u>

1) Open the **AH$_3$** and **VH** valve

2) Open the **AO$_3$** and **VO** valve

3) Open the **ASI$_3$** valve; to enter the KOH solution into stack #3

4) When the KOH solution reaches the required level in Stack #3, close **ASI$_3$** while keeping the **AC$_1$, AC$_2$, and AC$_3$** valves opened

26- Turn ON the electricity (DC) on Stack #3 by closing breaker **B$_3$**

27- Monitoring the solution level in Stack #3, pH, electrical voltage with current, and temperature through sensors

28- <u>Transfer the remaining solution in Stack #3 to the dry ice tank</u> in the following steps:

1) When the appropriate pH is reached (or the solution level drops to half or less if no solution is added), we disconnect the electrical current from the stack by opening breaker **B$_3$**

2) Close **AO$_3$** valve

3) Open the **ASO**$_3$ valve to empty the solution from the stack

4) Open **VMS**$_3$ valve, with keeping the **AD**$_3$ valves closed

29- When the stack is empty, close **VMS**$_3$

30- Add the right amount of dry ice into the dry ice tank intermittently and in small quantities

31- When the reaction of Dry ice with concentrated KOH solution is finished, Open the **AD**$_3$ valve

32- Open **AW**$_3$ - Open the **WV** valve if it is closed - and Turn ON the water pump (**WP**), if it isn't running

33- Setting a fire under the distillation tank

34- When the distillation process is finished, open the **ACS**$_3$ valve to add the rest of the KOH solution (5%) to the distilled water tank. Now the KOH solution is ready to be added to Stack #4

35- <u>To re-install stack #3</u>, close the **ASO**$_3$ valve, open the **ASI**$_3$, the **AH**$_3$ valve, and the **AO**$_3$ valve, and repeat the 25$^{th}$ step to 34$^{th}$ of operation steps

36- If Stack #1, Stack #2, and Stack #3 are turned OFF, Turn OFF the KOH solution pump (**SP**) and close the **SV** valve

37- <u>Add the new KOH solution</u> (Final solution extracted from Stack #3) <u>to Stack #4</u>

1) Open the **ASI**$_4$ valve; to enter the KOH solution into stack #4

2) Add the newest KOH solution (extracted KOH solution from Stack #3) to Stack #4

3) When the KOH solution reaches the required level in Stack #4, close **ASI**$_4$

38- Turn ON the electricity (DC) on Stack #4 by closing breaker $B_4$

39- Monitoring the solution level in Stack #4, pH, electrical voltage with current, and temperature through sensors

40- <u>Transfer the remaining solution in Stack #4 to the dry ice tank</u> in the following steps:

1) When the appropriate pH is reached (or the solution level drops to half or less if no solution is added), we disconnect the electrical current from the stack by opening breaker **$B_4$**

2) Open the **$ASO_4$** valve to empty the solution from the stack

3) Open **$VMS_4$** valve, with keeping the **$AD_4$** valves closed

41- When the stack is empty, close **$VMS_4$**

42- Add the right amount of dry ice into the dry ice tank intermittently and in small quantities

43- When the reaction of Dry ice with concentrated KOH solution is finished, Open the **$AD_4$** valve

44- Open **$AW_4$** - Open the **WV** valve if it is closed - and Turn ON the water pump (**WP**), if it isn't running

45- Setting a fire under the distillation tank

46- When the distillation process is finished, open the **$ACS_4$** valve to add the rest of the KOH solution (5%) to the distilled water tank. Now the KOH solution is ready to be added to Stack #5

47- When the fuel cell **$FC_1$** is run (when Stack #4 is running), the water coming out of Fuel cell **$FC_1$** must be collected and then added to the product solution from Stack #3 as well.

48- <u>To re-install stack #4</u>, close the **$ASO_4$** valve, open the **$ASI_4$** valve, and repeat the $37^{th}$ step to $48^{th}$ of operation steps

49- <u>Add the new KOH solution</u> (Final solution extracted from Stack #4) <u>to Stack #5</u>

1) Open the **$ASI_5$** valve; to enter the KOH solution into stack #5

2) Add the newest KOH solution (extracted KOH solution from Stack #4) to Stack #5

3) When the KOH solution reaches the required level in Stack #4, close **$ASI_5$**

50. Turn ON the electricity (DC) on Stack #5 by closing breaker **$B_5$**
51. Monitoring the solution level in Stack #5, pH, electrical voltage with current, and temperature through sensors

52. Transfer the remaining solution in Stack #5 to the dry ice tank in the following steps:

    1) When the appropriate pH is reached (or the solution level drops to half or less if no solution is added), we disconnect the electrical current from the stack by opening breaker $\mathbf{B_5}$

    2) Open the $\mathbf{ASO_5}$ valve to empty the solution from the stack

    3) Keep the $\mathbf{AD_5}$ valve closed

53- Add the right amount of dry ice into the dry ice tank intermittently and in small quantities

54- When the reaction of Dry ice with concentrated KOH solution is finished, Open the $\mathbf{AD_5}$ valve

55- Open $\mathbf{AW_5}$ - Open the **WV** valve if it is closed - and Turn ON the water pump (**WP**), if it isn't running

56- Setting a fire under the distillation tank

57- When pre-starting fuel cell $\mathbf{FC_2}$(when Stack #5 is running), the water coming out of Fuel cell $\mathbf{FC_2}$ must be collected in HW tank

58- When the fuel cell $\mathbf{FC_2}$ is run (when Stack #5 is running), the water coming out of Fuel cell $\mathbf{FC_2}$ must be collected and then added to the distilled water produced from Stack #5

59- When the distillation process is finished, the distilled water collected in the distilled water tank should be added to the HW tank. Now the HW is ready to be tested or used.

60- To re-install stack #5, close the $\mathbf{ASO_5}$ valve, open the $\mathbf{ASI_5}$ valve, and repeat the $49^{th}$ step to $59^{th}$ of operation steps

61- Turn OFF the water pump (**WP**)

### 5.6.4 Post - Operation

1- All breakers are opened ($\mathbf{B_1}$, $\mathbf{B_2}$, $\mathbf{B_3}$, $\mathbf{B_4}$, and $\mathbf{B_5}$)

2- Wash the system with nitrogen gas by using the following steps:

1) Open all inlet automatic controller valves of stacks
(Valve **$ASI_1$**, **$ASI_2$**, **$ASI_3$**, **$ASI_4$**, and **$ASI_5$**)

2) Close all outlet automatic controller valves of stacks
(Valve **$ASO_1$**, **$ASO_2$**, **$ASO_3$**, **$ASO_4$**, and **$ASO_5$**)

3) Open the automatic controller valves of hydrogen and oxygen gases
(Valves **$AH_1$**, **$AH_2$**, **$AH_3$**, **$AO_1$**, **$AO_2$**, and **$AO_3$**)

4) Open the ball valve of hydrogen gas **VH** and oxygen gas **VO**

5) Connect the nitrogen tank with the stacks by nitrogen valves
(valve **$AN_1$**, **$AN_2$**, **$AN_3$**, **$AN_4$**, and **$AN_5$**)

6) Open the nitrogen valves (Valve **$AN_1$**, **$AN_2$**, **$AN_3$**, **$AN_4$**, and **$AN_5$**)

7) Open the valve of Nitrogen tank for 5-10 minutes at 3 bars

8) Close the nitrogen tank **$VN_0$**, and nitrogen valves
(Valve **$VN_1$**, **$AN_2$**, **$AN_3$**, **$AN_4$**, and **$AN_5$**)

9) Close the Hydrogen valves (Valve **$AH_1$**, **$AH_2$**, and **$AH_3$**) & Oxygen valves
(Valve **$AO_1$**, **$AO_2$**, and **$AO_3$**)

10) Close the **VH** and **VO** valves

3- Wash the condensers with distilled water after operation using the following steps:

1) The **SP** pump is turned OFF

2) Close the KOH tank valve (**SV**)

3) Open the **$AC_1$**, **$AC_2$**, and **$AC_3$** valves

4) Open the **$DW_0$** valve

5) The **$ASI_1$** and **$AC_4$** valves is closed

6) Open the **$WI_1$** valve, Close the **$AW_1$**, **$AW_2$**, **$AW_3$**, **$AW_4$**, **$AW_5$**, **$AW_6$**, and **$AW_7$**

7) Open the **WV** valve and Turn ON the water pump (**WP**)

8) Wait 10-15 minutes and turn OFF the **WP** pump

9) Close the **WI**$_1$ valve

4- Wash the Stack#1 used in operation with water by following steps:

1) Close **AC**$_1$ and **DW**$_0$ valves

2) Open **ASI**$_1$ and **ASO**$_1$ valves

3) Open **WI**$_1$ valve

4) Turn ON the water pump **WP**

5) Check the level sensor to open the **DW**$_1$ valve

6) Wait 3 minutes then Turn OFF the **WP** pump and close the **ASI**$_1$ valve

7) Wait until the water stops coming out, then close the **ASO**$_1$ valve

8) Close the **DW**$_1$ valve

5- Wash Stack#2, Stack#3, Stack#4, and Stack#5 used in operation with water by following steps:

1) Open **WI**$_x$ valve appropriate to the stack

2) Open the **ASI**$_x$ and **ASO**$_x$ valves appropriate to the stack

3) Turn ON the water pump **WP**

4) Check the level sensor to open the **DW**$_x$ valve appropriate to the stack

5) Turn OFF the **WP** pump

6) Wait until the water stops coming out, then close the **ASI**$_x$ and **ASO**$_x$ valves appropriate to the stack

7) Close the **DW**$_x$ valve appropriate to the stack

6- Wash the Dry ice tank used in the operation with water

7- Wash the lower part of the distillation tank

8- Disconnect All electrical components

⚠ **N.B.:**

- **We can replace cooling water pipes with water hoses.**
- **As for the distillation tank and dry ice tank, we can manufacture (or purchase) them in one piece and use them alternately for all stages of operation, provided that they are cleaned after each use.**
- **We can cool the condensers with water instead of KOH solution, but this requires an adjustment at valves $AC_1$ and $AC_4$.**
- **We can replace the Nitrogen pipe with Nitrogen or Gas hoses.**
- **Instead of DW valves, we can separate the dry ice tank from the stack.**
- **We can replace the current fuel cell with a fuel cell based on Hydrogen and Oxygen for higher efficiency**

## 5.7 System Test Specifications

### 5.7.1 KOH-Dry ice reaction followed by distillation process

| Step | Step description | Expected result |
|---|---|---|
| Pre-condition | KOH solution is placed in the distillation tank (bottom part) | |
| Add Dry ice | - Put the bottom distillation tank in a place well ventilated<br>- Add the dry ice finger to the KOH solution | - Heavy white smoke rising<br>- The formed solution ($K_2CO_3$) in a liquid state |
| Distillation process | - Collect the upper part with the lower part of the distillation tank<br>- Put tape where the two parts meet<br>- Add the cooling water to the upper part of the tank<br>- Close the water drain hole<br>- Put the distillation tank on the fire<br>- Put the Erlenmeyer at the outlet of the distilled water | - No leakage of steam<br>- Condensation of water<br>- About 950 mL of distilled water is reclaimed<br>- The bottom of the distillation tank |

| | | |
|---|---|---|
| | - Change the cooling water every 10-15 minutes<br><br>- When about 950 ml of water is distilled, remove the distillation tank from the fire<br><br>- Empty the cooling water and wait for the tank to cool<br><br>- Separate the upper part from the lower part of the distillation tank<br><br>- Collect the distilled water resulting from the distillation process<br><br>- Measure the pH of the water using the pH meter | (bottom part) is corroded<br><br>- The pH of the distilled water is 7 |

### 5.7.2 Leakage, followed by installation of the stack (Step 4, and 5)

| Step | Step description | Expected result |
|---|---|---|
| Pre-condition | KOH solution is placed in the distillation tank (bottom part) | |
| Add Dry ice | - Put the bottom distillation tank in a place well ventilated<br><br>- Add the dry ice finger to the KOH solution | - Heavy white smoke rising<br><br>- The formed solution ($K_2CO_3$) in a liquid state |
| Distillation process | - Collect the upper part with the lower part of the distillation tank<br><br>- Put tape where the two parts meets<br><br>- Fixed the distillation tank in the water bath<br><br>- Put the water bath on fire<br><br>- Add water to the bath<br><br>- Add the cooling water to the upper part of the tank<br><br>- Close the water drain hole | - No leakage of steam<br><br>- Condensation of water<br><br>- About 950 mL of distilled water is reclaimed<br><br>- The bottom of the distillation tank (bottom part) is corroded<br><br>- The pH of the distilled water is 7 |

| | | |
|---|---|---|
| | - Put the Erlenmeyer at the outlet of the distilled water<br><br>- Change the cooling water every 10-15 minutes<br><br>When about 950 ml of water is distilled, remove the water bath distillation tank from the fire<br><br>- Remove the distillation tank from the water bath<br><br>- Empty the cooling water and wait for the tank to cool<br><br>- Separate the upper part from the lower part of the distillation tank<br><br>- Collect the distilled water resulting from the distillation process<br><br>- Measure the pH of the water using the pH meter | |

### 5.7.3 Leakage, followed by installation of the stack (step 1, 2, and 3)

| Step | Step description | Expected result |
|---|---|---|
| Pre-condition | - Stack is empty<br><br>- All equipment (electrical and mechanical) is connected properly | |
| Fill the stack | - Open the inlet ball valve to fill the stack with KOH solution<br><br>- Accurately introduce the KOH solution into the stack via the inlet hole, employing a funnel for precise pouring.<br><br>- When the stack is filled (two-thirds full), close the inlet ball valve. | - The stack is filled by the KOH solution<br><br>- No leak appears |

| | | |
|---|---|---|
| Verify connections and electrospinning | - Check electrical equipment is connected<br>- Put the multimeter on "Diode mode"<br><br>- Connect each pole of the multimeter (diode mode) to each end plate<br><br>- Connect each pole of the multimeter (diode mode) to each electrode<br><br>- Connect the poles of the multimeter (diode mode) to both the electrode and end plate | - All electrical equipment is connected<br><br>- The multimeter is functioned in "Diode mode"<br><br>- The multimeter is beeps<br><br>- The multimeter beeps<br><br>- The multimeter does not beep |
| Install the system | - Turn ON the power supply<br><br>- Regulate DC voltage and current | - The power is turned ON<br><br>- Gas bubbles ($H_2$ & $O_2$) popping in the gas purification tank |
| Burn the mixed gases formed | - Close the regulator valve of the torch handle<br><br>- Wait a few minutes for the gases to compress slightly<br><br>- Open the regulator valve of the torch handle and bring a spark beside the torch handle with the regulator valve knob | - The mixed gas is burned |
| Turn OFF the system | - Turn OFF the power supply | - The power supply is turned OFF<br><br>- After a few minutes, the flame dwindles and disappears |
| Measurement of pH | - Emptying the KOH solution from the stack<br><br>- Take a sample from the KOH solution<br><br>- Use the pH meter to find out the new pH | - The new pH is higher than the old one (initial pH) |

## 5.8 System Tests

### 5.8.1 KOH/Dry ice rx followed by distillation process test “MSE-T1” (Friday 20.09.2024)

This test is a validation of the application of the distillation process and therefore the correctness of the proposed design

#### 5.8.1.1 Materials

- **<u>Materials for the KOH slt° preparation</u>**

  KOH solid (200 gr)

  Distilled water (1000 mL)

  Spatula

  Beaker (V = 1L)

  Digital balance

  Spatula glass

- **<u>Materials for the KOH-Dry Ice reaction</u>**

  Dry ice (1 Kg finger)

  Spatula glass

- **<u>Materials for the distillation process</u>**

  Distillation tank (Consists of two parts: an upper part (cooling part) and a lower part)

  Water (for cooling)

  Stove (Source of heat)

  Erlenmeyer flask (V = 1L)

  pH-meter

#### 5.8.1.2 Safety precautions

1) Wear appropriate protective equipment:
   - Gloves
   - Goggles
   - Lab coat

2) Perform the reaction KOH/Dry ice in a well-ventilated area
3) Use a suitable reaction vessel
4) Add dry slowly

5) Avoid direct contact with the solution
6) Have a fire extinguisher readily available
7) Use a heat source with a variable temperature control
8) Secure the glassware
9) Avoid direct contact with the hot glassware
10) Be cautious when handling the distillate
11) Properly dispose of waste

#### 5.8.1.3 Pre-test of distillation tank

- **Preparation of KOH solution**

  1) Weigh 200 gr of crystal KOH using a digital scale, spatula, and beaker
  2) Add the KOH crystals in 1 L of the distilled water
  3) Stir until the KOH dissolves completely

- **Add the dry ice finger**

  1) After dissolving the KOH in the water, we put the KOH solution prepared in the bottom of the distillation tank
  2) We put the bottom distillation tank in a ventilated place
  3) Then we add the dry ice finger to the KOH solution
  4) We wait until the reactions between the KOH and the dry ice are complete

⚠ **N.B.: If we add a lot of dry ice, we may have to wait extra time for the ice to melt and the reacted solution to return to its liquid state**

#### 5.8.1.4 Distillation process test

1) When the reaction between the solution and dry ice is complete, we have $K_2CO_3$ dissolved in water, collect the parts of the distillation tank together (the upper part with the lower)

2) We put tape where the two parts meet, to prevent steam from leaking out of the tank

3) We add the cooling water to the upper part of the tank and close the water drain hole

4) We put the distillation tank on the fire

5) We put the Erlenmeyer at the outlet of the distilled water

6) We change the cooling water every 10-15 minutes; to ensure the condensation of the water

7) When about 950 ml of water is distilled, we remove the distillation tank from the fire

8) After emptying the cooling water and waiting for the tank to cool, we separate the upper part from the lower part of the distillation tank

9) After collecting the distilled water resulting from the distillation process, we measure the pH of the water using the pH meter; to confirm the distillation rate

#### 5.8.1.5 Responsibilities

| MSE-T1 : KOH/Dry ice rx followed by distillation process test | | |
|---|---|---|
| **Task** | **Responsible** | **Note** |
| KOH preparation | Maryam R. | |
| Purchase dry ice | Muhamad K. | |
| Deliver dry ice | Ali D., Muhamad K. | |
| Mixed KOH/Dry ice | Maryam R., Muhamad K. | |
| Fixed Distillation tank | Maryam R., Ali D. | |
| Heat source for dislillation process | Ali D., Maryam R., Muhamad K. | |
| Cooling for dislillation process | Ali D., Maryam R., Muhamad K. | |
| pH measure | Muhamad K., Maryam R. | |
| Documentation | Maryam R. | |
| Equipment re-cleaning | Ali D. | |

#### 5.8.1.6 Test specification and test results of MSE-T1

| Step | Step description | Expected result | Results |
|---|---|---|---|
| Pre-condition | KOH solution is placed in the distillation tank (bottom part) | | |
| Add Dry ice | - Put the bottom distillation tank in a place well ventilated | - Heavy white smoke rising<br>- The formed solution | ☑ Heavy white smoke rising |

| | | | |
|---|---|---|---|
| | - Add the dry ice finger to the KOH solution | ($K_2CO_3$) in a liquid state | ☑ The formed solution ($K_2CO_3$) in a liquid state **after waiting** (because we put an extra amount of the dry ice) |
| Distillation process | - Collect the upper part with the lower part of the distillation tank<br>- Put tape where the two parts meets<br>- Add the cooling water to the upper part of the tank<br>- Close the water drain hole<br>- Put the distillation tank on the fire<br>- Put the Erlenmeyer at the outlet of the distilled water<br>- Change the cooling water every 10-15 minutes<br>- When about 950 ml of water is distilled, remove the distillation tank from the fire<br>- Empty the cooling water and wait for the tank to cool | - No leakage of steam<br>- Condensation of water<br>- About 950 mL of distilled water is reclaimed<br>- The bottom of the distillation tank (bottom part) is corroded<br>- The pH of the distilled water is 7 | ☑ No leakage of steam<br>☑ Water condenses and collects in the Erlenmeyer<br>☑ Water collected is about 950 mL<br>☑ The base of distillation tank (bottom part of tank) is corroded<br>☒ The pH of distilled water formed is 10.4 |

| | | | |
|---|---|---|---|
| | - Separate the upper part from the lower part of the distillation tank<br><br>- Collect the distilled water resulting from the distillation process<br><br>- Measure the pH of the water using the pH meter | | |

Video of MSE-T1 test:

MSE-T1 _
20.09.2024 _ KOH-D

#### 5.8.1.7 Test result

1) Adding too much dry ice to the KOH solution causes all the $OH^-$ to react completely, but adding too much causes the solution to freeze, forcing us to wait some time before starting the distillation process

2) Corrosion appears in the bottom part of the distillation tank (when we put the $K_2CO_3$ solution) due to the increase in temperature and concentration of the $K_2CO_3$ solution as a result of evaporation

3) The high pH of distilled water formed (10.4) means that the distilled water contains anions, this may be due to the high temperature of the solution during the distillation process

#### 5.8.1.8 What's the next test

In our test, we need to recover the water as pure water free of $KCO_3^-$ ions. To achieve this goal, we must modify the distillation process in terms of reducing the temperature of the solution in the lower section

### 5.8.2 Distillation process with water bath test "MSE-T2" (Thursday 26.09.2024)

In the previous test (test MSE-T1) we noticed that the pH of the distilled water resulting from evaporating the $K_2CO_3$ solution was not 7 but 10.4. This test seeks to obtain distilled water with a pH of 7 by adding modifications to the distillation process.

#### 5.8.2.1 Materials

- **Materials for the KOH slt° preparation**

  KOH solid (200 gr)

  Distilled water (1000 mL)

  Spatula

  Beaker (V = 1L)

  Digital balance

  Spatula glass

- **Materials for the KOH-Dry Ice reaction**

  Dry ice (1 Kg finger)

  Spatula glass

- **Materials for the distillation process**

  Distillation tank (Consists of two parts: an upper part (cooling part) and a lower part)

  Water bath for the bottom part of the distillation tank

  Water (for cooling)

  Stove (Source of heat)

  Erlenmeyer flask (V = 1L)

  pH-meter

#### 5.8.2.2 Safety precautions

1) Wear appropriate protective equipment:
   - Gloves
   - Goggles
   - Lab coat

2) Perform the reaction KOH/Dry ice in a well-ventilated area
3) Use a suitable reaction vessel
4) Add dry slowly
5) Avoid direct contact with the solution
6) Have a fire extinguisher readily available
7) Use a heat source with a variable temperature control
8) Secure the glassware
9) Avoid direct contact with the hot glassware

10) Be cautious when handling the distillate
11) Properly dispose of waste

#### 5.8.2.3 Pre-test of distillation tank

- **Preparation of KOH solution**

  1) Weigh 200 gr of crystal KOH using a digital scale, spatula, and beaker
  2) Add the KOH crystals in 1 L of the distilled water
  3) Stir until the KOH dissolves completely

- **Add the dry ice finger**

  1) After dissolving the KOH in the water, we put the KOH solution prepared in the bottom of the distillation tank

  4) We put the bottom distillation tank in a ventilated place
  5) Then we add the dry ice finger to the KOH solution
  6) We wait until the reactions between the KOH and the dry ice are complete

⚠ **N.B.: If we add a lot of dry ice, we may have to wait extra time for the ice to melt and the reacted solution to return to its liquid state**

#### 5.8.2.4 Distillation process test

1) When the reaction between the solution and dry ice is complete, we have $K_2CO_3$ dissolved in water, collect the parts of the distillation tank together (the upper part with the lower)

2) We put tape where the two parts meet, to prevent steam from leaking out of the tank

3) We fixed the distillation tank in the water bath

4) We put the water bath on fire

5) We add water to the bath

6) We add the cooling water to the upper part of the tank and close the water drain hole

7) We put the Erlenmeyer at the outlet of the distilled water

8) We change the cooling water every 10-15 minutes; to ensure the condensation of the water

9) When about 950 ml of water is distilled, we remove the water bath distillation tank from the fire

10) We remove the distillation tank from the water bath

11) After emptying the cooling water and waiting for the tank to cool, we separate the upper part from the lower part of the distillation tank

12) After collecting the distilled water resulting from the distillation process, we measure the pH of the water using the pH meter; to confirm the distillation rate

#### 5.8.2.5 Responsibilities

| **MSE-T2 : Distillation process with water bath test** | | |
|---|---|---|
| **Task** | **Responsible** | **Note** |
| KOH preparation | Maryam R. | |
| Purchase dry ice | Muhamad K. | |
| Deliver dry ice | Ali D., Muhamad K. | |
| Mixed KOH/Dry ice | Maryam R., Muhamad K. | |
| Fixed Distillation tank | Maryam R., Ali D. | |
| Heat source for dislillation process | Ali D., Maryam R., Muhamad K. | |
| Cooling for dislillation process | Ali D., Maryam R., Muhamad K. | |
| pH measure | Muhamad K., Maryam R. | |
| Documentation | Maryam R. | |
| Equipment re-cleaning | Ali D. | |

#### 5.8.2.6 Test specification and test results

| Step | Step description | Expected result | Results |
|---|---|---|---|
| Pre-condition | KOH solution is placed in the distillation tank (bottom part) | | |
| Add Dry ice | - Put the bottom distillation tank in a place well ventilated | - Heavy white smoke rising<br>- The formed solution | ☑ Heavy white smoke rising |

| | | | |
|---|---|---|---|
| | - Add the dry ice finger to the KOH solution | ($K_2CO_3$) in a liquid state | ☑ The formed solution ($K_2CO_3$) in a liquid state **after waiting** (because we put an extra amount of the dry ice) |
| Distillation process | - Collect the upper part with the lower part of the distillation tank<br><br>- Put tape where the two parts meets<br><br>- Fixed the distillation tank in the water bath<br><br>- Put the water bath on fire<br><br>- Add water to the bath<br><br>- Add the cooling water to the upper part of the tank<br><br>- Close the water drain hole<br><br>- Put the Erlenmeyer at the outlet of the distilled water<br><br>- Change the cooling water every 10-15 minutes<br><br>When about 950 ml of water is | - No leakage of steam<br>- Condensation of water<br>- About 950 mL of distilled water is reclaimed<br>- The bottom of the distillation tank (bottom part) is corroded<br>- The pH of the distilled water is 7 | ☑ No leakage of steam<br><br>☑ Water condenses and collects in the Erlenmeyer<br><br>☑ Water collected is about 950 mL<br><br>☑ The base of distillation tank (bottom part of tank) is corroded<br><br>☑ The pH of distilled water formed is 7.8 |

| | | | |
|---|---|---|---|
| | distilled, remove the water bath distillation tank from the fire<br><br>- Remove the distillation tank from the water bath<br><br>- Empty the cooling water and wait for the tank to cool<br><br>- Separate the upper part from the lower part of the distillation tank<br><br>- Collect the distilled water resulting from the distillation process<br><br>- Measure the pH of the water using the pH meter | | |

#### 5.8.2.7 Verification test ($K_2CO_3$ detection test)

One common method to detect the presence of potassium carbonate ($K_2CO_3$) in a solution is the hydrochloric acid test.

Potassium carbonate ($K_2CO_3$) is a soluble salt that can be detected using hydrochloric acid (HCl). When HCl is added to a solution containing $K_2CO_3$, a carbon dioxide ($CO_2$) gas is produced. This gas can be easily identified by its effervescence (bubbling) when it is released into the solution.

Here's a step-by-step procedure for the test:

1) Prepare a sample: Obtain a sample of the solution you suspect contains $K_2CO_3$.
2) Add HCl: Add a few drops of dilute hydrochloric acid to the sample.
3) Observe effervescence: If $K_2CO_3$ is present, you will observe bubbles forming in the solution due to the release of carbon dioxide gas.

Balanced Chemical Equation:

$$K_2CO_3(aq) + 2HCl(aq) \rightarrow 2KCl(aq) + H_2O(l) + CO_2(g)$$

#### 5.8.2.8 Test pictures




| Preparation of KOH solution | pH measurement of KOH solution | KOH solution in the lower part of the distillation tank | Solution after adding the dry ice ($K_2CO_3$ solution |
|---|---|---|---|

WhatsApp Video 2024-10-01 at 12.16.

WhatsApp Video 2024-10-01 at 12.20.

| | | |
|---|---|---|
| Adding the dry ice to the KOH solution (formation of $K_2CO_3$ solution) | Water distillation components | $K_2CO_3$ detection test |

#### 5.8.2.9 Test result

1) Adding a water bath made the distillation process take extra time (slower than normal distillation)

2) Adding a water bath improves the pH of the distilled water produced, improving from 10.4 in the previous test (MSE-T1) to 7.8 in this test

3) The increase in the concentration of the $K_2CO_3$ solution caused corrosion in the hole in the lower part of the distillation tank, which led to water entering from the water bath into the lower part of the distillation tank

#### 5.8.2.10 What's the next test

The experimental objective was to recover ion-free water through distillation. The distilled water obtained exhibited a pH of 7.8, demonstrating a significant reduction in $K_2CO_3$. Consequently, multiple distillations will be conducted in the subsequent experiment to obtain distilled water with a neutral pH.

### 5.8.3 Leakage of Stack #5 test "MSE-T3" (Thursday, 10.10.24)

To ensure the design for stack 5 is leak-free and functions as intended, we've proposed this test.

#### 5.5.1.1. Materials

- KOH solution (pH = 12.39, V=200 mL)
- Beaker
- Funnel
- pH meter
- Stack #5
- Gas purification tank
- Torch handle with a regulator valve knob
- 2 multimeters
- Power supply
- Signal generator

- Resistors
- Wires
- Hoses
- Balls valves
- Lighter

#### 5.8.3.1 Safety precautions

**Alkaline Electrolysis Precautions**

1) Proper Ventilation: Ensure the area where you're conducting electrolysis is well-ventilated to prevent the buildup of hydrogen gas. this helps to prevent the accumulation of flammable gases and reduce the risk of explosions.
2) Personal Protective Equipment (PPE): Wear safety glasses and gloves to protect your eyes and skin from potential splashes of corrosive alkaline solutions. In addition, wear electrically insulated gloves and shoes.
3) Do not approach: Do not touch or approach while the system is running. If necessary, adhere to all safety standards.
4) Concentrated Alkaline Solutions: Handle concentrated alkaline solutions with extreme caution, as they can cause severe burns. Wear appropriate protective clothing and avoid contact with skin and eyes.

5) Electrical Hazards: Ensure that the electrical connections are secure and properly insulated to prevent electric shock.
6) Electrolyte Disposal: Dispose of used electrolyte solutions responsibly, following local regulations. Do not pour them down the drain or into the environment.

**Precautions for Burning Hydrogen-Oxygen Mixed Gases**

1) Proper Ventilation: Ensure the area where you're burning gases is well-ventilated to prevent the buildup of hydrogen gas. this helps to prevent the accumulation of flammable gases and reduce the risk of explosions.

2) Personal Protective Equipment (PPE): Wear safety glasses and gloves to protect your eyes and skin from potential splashes of corrosive alkaline solutions.

3) Ignition Source Control: Keep all ignition sources away from the area where the mixture is being handled or burned. This includes open flames, sparks, static electricity, and hot surfaces.

4) Grounding: Ground all equipment that comes into contact with the hydrogen-oxygen mixture to prevent static discharges. This is particularly important when handling high-pressure cylinders or working with metal objects.

5) Pressure Control: Maintain the hydrogen-oxygen mixture at a safe pressure. Avoid exceeding the recommended pressure limits for the equipment and containers being used.

6) Fire Extinguisher: Keep a fire extinguisher readily available in case of a fire.

7) Emergency Preparedness: Have a plan in place for handling emergencies, such as gas leaks or electrical faults.

**Additional Considerations:**

1) Equipment Inspection: Regularly inspect your electrolysis equipment for signs of wear or damage. Promptly address any leaks to prevent the accumulation of flammable gases.
2) Training: Ensure that anyone involved in the electrolysis process has received proper training understands the associated risks and is knowledgeable about safety procedures.
3) Emergency Procedures: Develop and practice emergency procedures in case of a fire or explosion. Have a clear evacuation plan and know the location of fire extinguishers and other safety equipment.

#### 5.8.3.2 Pre-test (installation of Stack #5)

**Components of stack #5:**

- Endplate (in/out)
- Gasket (in/out)
- Gasket (inter)
- Electrode plate

**Installation of Stack #5**

1) Connect the liquid-level gauge hose to the outlet on the endplate of the stack.
2) Connect the solution outlet and gas outlet hoses to the end plate outlet on the stack.
3) Secure the hoses to the end plate using a suitable adhesive, such as super glue.
4) A layer of thermal silicone was applied to the inside of the end plate to seal the gaps between the hoses and prevent leakage.
5) The inlet of the end plate follows the same process.
6) Next, we initiate the stack installation by following these steps:
    1. Mount the endplate firmly to the base, aligning it correctly for a stable and secure installation.

2. The stack is assembled sequentially, commencing with the gasket plate, followed by the alternating placement of intern gaskets and electrodes, culminating in the gasket plate followed by the end plate.
3. Bolts and nuts are tightly fastened throughout the stack to ensure a secure seal against gas and solution leakage.
4. Ball valves are positioned at the stack's inlet and outlet to manage solution flow.
5. A gas purification tank is attached to the gas outlet to filter impurities and safeguard the system from potential explosion hazards.
6. The gas purification tank's output is connected to a torch handle with a regulator valve knob for safe gas burning
7. The electrical equipment (power supply, voltmeter, amperemeter, and resistor(s)) has been successfully connected.

#### 5.8.3.3 Leakage of Stack #5 test steps

- Open the inlet ball valve to fill the stack with KOH solution.
- Accurately introduce the KOH solution into the stack via the inlet hole, employing a funnel for precise pouring.
- When the stack is filled suitable (two-thirds full), close the inlet ball valve
- We check the electrical connections
- Verify connections and electrospinning using a multimeter in diode mode.
- Turn ON the power supply
- After a few minutes, we bring a spark to burn mixed gases
- We monitor the process and collect the data
- When the test is finished, turn OFF the power supply
- The fire fades out gradually

#### 5.8.3.4 Post-test

1) Check the power supply is OFF
2) Disconnect the electrical equipment
3) Open the outlet ball valve to drain the rest of the KOH solution in a beaker
4) Close the outlet ball valve of the solution
5) Wash the stack in Nitrogen gas by introducing nitrogen from the inlet ball valve for a few minutes
6) Open the inlet ball valve and fill the stack with distilled water
7) Drain the distilled water by opening the outlet ball valve
8) Repeat this previous step several times
9) By the pH meter, measure the pH of the rest of the KOH solution

#### 5.8.3.5 Responsibilities

| MSE-T3: Leakage of stack #5 test | | |
|---|---|---|
| **Task** | **Responsible** | **Note** |
| KOH preparation | Maryam R., Muhamad K. | |
| Secure the hoses | Ali D., Maryam R. | |
| Thermal silicone apply | Ali D., Maryam R. | |
| Install the stack | Ali D., Maryam R. | |
| Electrical equipement | Abdallah K. | |
| Intall the gas purification | Maryam R., Ali D. | |
| Install the control burner valve | Ali D. | |
| Electrical control | Abdallah K. | |
| pH measure | Maryam R., Muhamad K. | |
| Collect data | Maryam R. | |
| Documentation | Maryam R. | |
| Equipment re-cleaning | Ali D. | |

#### 5.8.3.6 Test results

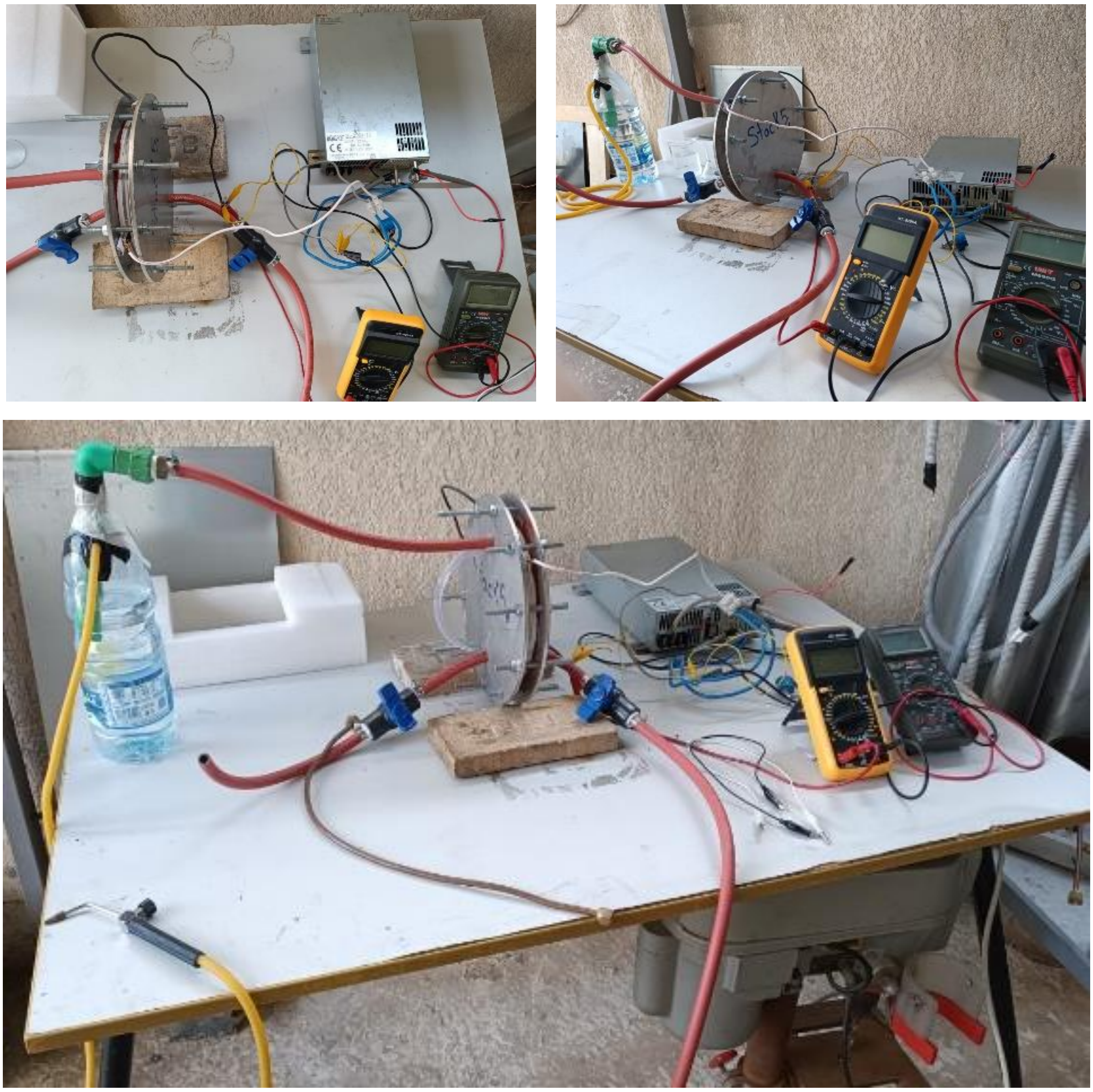
| Step | Step description | Expected result | Results |
|---|---|---|---|
| Pre-condition | - Stack is empty<br>- All equipment (electrical and mechanical) is connected properly | | |
| Fill the stack | - Open the inlet ball valve to fill the stack with KOH solution<br>- Accurately introduce the KOH solution into the stack via the inlet hole, employing a funnel for precise pouring.<br>- When the stack is filled (two- | - The stack is filled by the KOH solution<br>- No leak appears | ☑ The stack is filled with the KOH solution<br>☑ No leak |

| | | | |
|---|---|---|---|
| | thirds full), close the inlet ball valve. | | |
| Verify connections and electrospinning | - Check electrical equipment is connected<br>- Put the multimeter on "Diode mode"<br>- Connect each pole of the multimeter (diode mode) to each end plate<br>- Connect each pole of the multimeter (diode mode) to each electrode<br>- Connect the poles of the multimeter (diode mode) to both the electrode and end plate | - All electrical equipment is connected<br>- The multimeter is functioned in "Diode mode"<br>- The multimeter is beeps<br>- The multimeter beeps<br>- The multimeter does not beep | ☑ All electrical equipment is connected<br>☑ The multimeter is on "Diode mode"<br>☑The multimeter beeps; this means that two endplates are electrically connected from each other<br>☑ The multimeter beeps; this means that two electrodes are electrically connected from each other<br>☑ The multimeter does not beep; this means that the end plate and electrodes are electrically isolated from each other |

| | | | |
|---|---|---|---|
| Install the system | - Turn ON the power supply<br>- Regulate DC voltage and current | - The power is turned ON<br>- Gas bubbles ($H_2$ & $O_2$) popping in the gas purification tank | ☑ The power is turned ON<br>☑ The bubbles of gases popping in the gas purification tank |
| Burn the mixed gases formed | - Close the regulator valve of the torch handle<br>- Wait a few minutes for the gases to compress slightly<br>- Open the regulator valve of the torch handle and bring a spark beside the torch handle with the regulator valve knob | - The mixed gas is burned | ☒ The mixed gas exploded |
| Turn OFF the system | - Turn OFF the power supply | - The power supply is turned OFF<br>- After a few minutes, the flame dwindles and disappears | ☑ The power supply is turned OFF<br>☑ The flame flickers and dies |
| Measurement of pH | - Emptying the KOH solution from the stack | - The new pH is higher than the old one (initial pH) | ☑ The new pH ($pH_{(n)}$=12.54) is higher than the old one ($pH_{(i)}$= 12.39) |

| | | | |
|---|---|---|---|
| | - Take a sample from the KOH solution<br><br>- Use the pH meter to find out the new pH | | |

#### 5.5.1.2. Test pictures



*Overview of the System Components*

Test resumed in this video:

WhatsApp Video
2024-10-14 at 10.30.

#### 5.8.3.7 Test result analysis

- The super glue and the thermal silicone are suitable for fixing and electrically insulating the endplates.
- Unscrewing the regulator valve knob on the torch handle triggered a sudden ignition of the gas, resulting in an explosion.

#### 5.8.3.8 What's the next test

The experimental objective was to verify the effectiveness of the materials used as electrical insulators and the absence of leakage. The usage of the super glue with the thermal silicone demonstrates electrical insulation without reaction with the KOH solution.

Consequently, the other stacks will be insulated in the same method with the same materials.

## 5.9 What's next

After completing the design and installation part of the stacks, the stacks must be tested and then the system must be assembled for testing.

# 6 Project 4: Electrochemical Ammonia production (ICPT - AP)

## 6.1 Position of the ICPT-AP project

Work on this project began theoretically in 2022. In this year (2024), the study was followed up.

## 6.2 AP experimental process

### 6.2.1 Experimental introduction

SmFe0.7Cu0.1Ni0.2O3 is a mixed metal oxide compound composed of samarium (Sm), iron (Fe), copper (Cu), nickel (Ni), and oxygen (O). The numerical subscripts indicate the atomic ratio of each element in the compound. In this case, it consists of 1 atom of samarium, 0.7 atoms of iron, 0.1 atoms of copper, 0.2 atoms of nickel, and 3 atoms of oxygen.

### 6.2.2 SmFe0.7Cu0.1Ni0.2O3

To obtain SmFe0.7Cu0.1Ni0.2O3, you can follow these steps:

1. Dissolve Fe (NO3)3, Cu (NO3)2, Ni (NO3)2, and Sm2O3 in water.

2. Add citric acid to the solution with a molar ratio of 2:1.

3. Adjust the pH to 6-7 with NH3·H2O.

4. Evaporate the solution to obtain a viscous sol.

5. Dry the sol in a constant-temperature oven at 170℃.

6. Calcine the dried gel at 700℃ in a muffle furnace.

7. Compress the powder into ceramic discs and sinter at 1150℃ for 10 hours.

The molar ratio of citric acid (C6H8O7) can be calculated based on its molecular formula. Citric acid has a molar mass of approximately 192.12 g/mol.

The molecular formula of citric acid is C6H8O7. This means that in one molecule of citric acid, there are 6 carbon atoms, 8 hydrogen atoms, and 7 oxygen atoms.

Based on the molar ratios you provided in your question, the molar ratio of citric acid to SmFe0.7Cu0.1Ni0.2O3 is indeed 2:1.

Let's calculate the molar ratio for each compound:

1. Citric acid (C6H8O7):

- Carbon (C): 6 moles

- Hydrogen (H): 8 moles

- Oxygen (O): 7 moles

2. $SmFe_{0.7}Cu_{0.1}Ni_{0.2}O_3$:

- Samarium (Sm): 1 mole
- Iron (Fe): 0.7 moles
- Copper (Cu): 0.1 moles
- Nickel (Ni): 0.2 moles
- Oxygen (O): 3 moles

To find the molar ratio of citric acid to $SmFe_{0.7}Cu_{0.1}Ni_{0.2}O_3$, we compare the moles of citric acid to the moles of $SmFe_{0.7}Cu_{0.1}Ni_{0.2}O_3$:

Citric acid ($C_6H_8O_7$):

- Total moles = 6 (C) + 8 (H) + 7 (O) = 21 moles

$SmFe_{0.7}Cu_{0.1}Ni_{0.2}O_3$:

- Total moles = 1 (Sm) + 0.7 (Fe) + 0.1 (Cu) + 0.2 (Ni) + 3 (O) = 5 moles

Therefore, the molar ratio of citric acid to $SmFe_{0.7}Cu_{0.1}Ni_{0.2}O_3$ is 21 moles : 5 moles, which simplifies to 4.2 : 1 or approximately 2 : 1.

### 6.2.3 Convert Ni metal to $Ni(NO_3)_2$

To convert Ni metal to **$Ni(NO_3)_2$**, you can use nitric acid ($HNO_3$). Here's the balanced chemical equation for the reaction:

$Ni(s) + 2HNO_3(aq) \rightarrow Ni(NO_3)_2(aq) + H_2(g)$

#### 6.2.3.1 Procedure:

1. **Obtain Ni metal and nitric acid:** Ensure that the Ni metal is clean and free of any oxides or impurities. Nitric acid is a strong oxidizing agent and should be handled with care.
2. **Set up a reaction vessel:** Place the Ni metal in a suitable container, such as a beaker or Erlenmeyer flask.
3. **Add nitric acid:** Slowly pour nitric acid into the container containing the Ni metal. The reaction will be vigorous and may produce heat and nitrogen oxide gas (NOx). Exercise caution and avoid inhaling the fumes.
4. **Stir or heat:** Gently stir the mixture to ensure complete reaction. If necessary, you can apply gentle heat to accelerate the process.
5. **Filter:** Once the reaction is complete, filter the solution to remove any unreacted Ni metal or impurities.

6. **Evaporate:** To obtain solid Ni(NO3)2, carefully evaporate the water from the filtrate. This can be done by heating the solution gently on a hot plate or in a water bath.

#### 6.2.3.2 Safety precautions:

- Nitric acid is a strong acid and can cause severe burns. Wear appropriate protective equipment, including gloves, eye protection, and a lab coat.
- Work in a well-ventilated area to avoid inhaling nitrogen oxide fumes.
- Avoid direct contact with nitric acid and its solutions.
- If you come into contact with nitric acid, immediately rinse with plenty of water and seek medical attention.

#### 6.2.3.3 Additional considerations:

- The concentration of nitric acid used can affect the reaction rate and the purity of the final product.
- If you need a high-purity Ni(NO3)2, you may need to perform additional purification steps, such as recrystallization.

By following these steps and taking appropriate safety precautions, you can successfully convert Ni metal to Ni(NO3)2.

### 6.2.4 Recrystallization of Ni(NO3)2

**Recrystallization** is a technique used to purify substances by dissolving them in a hot solvent, allowing the solution to cool slowly, and then isolating the crystals that form. For Ni(NO3)2, a suitable solvent is **water**.

#### 6.2.4.1 Procedure:

1. **Dissolution:**
   - **Heat water:** Heat a suitable amount of water to boiling in a beaker.
   - **Add Ni(NO3)2:** Gradually add your Ni(NO3)2 powder to the boiling water while stirring continuously. Keep adding until no more Ni(NO3)2 dissolves. This is called saturation.

2. **Filtration (optional):**
   - If there are any insoluble impurities, filter the hot solution while it's still hot to remove them.

3. **Cooling:**
   - **Slow cooling:** Allow the filtered solution to cool slowly to room temperature. This will encourage the formation of larger, purer Ni(NO3)2 crystals. You can cover the beaker with a watch glass to prevent dust from contaminating the solution.

4. **Crystallization:**
   - As the solution cools, $Ni(NO3)2$ crystals will begin to form.

5. **Filtration:**
   - Once crystallization is complete, filter the solution to isolate the $Ni(NO3)2$ crystals. Use a Buchner funnel and filter paper.

6. **Washing:**
   - Wash the crystals with a small amount of cold water to remove any remaining impurities.

7. **Drying:**
   - Allow the crystals to air-dry on a filter paper or in a desiccator. Avoid using heat to dry them, as this can cause decomposition.

#### 6.2.4.2 Additional Tips:

- **Purity check:** After recrystallization, you can check the purity of your $Ni(NO3)2$ using techniques like melting point determination or elemental analysis.

By following these steps, you can effectively recrystallize $Ni(NO3)2$ to obtain a pure product.

### 6.2.5 Convert Fe metal to Fe(NO3)3

#### 6.2.5.1 Reaction:

The reaction between iron metal (Fe) and nitric acid (HNO3) produces iron(III) nitrate (Fe(NO3)3) and hydrogen gas (H2).

#### 6.2.5.2 Balanced Equation:

$Fe(s) + 3HNO3(aq) \rightarrow Fe(NO3)3(aq) + 3H2(g)$

#### 6.2.5.3 Procedure:

1. **Obtain Materials:**
   - **Iron metal:** Ensure it's clean and free from rust.
   - **Nitric acid:** A concentrated solution is typically used. Handle with care as it's a strong oxidizing agent.
2. **Safety Precautions:**
   - **Ventilation:** Work in a well-ventilated area as nitric acid fumes can be harmful.
   - **Protective Gear:** Wear gloves, eye protection, and a lab coat.
3. **Reaction Setup:**
   - **Container:** Place the iron metal in a suitable container, such as a beaker.
   - **Nitric Acid:** Slowly add the concentrated nitric acid to the container. The reaction will be vigorous and may produce brown fumes of nitrogen dioxide (NO2).

4. **Observe Reaction:**
   - The iron metal will dissolve, and a solution of iron(III) nitrate will form. Hydrogen gas will be released.
5. **Filtering (Optional):**
   - If there are any unreacted iron particles or impurities, filter the solution to remove them.
6. **Evaporation (Optional):**
   - If you need solid iron(III) nitrate, carefully evaporate the water from the solution. This can be done by heating it gently on a hot plate.

**Note:** The reaction with nitric acid is a redox reaction. The iron is oxidized to iron(III), while the nitric acid is reduced to nitrogen dioxide.

#### 6.2.5.4 Additional Considerations:

- **Concentrated Nitric Acid:** Using a more dilute solution might result in a slower reaction or the formation of iron(II) nitrate.
- **Temperature:** The reaction rate can be influenced by temperature. A higher temperature might accelerate the reaction.
- **Purity:** If a high-purity iron(III) nitrate is required, additional purification steps like recrystallization might be necessary.

By following these steps and adhering to safety guidelines, you can successfully convert iron metal to iron(III) nitrate.

### 6.2.6 Convert metal to Cu(NO3)2

#### 6.2.6.1 Reaction:

The reaction between copper metal and nitric acid (HNO3) produces copper nitrate (Cu(NO3)2) and nitrogen dioxide gas (NO2).

Cu(s) + 4HNO3(aq) → Cu(NO3)2(aq) + 2NO2(g) + 2H2O(l)

#### 6.2.6.2 Procedure:

1. **Obtain Materials:**
   - **Copper metal:** Ensure it's clean and free from oxides.
   - **Nitric acid:** A concentrated solution is typically used.
   - **Safety equipment:** Gloves, eye protection, and a lab coat.
2. **Set Up the Reaction:**
   - **Fume hood:** Conduct the reaction in a fume hood due to the toxic nature of nitrogen dioxide gas.
   - **Reaction vessel:** Place the copper metal in a suitable container (e.g., a beaker).
3. **Add Nitric Acid:**
   - **Slowly add:** Pour nitric acid over the copper metal. The reaction will be vigorous, producing brown nitrogen dioxide gas.
   - **Stir:** Gently stir the mixture to ensure complete reaction.

4. **Evaporate:**
    - **Heat:** Heat the solution to evaporate the excess water. This can be done on a hot plate or in a water bath.
    - **Crystallization:** As the water evaporates, copper nitrate crystals will form.
5. **Filter:**
    - **Separate crystals:** Filter the solution to separate the crystals from any remaining liquid.
6. **Dry:**
    - **Air dry:** Allow the crystals to air dry on a filter paper.

#### 6.2.6.3 Safety Precautions:

- **Nitric acid:** It's a strong acid and can cause severe burns. Handle it with care.
- **Nitrogen dioxide:** It's a toxic gas. Work in a well-ventilated area or use a fume hood.
- **Protective equipment:** Wear appropriate safety gear to protect yourself from acid spills and fumes.

**Note: The concentration of nitric acid and the reaction conditions can affect the rate of the reaction and the purity of the final product.**

### 6.2.7 Convert Sm metal to Sm2O3

#### 6.2.7.1 Reaction:

Samarium metal reacts with oxygen to form samarium oxide.

$4Sm(s) + 3O_2(g) \rightarrow 2Sm_2O_3(s)$

#### 6.2.7.2 Procedure:

1. **Obtain Materials:**
    - **Samarium metal:** Ensure it's clean and free from oxides.
    - **Oxygen:** A source of oxygen, such as a cylinder or oxygen gas generator.
    - **Crucible:** A heat-resistant container to hold the samarium metal.
    - **Furnace:** A high-temperature furnace capable of reaching temperatures above 800°C.
2. **Prepare the Crucible:**
    - **Clean:** Ensure the crucible is clean and free from contaminants.
    - **Place metal:** Place the samarium metal into the crucible.
3. **Heat in Oxygen:**
    - **Furnace:** Place the crucible containing the samarium metal into the furnace.
    - **Oxygen flow:** Introduce a flow of oxygen into the furnace.
    - **Temperature:** Heat the furnace to a temperature above 800°C. The exact temperature may vary depending on the purity and particle size of the samarium metal.
4. **Cool and Collect:**
    - **Cool:** Allow the furnace to cool down naturally.
    - **Remove:** Remove the crucible from the furnace and carefully handle the resulting samarium oxide.

#### 6.2.7.3 Safety Precautions:

- **Oxygen:** Oxygen is a flammable gas. Handle it with care and avoid contact with combustible materials.
- **High temperatures:** The furnace can reach very high temperatures. Use appropriate safety equipment and handle hot materials with caution.
- **Samarium oxide:** Samarium oxide is a rare earth oxide and should be handled with care. Avoid inhaling dust or ingesting the compound.

**Note: The specific conditions and equipment required may vary depending on the desired purity and quantity of samarium oxide. It's recommended to consult with a chemist or materials scientist for more specific guidance.**

### 6.2.8 Process to make SmFe0.7Cu0.1Ni0.2O3

The process to make $SmFe_{0.7}Cu_{0.1}Ni_{0.2}O_3$ involves several steps, as outlined in the document. Here's a summary of the preparation method:

1. **Materials Preparation**:
   - The starting materials include $Sm_2O_3$, $Fe(NO_3)_3$, $Cu(NO_3)_2$, and $Ni(NO_3)_2$, which are analytically pure reagents.
2. **Citrate Method**:
   - A solid citric acid with a molar ratio of citric acid to metal ions of 2:1 is added to a solution containing the metal ions.
   - The solution is stirred until the solid citric acid has completely dissolved.
3. **pH Adjustment**:
   - The pH of the solution is adjusted to between 6 and 7 by adding $NH_3 \cdot H_2O$.
4. **Evaporation**:
   - The solution is slowly evaporated on a water bath at 70°C until a viscous liquid sol is obtained.
5. **Drying**:
   - The viscous sol is placed in a constant-temperature drying oven at 170°C until a solid mass is formed.
6. **Calcination**:
   - The dried gel is calcined at 700°C in a muffle furnace for 5 hours to form the desired powder.
7. **Sintering**:
   - The powder is then compressed into ceramic discs under a pressure of about 80 MPa.
   - These discs are sintered in air at 1150°C for 10 hours to prepare the final ceramic cathode material.
8. **Final Preparation**:
   - The ceramic discs are polished on both sides to achieve smooth surfaces, and a thick Ag—Pt slurry is applied to one side to act as the current collector.

This method ensures the formation of the $SmFe_{0.7}Cu_{0.1}Ni_{0.2}O_3$ material with the desired properties for use in ammonia synthesis

### 6.2.9 SmFe0.7Cu0.1Ni0.2O3 is a cathode, what is the anode

In the study, the anode used in the electrochemical synthesis of ammonia is made from NiO-SDC (Nickel Oxide - Samaria-Doped Ceria). The NiO-SDC ceramic flake is prepared using established methods in literature.

### 6.2.10 Process to make NiO-SDC

The process of making NiO-SDC (Nickel Oxide - Samaria-Doped Ceria) involves several steps, which are typically based on established methods. Here's a typical process:

1. **Materials Preparation**:
   - The starting materials include cerium oxide ($CeO_2$) and samarium oxide ($Sm_2O_3$) for the Samaria-doped ceria (SDC) component, along with nickel nitrate ($Ni(NO_3)_2$) for the nickel oxide component.
2. **Doping Process**:
   - The desired amount of $Sm_2O_3$ is mixed with $CeO_2$ to achieve the desired doping level (e.g., 20% Sm doping in $CeO_2$).
3. **Solution Preparation**:
   - Nickel nitrate is dissolved in distilled water to create a solution.
4. **Mixing**:
   - The ceria and samaria powders are mixed with the nickel nitrate solution. This can be done using a ball mill or other mixing techniques to ensure a homogeneous mixture.
5. **Drying**:
   - The mixed solution is dried to remove water, often by evaporating it at a controlled temperature.
6. **Calcination**:
   - The dried mixture is then calcined at a high temperature (typically around 500-700°C) in air or an inert atmosphere for several hours. This step helps to convert the nitrates into oxides and to form the desired NiO-SDC phase.
7. **Reduction**:
   - If the final product is to be NiO-SDC, it may need to be reduced in a hydrogen atmosphere at elevated temperatures (e.g., 500°C) to convert NiO to metallic Ni, depending on the specific application.
8. **Sintering**:
   - The resulting powder can be pressed into pellets or discs and sintered at a higher temperature (e.g., 1150°C) to achieve the desired density and microstructure.

This general method provides a framework for synthesizing NiO-SDC, which is used as the anode material in the electrochemical synthesis of ammonia

### 6.2.11 Details of the reduction part

The reduction of NiO to metallic Ni is a crucial step in the preparation of NiO-SDC (Nickel Oxide - Samaria-Doped Ceria) when the nickel oxide is intended to be used in its reduced form for enhanced catalytic activity. Here are the detailed steps typically involved in the reduction process:

1. **Preparation of the Sample**:

- After the calcination step, where the nickel nitrate and ceria-samaria mixture is heated to form NiO-SDC, the resulting material is typically in the form of a powder or ceramic disc.

2. **Setting Up the Reduction Environment**:
   - The reduction is performed in a controlled atmosphere, usually in a tube furnace or a muffle furnace.
   - A hydrogen gas source is required for the reduction process. The hydrogen can be supplied from a gas cylinder or generated in situ.
3. **Temperature Control**:
   - The reduction process is typically carried out at elevated temperatures, commonly around 500°C. This temperature is sufficient to facilitate the reduction of NiO to Ni.
4. **Hydrogen Atmosphere**:
   - The sample is placed in the furnace, and a flow of hydrogen gas is introduced. The flow rate is usually controlled to ensure a consistent atmosphere around the sample.
   - The reduction reaction can be represented as follows: NiO+H2→Ni+H2O
   - This reaction indicates that nickel oxide (NiO) is reduced to metallic nickel (Ni), while hydrogen ($H_2$) is oxidized to water ($H_2O$).
5. **Duration of Reduction**:
   - The reduction process typically lasts for about 2 hours, allowing sufficient time for the complete reduction of NiO to Ni. The exact duration may vary depending on the specific material and desired properties.
6. **Cooling**:
   - After the reduction is complete, the furnace is allowed to cool down to room temperature while maintaining a hydrogen atmosphere to prevent oxidation of the reduced nickel.
7. **Post-Reduction Treatment**:
   - Once cooled, the reduced NiO-SDC can be removed from the furnace. It is important to handle the material in an inert atmosphere (e.g., under nitrogen or argon) if it is to be stored, to prevent re-oxidation of the metallic nickel.
8. **Characterization**:
   - After reduction, the material can be characterized using techniques such as X-ray diffraction (XRD) and scanning electron microscopy (SEM) to confirm the successful reduction and to analyze the microstructure.

This reduction step is critical for enhancing the catalytic properties of the NiO-SDC anode material, making it more effective for applications such as electrochemical synthesis of ammonia.

### 6.2.12 Materials need for cathode preparation

The materials needed for the preparation of the cathode, specifically for the $SmFe_{0.7}Cu_{0.3-x}Ni_xO_3$ (SFCN) cathode used in the electrochemical synthesis of ammonia, include the following:

1. **Metal Nitrates**:

   - **Iron Nitrate ($Fe(NO_3)_3$)**: This serves as a source of iron in the cathode material.
   - **Copper Nitrate ($Cu(NO_3)_2$)**: This provides copper, which is a component of the cathode.

- **Nickel Nitrate ($Ni(NO_3)_2$)**: This is used for doping the cathode material with nickel.

2. **Samarium Oxide**:

   - **Samarium Oxide ($Sm_2O_3$)**: This is used as a dopant in the ceria structure to enhance the properties of the cathode.

3. **Citric Acid**:

   - **Citric Acid**: This is used as a chelating agent in the preparation process, helping to form a homogeneous solution with the metal ions.

4. **Distilled Water**:

   - **Distilled Water**: Used to dissolve the metal nitrates and to prepare the solution for the citrate method.

5. **Hydrochloric Acid or Ammonia**:

   - **Ammonia ($NH_3{\cdot}H_2O$)**: This is used to adjust the pH of the solution during the preparation process.

6. **Solvent for Drying**:

   - **Water**: Used in the initial steps for dissolving and mixing the components.

7. **Additional Materials**:

   - **Ag-Pt Slurry**: This is used as a current collector on the cathode.
   - **Nafion Membrane**: While not part of the cathode itself, it is essential for the assembly of the electrochemical cell.

8. **Equipment**:

   - **Furnace**: For calcination and sintering of the prepared material.
   - **Ball Mill or Mixer**: For mixing the powders and ensuring homogeneity.
   - **Pressing Equipment**: For forming the ceramic discs from the powder.

These materials and equipment are essential for synthesizing the SFCN cathode, which is characterized by its perovskite structure and is used in the electrochemical synthesis of ammonia.

### 6.2.13 Materials need for anode preparation

The materials needed for the preparation of the anode, specifically for the nickel-doped samaria-doped ceria (Ni-SDC) anode used in the electrochemical synthesis of ammonia, include the following:

#### 6.2.13.1 Nickel Oxide:

- **Nickel Oxide (NiO)**: This serves as the primary source of nickel for the anode material. It is later reduced to metallic nickel during the preparation process.

#### 6.2.13.2 Samaria-Doped Ceria:

- **Ceria ($CeO_2$)**: This is the base material for the anode, which is doped with samarium to enhance its ionic conductivity.
- **Samarium Oxide ($Sm_2O_3$)**: This is used to dope ceria, improving its properties for use in solid oxide fuel cells and electrochemical applications.

#### 6.2.13.3 Citric Acid:

- **Citric Acid**: Similar to the cathode preparation, citric acid is used as a chelating agent to help form a homogeneous solution with the metal ions.

#### 6.2.13.4 Distilled Water:

- **Distilled Water**: Used to dissolve the metal nitrates and prepare the solution for the citrate method.

#### 6.2.13.5 Hydrochloric Acid or Ammonia:

- **Ammonia ($NH_3 \cdot H_2O$)**: This is used to adjust the pH of the solution during the preparation process.

#### 6.2.13.6 Additional Materials:

- **Ag-Pt Slurry**: This is used as a current collector on the anode.
- **Nafion Membrane**: While not part of the anode itself, it is essential for the assembly of the electrochemical cell.

#### 6.2.13.7 Equipment:

- **Furnace**: For calcination and sintering of the prepared material.
- **Ball Mill or Mixer**: For mixing the powders and ensuring homogeneity.
- **Pressing Equipment**: For forming the ceramic discs from the powder.
- These materials and equipment are essential for synthesizing the Ni-SDC anode, which plays a critical role in the electrochemical synthesis of ammonia.

### 6.2.14 Details of Sintering part

The sintering process is a crucial step in the preparation of ceramic materials, including the cathode and anode used in the electrochemical synthesis of ammonia. Here are the details of the sintering part as described in the document:

1. **Preparation of the Precursor**:
   After the citrate precursor is formed by evaporating the solution containing the metal nitrates and citric acid, the dried gel is obtained.

2. **Calcination**:
   The dried gel is calcined at **700°C** in a muffle furnace for **5 hours**. This step is essential for decomposing the organic components and forming the desired metal oxide phases.
3. **Formation of Ceramic Discs**:
   The calcined powder is then compressed into ceramic discs under a pressure of about **80 MPa**. This step ensures that the material has sufficient density and mechanical strength.
4. **Sintering**:
   The ceramic discs are sintered in air at **1150°C** for **10 hours**. Sintering is a process where the ceramic material is heated to a temperature below its melting point, allowing the particles to bond together, reduce porosity, and enhance the mechanical and electrical properties of the material.
5. **Cooling**:
   After the sintering process, the discs are allowed to cool down gradually to room temperature. Controlled cooling is important to avoid thermal shock and cracking of the ceramic material.
6. **Polishing**:
   The sintered ceramic discs (both the cathode and anode) are polished on both sides to achieve smooth surfaces. This step is important for ensuring good contact with the Nafion membrane and the current collectors.
7. **Final Assembly**:
   After polishing, a thick Ag-Pt slurry is smeared on one side of each disk to act as the current collector. Platinum wire is then bonded to each disk to serve as a lead. The final assembly involves placing the Ni-SDC and SFCN discs on opposite sides of the Nafion membrane, which is used to bind them together.

These steps ensure that the ceramic materials have the necessary structural integrity and electrochemical properties for effective performance in the ammonia synthesis process.

## 6.3 Ammonia Production (AP) simulation

### 6.3.1 Green Hydrogen

Green hydrogen, produced from renewable sources of raw materials and energy, water (H2O) can be converted into hydrogen gas (H2) and oxygen gas (O2) this is represented by equation:

$H2O \rightarrow H2 + ½ O2$

equation of Ammonia synthesis:

$N2+H2 \rightarrow NH3$

water electrolysis is the process whereby water is split into hydrogen and oxygen through the application of electrical energy, the total energy that is needed for water electrolysis is increasing with temperature, while the required electrical energy decreases.

**At the cathode:** hydrogen ions are converted into hydrogen: 2 H2O + 2e- ->2 OH- + H2 anode :oxidation

$2OH^- \rightarrow H_2O + 2e^- + ½ O_2$

### 6.3.2 The Electrolysis of water equation

$2H_2O$ + electrical energy -> $H_2 + 0.5\ O_2 + H_2O$

#### 6.3.2.1 Parameters to be determined before water electrolysis

cell voltage

power requirement of the Electrolysers.

conversion of water into hydrogen gas.

In ICPT there is already a prototype Water Electrolyzer, where system tests where undergone:

### 6.3.3 The Haber Bosch revolution :

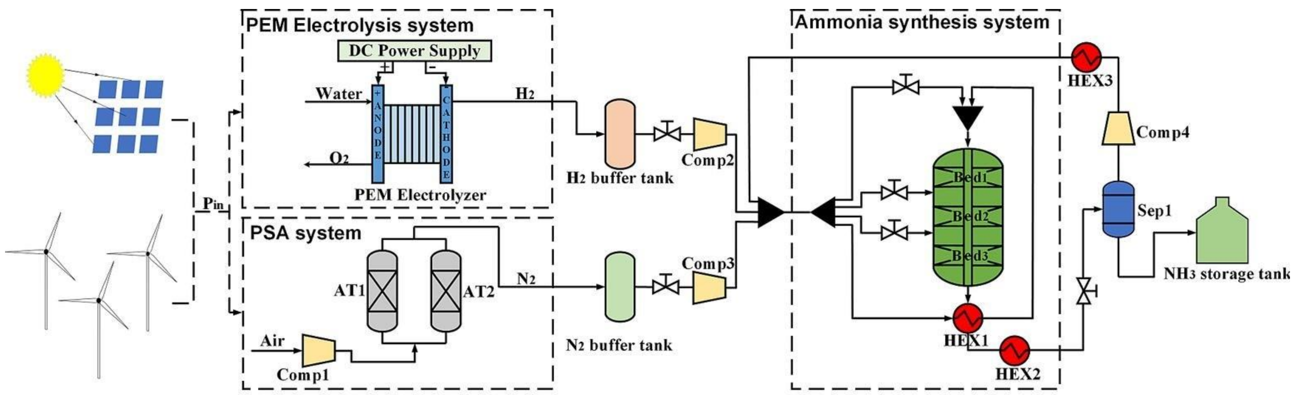
$N_2+3H_2 \rightarrow 2NH_3$

Ammonia is a precursor for fertilizers (ammonium nitrate).

our objective is to storage $H_2$ under ammonia

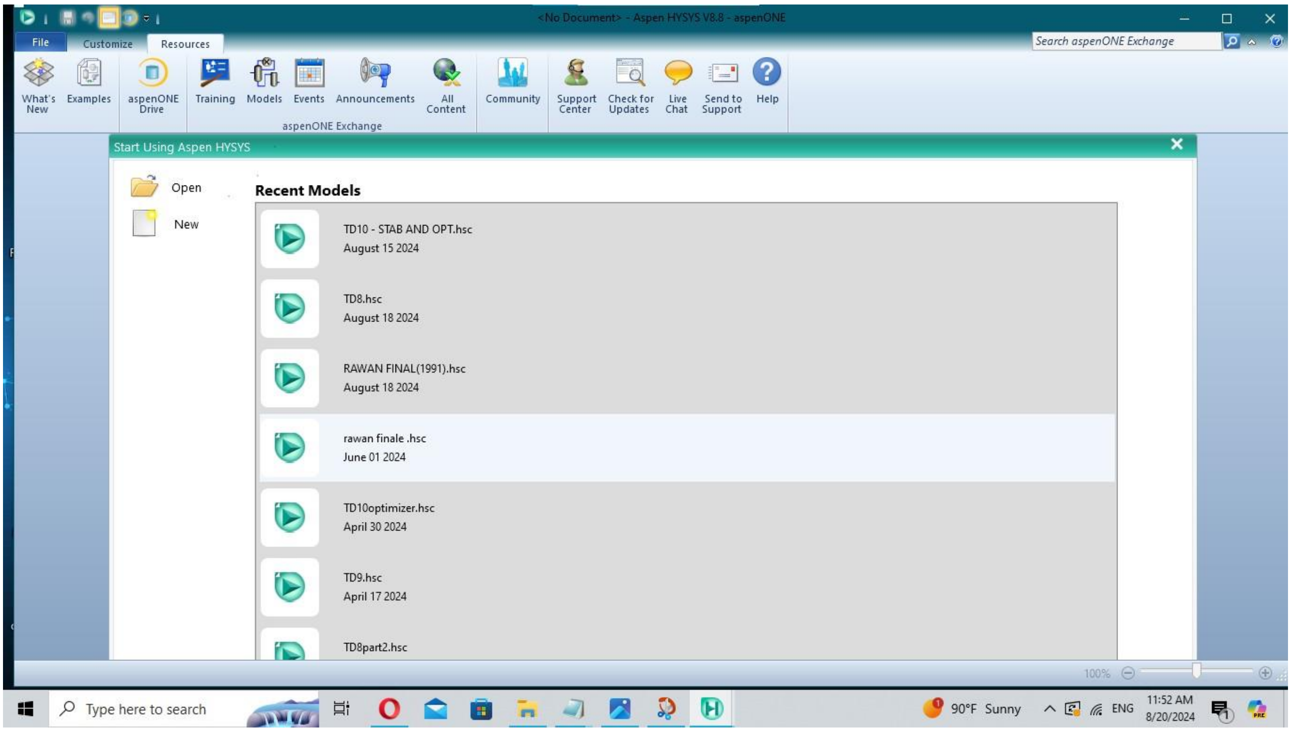
The disadvantage of $H_2$ as an energy carrier is its low volumetric energy density

solution $NH_3$ as energy storage for $H_2$ ($H_2$ should be converted into $NH_3$ using the Haber Bosch process).

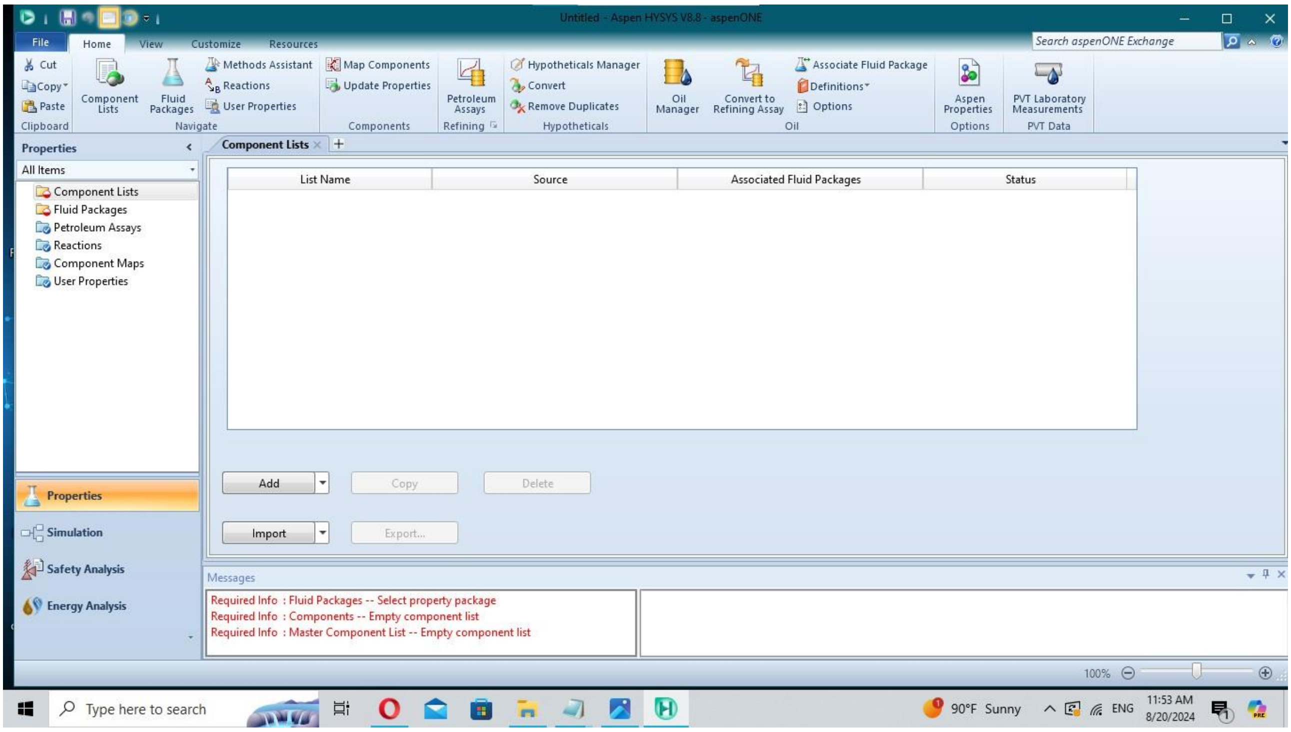


### 6.3.4 Simulation using Aspen Hysys

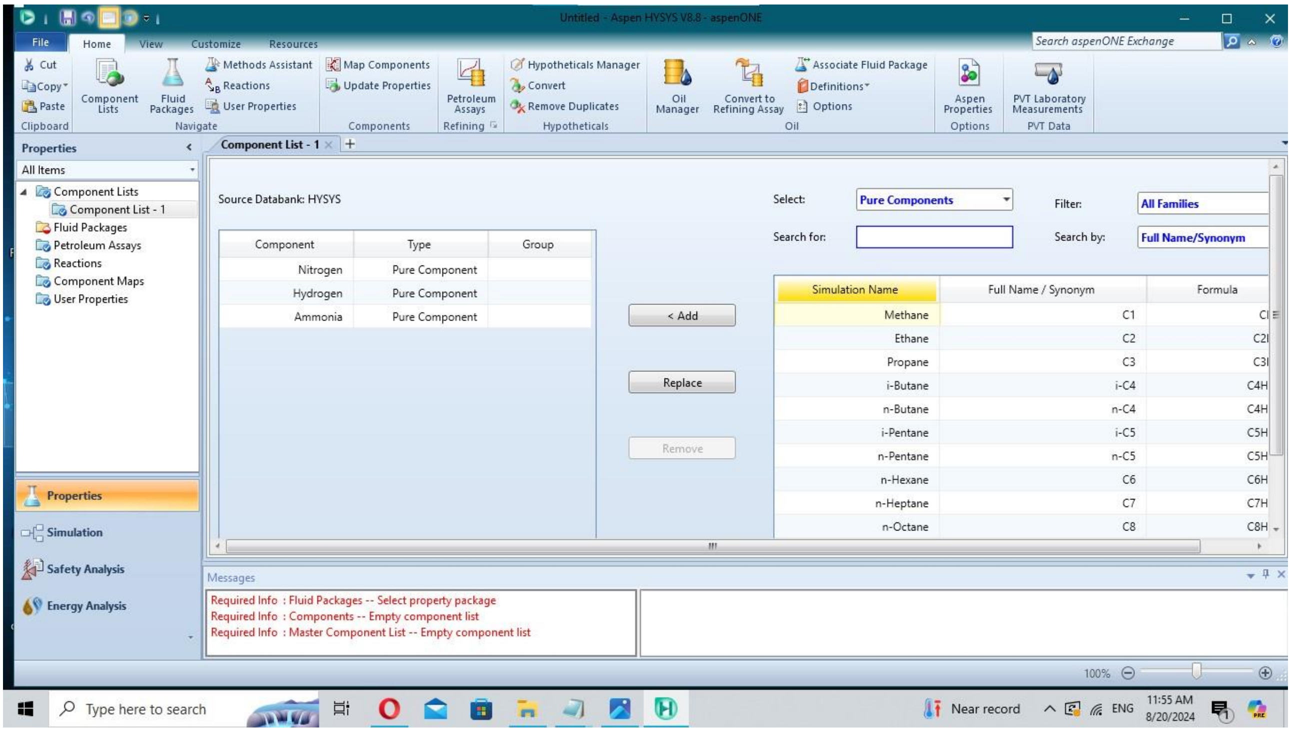
- **Create new File**



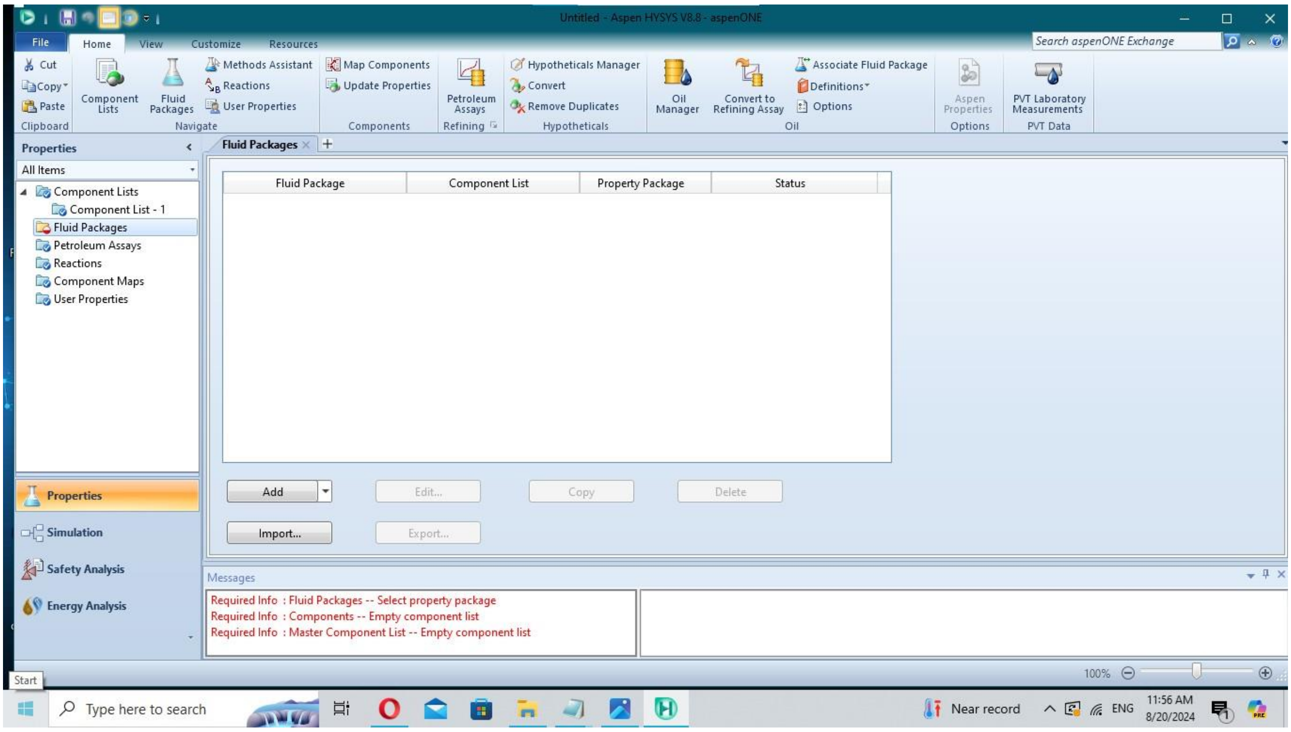

- **Add Component list**



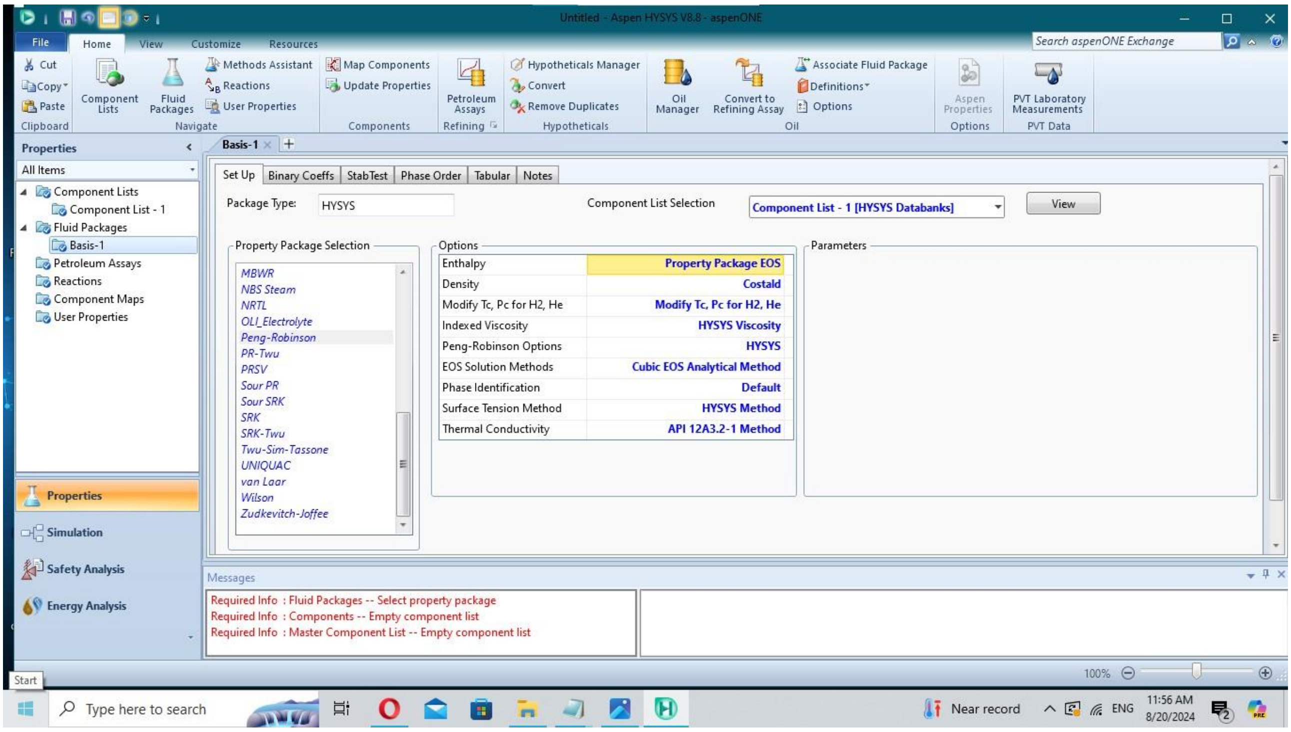
- **Add Nitrogen, Hydrogen and Ammonia**



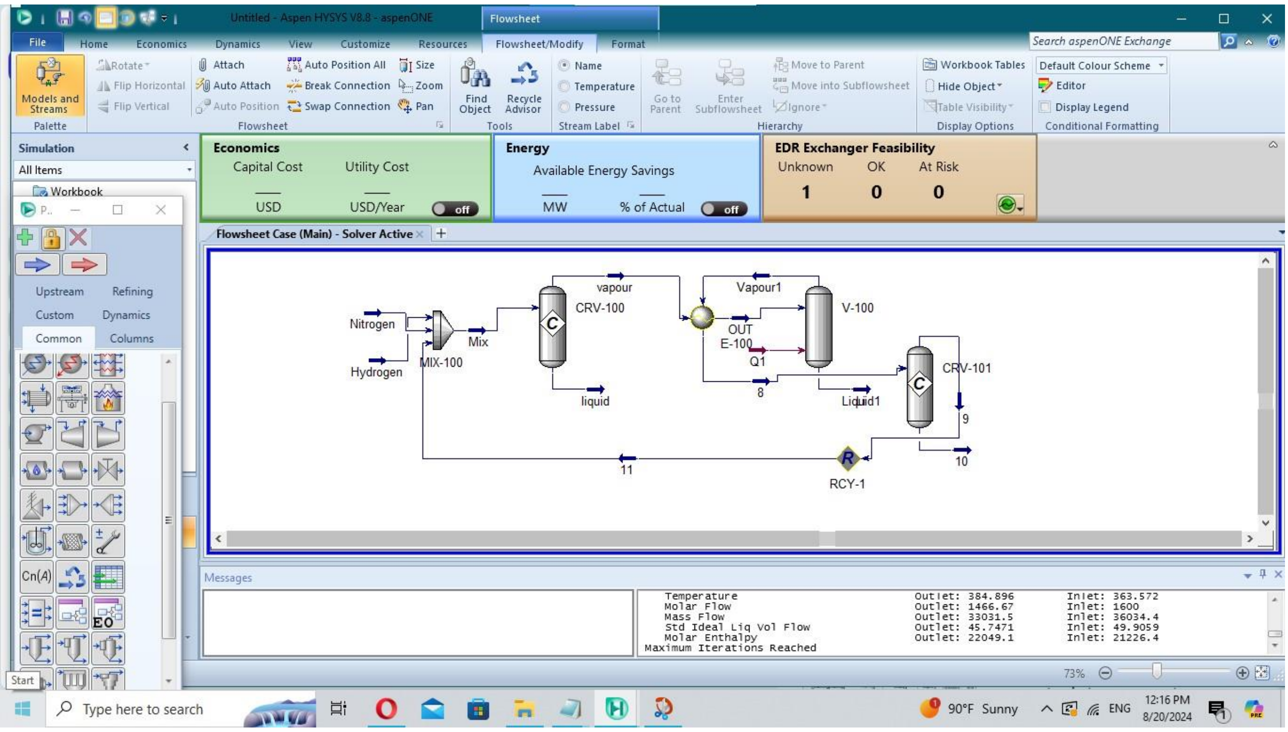

- **Add Fluid packages**



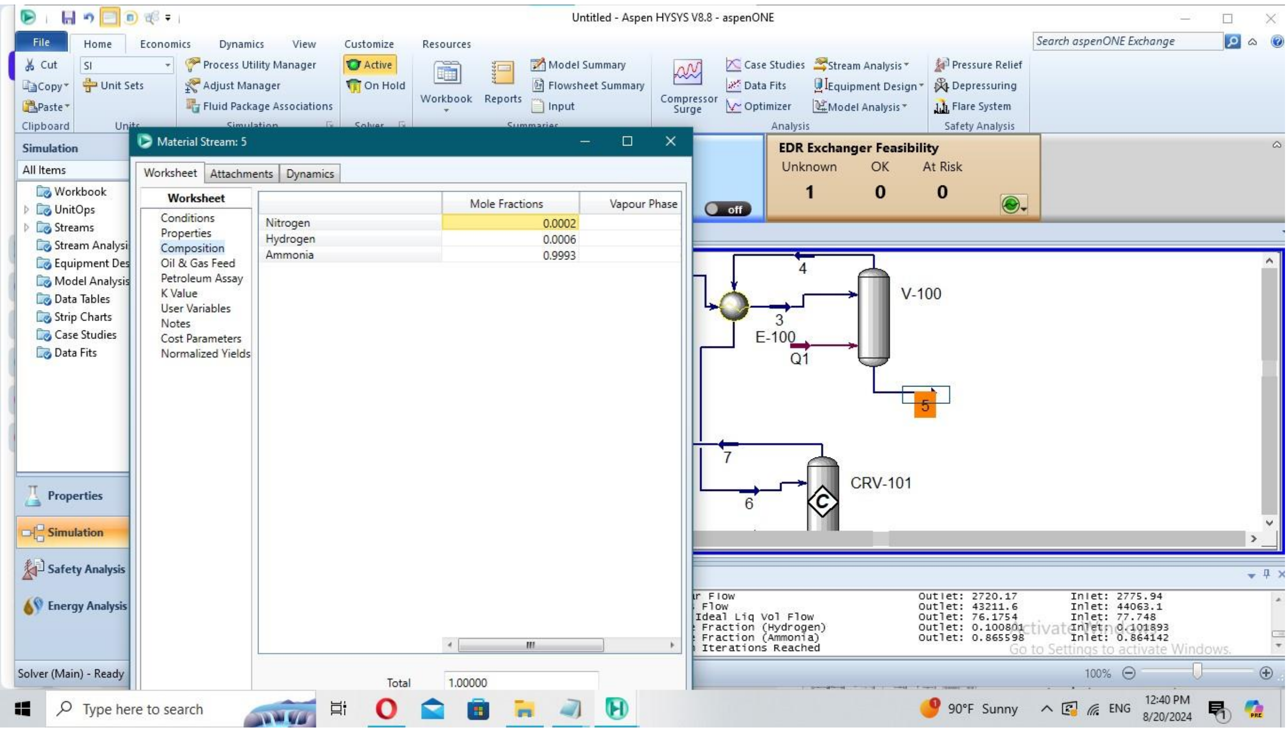
- **search and select Peng Robinson**




- **Start Simulation**



- **<u>Result</u>**

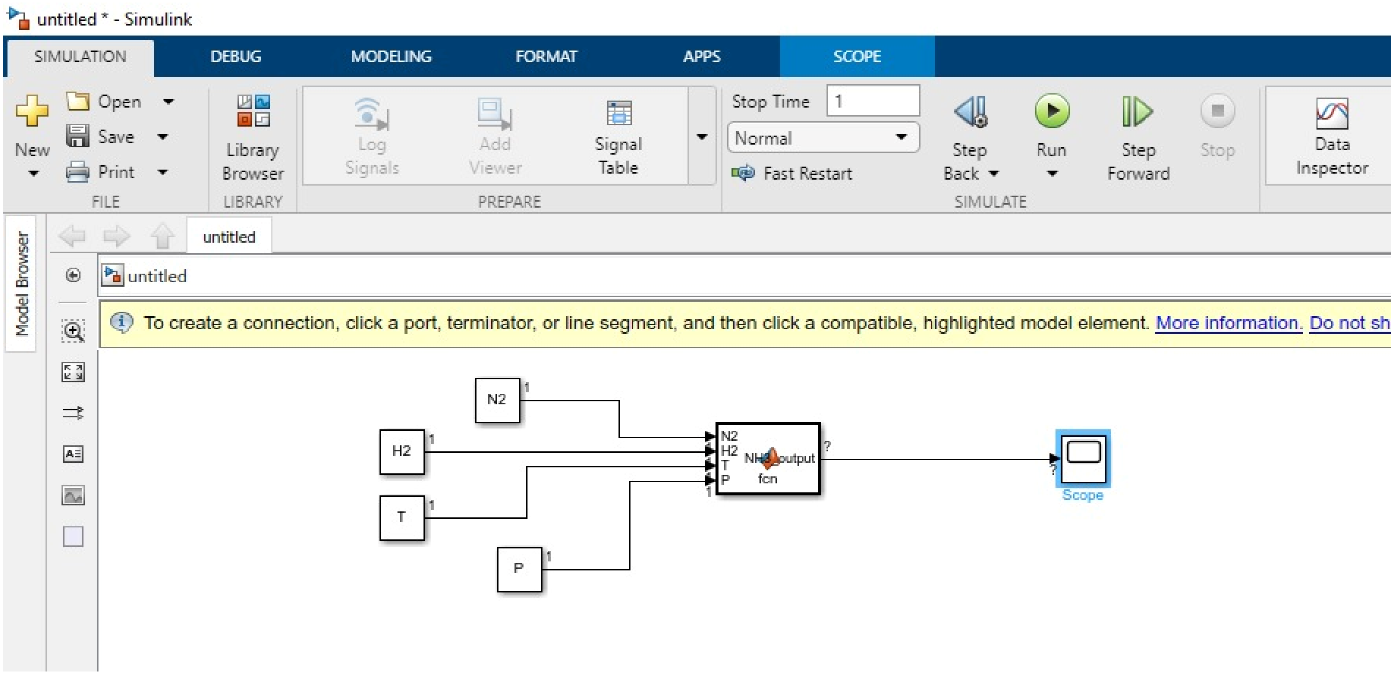


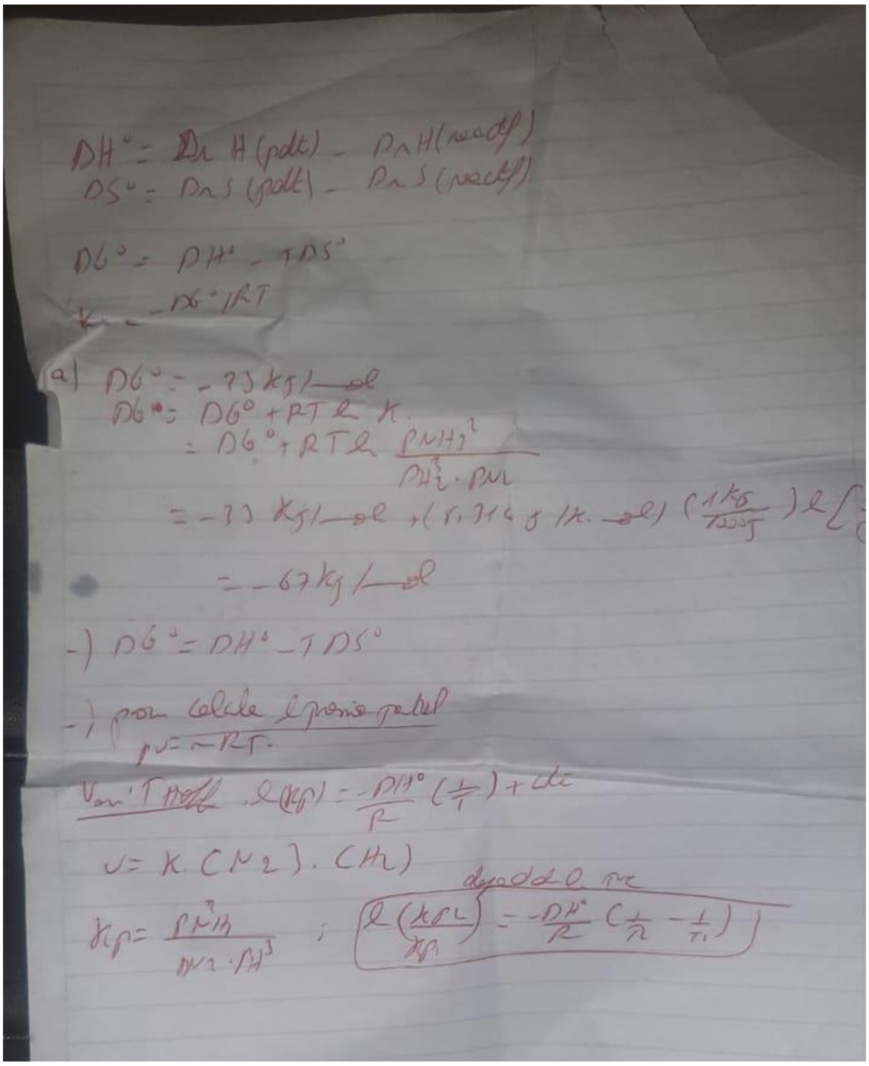

## 6.3.5 Principal features of Aspen, COCO, and CHEMCAD simulators concerning H2 storage in ammonia

| **Feature/Aspect** | **Aspen** | **Coco** | **CHEMCAD** |
|---|---|---|---|
| *process Modeling* | Advanced process modeling with extensive thermodynamic and kinetic models | Basic modeling capabilities with customizable units | Good modeling capabilities with a focus on usability |
| *Thermodynamic packages* | Wide variety | supports CAPE_OPEN thermodynamic models | Extensive thermodynamic models, user_friendly selection |
| *Reaction Kinetics* | Comprehensive Kinetic modeling for reactions, including custom Kinetics | Custom Kinetic modeling is possible with CAPE_open units | Kinetic modeling supported, with a focus on ease of use |

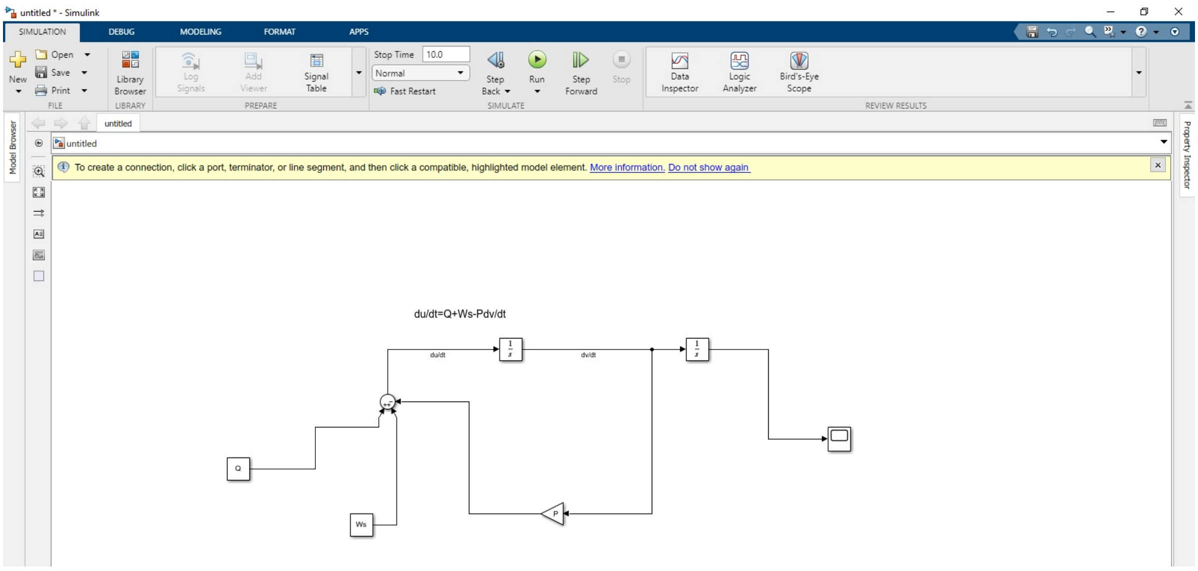
| | | | |
|---|---|---|---|
| *custom unit operations* | Highly customizable unit operations, including custom coding | customizable through CAPE_open compliant modules | custom unit operations with intuitive interfaces |
| *Simulation Flexibility* | High flexibility in process simulation, suitable for complex systems | Flexible but may require manual setup and coding | Flexible, with a balance between complexity and usability |
| *user interface* | complex | simple, basic | user friendly |
| *cost* | Expensive | Free | Moderate |
| *Industry Application* | widely used in chemical petrochemical | More suited for academic and simple industrial application | common in chemical, pharmaceutical, and food industries |

### 6.3.1. Simulation with MATLAB

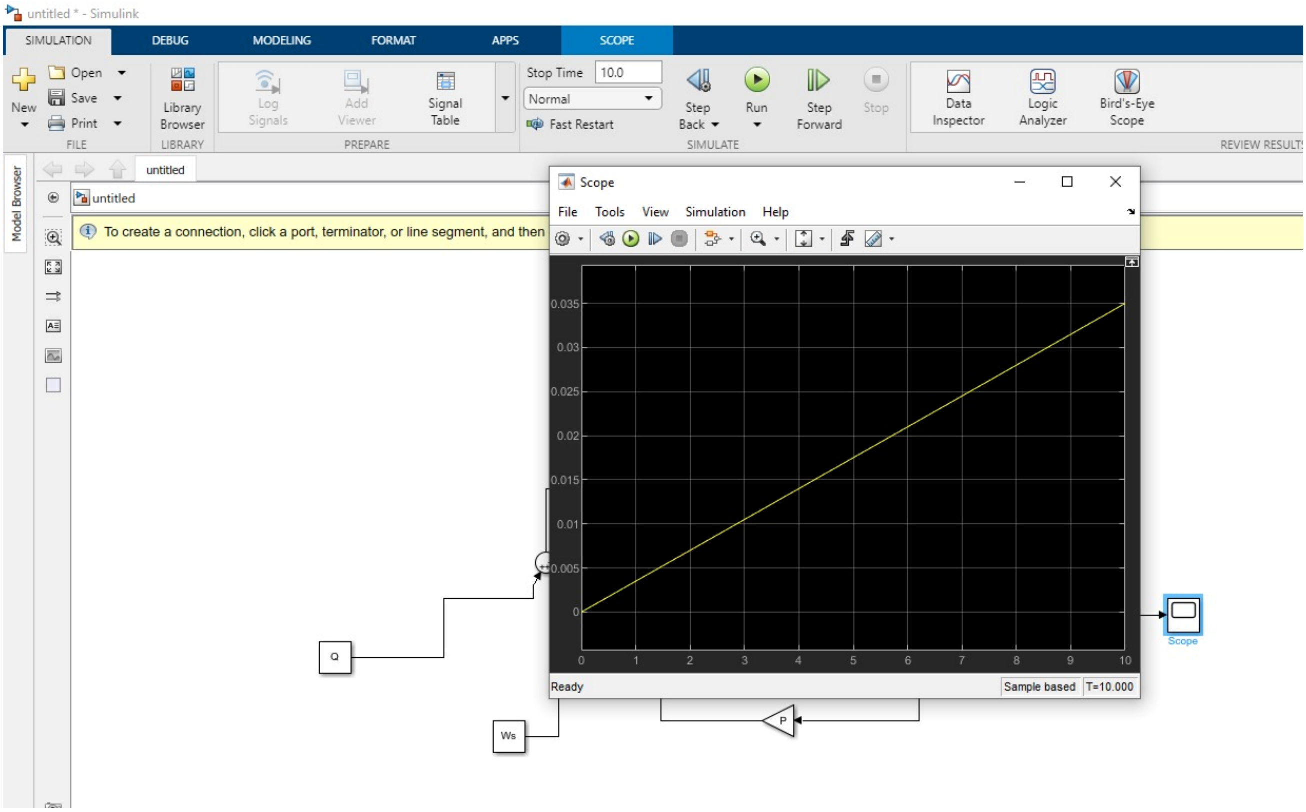




### 6.3.5.1 Differential equation used MATLAB



### 6.3.5.2 The result




>>- $PV=nRT$ ; $\Delta H=\sum \Delta H f^{\circ}(products)-\sum \Delta H f^{\circ}(reactants)$ $\Delta S=\sum S^{\circ}(products)-\sum S^{\circ}(reactants)$

$\Delta G=\Delta H-T\Delta S$

$\Delta G=-RT\ln K$

A l equilibre

$\Delta G=0$------->$K=e^{-\Delta G/RT}$

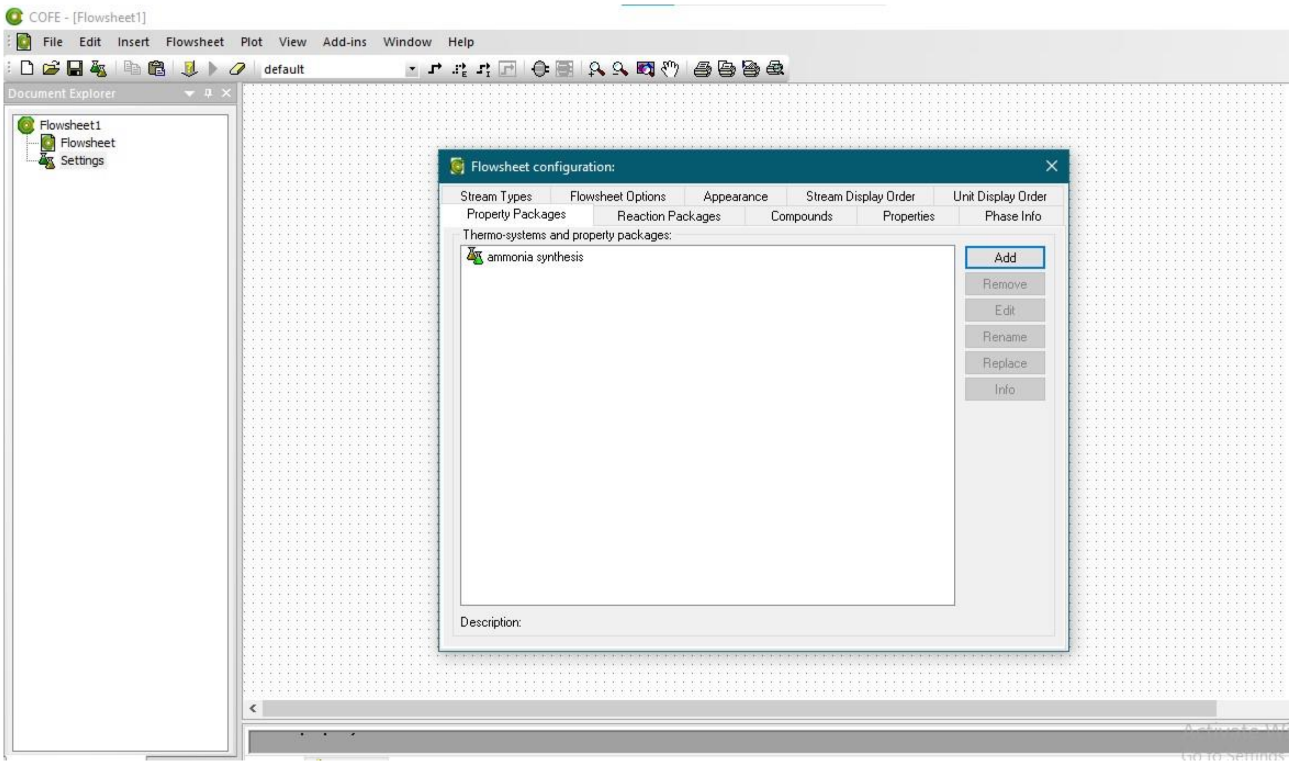
Perfect gas eq.: $PV=nRT$

### 6.3.2. Simulation with COCO

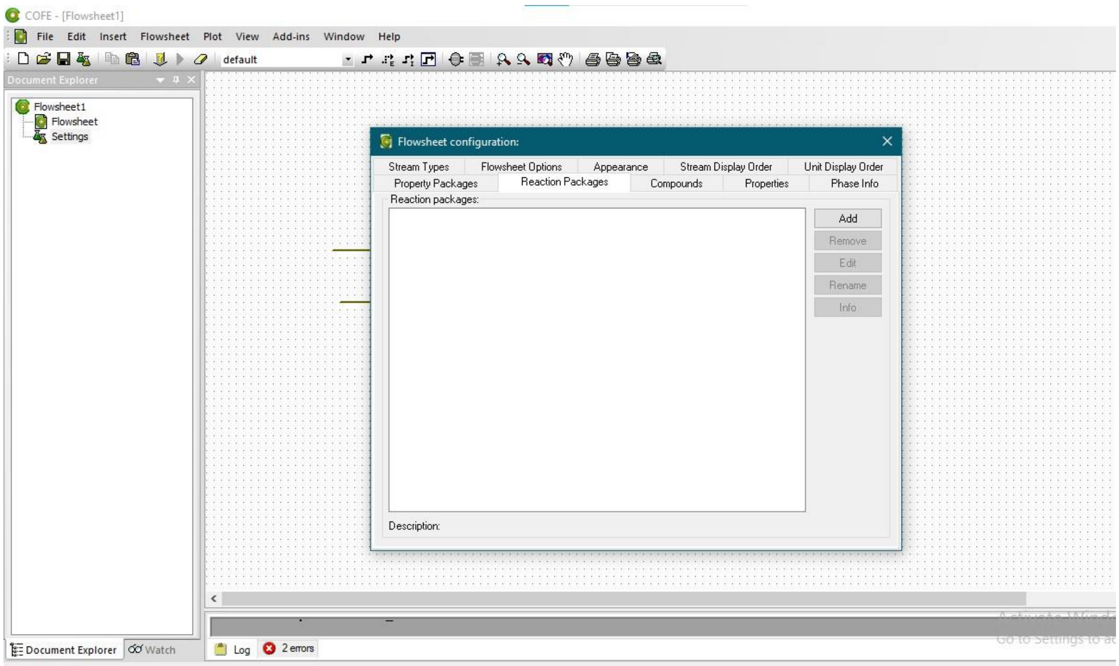
step 1: Open the program COFE to simulate with coco:

step 2: Click on settings.

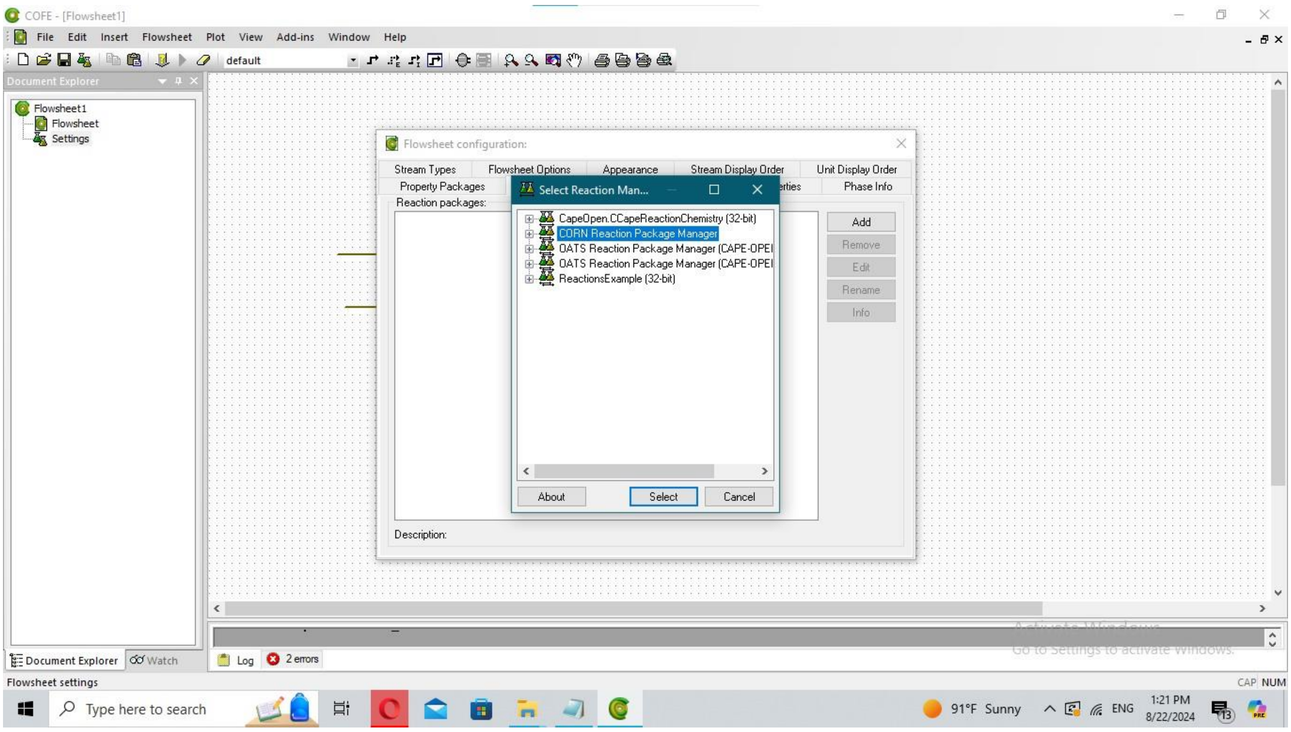
- Packages ammonia



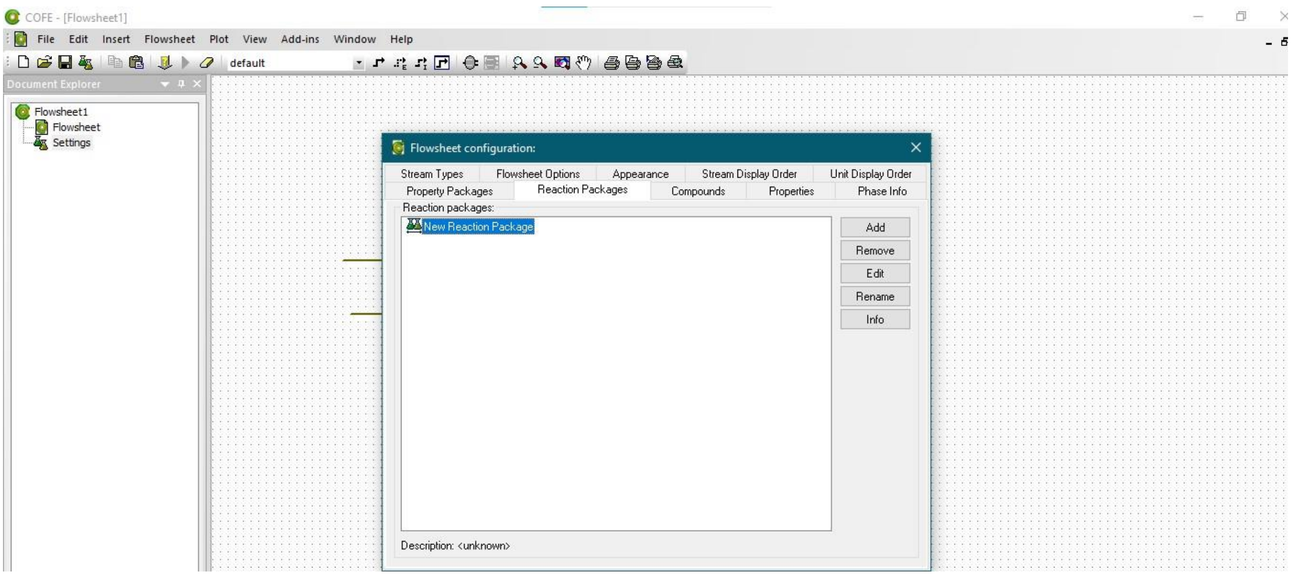

- Add reaction



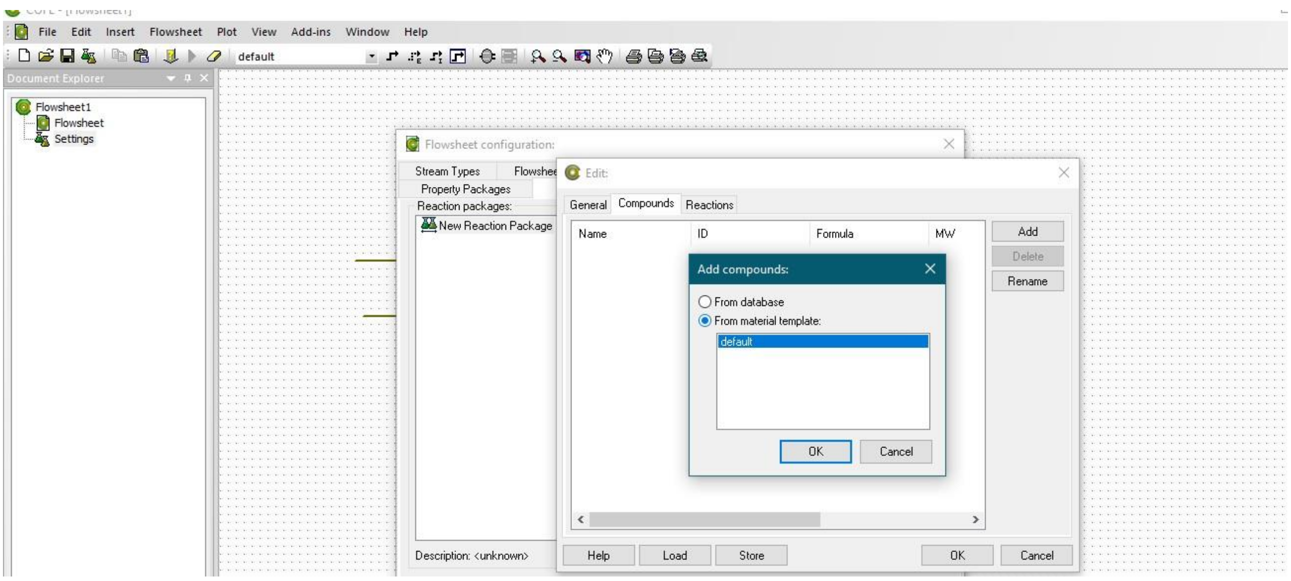

- Add reaction manager



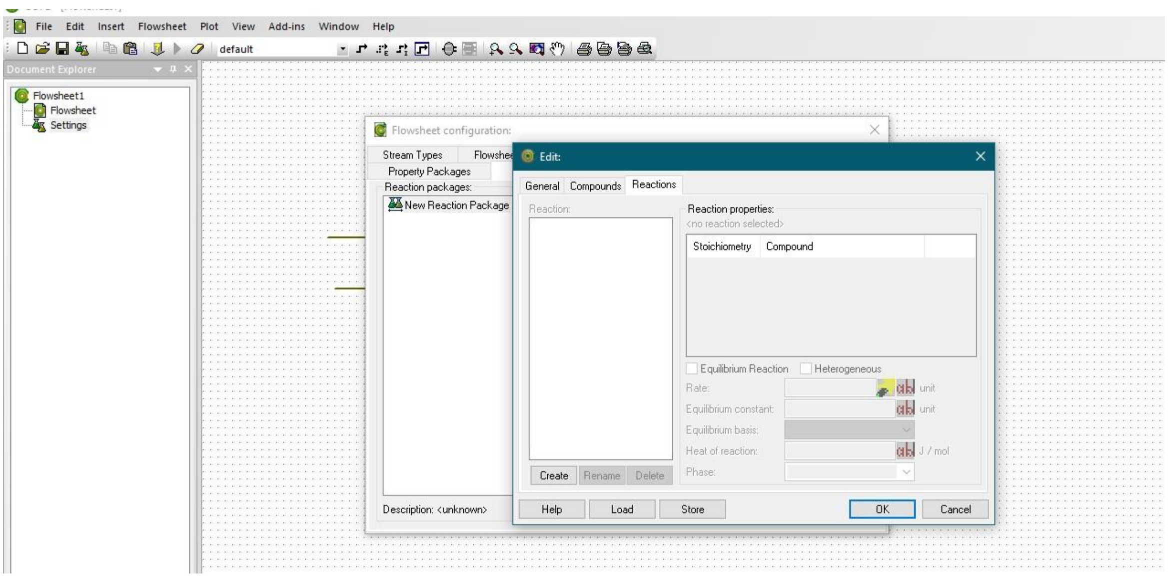

- Edit new reaction



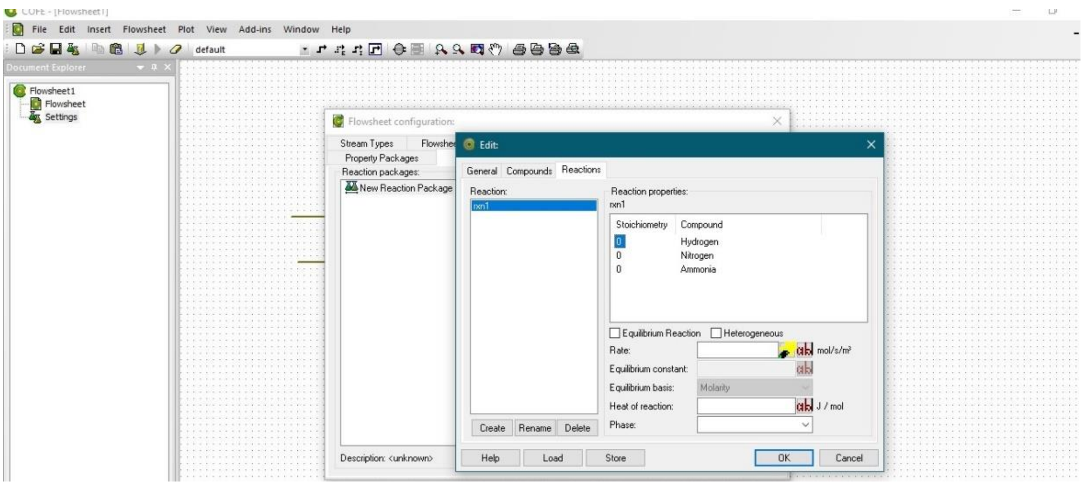

- Add compound of material



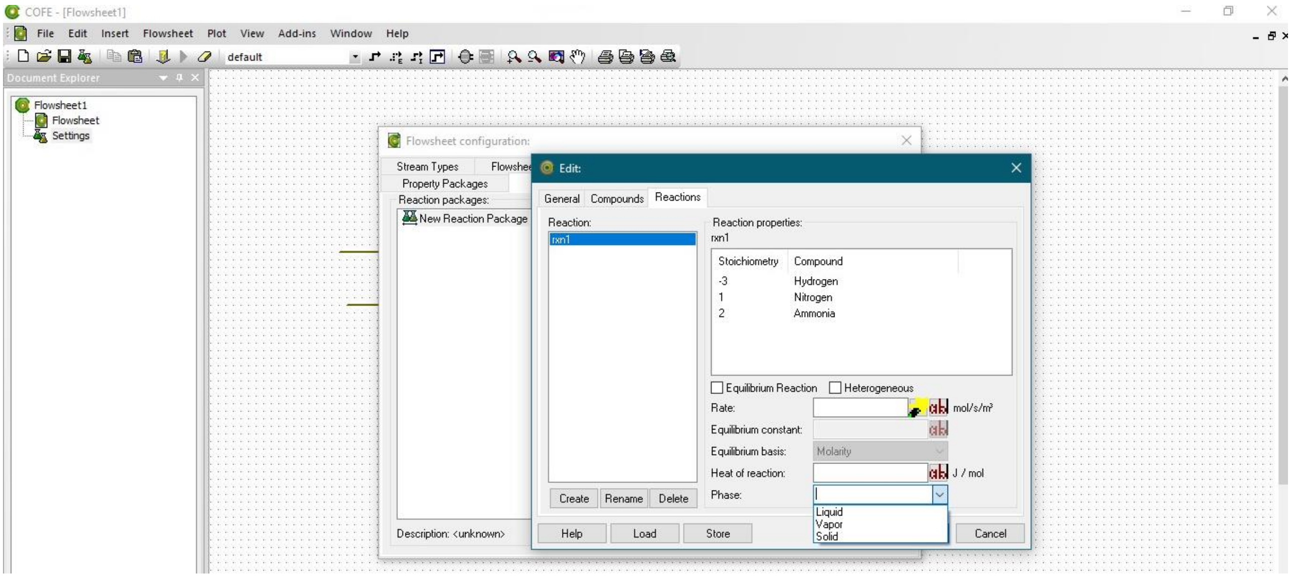

- Select reaction



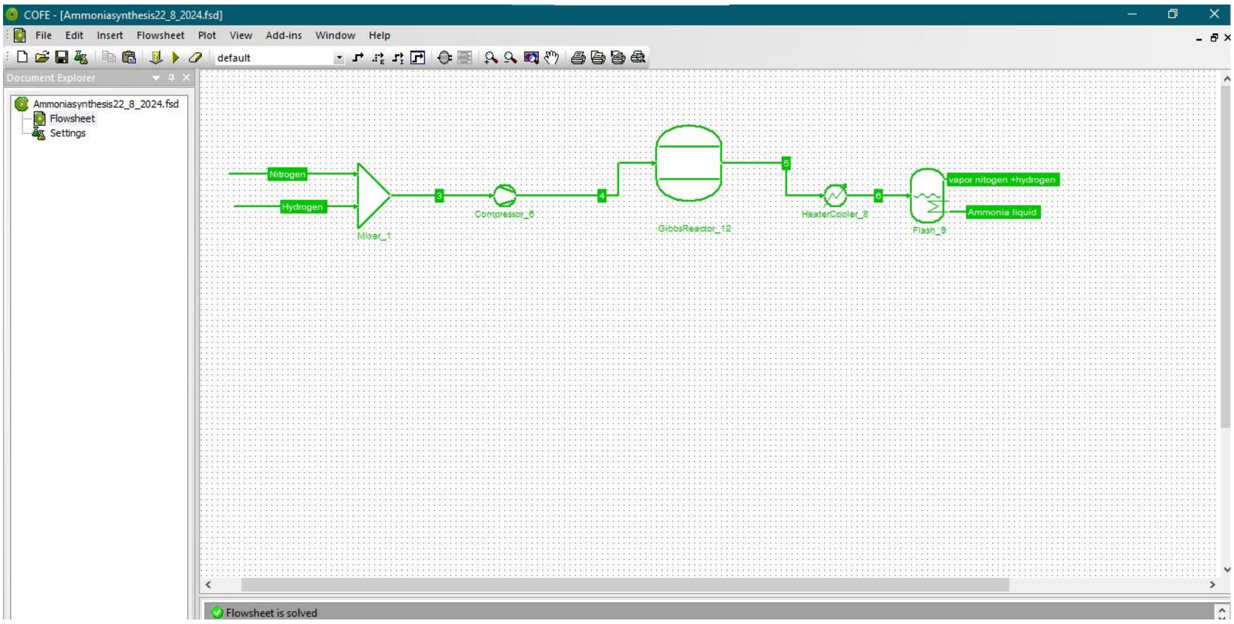

- Stochiometrics



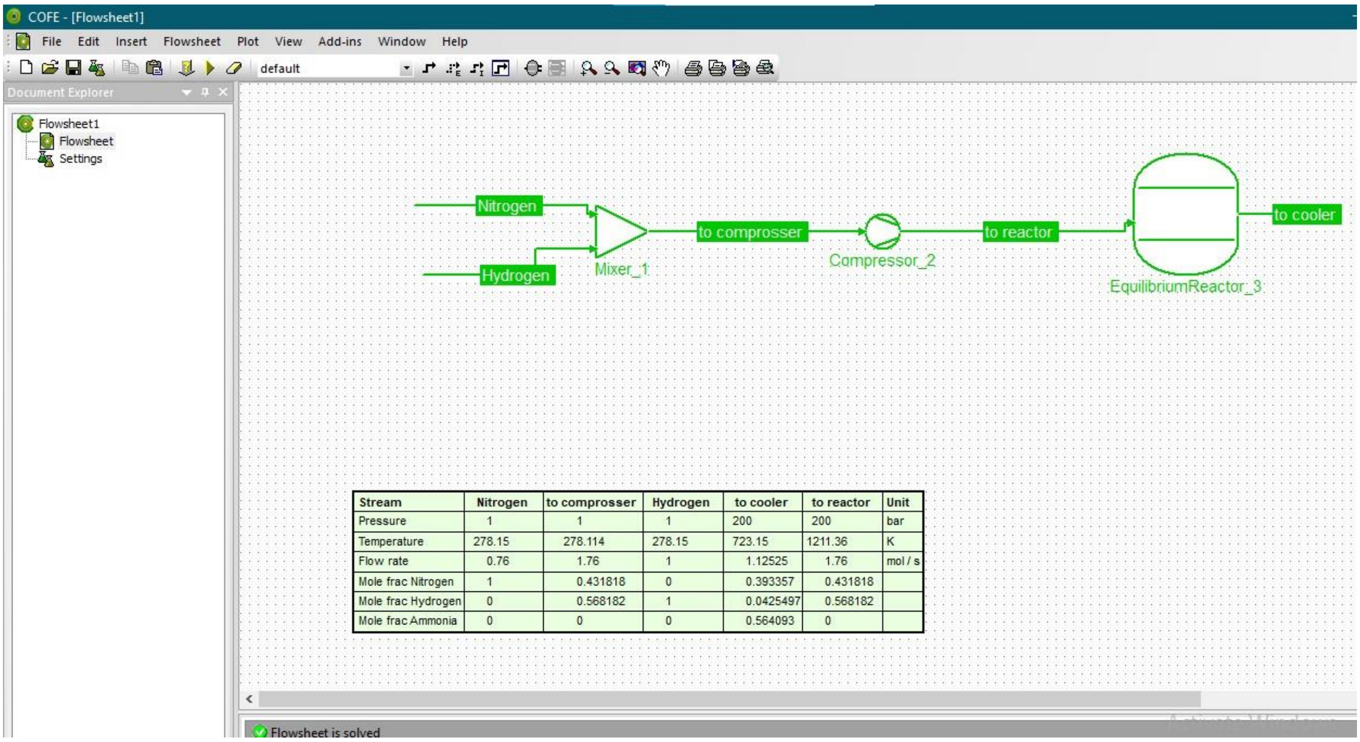

- Select GAS phase




- The unit operation used

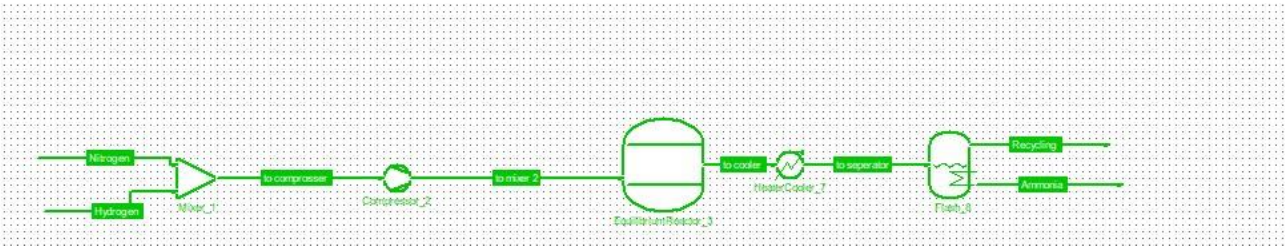



- Streams info

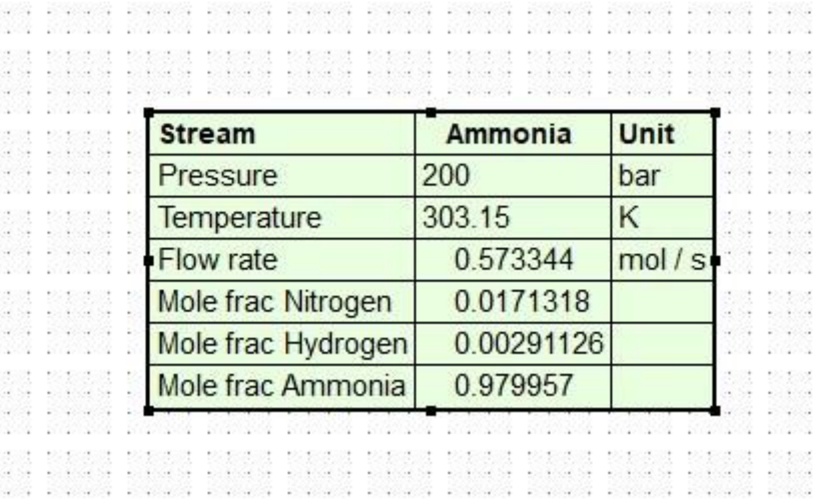



| Stream | Nitrogen | to compresser | Hydrogen | to cooler | to reactor | Unit |
|---|---|---|---|---|---|---|
| Pressure | 1 | 1 | 1 | 200 | 200 | bar |
| Temperature | 278.15 | 278.114 | 278.15 | 723.15 | 1211.36 | K |
| Flow rate | 0.76 | 1.76 | 1 | 1.12525 | 1.76 | mol / s |
| Mole frac Nitrogen | 1 | 0.431818 | 0 | 0.393357 | 0.431818 | |
| Mole frac Hydrogen | 0 | 0.568182 | 1 | 0.0425497 | 0.568182 | |
| Mole frac Ammonia | 0 | 0 | 0 | 0.564093 | 0 | |

- Simulation



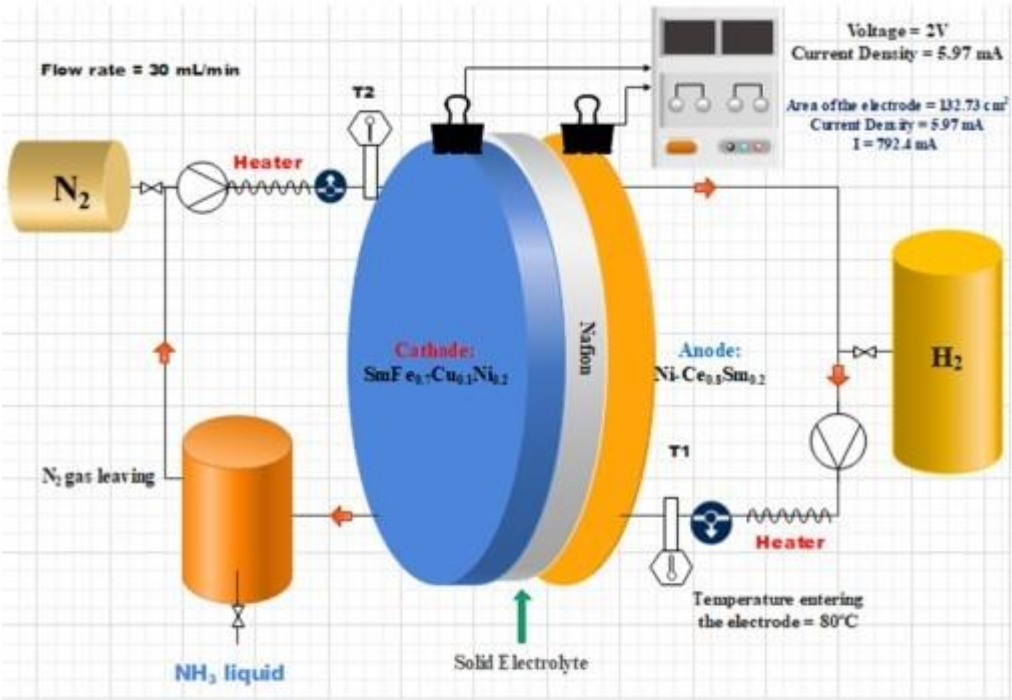

- Result



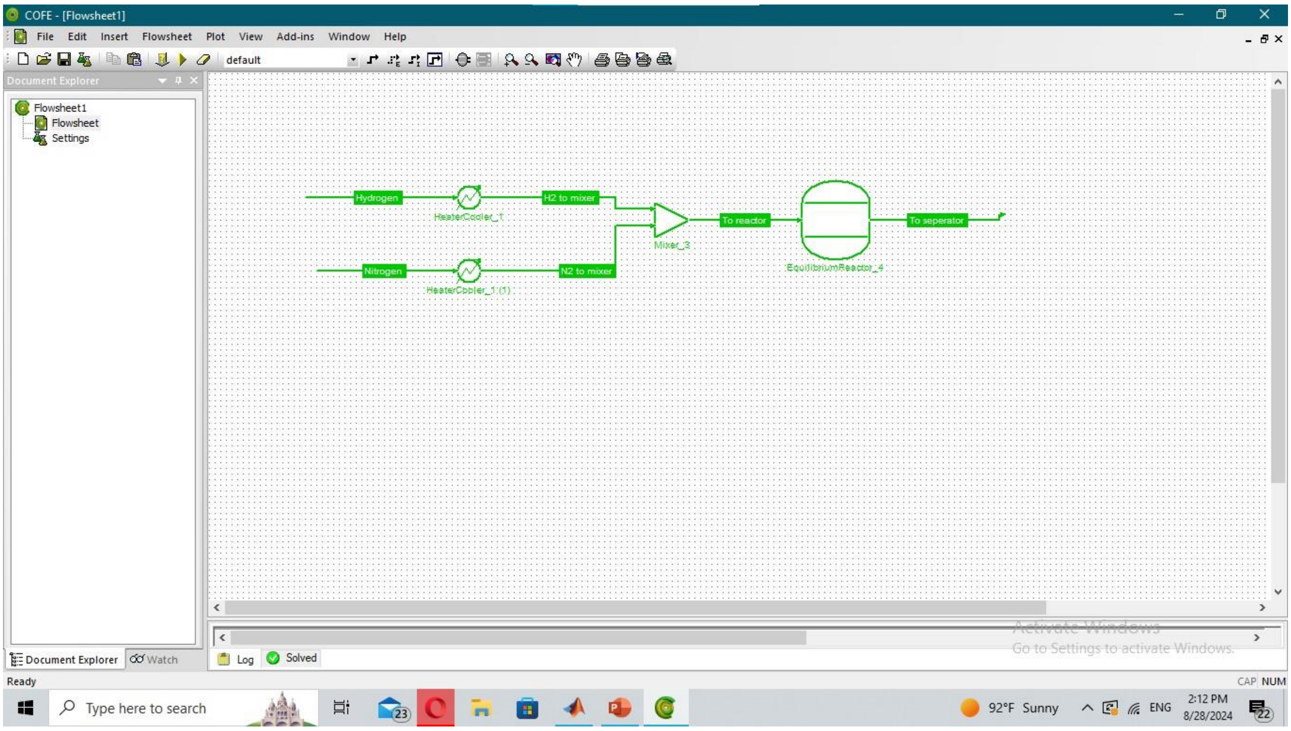
| Stream | Ammonia | Unit |
|---|---|---|
| Pressure | 200 | bar |
| Temperature | 303.15 | K |
| Flow rate | 0.573344 | mol / s |
| Mole frac Nitrogen | 0.0171318 | |
| Mole frac Hydrogen | 0.00291126 | |
| Mole frac Ammonia | 0.979957 | |

### 6.3.6 Electrochemical synthesis Simulation

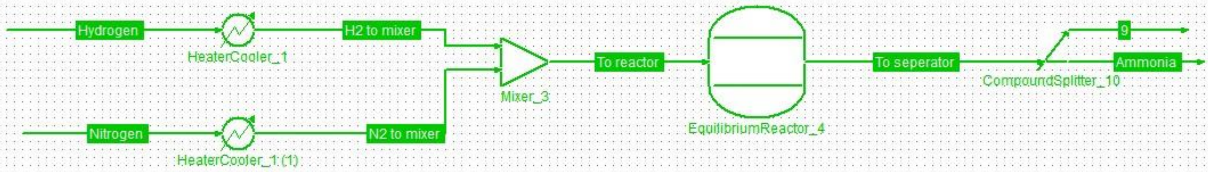
We should simulate this process with coco simulation




- **Electrochemical coco simulation :**




- **FINAL simulation**




| Stream | Hydrogen | Nitrogen | H2 to mixer | To reactor | To seperator | N2 to mixer | 9 | Ammonia | Unit |
|---|---|---|---|---|---|---|---|---|---|
| Pressure | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | atm |
| Temperature | 25 | 25 | 80 | 79.9775 | 80 | 80 | 80 | 80 | °C |
| Flow rate | 0.000181429 | 0.00252121 | 0.000181429 | 0.00270264 | 0.00270264 | 0.00252121 | 0.00205138 | 0.000651255 | kg / s |
| Mole frac Hydrogen | 1 | 0 | 1 | 0.5 | 0.230244 | 0 | 0.315297 | 0 | |
| Mole frac Nitrogen | 0 | 1 | 0 | 0.5 | 0.5 | 1 | 0.684703 | 0 | |
| Mole frac Ammonia | 0 | 0 | 0 | 0 | 0.269756 | 0 | 0 | 1 | |

## 6.4 What's next

After drawing up the initial design of the AP project, the electrodes should be made – following section 6.2 (AP experimental part)

After that, we will be able to install the whole system.

PLC automation should also be worked on.

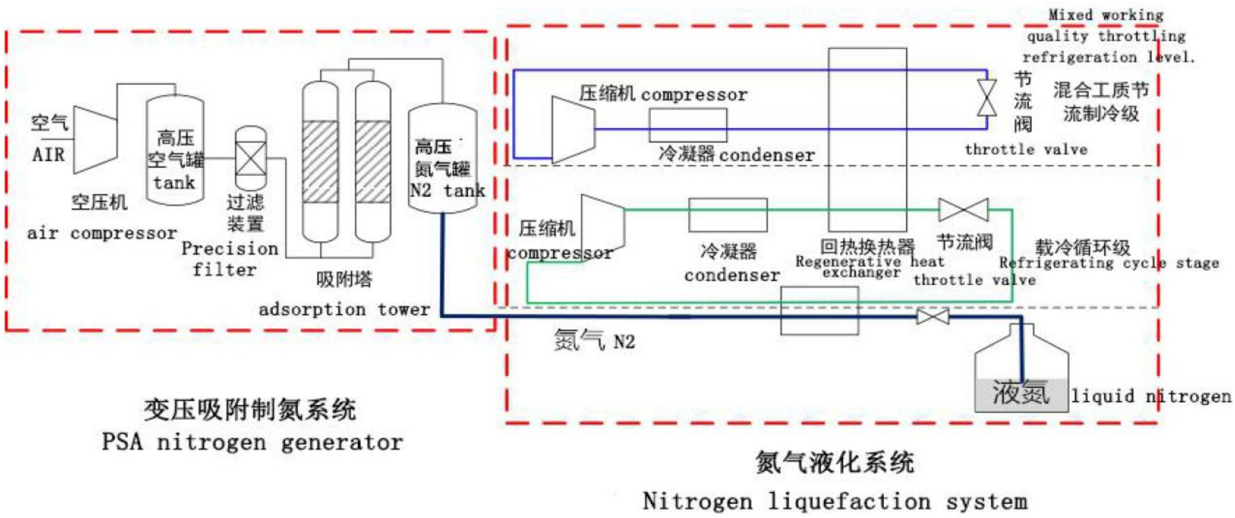
# 7 Project 5: Liquefaction of Oxygen (ICPT - LOX), Cooling and Cryogenics

## 7.1 Position of LOX project

Work on this project began theoretically in the past years. In Jan-March 2025, the focus was on the practical, operational side.

## 7.2 From NLAP-WEDC Report 2023

### 7.2.1 Nitrogen Liquefication System Design Apr 2023 (based on Chinese supplier)[8]




[8] Ref : https://aecenar.com/index.php/institutes/icpt/liquefication-of-air-and-oxygen/icpt-lox-system-concept-design

### 7.2.2 LOX Mechanical Realization

#### 7.2.2.1 Prototype Location

#### 7.2.2.2 Prototype Installation

#### 7.2.2.3 Compressor:

Figure 4. LR25B Compressor

#### 7.2.2.4 Cooler:

Figure 6. Cooler Tube Implementation

#### 7.2.2.5 Evaporator:

Figure 7. Evaporator

#### 7.2.2.6 Heat exchanger

### 7.2.3 Liquefication of oxygen System Test Specification[9]

#### 7.2.3.1 First Experiment:

The first experiment (Expr #1) aims to:

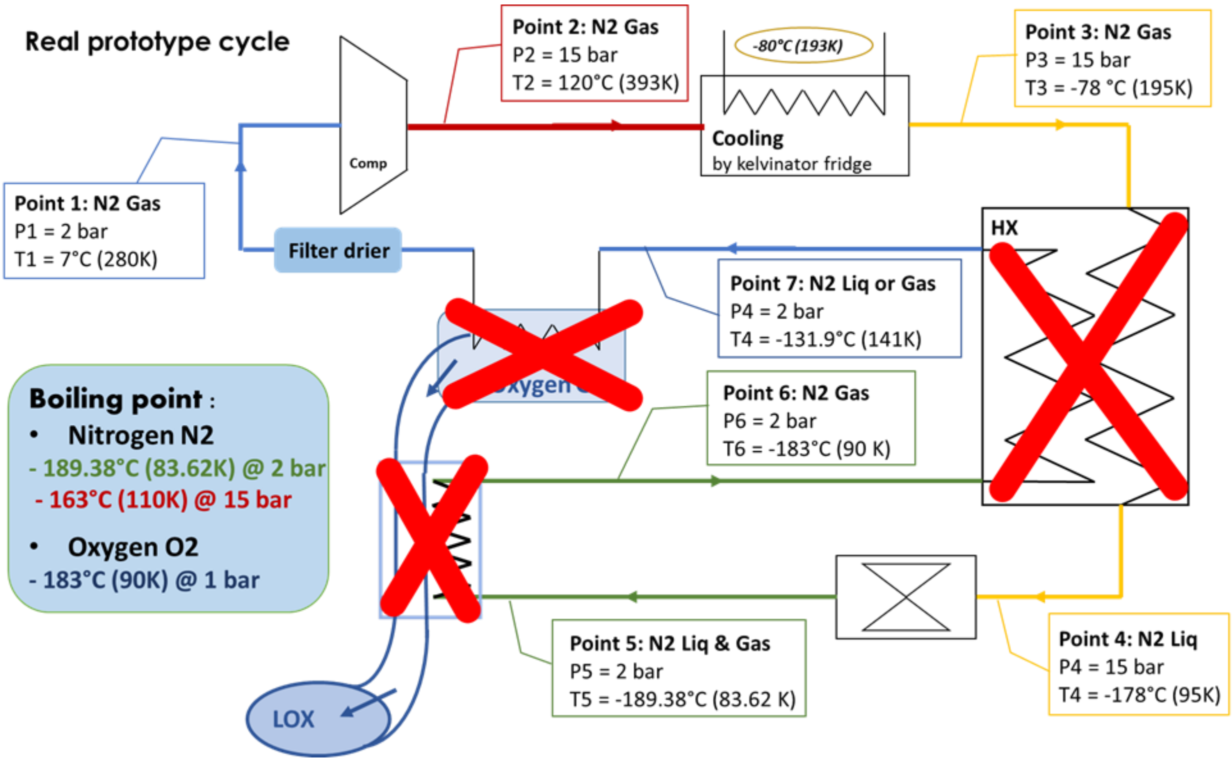
1- Compressor operation test with nitrogen gas instead of R-134a,

2- Make sure that the Kelvinator refrigerator is running correctly

3- Ensure that the expansion valve is compatible with the design.

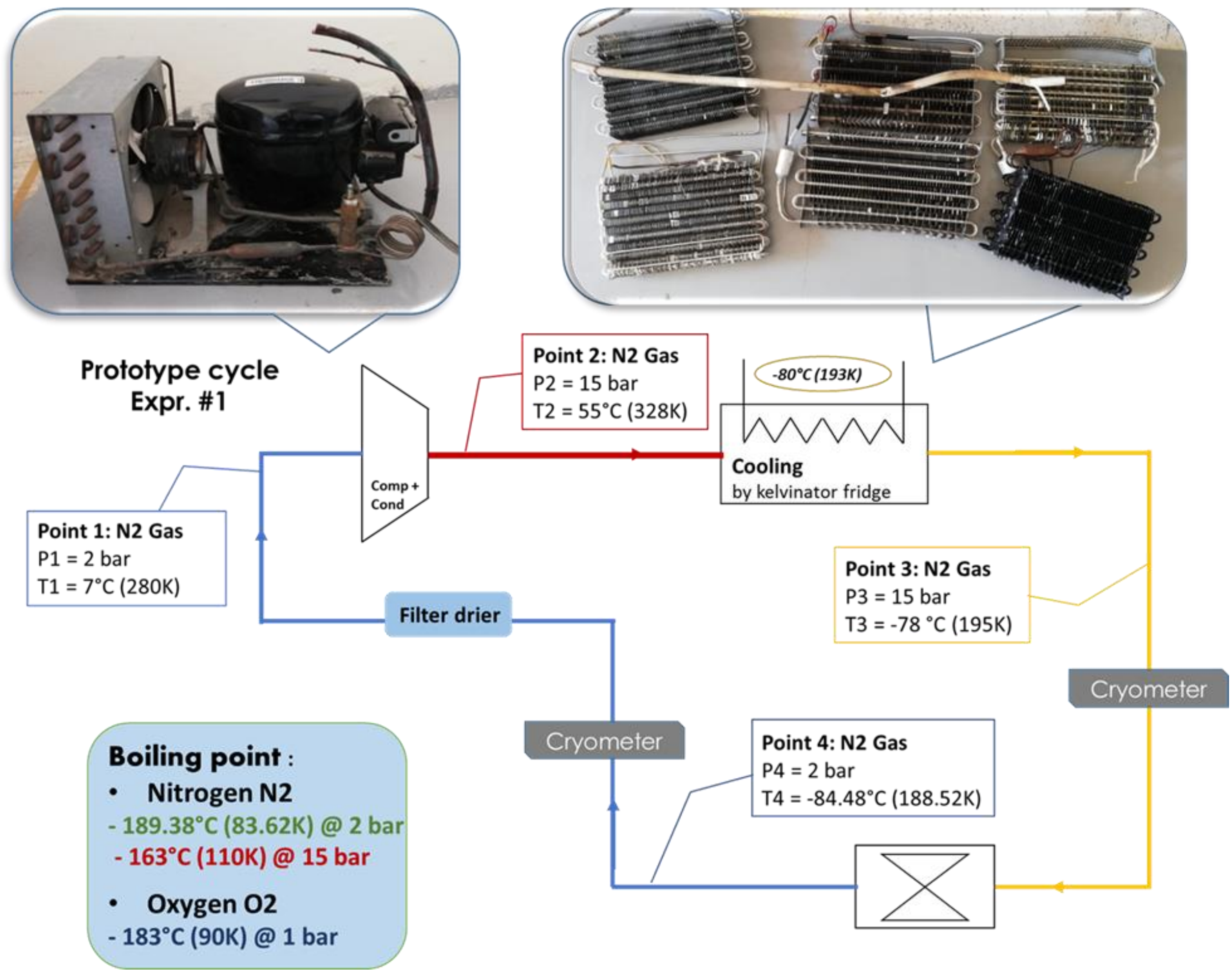
Therefore, the three heat exchangers (HX-N2/N2, HX-N2/O2 main, and HX-N2/O2 2nd) will be excluded from this experiment.

In this experiment, the oxygen will not be liquefied, but only the components will be tested and designed to ensure the proper functioning of the refrigeration cycle.




The first experiment consists of a simple cycle consisting of a compressor (LR25B Laboratory) with a condenser, cooling through a Kelvinator refrigerator, and an expansion valve (taken from an LR25B Laboratory refrigerator).

[9] Ref : https://aecenar.com/index.php/institutes/icpt/liquefication-of-air-and-oxygen/icpt-lox-system-test-specification




The components that must be provided to carry out this experiment:

- Filling the design with nitrogen gas, immediately before the pump.
- Covering the design with thermal insulation material to maintain the temperature of the refrigeration cycle,
- The presence of a thermometer (below -100˚C (173 K)) to measure the cooling outlet (an inlet of the expansion valve) and the outlet of the expansion valve,
- Also, a weather thermometer (from -10˚C to 20˚C (263 K to 293 K)) to measure the temperature of the compressor inlet.

For the safety of the compressor:

- In the **first hour of operation**, a 5-minute break must be taken for the compressor every 15 minutes of operation, in order to avoid an explosion of the compressor or one of the designed cables.
- Also, the compressor must **not run for more than two hours** in a row.
- Also, **cold nitrogen gas must be entered into the compressor** to reduce the speed of nitrogen flow, in addition to its role in cooling the compressor.

During this experiment (Expr. #1), the **amount of nitrogen gas filled** in the cycle, the **time of the experiment**, the **temperature reached** by the refrigeration cycle, and the **pressure during operation** will be calculated.

## 7.2.4 LOX Requirements

### 7.2.4.1 System requirements

- The LOX system shall be able to liquefy oxygen.

### 7.2.4.2 Physical requirements

- The pipes shall be able to withstand the temperatures and pressures that exist at the points.

- Temperature that shall be withstood:

- Pressure that shall be withstood:

The different temperatures and pressures are listed in the figures below:

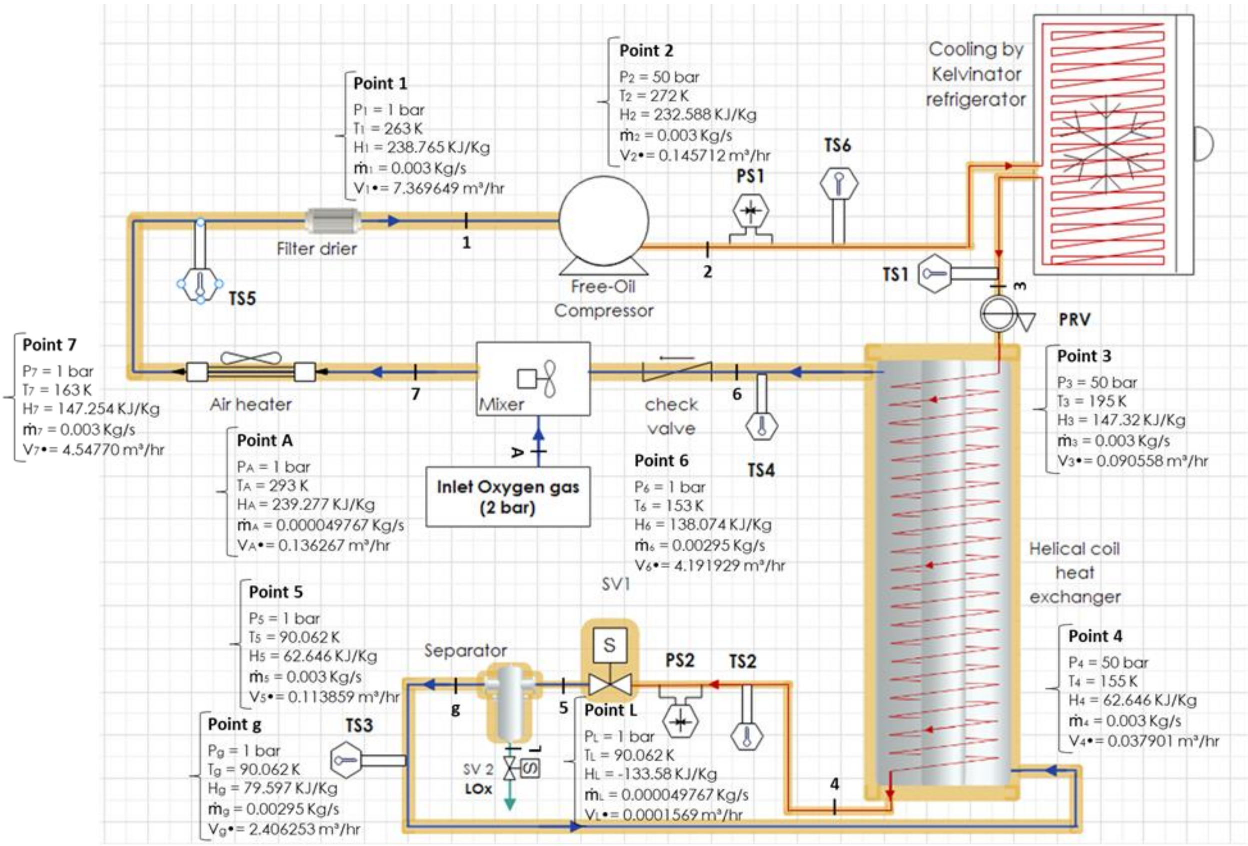



Fig-1-

| Points | Pressure | Temperature | Enthapy | Mass flow | | Density | Volumetric flow | |
|---|---|---|---|---|---|---|---|---|
| | P [bar] | T [°K / °C] | H [KJ/Kg] | m• [Kg/s] | m• [Kg/h] | D [Kg/m³] | V• [L/s] | V• [m³/hr] |
| Pt 1 | 1 | 263 / -10 | 238.765 | 0.003 | 10.8 | 1.46547 | 2.047124813 | 7.369649328 |
| Pt 2 | 50 | 272 / + 10 | 232.588 | 0.003 | 10.8 | 74.1186 | 0.04047567 | 0.145712412 |
| Pt 3 | 50 | 195 / -78 | 147.32 | 0.003 | 10.8 | 119.26 | 0.025155123 | 0.090558444 |
| Pt 4 | 50 | 155 / -118 | 62.646 | 0.003 | 10.8 | 284.95 | 0.010528163 | 0.037901386 |
| Pt 5 | 1 | 90.062 / -183 | 62.646 | 0.003 | 10.8 | 94.854 | 0.031627554 | 0.113859194 |
| Pt g | 1 | 90.062 / -183 | 79.597 | 0.00295 | 10.62 | 4.4135 | 0.668403761 | 2.40625354 |
| Pt L | 1 | 90.062 / -183 | -133.58 | 0.000049767 | 0.1791612 | 1141.8 | 4.35864E-05 | 0.000156911 |
| Pt 6 | 1 | 153 / -120 | 138.074 | 0.00295 | 10.62 | 2.53344 | 1.164424656 | 4.191928761 |
| Pt 6' | 1 | 263 / -10 | 238.765 | 0.00295 | 10.62 | 1.22598 | 2.406238275 | 8.662457789 |
| Pt A' | 1 | 263 / -10 | 238.765 | 0.000049767 | 0.1791612 | 1.22598 | 0.040593648 | 0.146137131 |
| Pt A | 1 | 293 / + 20 | 239.277 | 0.000049767 | 0.1791612 | 1.31478 | 0.03785196 | 0.136267056 |
| Pt 7 | 1 | 163 / -110 | 147.254 | 0.003 | 10.8 | 2.3751 | 1.263104711 | 4.547176961 |
| This table is based on thermodynamic properties tables of oxygen and formula of ideal gas law | | | | | | | | |

Table -1-

- The heat exchanger shall be able to decrease the temperature of the oxygen in order to become close to liquefaction temperature at the pressure present.

The temperature that must be reached: -120°C (154 K) @50bar.

- The cooler (Kelvinator refrigerator) shall be able to supply a temperature that is low enough.

The temperature that shall be reached: -80°C (193K).

- The separator shall be sufficient in volume to allow the gas expansion.

- The separator shall be able to separate the oxygen gas from the liquid oxygen.

- The heater shall be able to warm the cryogenic gas, so that their temperature is suitable for entering the compressor.

### 7.2.4.3 Chemical requirements

- The compressor shall be free of oil (oil-free) to avoid its reaction with oxygen.

### 7.2.4.4 Mechanical requirements

- The material of the pipes shall be made a Copper (the ideal shall be made a stainless steel)

- The dimensions of the pipes that shall be:

Diameters are listed in the figure below:

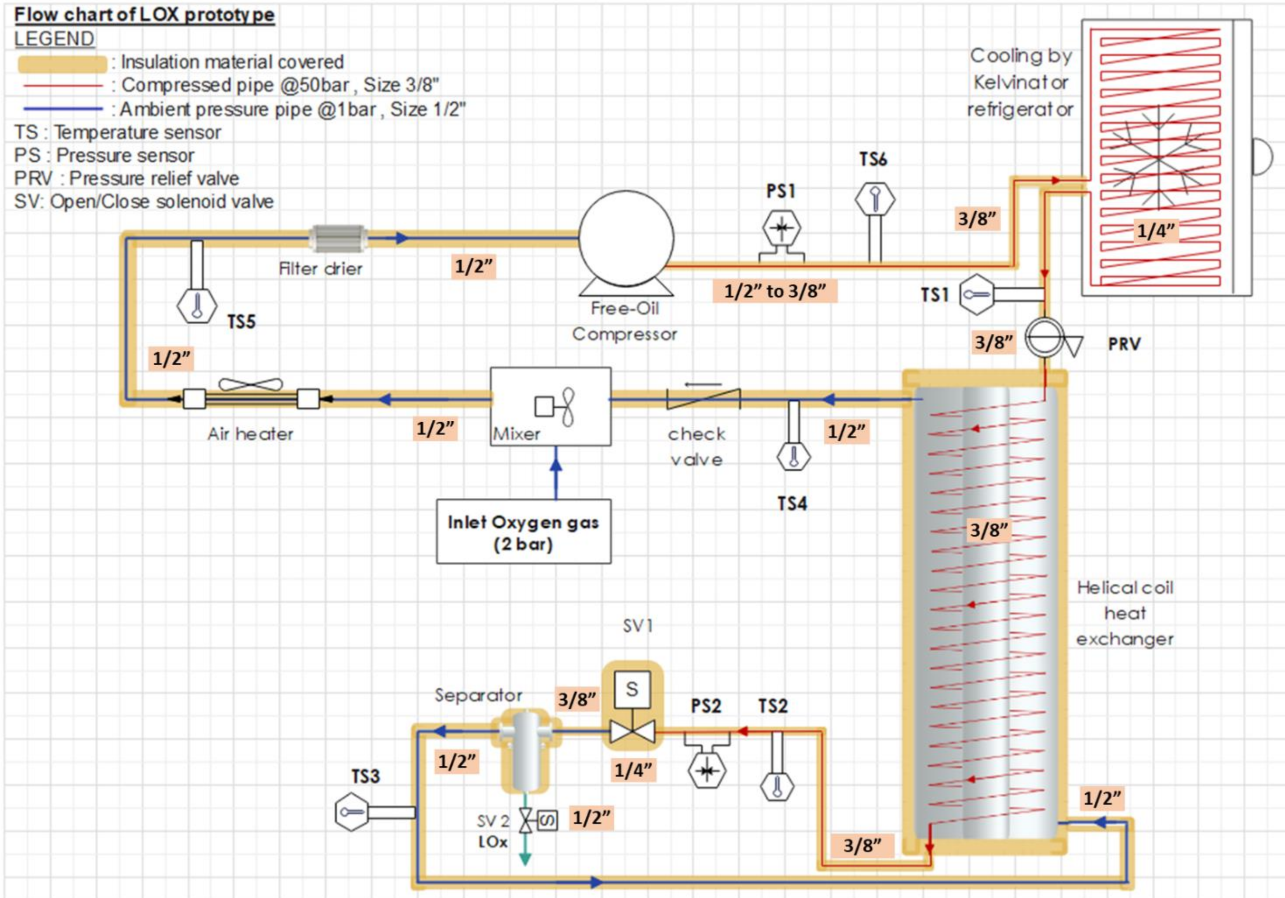



Fig-2-

- The compressor shall be able to increase the pressure of the gas to the required level, from -15°C (258K) @1bar (inlet temperature) - ambient temperature @50bar (outlet pressure).
- The sensors shall be able to measure in the temperature and pressure range, shows in Fig -1-.
- The expansion valve (solenoid valve with separator) shall be able to drop the pressure abruptly, from 50 bar to 1 bar.
- The mixer shall be able to introduce an appropriate amount of fresh oxygen gas into the system; the amount of fresh oxygen gas added shall be equal the amount of liquid oxygen, taking into account the effect of the temperature difference.
- The filter drier shall be able to dry the oxygen gas before entering the compressor.
- The thermal insulation material shall be able to isolate pipes and components from any heat leakage.
- The thermal insulation material shall be made a fiber glass (the ideal thermal insulation shall be made a Flexible EPDM).
- The separator shall be made of stainless steel.
- The LOx system shall be design according to " LOx Mechanical Design ".

#### 7.2.4.5 Automation requirements

- The sensors shall be able to be controlled from the GUI.

- The valves shall be able to be controlled from the GUI.

## 7.3 Air Liquifecation - Realization

### 7.3.1 Connections for oxygen liquefaction project

## 7.4 Heat exchanger (HX) leakage repairing and tests

### 7.4.1 27 Jan 2025

A leakage test was conducted on the heat exchanger to ensure there were no leaks in the system. The test took place on this date and revealed multiple leaks in the heat exchanger's inlets and outlets.

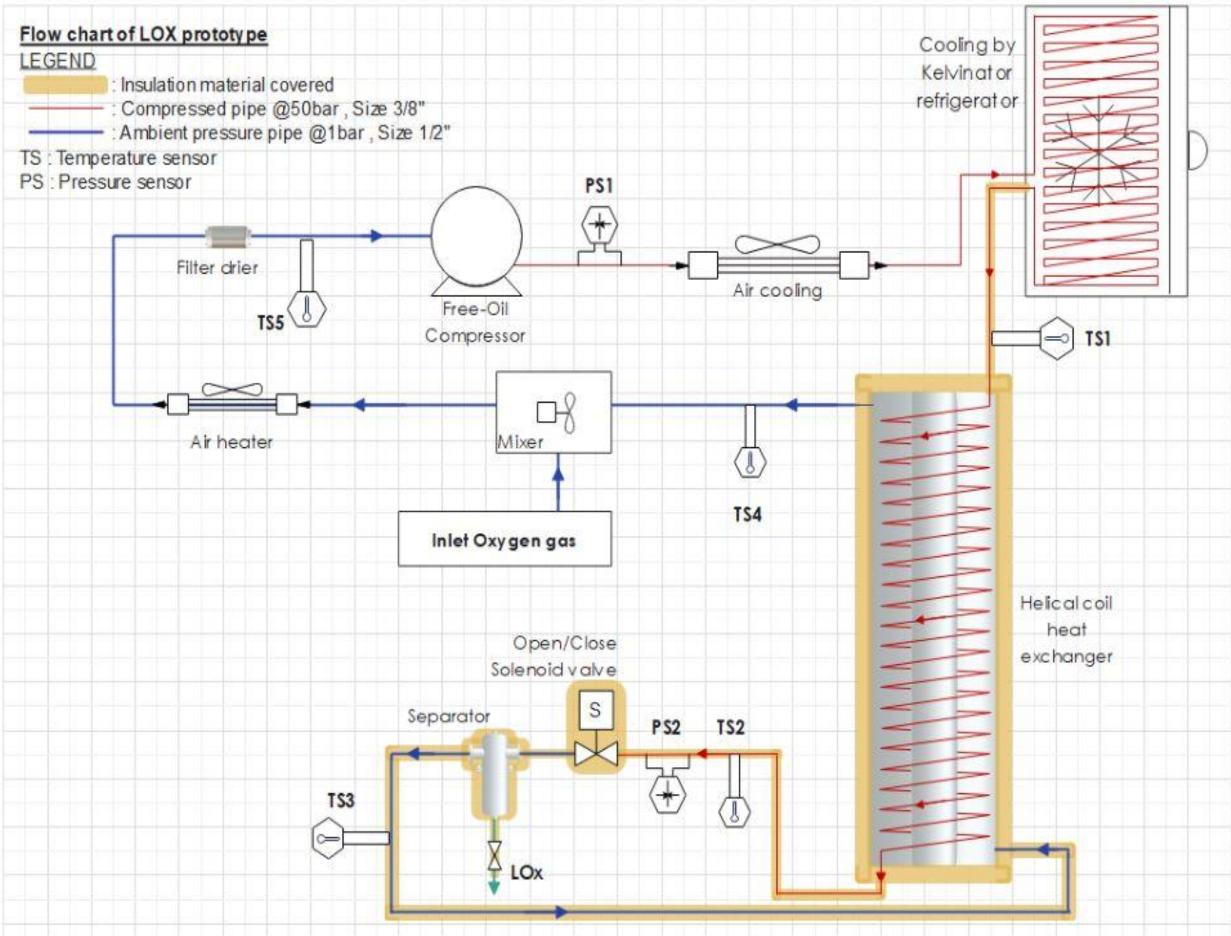
The leaks were due to old rubber connections affected by the sun and natural factors and other wrong connections way. These Pictures related to the test above:




### 7.4.2 30 Jan 2025

On this date new accessories were added to the heat exchanger sealed all the leaks and the system is now fully enclosed.

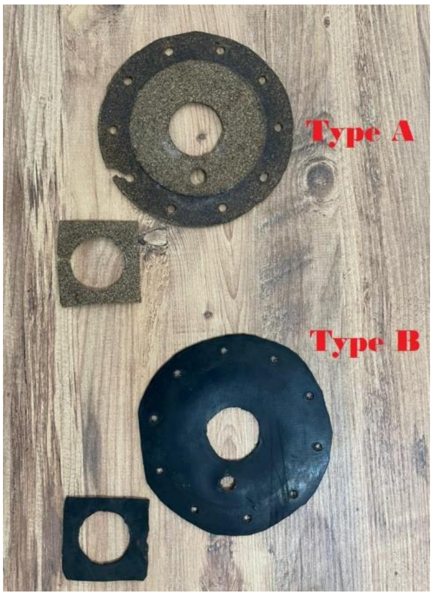
The system was connected depending on the drawing below:




### 7.4.3 4 Feb 2025

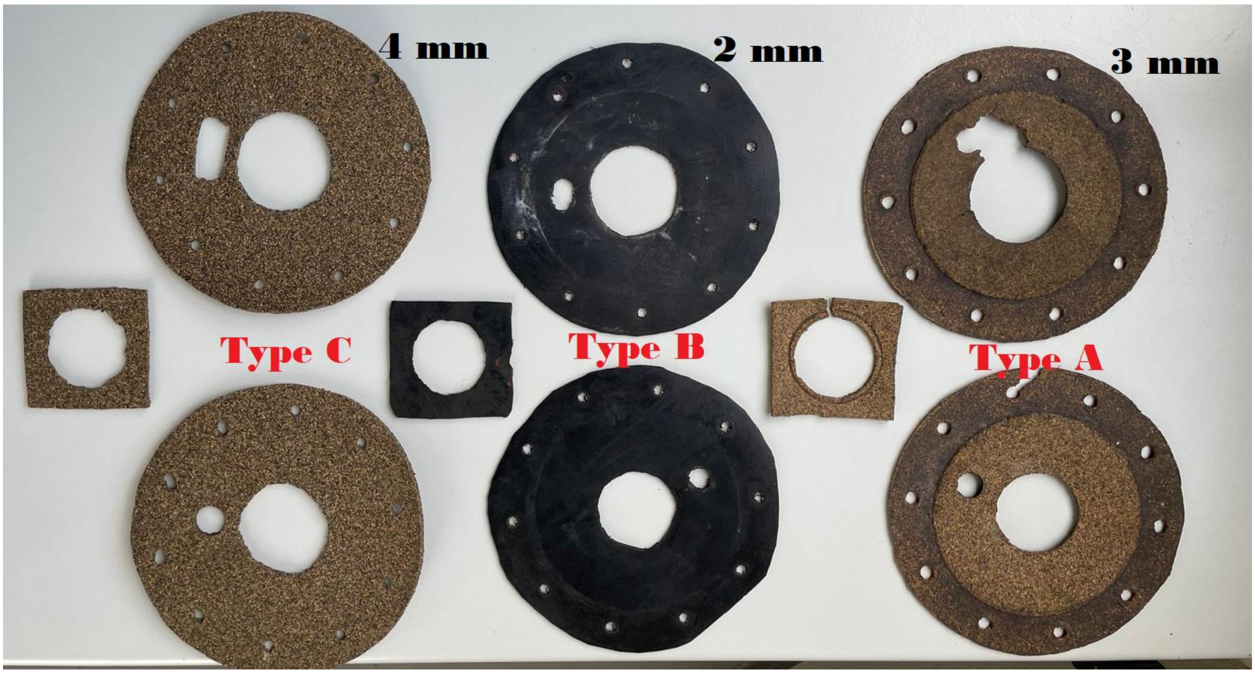
A leakage test was conducted again on the system, revealing leaks in the rubber connection as well as in the stainless-steel components. Due to these issues, the system should be sealed from both the upper and lower openings.

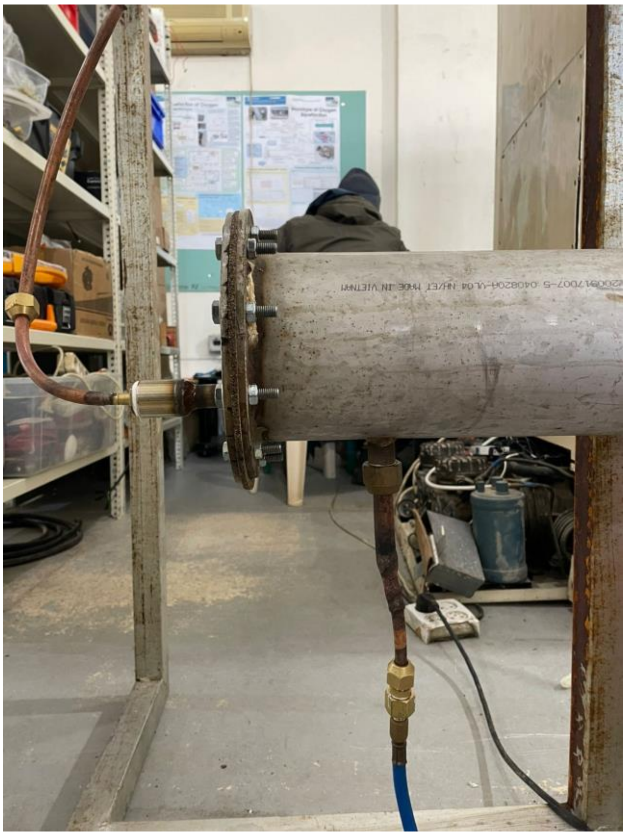
After testing a black rubber (Type B) shown in the picture below, we found that the old rubber (Type A) performed better, as the new one resulted in significant leakage during the test.

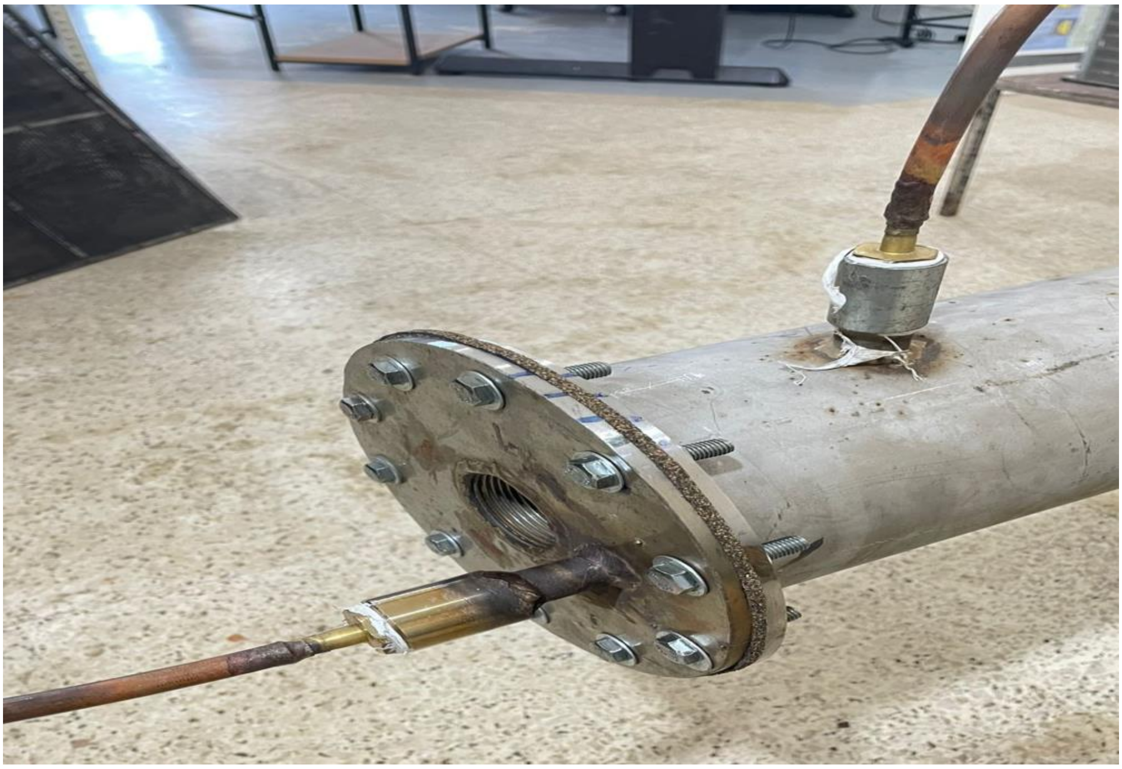



- **<u>10 Feb 2025</u>**

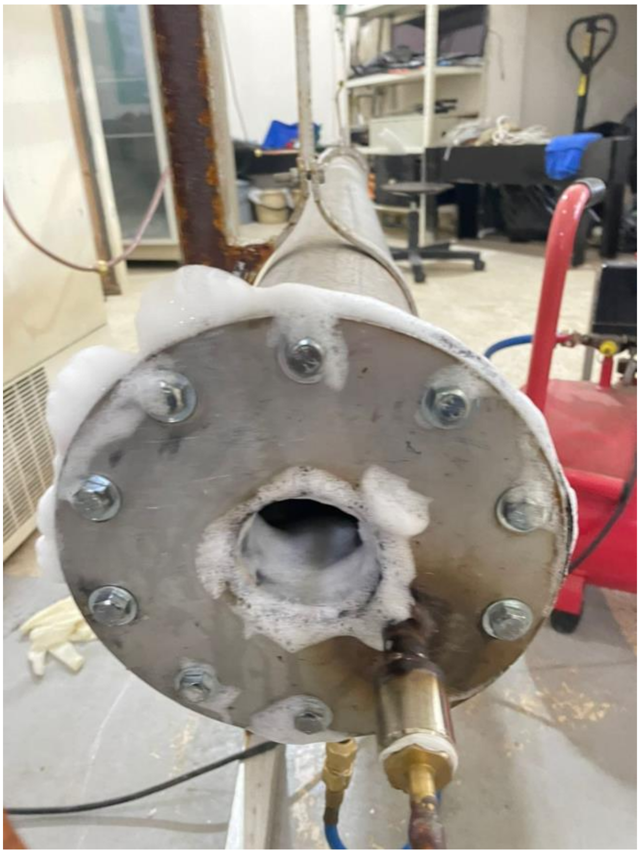
A leakage test was conducted on the heat exchanger after using Type C 4 mm Anti-leakage synthetic rubber when both Type A and B didn't give good results.


4 mm
2 mm
3 mm
Type C
Type B
Type A





The leaking test started and unfortunately, the third type didn't work due to leakage



#### 7.4.4 12 Feb 2025

On this day, High Temp Silicone Sealant was used instead of the different types of Rubbers used before to make the system sealed

We put the first layer and then a second layer and put the nuts immediately.




Also the 2 holes in the top and bottom were closed with stainless steel because the system was leaking in the middle of the pipe.


### 7.4.5 15 Feb 2025

A leakage test was performed on the side part of the heat exchanger, and no leaks were detected, confirming that the red silicone sealant was effective.

A second leakage test was then conducted on the coil sectio Figure above: realization

n of the heat exchanger, specifically in the upper and lower positions.

The results showed a leak in the upper section, as indicated by a significant

pressure drop on the gauge within just half an hour.


When the heat exchanger finally gets into a full leakage test and is tested.

Then we can get into the other step which is the connection of the full process and we will make another leakage test for the full process of the lox and make sure there is no leaking in the system.

## 7.5 Pilot Plant with air as working fluid: Integration and System Test

### 7.5.1 System Integration

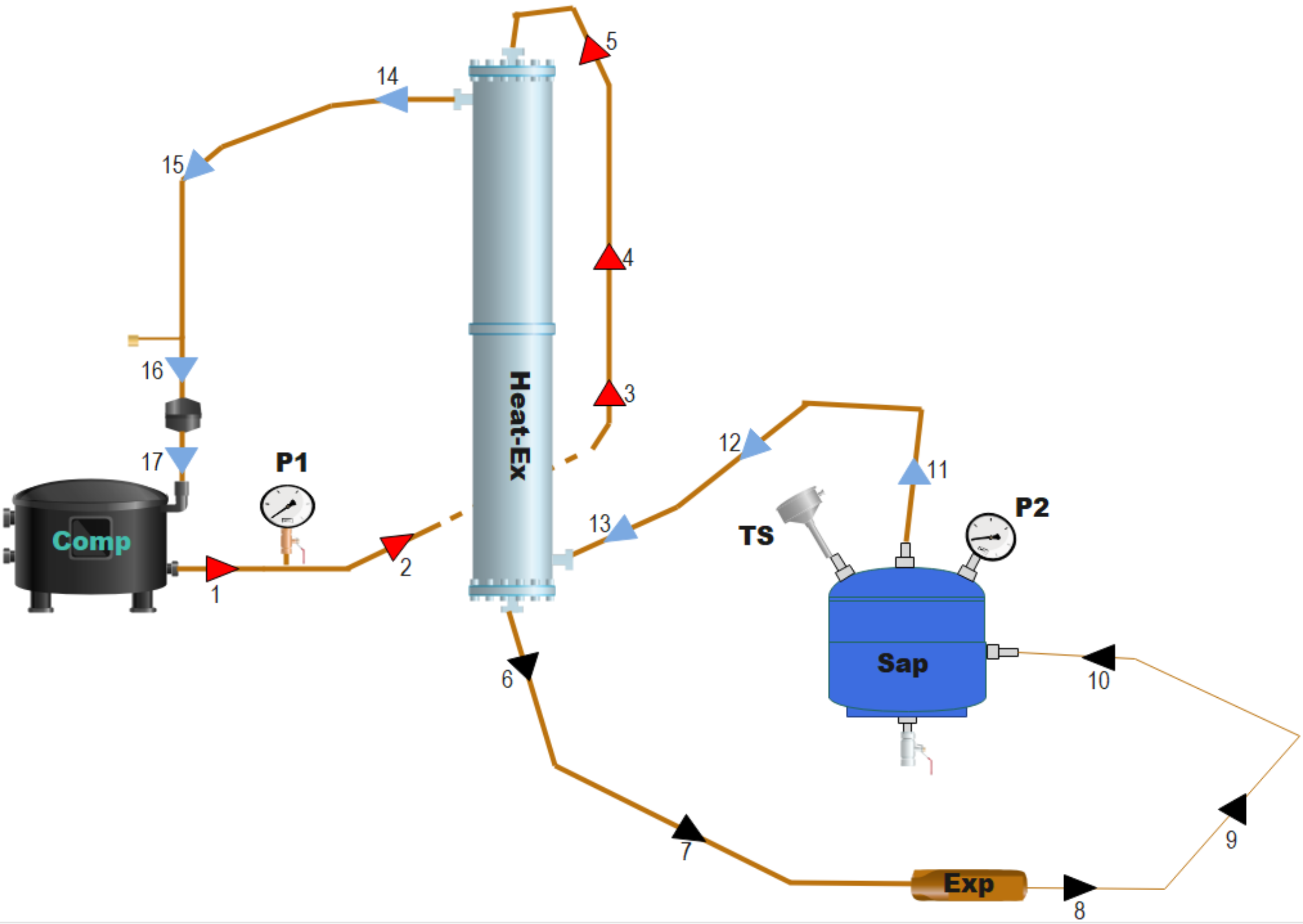
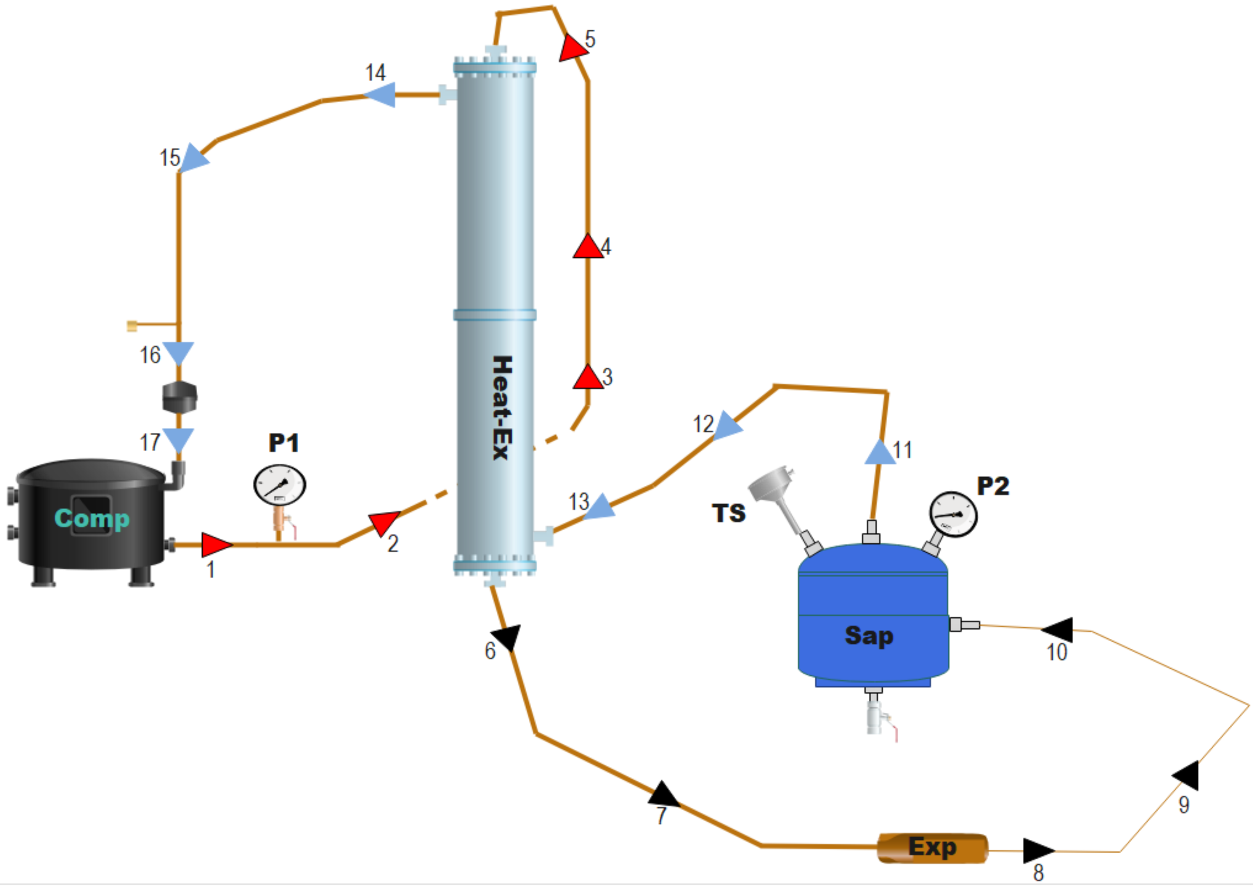



Figure above: Scheme

| | |
|---|---|
|  | Figure left: realization<br><br>in green cycle: expansion valve |

### 7.5.2 How does the new cycle Actually work?




The cycle begins with the compressor, which compresses the air from 2 bar to a pressure between 8 and 12 bar.

The compressed air then travels through points 1, 2, 3, 4, and 5, entering the heat exchanger, where it loses some heat.

After exiting the heat exchanger at point 6, it moves through point 7, where the pipe diameter decreases, followed by points 8 and 9, eventually reaching point 10, where it enters the separator. Inside the separator, the gas undergoes sudden heat loss, causing the liquid portion to settle at the bottom while the remaining gas continues in the cycle.

The gaseous phase moves through points 11, 12, and 13, re-entering the heat exchanger. Here, it helps cool the incoming compressed gas from the compressor before proceeding through points 14, 15, 16, and 17, finally returning to the compressor to restart the cycle.

#### 7.5.2.1 Remarks

والexpansion valve بتعمل فعالية لما يكون refrigerant لي داخل عليها صار سائل وهيدي مش الحالة لي عنا لأن استخدمنا الهواء

الthrottle valve بتعمل فرق ضغط مفاجئ للrefrigerant قبل وبعد

الseparator هي المكان لي بينفصل فيه الغاز عن السائل بعد ما خسر ضغطه

Throttle valve: ما وضعناها لأنها غالية ومخصصة لحسب نوع الغاز

وضعنا بدلها والexpansion valve

والexpansion valve هو الcapillary pipe لي على شكل spring

وتابع له الfilter drier لي موجود قبله

### 7.5.3 System Test 14 March 2025

We disconnected the heat exchanger of the refrigerator, which operates at -80°C, due to a malfunction in one of its compressors and an incorrect connection of the 9 heat exchangers inside it. This error occurred because the expansion valves for each cycle were not removed before welding them together. The system was then reconnected according to the scheme above.

The test was conducted using 2 bar of air instead of the refrigerants R-134, R-290, or R-744. During the test, we observed a cooling effect of 1°C.

However, after a few seconds, the compressor began to overheat.



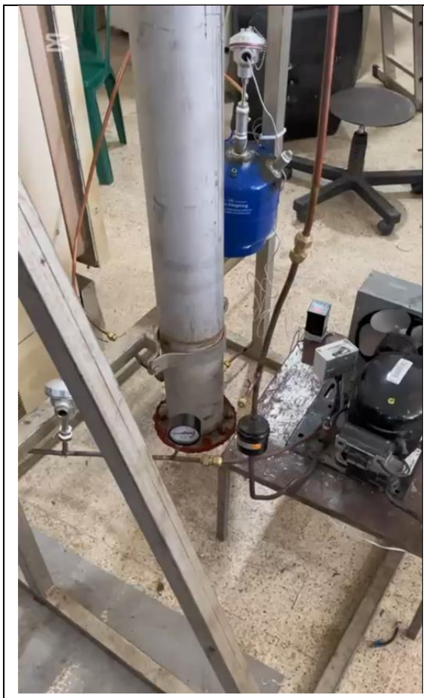
This below is the high pressure side of the compressor:

When we open the system, the high pressure side gets pressurized.


The low-pressure side was kept at 2 bar pressure, and it didn't change.


### 7.5.4 System test 19.3.25 (Video)

WhatsApp Video
2025-03-19 at 15.11.3

| | | |
|---|---|---|
|  |  |  |

Exit of separator


22 °C

Starting the compressor:

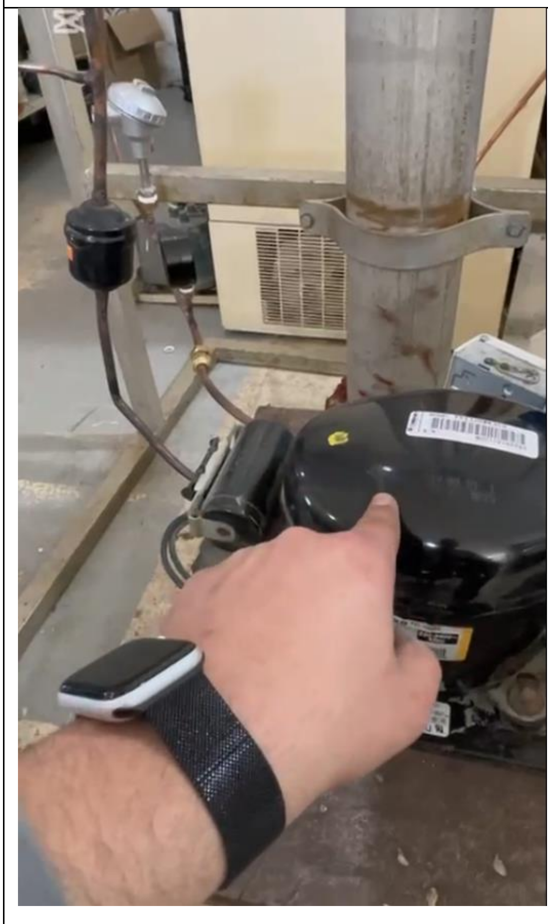

21.5 °C


bar
psi
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
250
300

12 bar


INTELLIGENT METER
PV
SV
21.6
10.0

21.6 °C



## 7.6 What's next

### 7.6.1 Testing with butane as working fluid

TODOs:

Changing compressor: integration of compressor which was used for biogas(methan) compression

### 7.6.2 Repairing -80 °C refrigator

- Actual malfunction in one of its compressors
- and an actually incorrect connection of the 9 heat exchangers inside it (9 expansion valves inside to be deleted).

### 7.6.3 ICPT LOX Compressor Development[10]

to be done:

- Specification of Oil Free Compressor for LOX Testrig (M. El Rez)

- Design of Oil Free Compressor for LOX Testrig (M. El Rez/J.Bachir)

[10] Ref : https://aecenar.com/index.php/institutes/icpt/liquefication-of-air-and-oxygen/icpt-lox-compressor-development

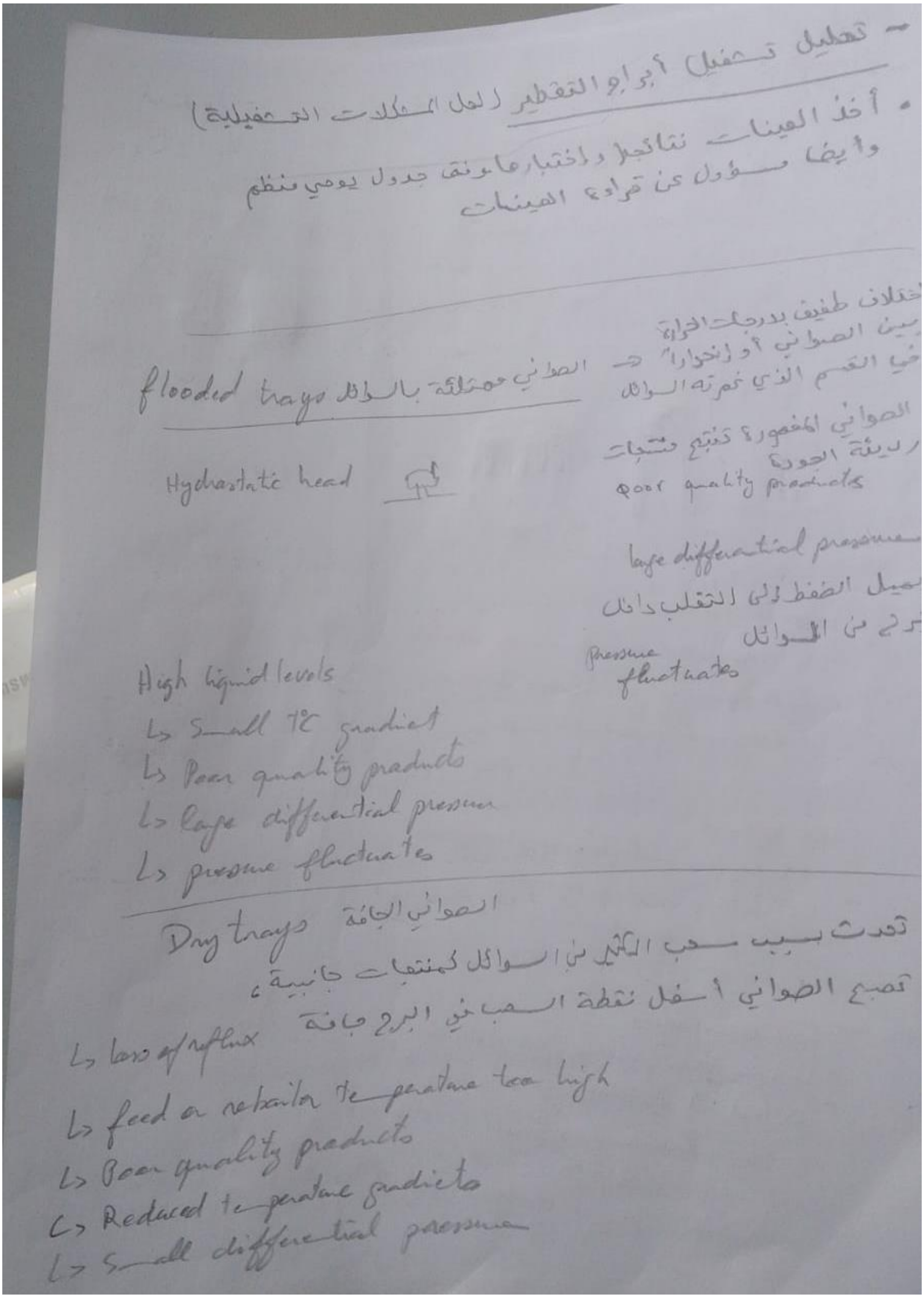
- Manufactoring Oil Free Compressor for LOX Testrig (J. Bachir)

### 7.6.4 Further

To complete the practical part of the LOX project, it is necessary to replace the pipes inside the cooling system and to purchase the oil-free compressor and several other equipment. Based on compressor selection, the features and design of the heater, and mixer will be determined, and the remote control will be finalized. After completing these steps, we will be ready to perform the first run.

# 8 Project 6: Air Separation and Distillation Unit

## 8.1 Air Distillation Concept and Design



- تحليل تشغيل أبراج التقطير (لحل المشكلات التشغيلية)

• أخذ العينات نتائجها واختبارها وفق جدول يومي منظم
وأيضا مسؤول عن قراءة العينات

flooded trays الصواني ممتلئة بالسوائل → اختلاف طفيف بدرجات الحرارة بين الصواني أو انخفاضها في القسم الذي تمر به السوائل

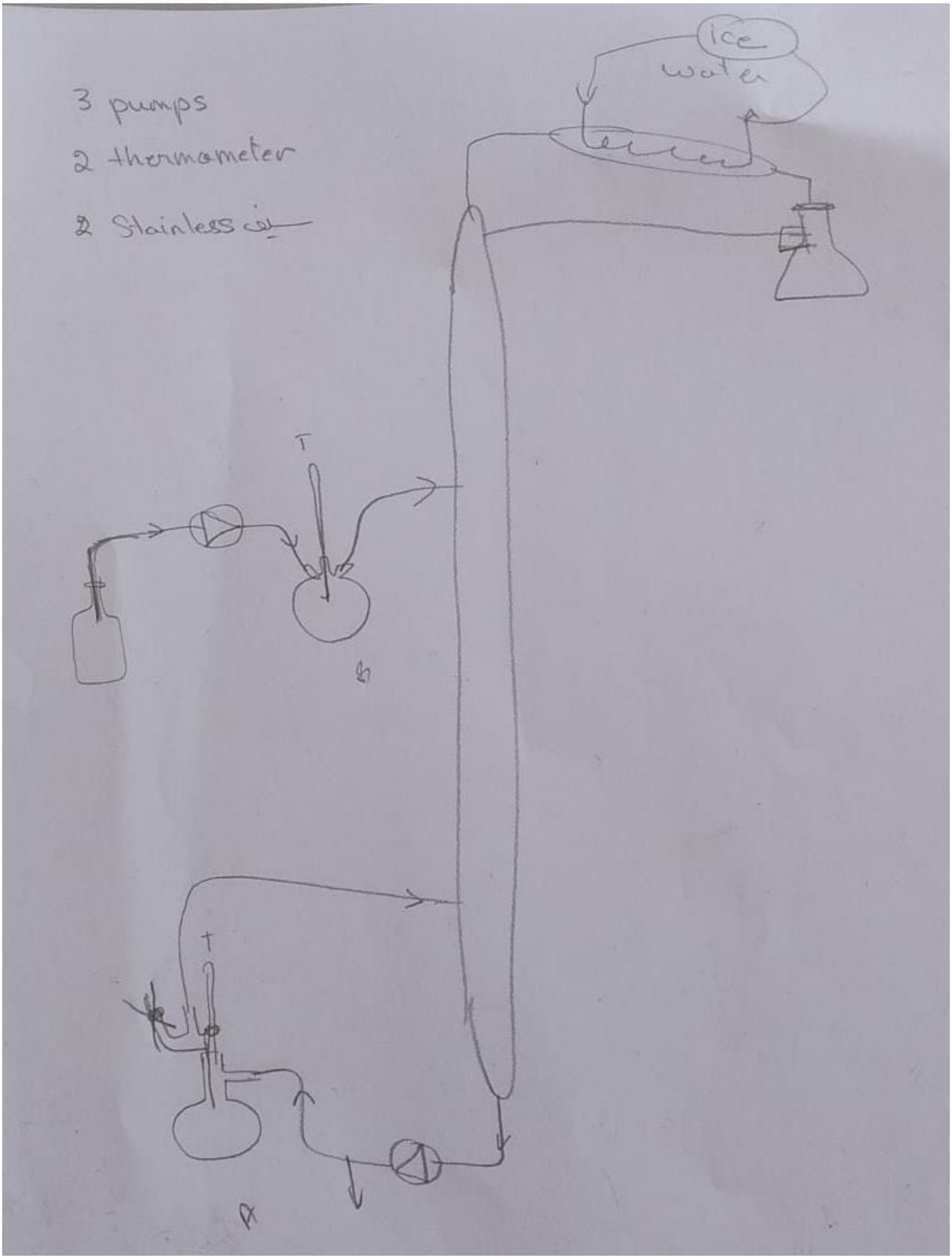
Hydrostatic head

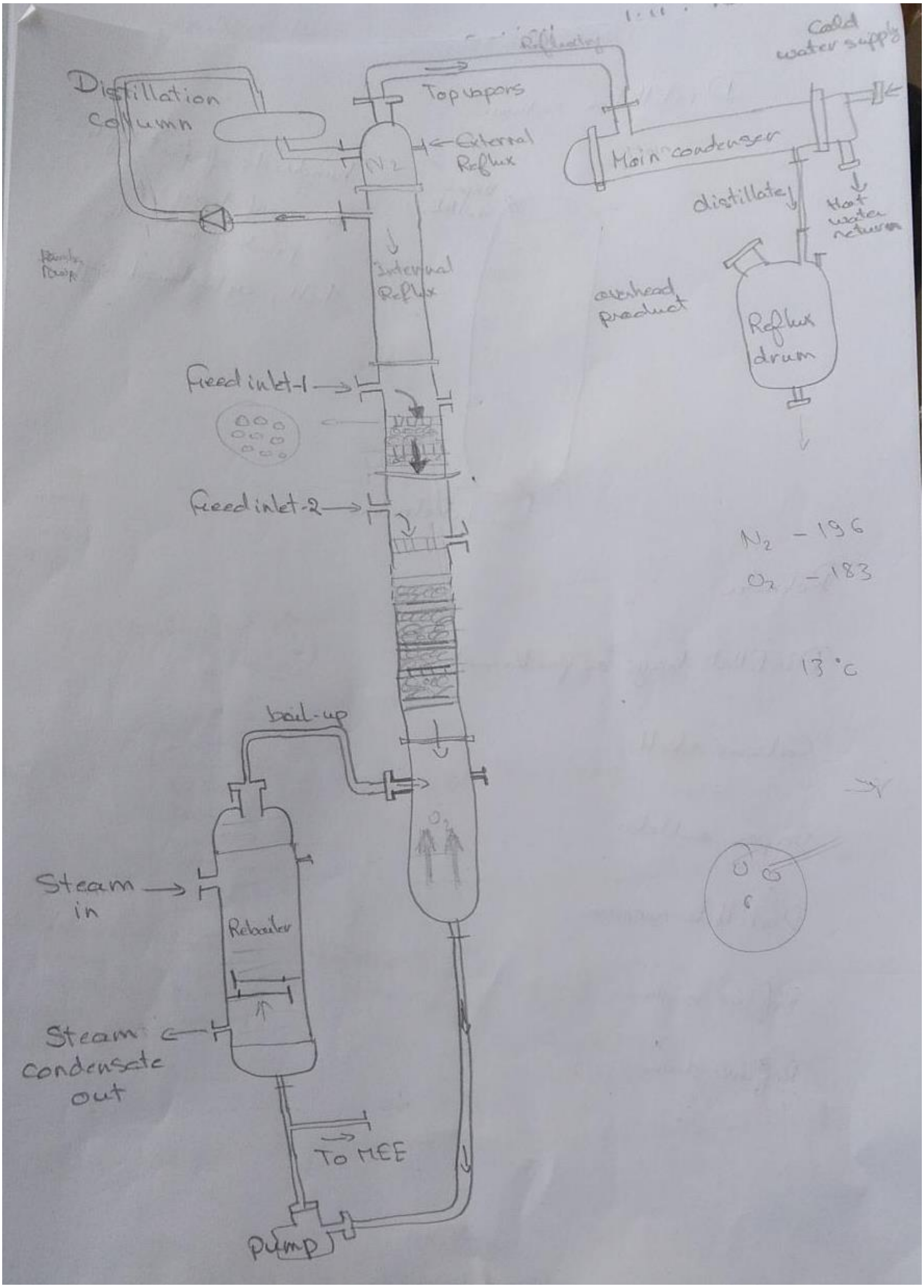
الصواني المغمورة تنتج منتجات رديئة الجودة
poor quality products

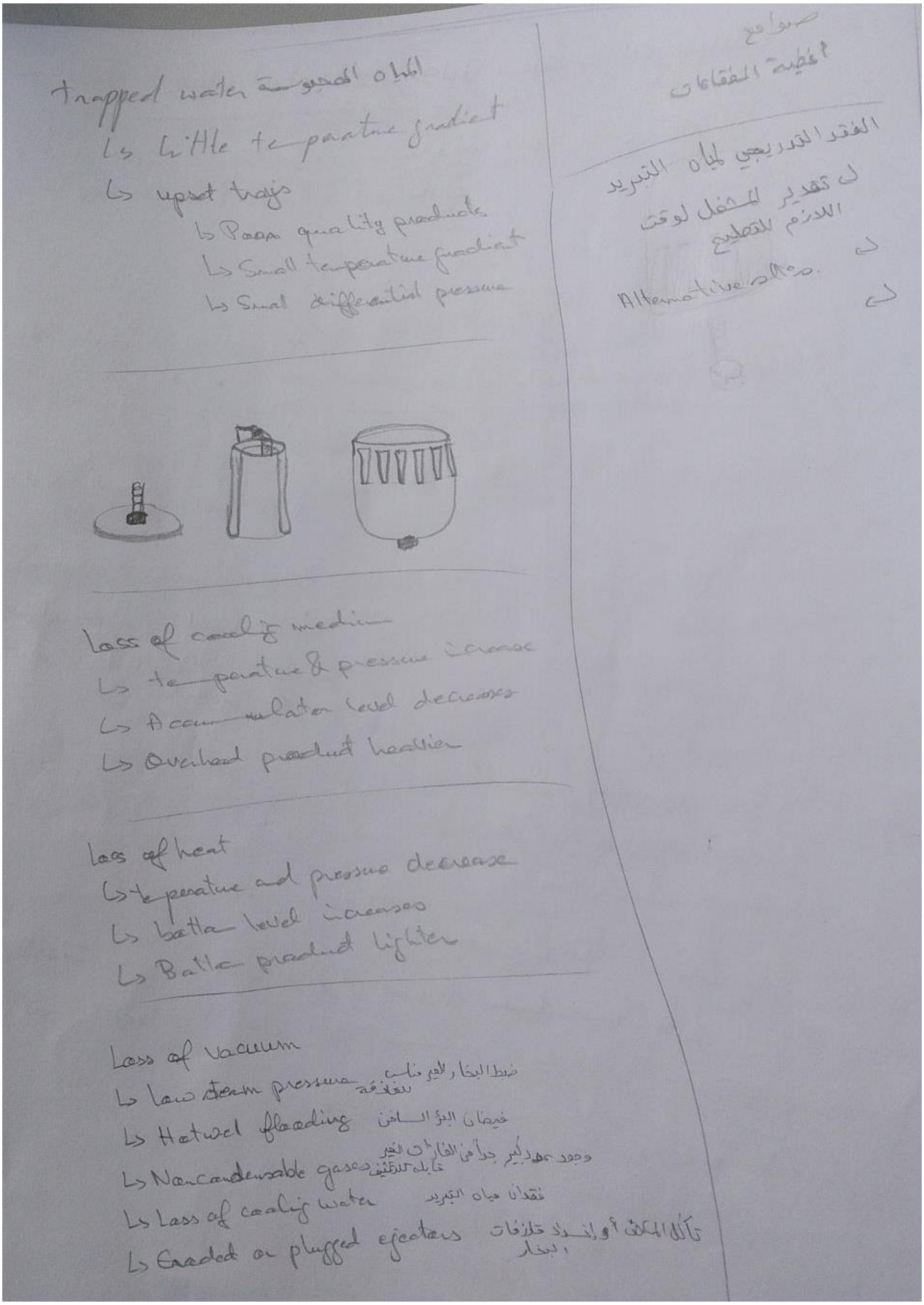
large differential pressure
تميل الضغط إلى التقلب داخل البرج من السوائل
pressure fluctuates

High liquid levels
↳ Small T°C gradient
↳ Poor quality products
↳ large differential pressure
↳ pressure fluctuates

Dry trays الصواني الجافة
تحدث بسبب سحب الكثير من السوائل كمنتجات جانبية،
تصبح الصواني أسفل نقطة السحب في البرج جافة
↳ loss of reflux
↳ feed or reboiler temperature too high
↳ Poor quality products
↳ Reduced temperature gradients
↳ Small differential pressure


3 pumps
2 thermometer
2 Stainless
ice
water
T
T


Distillation column
Top vapors
External Reflux
$N_2$
Cold water supply
Main condenser
distillate
Hot water return
Internal Reflux
overhead product
Reflux drum
Feed inlet-1
Feed inlet-2
$N_2$ -196
$O_2$ -183
13 °c
boil-up
$O_2$
Steam in
Reboiler
Steam condensate out
To MEE
Pump



Trapped water المياه المحبوسة
↳ Little temperature gradient
↳ upset trays
↳ Poor quality products
↳ Small temperature gradient
↳ Small differential pressure

صوامع
أغطية الفقاعات

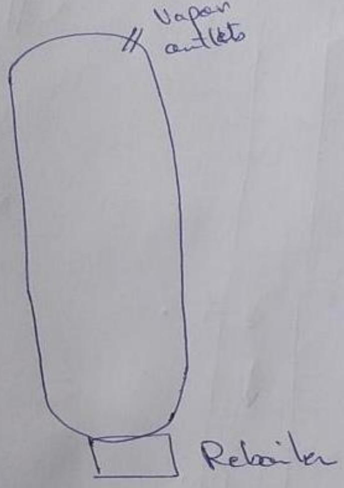
الفقد التدريجي لمياه التبريد
↳ تقدير المحفل لوقت اللازم للتصليح
↳
Alternative also.
↳

Loss of cooling medium
↳ temperature & pressure increase
↳ Accumulator level decreases
↳ Overhead product heavier

Loss of heat
↳ temperature and pressure decrease
↳ bottom level increases
↳ Bottom product lighter

Loss of vacuum
↳ low steam pressure ضغط البخار الغير مناسب للغلاية
↳ Hotwell flooding فيضان البئر الساخن
↳ Noncondensable gases وجود عدد كبير جداً من الغازات الغير قابلة للتكثيف
↳ Loss of cooling water فقدان مياه التبريد
↳ Eroded or plugged ejectors تآكل المكثف أو انسداد قاذفات البخار

Distillation column




hundreds of feet high
array of trays or
packing materials
tall, cylindrical eqpt.

~~charge~~
~~4:45 (45%)~~
discharge
8:48 (98%)

Reboiler

Distillat: trays or packs materials

Column shell

Vapor outlets.

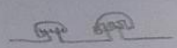
Distillate receiver

Reflux system  Part of liq condensed return to the distillat: colum to conserve T°C and equilibrium between liq and vapor

Reflux drum

الرواجع Refluxing لتنقية القطارة

صواني القبعات الفقاعية bubble cup



درجة الحرارة في أعلى البرج يجب أن تكون أعلى من درجة الغليان المطلوبة للمنتجات العلوية عند ضغط تشغيل البرج

- إذا كانت درجة الحرارة في الجزء العلوي أعلى مما ينبغي، المزيد من المنتجات الثقيلة سوف تتبخر وتصبح جزءاً من المنتج العلوي (بدلاً من نزولها وتسييلها)
- إذا كانت درجة الحرارة في الجزء العلوي أقل مما ينبغي، فإن تبخير المواد الخفيفة سوف يكون أقل، بعض من المكونات الخفيفة سوف تظل سائلة (تتدفق إلى الأسفل)

درجة الحرارة في قاع البرج

- عادة ما تكون أقل قليلاً من درجة غليان المنتج السفلي
- إذا كانت درجة الحرارة مرتفعة جداً، الكثير من المواد الثقيلة سوف تتبخر المواد الثقيلة
- إذا كانت درجة الحرارة منخفضة جداً، القليل من المواد الخفيفة سوف تتبخر ويقل التصاعد إلى الأعلى

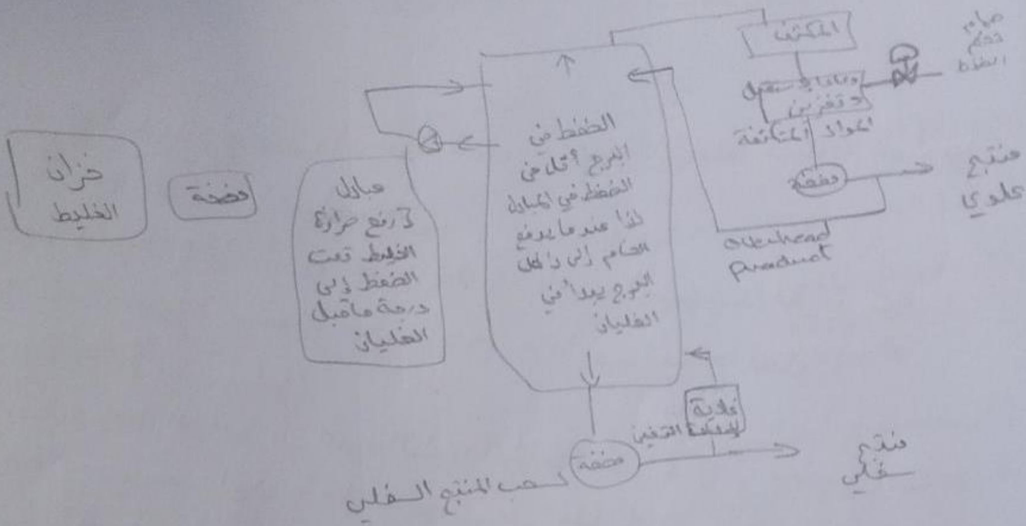
درجة حرارة منطقة التغذية

- ينبغي أن تكون ضمن منطقة نطاق غليان الخام (التغذية)، تقريباً مساوية لدرجة حرارة صينية التغذية

درجة حرارة صينية التغذية تعتمد على الموقع الفيزيائي في البرج فحيث كلما انخفضت صينية التغذية كلما كانت درجة الحرارة أعلى

- إذا كانت درجة الحرارة صينية التغذية أعلى مما ينبغي، كثير من المواد الثقيلة سوف تتبخر (بدلاً من سريانها إلى الأسفل)
- إذا كانت درجة حرارة صينية التغذية أقل مما ينبغي، المواد الخفيفة سيقل تبخرها

سائل الخليط : الخام ، التغذية
المواد التي تنفصل : القطارة ، الثمالة

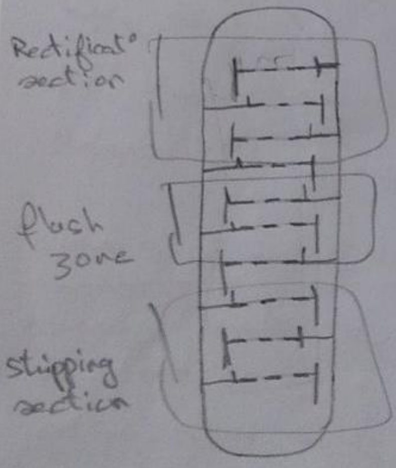



الغلاية هي مبادل حراري تستخدم لتبخير المواد الخفيفة المتبقية في السائل بقاع البرج

المكثف هو تبريد وتكثيف الأبخرة إلى سوائل

محتوى البرج

- صواني لفصل الأبخرة (Sieve trays) عن السوائل
الصواني المنخلية



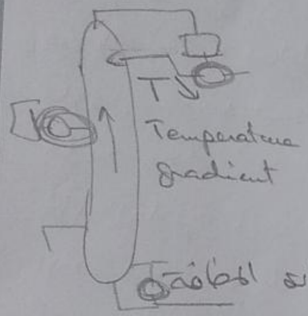

المنطقة الوسطى حيث دخول الخام (التغذية) إلى البرج
التبخر الناتج عن هذه التغذية تسمى الوامض (Flash zone)

الجزء الأعلى من البرج يسمى منطقة المعالجة
(Rectification section)
في هذا الجزء يزيد تركيز المواد الخفيفة

الجزء الأسفل من البرج يسمى منطقة النزع (stripping sect) وفي هذا الجزء المواد الخفيفة تتبخر أو تنزع من المواد الثقيلة

للتحكم في تدرج الحرارة في البرج يجب التحكم في درجة حرارة النقاط الحرجة في النظام، وهذا يحدث عن طريق : ٢ طرق

الطريقة الأولى




• التحكم في درجة حرارة التغذية عن طريق المسخن (هذا ينظم درجة الحرارة عند نقطة التغذية)

• في أسفل البرج يتم التحكم بدرجة الحرارة عبر التحكم في كمية الحرارة التي يتم إضافتها للغلاية ويشار للحرارة المضافة بـ Boil-up

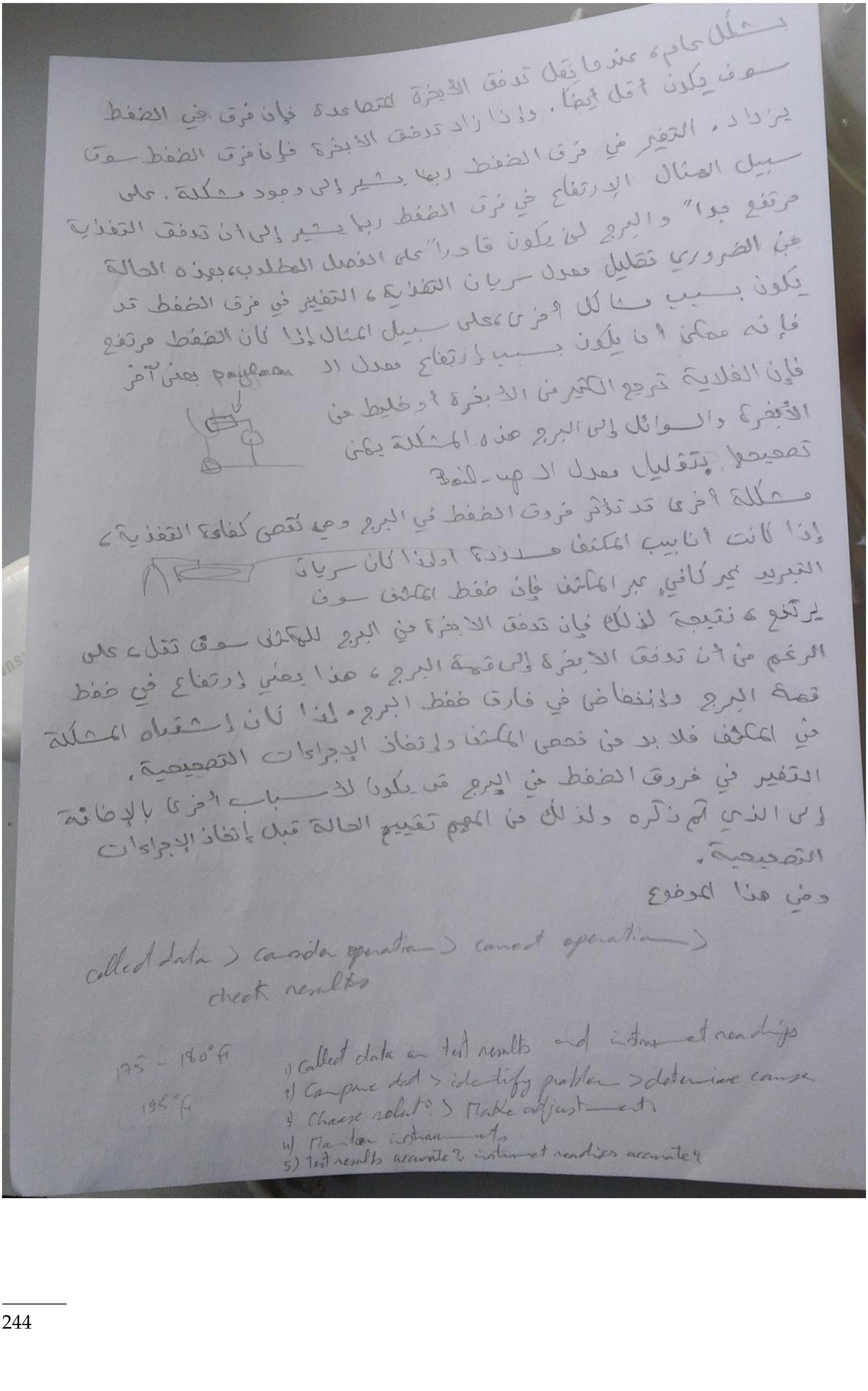
• يتم التحكم في درجة حرارة قمة البرج عن طريق كمية أو حرارة السوائل الباردة التي يتم إعادة ضخها من وعاء الاستقبال وهذا ما يسمى بـ Reflux rate. زيادة معدل الرواجع يقلل من درجة حرارة قمة البرج

• بعض أنظمة التقطير تحتوي على تجهيزات بـ ___ الغرض منها إزالة السوائل الساخنة من البرج وضخها عبر مبرد إلى مستوى أعلى البرج، إنها تساعد على التحكم في درجة حرارة الرواجع الداخلية

• بما أن الضغط يؤثر على درجة الغليان للسوائل فهو عامل مهم في نظام التقطير، غالبًا ما يكون التحكم في ضغط البرج عن طريق صمام تحكم يقع في وعاء الاستقبال
يتم التحكم في الضغط عن طريق التحكم تحرير الأبخرة والغازات الغير مكثفة المتجمعة في وعاء الاستقبال

• في بعض الحالات يقوم النظام التفريغ (Vaccum) بسحب الغازات من وعاء الاستقبال للتحكم في ضغط البرج

• نقطة مهم للمشغل هي فروق الضغط في البرج وهو الفرق بين القمة وقاع البرج. هذا الفرق في الضغوط بسبب تدفق الأبخرة في البرج ولا يتواجد فرق للضغط بدون تدفق للأبخرة.
بشكل عام، عندما يقل تدفق الأبخرة المتصاعدة فإن الفرق في الضغط



بشكل عام، عندما يقل تدفق الأبخرة المتصاعدة فإن فرق في الضغط
سوف يكون أقل أيضاً. وإذا زاد تدفق الأبخرة فإن فرق الضغط سوف
يزداد. التغير في فرق الضغط ربما يشير إلى وجود مشكلة. على
سبيل المثال الإرتفاع في فرق الضغط ربما يشير إلى أن تدفق التغذية
مرتفع جداً" والبرج لن يكون قادراً على الفصل المطلوب، بهذه الحالة
من الضروري تقليل معدل سريان التغذية، التغير في فرق الضغط قد
يكون بسبب مشاكل أخرى، على سبيل المثال إذا كان الضغط مرتفع
فإنه ممكن أن يكون بسبب إرتفاع معدل الـ [illegible] بمعنى آخر
فإن الغلاية ترجع الكثير من الأبخرة أو خليط من
الأبخرة والسوائل إلى البرج هذه المشكلة يمكن
تصحيحها بتقليل معدل الـ Boil-up
مشكلة أخرى قد تؤثر فروق الضغط في البرج وهي نقص كفاءة التغذية،
إذا كانت أنابيب المكثف مسدودة أو إذا كان سريان
التبريد غير كافي عبر المكثف فإن ضغط المكثف سوف
يرتفع. نتيجة لذلك فإن تدفق الأبخرة في البرج للمكثف سوف تقل على
الرغم من أن تدفق الأبخرة إلى قمة البرج، هذا يعني إرتفاع في ضغط
قمة البرج وانخفاض في فارق ضغط البرج. إذا كان إشتباه المشكلة
في المكثف فلا بد من فحص المكثف واتخاذ الإجراءات التصحيحية.
التغير في فروق الضغط في البرج قد يكونوا لأسباب أخرى بالإضافة
إلى الذي تم ذكره ولذلك من المهم تقييم الحالة قبل إتخاذ الإجراءات
التصحيحية.
وفي هذا الموضوع

collect data > consider operation > correct operation >
check results

175 - 180°F
195°F

1) Collect data on test results and instrument readings
2) Compare data > identify problem > determine cause
3) Choose solut° > Make adjustments
4) Monitor instruments
5) Test results accurate? instrument readings accurate?

## 8.2 Pilot project: Distillation of Ethanol (Ethanol separation)

### 8.2.1 Equipment and Steps for a Distillation Column Experiment (Water-Ethanol Mixture)

#### 8.2.1.1 Equipment

- Distillation Apparatus:

  - Round-bottom flask (500 mL or 1 L)
  - Fractionating column (packed or unpacked)
  - Condenser (Liebig or water-jacketed)
  - Adapter (to connect the flask to the column)
  - Thermometer adapter
  - Receiving flask (or multiple flasks for collecting fractions)

- Heat Source: Heating mantle or hot plate

- Thermometer: To measure the temperature of the vapor

- Stand and Clamps: To secure the apparatus

- Other Supplies:

  - Water-ethanol mixture (known composition)
  - Boiling chips
  - Ice water bath for the condenser
  - Wash bottle with distilled water
  - Safety glasses and gloves

#### 8.2.1.2 Steps

1 Set up the Apparatus:

* Assemble the distillation apparatus as shown in the diagram, ensuring all connections are secure.

* Insert the thermometer into the thermometer adapter so that the bulb is just below the sidearm of the adapter.

* Place boiling chips in the round-bottom flask to prevent bumping.

2. Add the Mixture:

* Carefully pour the water-ethanol mixture into the round-bottom flask.

3. Heat the Mixture:

* Turn on the heat source and gradually increase the temperature.

* Monitor the temperature closely.

4. Collect the Distillate:

* Once the mixture begins to boil and vapor rises into the column, the temperature will stabilize.

* Collect the distillate in the receiving flask(s).

* You may observe a gradual increase in temperature as the more volatile component (ethanol) is distilled off.

5. Monitor and Adjust:

   * Continuously monitor the temperature and adjust the heating rate as needed to maintain a steady distillation rate.

   * You can collect different fractions of the distillate at different temperature ranges.

6. 6.Analyze the Results:

   * Measure the volume of each fraction collected.

   * Determine the ethanol content of each fraction using a refractometer or other analytical methods.

   * Compare the composition of the distillate to the original mixture to assess the efficiency of the separation.

**Note:**

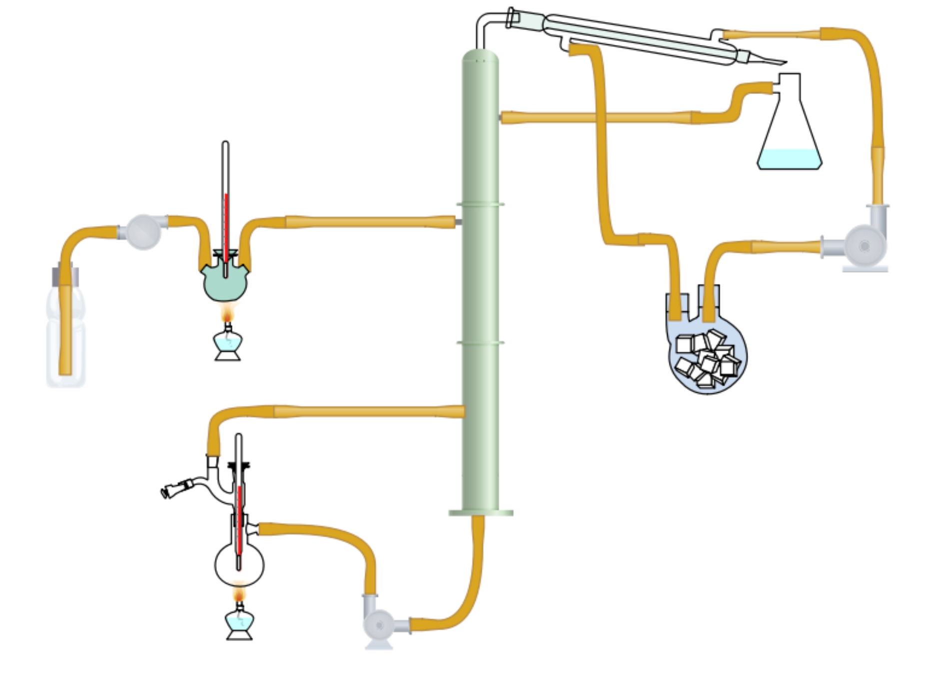
*** This is a simplified procedure. The actual steps and conditions may vary depending on the specific experimental objectives and the complexity of the distillation column.**

*** It's important to follow proper safety procedures and handle chemicals with care.**

*** For a more accurate and efficient separation, you may need to use a more sophisticated distillation column with a greater number of theoretical plates.**

By following these steps and using the appropriate equipment, you can conduct a distillation column experiment to separate a mixture of water and ethanol and gain a better understanding of the principles of dis

### 8.2.2 Preliminary design



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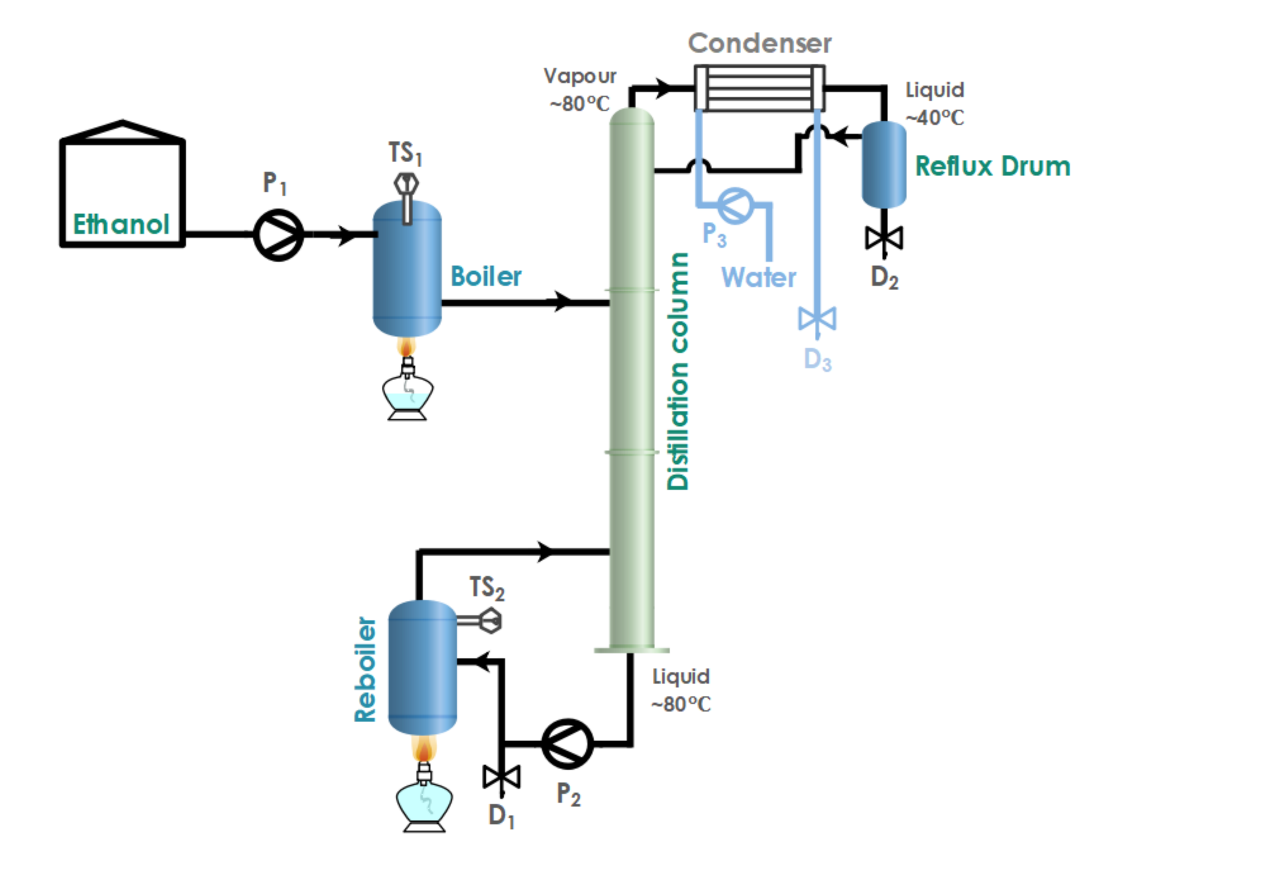
### 8.2.3 Flow Chart of pilot distillation (distillation of ethanol)



<table>
<tr>
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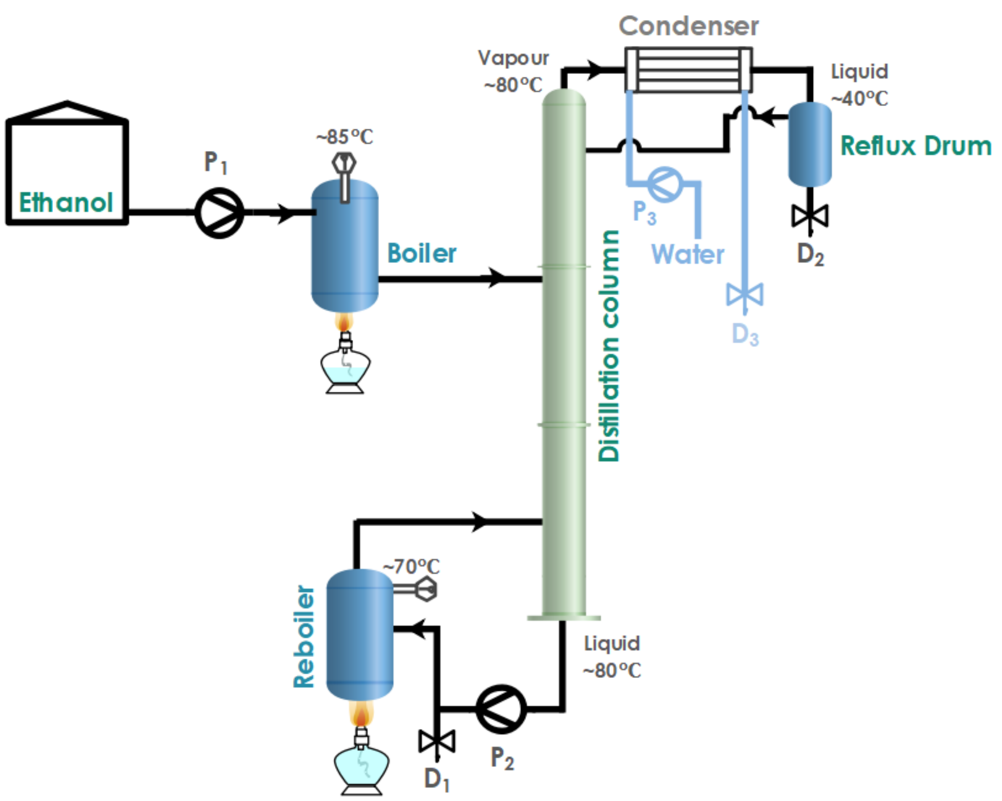

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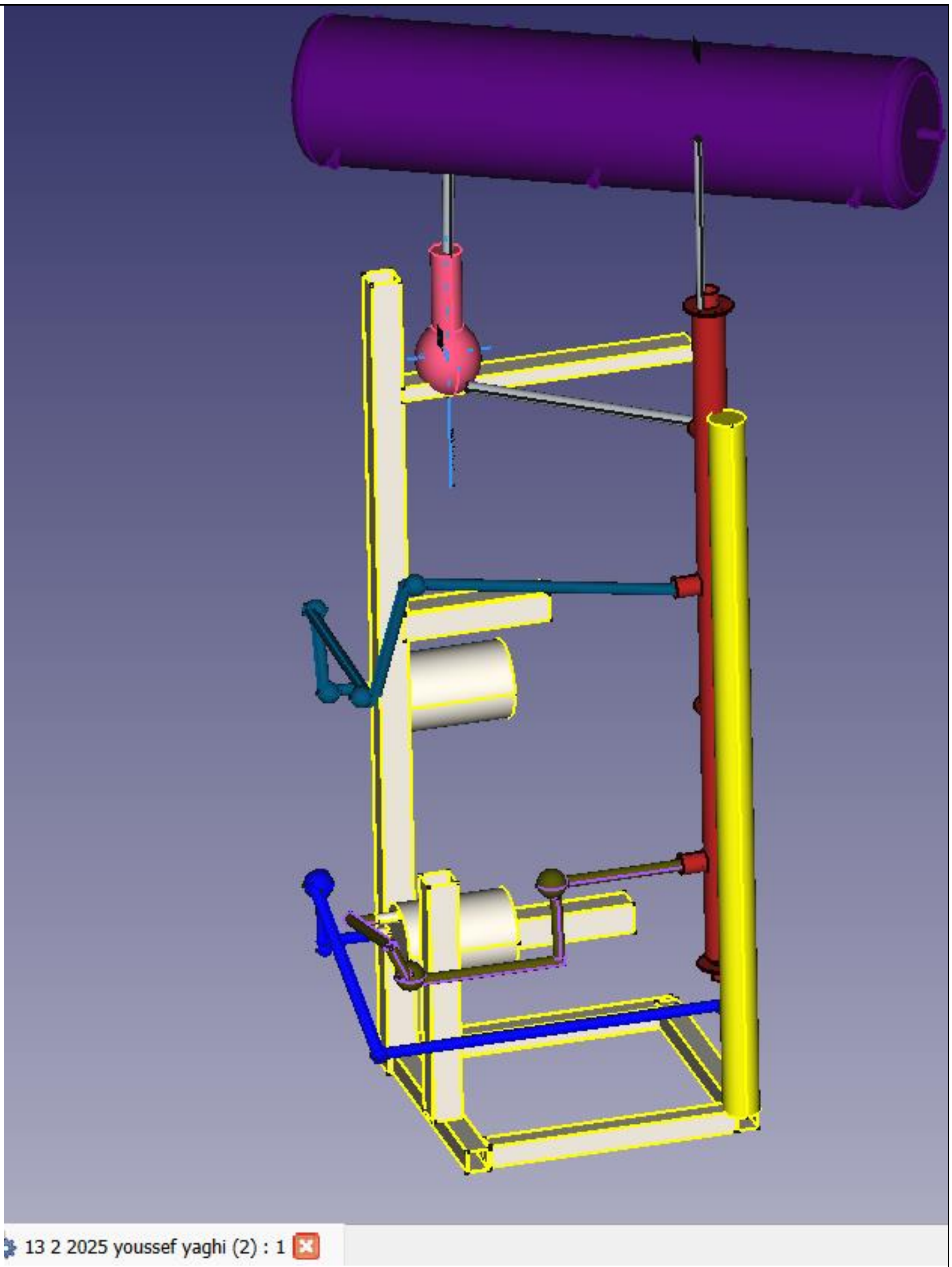
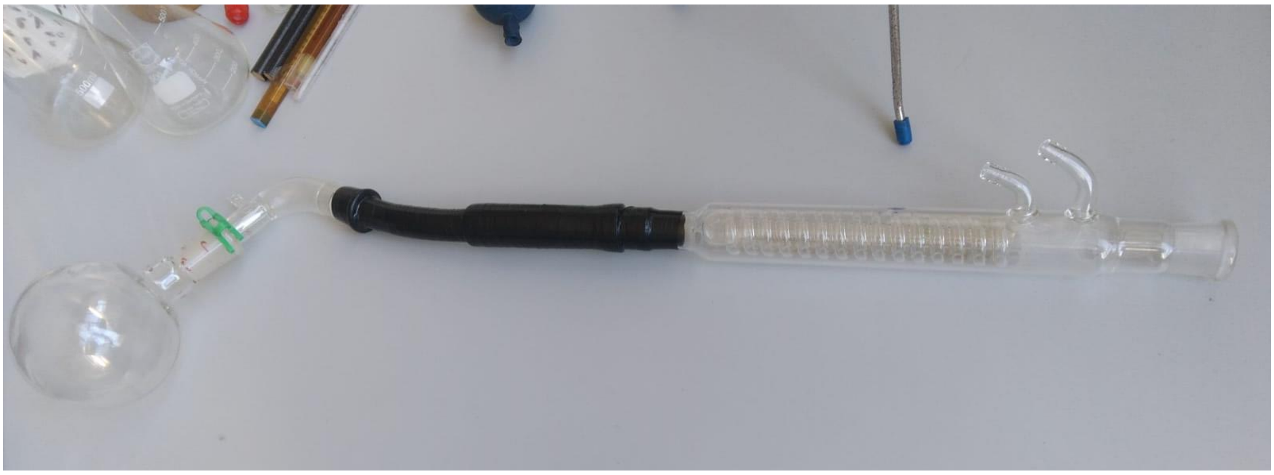
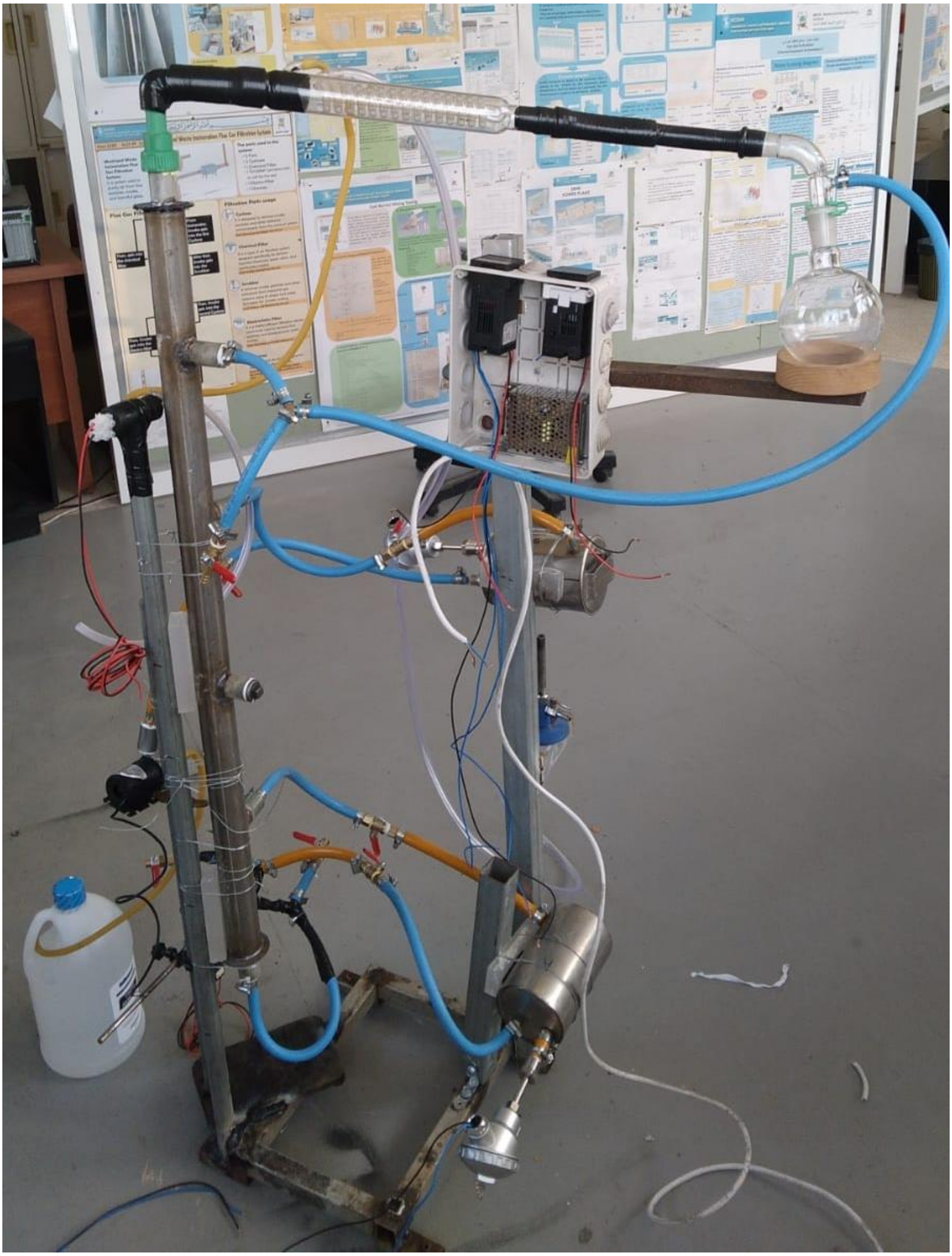
|---|---|
| FreeCAD file 13.02.2025:<br>13 2 2025 youssef yaghi.FCStd |  |

### 8.2.4 Distillation of Ethanol – Realization of apparatus



28.1.25:

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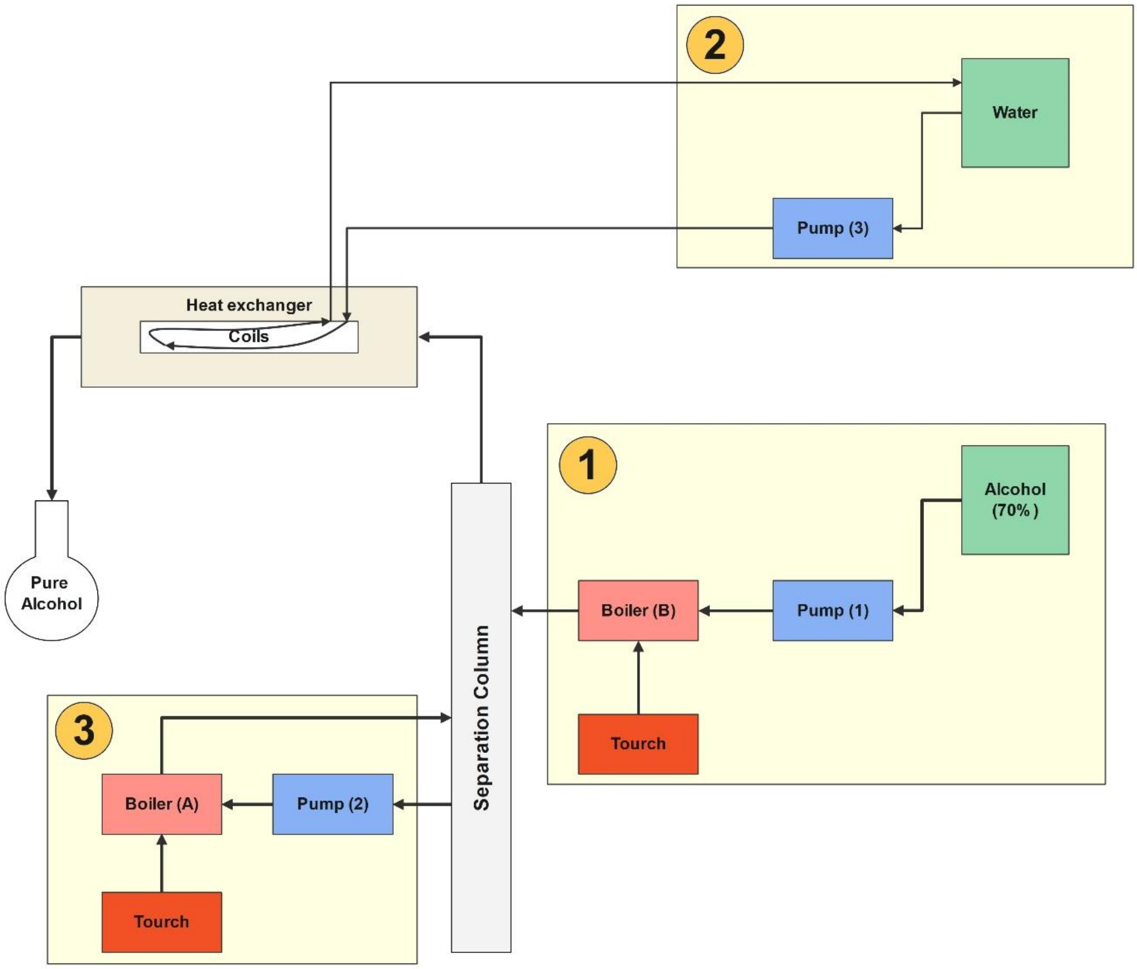
2

### 8.2.5 Ethanol separation - test specification




1. First, the ethanol (70%) is transported via pump (1) to boiler (B). The ethanol in boiler (B) is then heated up until it reaches a temperature of approx. 80-90°C.
   As soon as the temperature is reached, the ethanol begins to evaporate. The steam passes through the tower into the heat exchanger.
2. Now cold Water is transported via pump (3) into the coils of the heat exchanger. This is where the condensation process takes place. Because of the cold water, the steam loses its heat and begins to condense. The condensed ethanol (pure ethanol) now drips into the tube.
3. The ethanol that has not yet evaporated is transported via pump (2) into boiler (A) and heated up there. Once the temperature is reached, the steam passes through the tower so that it can also condense. This process is repeated until only pure ethanol remains.

### 8.2.6 Ethanol separation - test documentation (test date: 20.02.2025)

<table>
<tr><td></td><td colspan="2">In the lower bottle we have ethanol (70% ethanol) and in the upper bottle we have cold water for the condensation process. The bottles were connected via a rubber hose with the system.</td></tr>
<tr><td></td><td></td><td>The ethanol is heated up in the boiler until it reaches a temperature of approx. 80-90°C.</td></tr>
<tr><td></td><td></td><td>Cold water is transported via pump into the heat exchanger. Here the hot steam meets the cold water. Now the condensation process has started. In the right picture you can see the pure liquid ethanol in teardrop form</td></tr>
</table>

<table>
<tr>
<td></td>
<td></td>
<td>Now the pure ethanol drips into the tube. After the test we filled the ethanol from the tube in a bottle like you can see in the right picture.</td>
</tr>
<tr>
<td colspan="2"></td>
<td>The ethanol that has not yet evaporated is heated again in the lower boiler and brought back into the system circuit.</td>
</tr>
</table>

tillation.

### 8.2.7 e-test

## 8.3 Example for Distillation: H2O2 50% to 90% upgrading

Hydrogen peroxide is often referred to as water with one more oxygen atom. It is acidic in nature, and PH is about 4.5. It is a 100 per cent degradable compound.

Hydrogen Peroxide Chemical Formula H2O2

Molecular Weight/Molar Mass 4.0147 g/mol

Density 1.05 g/cm3

Boiling Point 150.2 °C

Melting Point -0.43 °C

Properties of Hydrogen Peroxide

Physical Properties

- In the pure state, hydrogen peroxide is an almost colourless (very pale blue) liquid.
- It melts at 272.4 K and has a boiling point of 423 K (extrapolated).
- It is miscible in water in all proportions and forms hydrates.

Chemical Properties

Hydrogen peroxide in both acidic and basic mediums acts as an oxidising as well as a reducing agent. The following reactions will give a clear picture:

Why Is Hydrogen Peroxide Stored in Plastic Containers?

Hydrogen peroxide decomposes when exposed to sunlight, this process is catalysed by traces of alkali metals. Therefore, H2O2 is stored in wax-lined glass or plastic containers and kept in the dark.

It should also be kept away from dust particles because dust can induce explosive decomposition of this compound.

==============================

Boiling Point Of Hydrogen Peroxide

The boiling point of hydrogen peroxide is 150.2 °C (302.3 °F) at atmospheric pressure (1 atm, which converts to 14.6 PSI). This is approximately 50 °C higher than the boiling point of water, which is 100 °C. This chemical undergoes thermal decomposition (which is decomposition caused by heat) and boils explosively at this temperature, so it is not advisable.

Heat Capacity Of Hydrogen Peroxide

The specific heat capacity of liquid hydrogen peroxide is 2.619 J/(g-K), and in gas form, it is 1.267 J/(g-K). This (specific heat) refers to the amount of energy required to raise the temperature of hydrogen peroxide, not the latent heat. Latent heat refers to heat that results in the chemical's expansion. The latent heat of vaporization for hydrogen peroxide is 542 BTU/pound.

This means it takes 542 BTU of heat to convert 1 pound of H2O2 into its gas phase (convert it into a gas).

Density Of Hydrogen Peroxide

The density of hydrogen peroxide is 1.11 g/cm3 (1.11 grams per cubic centimeter), which means that a cubic centimeter of H2O2 weighs 1.11 grams.

============

Purifying hydrogen peroxide from water is challenging due to several factors:

• Azeotrope Formation: Water and hydrogen peroxide form an azeotrope at a specific concentration. This means that at this point, the vapor phase has the same composition as the liquid phase, making further separation by simple distillation impossible.

• Thermal Decomposition: Hydrogen peroxide is thermally unstable and decomposes into water and oxygen at elevated temperatures, making traditional distillation methods difficult.

Methods for Concentration (but not complete purification):

• Vacuum Distillation: Lowering the pressure reduces the boiling points of both water and hydrogen peroxide, allowing distillation at lower temperatures and minimizing decomposition.

• Extractive Distillation: Using a third component (entrainer) to break the azeotrope.

### 3.5 Hydrogen Peroxide Distillation Unit

Possibly the main impediment in starting the $H_2O_2$ based rocket research in a university is the difficulty in getting the rocket grade $H_2O_2$, say 90 percent or more of concentration. To solve this problem, a distillation unit has been realized and this is shown in Figure 2.

In the 20 liter flask, Figure 2, low concentration $H_2O_2$ solution is stored. The distillation unit is evacuated to a pressure of about 100mm of mercury. The 20 liter flask is heated to a temperature around 70°C. The $H_2O_2$ solution in the 20 liter flask starts boiling and the water contained in it evaporates to get condensed in the 10 liter flask. Thus the concentration of the sample in the 20 liter flask keeps increasing with time. Cold water is circulated in the condenser for the easy condensation of the water vapor. At any time, the concentration of the $H_2O_2$ in the 20 liter flask can be found from the known initial concentration of $H_2O_2$ solution and its initial volume, and the volume of the water condensed in the 10 liter flask. Once the required concentration is reached in the 20 liter flask, the heating is stopped. After the unit gets cooled to ambient temperature, the vacuum is released. The concentrated $H_2O_2$-solution from the 20 liter flask is collected. The concentration of $H_2O_2$ in the solution is evaluated accurately by weighing the known volume of the concentrated $H_2O_2$. If the concentration is found at the desired level, the concentrated $H_2O_2$ is stored for the use in the rocket. The industrial grade $H_2O_2$ of 50% concentration and the laboratory reagent grade, a variety purer than the former, of 30% concentration are freely available. For the present studies, the laboratory reagent grade is concentrated to 90% level.

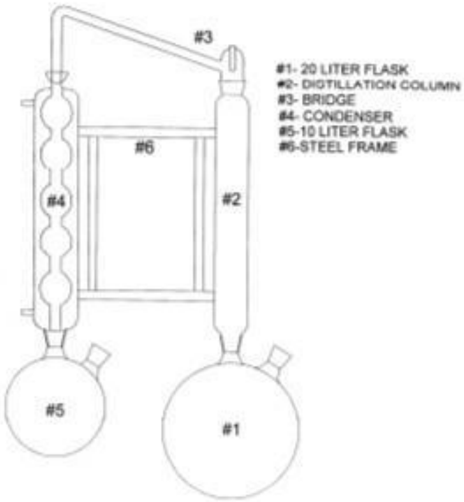
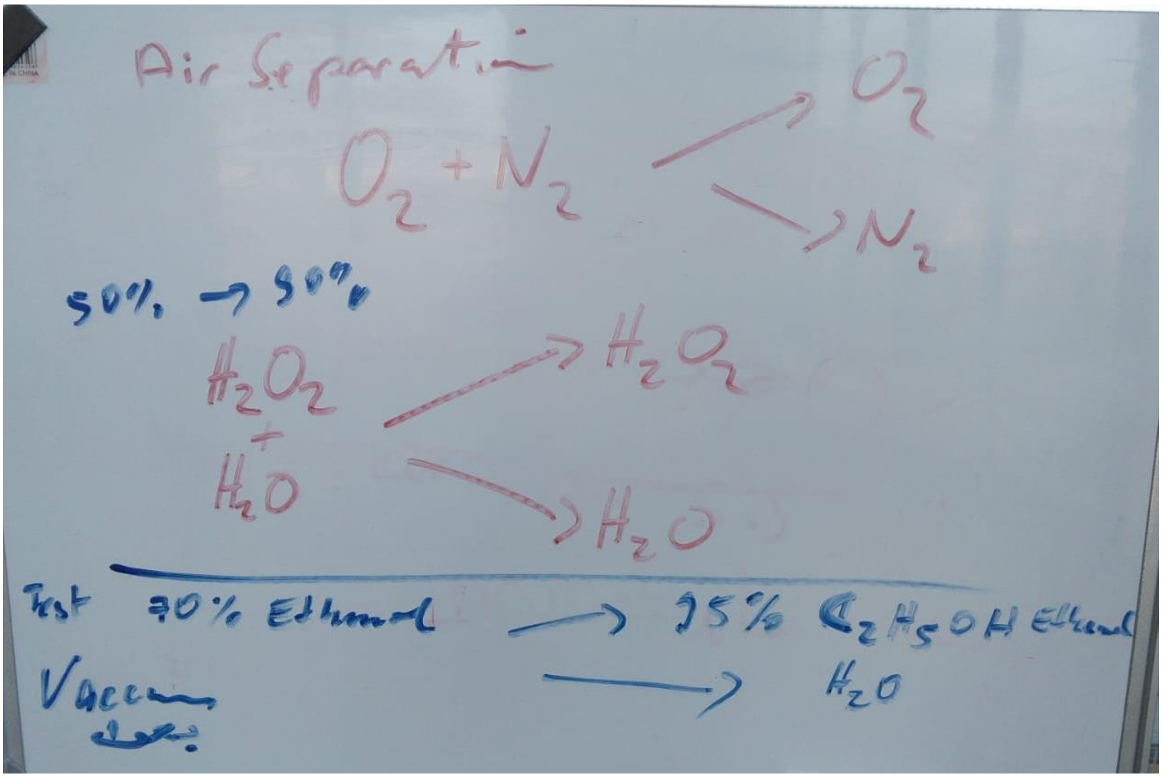



Figure 2: Hydrogen peroxide distillation unit.

## 8.4 Liquefication of Oxygen Prototype (ICPT-LOX) and Air Distillation

Distillation/Separation of oxygen, nitrogen, and noble gases from liquid air



# 9 Project 7: Metallurgical project

## 9.1 Metallurgical test 2 _ 31.01.2023

### 9.1.1 Melting System Test Specification

- **Pre-Starting**

Please read these instructions thoroughly. This will make sure you obtain full safe use, Keep this instruction manual in a handy place for future reference.

- **Safety precaution**

Wear the thermal gloves

Wear the face shield

Keep a safe distance (1m_1.5m)

- **Caution**

- Never leave a hot graphite crucible with metal liquid cooling in the machine naturally, otherwise it will damage the machine. grab the crucible out immediately when the melting is finished.
- Anytime when the water circulation is stopped or fails if the crucible is hot and stays in the coil. Ensure it immediately leaves the coil, otherwise, the coil will be damaged.
- This melting furnace must use ceramic and graphite crucible together. other kinds and shapes crucible alone must use both or the coil might be damaged.
- Turn off the working switch before pouring the liquid metal.
- After completion of smelting, turn off the operating switch on the melting furnace. Keep the water cycle cooling system running for more than 20 seconds, then turn off the power switch on the melting furnace and water chiller.
- When using the machine with a pump (without a chiller) for cooling, do not reuse the outlet hot water, need to change new water whenever one crucible melting finishes.

### 9.1.2 Test 002: 31012023_ Iron melting – Test steps

| Step | Step Description | Expected Result |
|---|---|---|
| Precondition | System is Off | |
| Switch on the system | Turn on the heating switch | System is On |
| Heating of the melting pot | Heating should be in three stages: | Melting pot is ready |

| | | |
|---|---|---|
| | - Low heat for three minutes (500 °C),<br>- Double heat for 5 minutes (1000°C),<br>- Melting heat for 2 minutes (1600° C) | |
| Put the iron pieces | The heat must be reduced before putting the pieces and reheated after putting the pieces | The iron is melting |
| Switch off the system | Turn off the heating switch | System is off |
| Postcondition | System is Off | |

### 9.1.3 Operation steps

1. Starting: 1: 55 pm
2. Heating stage 1: 1600 watts for 3 min
3. Heating stage 2: 3000 watts for 5 min

4. Heating stage 3: 5000 watts for 2 min
5. Putting the pieces 500 g of iron within 10 min
6. Melting iron within 10 min
7. Cooling of system within 10 min
8. Switch off the system

#### 9.1.4 Result

- The Iron melted within 10 min.

#### 9.1.5 Analysis of the test results

The reason we couldn't get the desired disc shape was the use of an unsuitable sand shape.

#### 9.1.6 What we have to do:

Repeat the experiment using a refractory sand mold.

### 9.2 Metallurgical Test 003: 11022023_ iron melting

| Step | Step Description | Expected Result | result |
|---|---|---|---|
| Precondition | System is Off | | |
| Switch on the system | Turn on the heating switch | System is on | positive |
| Heating of the melting pot | Heating should be in three stages:<br>- Low heat for three minutes (500°C),<br>- Double heat for 5 minutes (1000°C),<br>- Melting heat for 2 minutes (1600°C) | Melting pot is ready | positive |
| Put the iron pieces | The heat must be reduced before putting the pieces and reheated after putting the pieces | The iron is melting | positive |

| | | | |
|---|---|---|---|
| Switch off the system | Turn off the heating switch | System is off | positive |
| Postcondition | System is Off | | positive |

### 9.2.1 Operating steps

Sand operation steps:

1. Sand purification
2. Put the sand in an iron pot
3. Pour a little water on the sand (helps create the sand shape)
4. Create the sand shape
5. Heating the sand in three stages to dry it and conserve shape

Iron preparation steps:

1. Cutting iron (30*60)
2. The weight of the iron
3. Heating iron (low degree)

Iron melting operation steps

1. Starting: 1: 32 pm
2. Heating stage 1: 1600 watts for 3 min


3. Heating stage 2: 3000 watts for 5 min


4. Heating stage 3: 5000 watts for 2 min

5. Putting the pieces 650 g of iron within 10 min

6. Melting iron within 10 min

7. Cooling of system within 10 min
8. Switch off the system

1.1.1. Result

Obtain a piece of iron that has the same shape as the sand and pure

A piece has some holes and voids

Corrosion of graphite crucible

### 9.2.2 Analysis of the test results

- The reason for piece holes and voids is to let the melting iron in the shape without pressure
- We get a graphite crucible corrosion because this crucible is not intended for melting iron

1.1.2. What we have to do

- Use a crucible for melting iron
- Manufacturing of a piston to press the melting iron in the sand shape

## 9.3 Metallurgical test 4_09092024

There was another test on September 9, 2024, and here are some pictures related to the test:

The steps we followed:

1. First, we mixed the soil and broke the larger parts.

2. We added water to the soil and mixed it well.
3. We placed the mixture into a mold to take the desired shape.

4. We dried the Soil Mold to remove the Moisture.

5. We placed the clay core pot and the lead pot with the Iron parts to melt them


1600

6. The problem occurred when we added too much iron into the pot, and the amount was more than necessary.

7. The iron expanded excessively due to this excess amount and resulting heat.

8. As a result, the clay pot exploded due to the pressure from the excessive expansion.

It’s essential to measure the right amount of iron, ensuring it fits within the lead pot. If the amount exceeds the capacity, the pressure and heat will cause expansion and explosion. and we should ensure that the lead pot can accommodate the molten iron, without exceeding its capacity. And another solution is that if larger amounts of iron are needed, consider using a pot with greater durability to withstand thermal stress.

Video of the Metallurgical test:

Metallurgical test 4_09092024.mp4

## 9.4 What's next

### 9.4.1 Development of prototype of a electrical furnace for making alloys:

# 9.5 Electric Arc Furnace for making alloys

**ELECTRIC ARC STEEL MAKING**

The electric arc furnace (EAF) has historically been used for high-grade steels and scrap melting, but it is growing in use for ordinary grades. It is an integral part of the 'mini-mill' steel making process consisting of an EAF along with a continuous caster to provide a small, low capital cost steel mill utilising abundant, inexpensive steel scrap. Today, mini-mills can produce over 80 per cent of all steel products. The electric arc furnace is also usually used to refine high alloy steels, such as stainless steels.

The electric arc furnace is illustrated in Figure 1-4 and is from 25 to more than 150 tonnes capacity. The charge can be of scrap of the required final composition although carbon is usually lost during the carbon boil. The carbon electrodes in the roof strike an arc directly with the metal to melt it. Reducing conditions allow for removal of sulphur in the slag, and alloying elements such as nickel, chromium, manganese, vanadium etc. can be added and will not be lost through oxidation. Oxygen can be blown into the furnace to purify the steel, and lime and fluorspar added to combine with impurities to form slag. At the end of the process, the furnace is tilted, first to pour off the slag, and then in the opposite direction where the molten steel is tapped into a ladle.

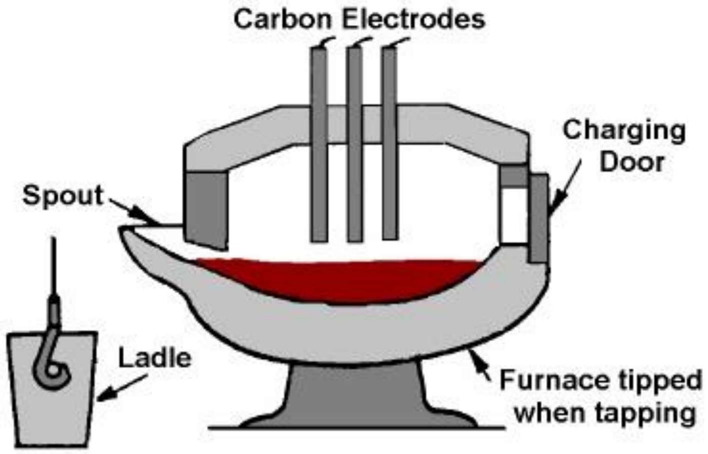
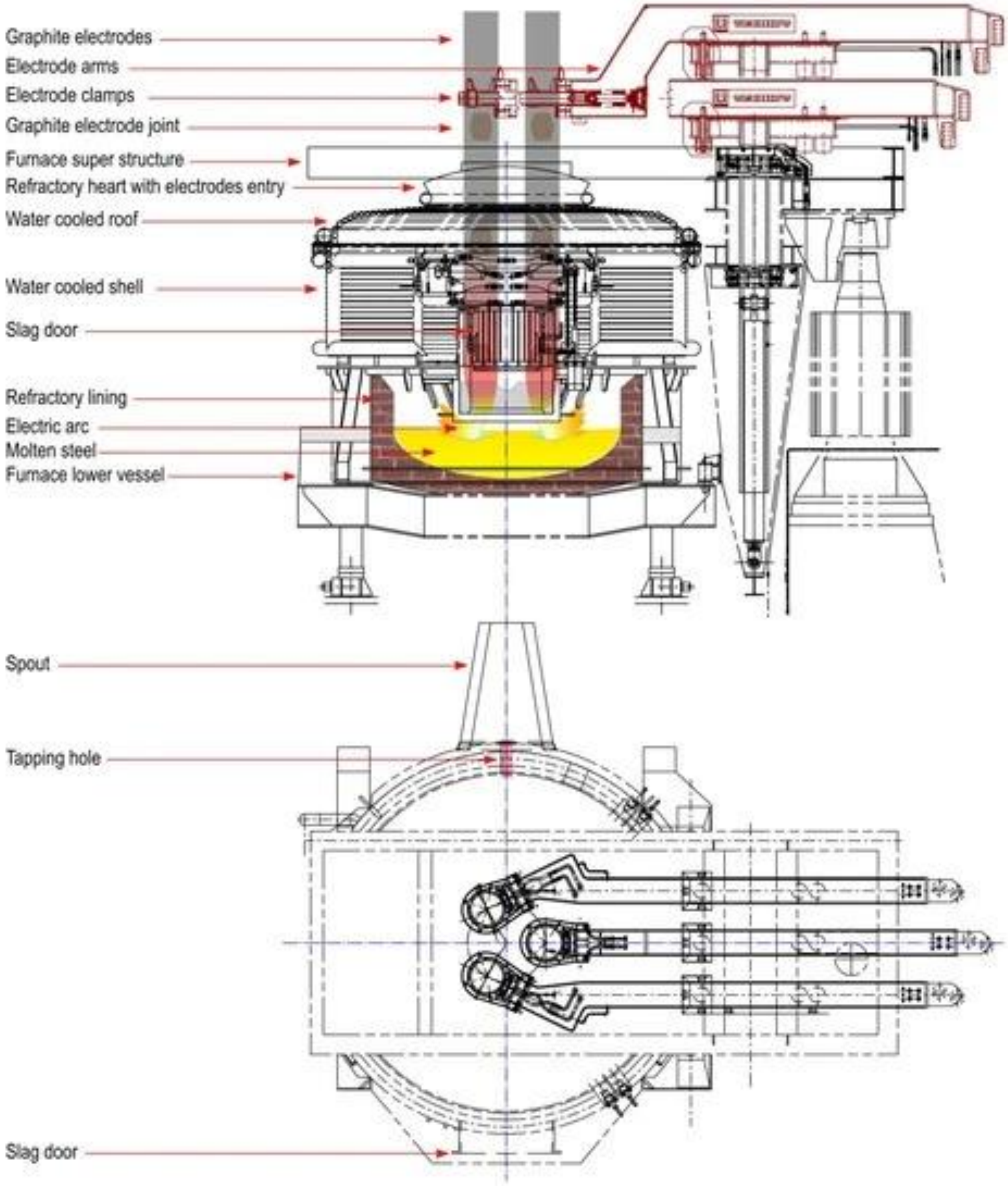



*Figure 1-4: Electric arc furnace.*

The efficiency of electric arc steel making has been substantially improved in recent years. As well as adopting oxygen injection, oxy fuel burners, coal powder injection, high-power transformers, preheating scrap and new systems of cooling and protecting furnace walls have been introduced, enabling production efficiency increases from 80 to 120 tonnes per hour.


Graphite electrodes
Electrode arms
Electrode clamps
Graphite electrode joint
Furnace super structure
Refractory heart with electrodes entry
Water cooled roof
Water cooled shell
Slag door
Refractory lining
Electric arc
Molten steel
Furnace lower vessel
Spout
Tapping hole
Slag door



**Electric Arc Steel Melting Furnace**

**US$20,000.00-100,000.00** / Piece
1 Piece (MOQ)

**Product Details**

| | |
|---|---|
| Customization: | Available |
| Type: | Concentrate Smelting F |
| Usage: | Ron Ore Smelting, Steel |

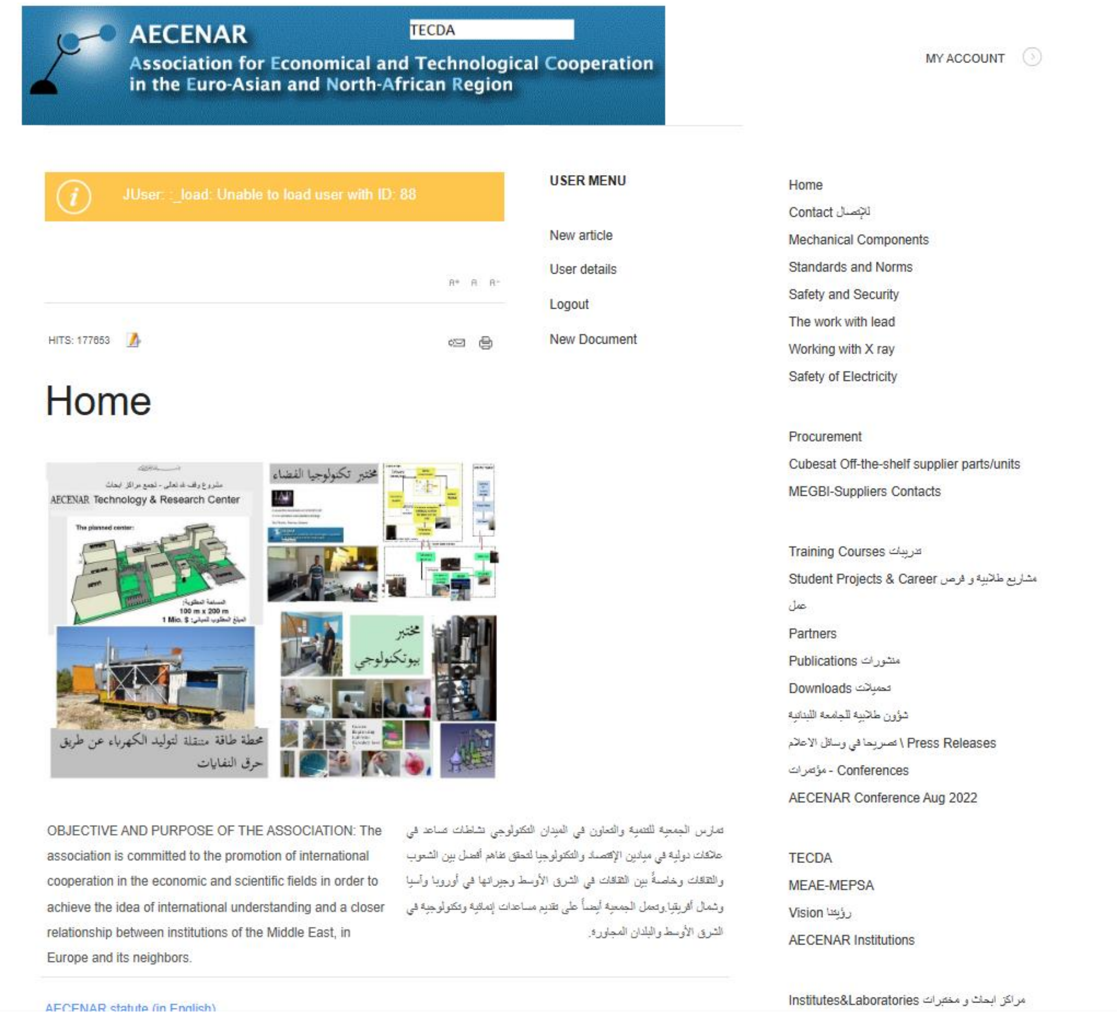
Contact Supplier

Shanghai Fortune Electric Co., Ltd. >

Diamond Member Since 2009

From: [Electric Arc Steel Melting Furnace - Eaf and Electric Arc Furnace (made-in-china.com)]

## References - www.aecenar.com menu




- Home
- Contact للإتصال
- Mechanical Components
- Standards and Norms
- Safety and Security
  - The work with lead
  - Working with X ray
  - Safety of Electricity
- Procurement
  - Cubesat Off-the-shelf supplier parts/units
    - OBC Hardware
    - OBC Software
    - OBC Mechanical Design, Irvine

- OBC (On Board Computer)
- TT&C and COM Transceivers
- Satellite Power Supply System (PPS) - Mech
- Cubesat PSS (Power Supply System)
  - AS-COMSAT 1 PSS Hardware
  - AS-COMSAT 1 PSS Software
- TT&C Ground Segment
- Cubesat Ground Support Equipment
- Cubesat ACS Off-the-shelf parts

- MEGBI-Suppliers Contacts

- Training Courses تدريبات
- Student Projects & Career مشاريع طلابية و فرص عمل
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- تصريحا في وسائل الاعلام \ Press Releases
- مؤتمرات - Conferences
  - AECENAR Conference Aug 2022
- TECDA
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- Vision رؤيتنا
  - AECENAR Institutions
- Institutes&Laboratories مراكز ابحاث و مختبرات
  - AECENAR Backlog
  - AECENAR IT
  - Planning & Controlling 2021

- Planning & Controlling 2024
  - Staff Schedule 2024
  - ICP Planning & Controlling 2024
  - MEGBI/NLPBI Planning&Controlling 2024
  - Weekly TODOs 2024
- Planning & Controlling 2023
  - MEGBI Planning 2023
  - Planning & controlling IAP
  - Budget QIV 23
  - Weekly Project Meetings 2023
- Planning & Controlling 2022
  - ICPT Planning/Controlling 2022
  - Physics Lab Planning&Controlling 2022
  - NLAP-IPP Commisioning Planning/Control 2022
  - MEGBI Planning 2022
  - IEP Planning&Controlling 2022
- Documentation/Database Reference
- MEGBI
  - Lab Scale Penicillin production
    - Penicillin Quantification
    - Penicillin Production and Quantification 2023
  - Pilot Plant Scale Penicillin/Aspirin Production
    - Pilot scale test specification
    - Pilot scale system test
      - WHOLE SYSTEME TEST (AUTOCLAVE TEST) 07/11/2022
      - Aspirin Production System Test (Water test) 28/11/2023
      - Aspirin Production System Test (Water test) 01/12/2023
      - Aspirin Pilot Plant Flow sensor test 6-7/12/2023
      - Aspirin Production System Test (Water test) 14/12/2023
      - Aspirin Pilot Plant Flow sensor test 14/12/2023
      - ASPIRIN PILOT PLANT TEST (AUTOCLAVE TEST) 14/12/2023
      - Aspirin Pilot Plant (Aspirin Production : TEST 1) 08/01/2024

- مشروع ادارة النفايات في بلدية بقاع صفرين
    - Possible land for Biogaz plant
- SDM-WasteManagementNorthLebanon
- EIA Waste to Energy Plants in North Lebanon
    - EIA for B.P.P
- مشروع ازالة جبل النفايات في طرابلس
- معمل ريمون مِتري في بلاط – جبيل
- مشروع تنظيف طرابلس
    - المكبات العشوائية في طرابلس
- ارض الاوقاف في مجدليا مرشحة لوضع المحطة وقسم من المركز
- حملة لتنظيف الضنية
- نقل المحطة الى كفرشلان
- NLAP-IPP at Central Mina next to Masjid as-Salam (Sep 21-Jul 22)
- Biogas Pilot Plant in Assoun/Dinniye - North Lebanon
    - Assoun Biogas Plant Official Papers
    - EIA assoun project
    - الجدوى الاقتصادية لمشروع الهاضم اللاهوائي
- Waste Management for Tripoli
- EIA Ras Nhash
- لائحة بأسماء المطاعم في طرابلس
- EIA Biogas Plants
- BiogasTest 21.06.2023
- Jezzine Biogas Plant Proposals
- Jezzine Biogas & Compost Plant
- Meeting at Deir Amar Municipality 28.10.24

- IEP-MEPSA

  - قطاع الطاقة الكهربائية في السعودية
  - Electricity Supply in North Lebanon Region - تغطية لبنان الشمال بالكهرباء
- SDM-EnergyEconomyIndonesia
- النظام السياسي في لبنان
- TrafficManagementSystem
  - برنامج للسكة الحديدية في الشرق الادنى
  - مبادرة اصلاح طريق العمارة عكار
  - Roads repairs cost in North LEBANON
- Water and Waste Water
- IEP-UrbanicPlanning
- نشاطات لمؤسسات اجنبية في شمال لبنان
- الزراعة في لبنان
  - مشروع زراعة القمح في عكار
- Telecom
- الضرائب في لبنان
- منشئات تابعة للدولة اللبنانية موقوفة حاليا
- عقبات اجتماعية :
- وزارات
- North Lebanon Maps
- Environmental impact assessment
- Possible land for Biogaz plant
- Oil and Gas Reserves in Lebanon
- Méthanisation: Processus, condition,étapes..

        - مبادرات
            - اصلاح الطرقات وتنظيم إدارة النفايات في منطقة الجامعة اللبنانية في راس مسقا
        - قسم التنظيم المدني
        - قسم جودة التغذية
        - Lebanon economical analysis
        - Pilot Biogas Project
        - Environmental Conference
    - IAP
        - IAP Physics Lab
            - IAP Physics Lab Initial Mechanical Realization
            - PhysicsLab Initial PCS
            - IECF
                - IECF System Concept/ Design
                    - IECF Mechanical Design
                    - IECF PCS Design
                - IECF Realization /Implementation
                    - IECF Mechanical Realization
                    - IECF PCS Implementation
                - IECF System Test Specification
                - IECF System Testing
            - IAP-XRAMS
                - XRAMS System Concept/Design
                    - XRAMS Mechanical Design
                    - XRAMS PCS Design
                - XRAMS Realization /Implementation
                    - XRAMS Mechanical Realization
                    - XRAMS PCS Implementation
                - XRAMS System Test Specification
                - XRAMS System Testing

                - HM Mass Spectrometer - System Tests
        - Vacuum pump
        - PhysicsLab ICF Device
            - IAP-ICF light ion driver
                - Pulsed power diode accelerator Basics - Components
                - IAP-Light ion driver, Marx Generator
                - Basics Pulsed Power Diode Accelerator & RF LINAC
                    - Pulsed Diode System Test Specification
                    - Pulsed Diode System Testing
        - Linear Accelerator (LINAC)
            - LINAC RF Concept
                - Pulsed diode Mechanical Design
                - Pulsed Diode PCS Design
            - Electron Source
            - Requirements of LINAC with Glass Tube 2022-2023
            - system test specification of LINAC with Glass Tube 2022-2023
            - system test of LINAC with Glass Tube 2022-2023
                - LINAC Vacuum Test 16.01.23
                - LINAC Test 16/01/23
                - LINAC Test 18/01/23
                - LINAC TEST 28/01/23
                - LINAC test 30_01_23
                - LINAC Test 31/01/23
                - LINAC Test 08/02/23
                - LINAC test 10/02/23
                - LINAC Test 03.03.23
            - Pulsed Diode Realization/Implementation
                - Pulsed Diode Mechanical Realization
                - Pulsed Diode PCS Implementation
        - IAP-Cyclotrone
    - IAP Observatory
        - IAP-SRWDA
        - IAP-GAMS

- IAP-SPECT
- IAP-IRS
- IAP Planning&Controlling 2024
- ICS
  - Agriculture Surfaces Burn Detection
- ICPT
  - ICPT-Electrolyser
    - System Concept/ System Design
      - Mechanical Design
      - PCS Design
    - Realization /Implementation
      - Mechanical Realization
      - Process Control System Realization
    - Electrolyser System Test Specification
    - Electrolyser System Test
      - Test 22.06.22 (Hydaulic Test of pipes)
      - Electrolyzer Test 4.7.22
      - Electrolyser whole system Test 04.07.2022
      - KOH pipes systeme test 04.07.2022
      - Electrolyser whole system Test 05.07.2022
      - Electrolyser whole system Test #2 05.07.2022
      - WHOLE SYSTEME TEST WITH ANOTHER POWER SUPPLY 15.07.2022
      - WHOLE SYSTEME TEST WITH WITH ONLY ONE CELL CONNECTED 05.07.2022
      - Test whether the membrane is ruptured 29.07.2022
      - Electrolyser Test 14.11.2022
      - Electrolyzer test 05.05.2023
      - Electrolyzer test 28.06.2023
    - Elektolyser Systeme Requirements
      - Requirements for the multistage electrolyser
    - ICPT-WEDC Testrigs PCS
      - Electrolyzer PLC&Instruments

    - ICPT-FuelCell
        - Fuel Cell System Concept/ System Design
            - Fuel Cell Mechanical Design
            - Fuel Cell PCS Design
        - Fuel Cell Realization /Implementation
            - Fuel Cell PCS Implementation
        - Fuel Cell System Test Specifications
        - Fuel Cell System Test
        - Fuel Cell Simulation
        - ICPT -Fuel Cell [Bascis]
    - Analytical Chemistry Lab
    - Metallurgical Lab
        - system test specification
        - Metallurgical tests
            - Metallurgical test 1 _ 24.12.2022
            - Metallurgical test 2 _ 31.01.2023
            - Metallurgical test 3_11022023
            - Metallurgical test 4_09092024
    - ICPT-AP (Electrochemical)
        - Ammonia Production methods
            - Haber Bosch
            - Electrochemical
        - ICPT-AP System Concept/ Design
        - ICPT-AP Requirements
        - ICPT-AP System Realization
        - ICPT-AP System Test Specification
        - ICPT- AP Mechanical Design
        - ICPT-AP Simulation
- INT
    - Medical Laser Devices
    - AFM
- ICP
    - CFD NC

        - IAP-SNS
        - IAP-PSC
        - Heat transfer in incineration power plants
        - ICP Development Environment & Tools
        - ICF Simulation
            - ICF Simulation - Code Implementation Documentation
    - ICPT Lab
- AECENAR Technology Center مشاريع تكنولوجية تطبيقية
    - MEGBI-VPP / APP
    - IAP-SAT
    - AECENAR Buildings Complex
    - NLAP-WEDC (Waste to Electricity Demonstration Cycle)
        - NLAP-WEDC System Specification - Posters
        - NLAP-IPP (Mechanical Design (CAD))
            - NLAP-IPP Incineration Chamber Design (CAD)
            - NLAP-IPP Filtersystem Design (CAD)
                - NLAP-IPP Electrofilter Design (CAD)
            - NLAP_IPP Waste Inlet New Design (CAD)
        - NLAP-IPP (Mechanical Realization)
            - NLAP-IPP Chemical Filter (Realization)
            - NLAP-IPP Sieve Filter
            - Condenser
                - Steam piping direction modification (coming from condenser and turbine)
            - Electrofilter product From Chinese Supplier
            - NLAP-IPP Flow gas system (Realization)
            - ultrasonic Nozzles for Exhaust gas cooling
            - Barrel Water Filter
        - NLAP-IPP PCS
            - NLAP-IPP PCS - PLC Program and Instruments
                - NLAP-IPP PLC Panel
                - NLAP-IPP Turbine Govering System (TGS)

        - NLAP-IPP Boiler Pressure Control (BPC)
    - NLAP-IPP PCS GUI
- NLAP-IPP System Test Cases (System Test Specifications)
- NLAP-IPP System Tests
    - Test 26.04.22
    - Electrofilter Test 23.05.22
    - Chemical Filter Test 17.06.22
    - Cyclone test after the modification 21.06.22
    - Sieve Filter First Test 02-07-22
    - Test 26-5-2022 / Doniyye-Bikasefrin
    - Test 11-8-2022 / Doniyye-Bikasefrin
    - Test 01.09.2023 - Ras Maska
    - Filtration test ( 18.12.2023)
    - 04272024.Test.Atomizing Nozzle Air to Fluid ratio
    - 08052024.Test.Atomizing Nozzle Air to Fluid ratio
    - Flue Gas into Water test 12.06.2024
    - Flow gas into Barrel water Filter Test 24.6.2024
    - Filtration test ( 27.06.2024)
    - Filtration test ( 02.07.2024)
    - Cleaning Electro-Filter (08.07.2024)
    - Filtration test (10.072024)
    - Cleaning Electro-Filter (11.07.2024)
- متطلبات نقل المحطة
- صيانة المحطة بعد النقل الى الضنية و تجهيزها للعمل
- Mobile Waste Separation Plant
- Mobile Biogas Generation and Gas Turbine Testrig
    - ICPT-Biogas Turbine
        - FBurner System Concept/ System Design
            - FBurner Mechanical Design
            - FBurner PCS Design
        - FBurner System Realization/Implementation
            - FBurner Mechanical Realization

        - FBurner PCS Implementation
    - FBurner System test specification
    - FBurner System Test
    - Biogas Turbine System Test
    - ICPT - GasTurbine Version 1
        - Gas turbine pieces
        - Gas turbine compressor
        - combustion chamber
    - ICPT - GasTurbine Version 2
    - ICPT - FB Ethanol combustion
        - ICPT-FB PCS Ethanol combustion
    - Requirements
    - Biogas Turbine Test using Air-compressor on 12.2.2024
    - Biogas Turbine test using Butane/Oxygen on 20.02.2024
    - Biogas Turbine test using Butane/Oxygen on 29.03.2024
    - Biogas Turbine test using Butane/Oxygen with Turbocharger on 02.0342024
    - Biogas Turbine test using Butane/Oxygen with Turbocharger on 02.04.2024
- Biogas production from municipal waste
    - ICPT Biogas Test Specification
    - system concept / system design
        - Ras Maska Biogas Prototype Reactor - Design
    - Ras Maska Biogas Prototype Reactor - Mechanical Realization
    - Biogas PCS implementation
    - ICPT - Biogas Purification
        - ICPT-Biogas Purification Test specification
        - ICPT-Biogas Purification Requirements
        - ICPT-Biogas Purification System concept
        - ICPT-Biogas Purification Mechanical design
        - ICPT-Biogas Purification Mechanical realization/Implementation
    - ICPT-Biogas tests

- AS-COMSAT
  - AS-COMSAT SW&HW Repository
  - AS-COMSAT Planning&Controlling
    - TEMO Lebanon 2016 - 2020
      - Ballon/Airship Based Communication Platforms
      - Satellite Based Communication Platforms
      - Management Software
    - AS-COMSAT Planning and Controlling 2022
    - AS-COMSAT Planning&Controlling 2023
      - AS-COMSAT Procurement 2023
      - AS-COMSAT Office&Atelier Istanbul
    - AS-COMSAT Planning & Controlling 2024
  - AS-COMSAT Platforms&Devices
    - AS-COMSAT_1 (LEO Communication Satellite)
      - AS-COMSAT_1 (LEO Satellite) System Architecture
      - AS-COMSAT_1 ACS (Design&Realization&Testing)
        - AS-COMSAT_1 ACS Board STM32 SW
        - ACS Board - Ver. 0524
        - AS-COMSAT_1 ACS Sun Sensor
        - AS-COMSAT_1 ACS Teststand (Requirements&Design&Realization)
      - AS-COMSAT_1 Power Management Unit (PMU)
        - AS-COMSAT_1 PMU SW
      - AS-COMSAT_1 LEO Satellite - Structure and Integration
        - AS-COMSAT_1 Space Radiation Protection
      - AS-COMSAT_1 TT&C
        - AS-COMSAT_1 TT&C Ground Station HW
        - AS-COMSAT TT&C GUI
        - TT&C Ground Station and Satellite Transceiver Boards STM32 SW
        - Monitoring values of TT&C Ground Station Transceiver STM32 C Code
      - AS-COMSAT_1 On-Board-Computer (OBC)

        - Monitoring values of OBC RaspberryPi python code
        - ACS_ControlCodePython
    - AS-COMSAT_1 Launching
    - AS-COMSAT_1 LEO Satellite Concepts
        - AS-COMSAT_1 COM Concept with HackRF
            - AS-COMSAT_1 COM Hardware
            - AS-COMSAT_1 COM Software
        - AS-COMSAT 4U Cubesat Integration Concept
    - AS-COMSAT_1 LEO to GEO Orbit Change Module
        - LEO to GEO transfer orbit basics
        - AS-COMSAT_1 LEO to GEO Transfer Requirements
        - AS-COMSAT_1 LEO to GEO Transfer Module Propulsion System Design&Realization
            - Regenerative Cooling for AS-COMSAT_1 OrbitChange Module
        - AS-COMSAT_1 LEO to GEO Orbit Change Teststand
            - AS-COMSAT_1 LEO to GEO Orbit Change Teststand - Test Specification
                - ACS Teststand Systemtest Specification
            - AS-COMSAT_1 LEO to GEO Orbit Change Teststand - System Test
                - 22.12.2023 - AS-COMSAT_1 Orbit Change Teststand System Test
            - AS-COMSAT_1 Orbit Change HIL Teststand
        - AS-COMSAT_1 Orbit Change Module CFD-NC Simulation
- RF 2.4GHz Tranceiver Unit Prototype
    - RF System Implementation
        - System Design
        - Amplifier Design
        - Oscillator Design
        - Mixer Design
        - Filter Design
        - AS-COMSAT Patch Antenna Design & Realization

                - DevOps CI/CD Development Environment (HW, GUI and embedded SW)
                - AS-COMSAT Testbeds CNA+LEO-Sat, Antenna
                    - Testing of CNA 3-1-2024
                    - Reduced Testbed (Defined 8 Jan 2024)
                    - Antenna Testing and Sending&Receiving Testing with gnu radio and HackRF
                - Launch Issues (SpaceX and other suppliers from India and Russia)
            - hi enterprises
                - hi enterprises Planning 2024
            - Green Chemistry
                - todos for 2024
                - Caustic Soda Production
                    - market research for parts
                    - Calculation
                    - System design / system concept
                        - Mechanical design
                    - System requirements
                    - system test specification
                - Green Chemistry Planning&Controlling 2024
                - NTA Production
                    - system desgin / system concept
                        - Mechanical design
                        - PCS implementation
                    - Requirements
                    - NTA test specification
                    - NTA system test
                    - Realization / Implementation
                    - Protocol
                - Green Chemistry Pharma Tabletting
                - Chemicals for Aspirin Production
                    - Acetic anhydride Production
                        - Pilot Plant Scale Acetic Anhydride Production
                            - system desgin / system concept