EXPERIMENT DESIGN

UNIVERSITEIT UTRECHT

Documentation BCCT

Bram van de Zande, Evdoxia Karagianni, Steven Bos

October 11, 2021

1 Introduction

This is the documentation file of the Battery Construction and Cell Testing (BCCT) team of the FLowerPower group. In this file all the information required to conduct the experiment will be included. Our group focused on building a rechargeable all-iron flow battery, and also conduct experiments on the battery cell. The purpose of this documentation is for other people to be able to reproduce our results. The goal of our measurement is to get a better understanding of the influence of the battery cell design of the fluid flow through the cell. The amount of fluid that can flow through holds a strong relation with the performance of the cell. More fluid that passes through the cell results in potentially more electrons interacting with the electrode. This documentation goes together with the Mathematica program provided which is named $PressureMeasurementRepro.nb$ and can be found in the Gitlab repository. The program is well commented and the information on how to do the measurement together with this program is provided below.

2 Cell Testing

The quantitative research on the battery cell will consist of a measure of the pressure drop due to the battery cell. The battery cell performance has a lot of dependencies, i.e. fluid flow rate, cell pressure electrode geometry to name a few. The focus of our group was on the measurement of a pressure drop depending on the battery cell volume. By increasing the volume between the electrode/anode and the membrane, more fluid is able to pass through the cell. The pressure drop corresponding to this change is what we are interested in. However we where not able to build the battery cell correctly, with not too much fluid leaking out of the system, creating a pressure loss. Thus this measurement is left out. However there are other experiments to be done before being able to do measurements on the battery cell. The measurement device needs to be calibrated, and there will be a reference measurement done over the battery system without the battery cell in between the pipes. The pressure drop over a pipe of length L is thus measured.

2.1 Theory

The measurement of the pressure drop over the battery cell will not consist of a theoretical value of the pressure drop. This is due to the complexity of the problem. The flow of a fluid through a box of dimensions (x,y,z) is hard to calculate, and should be conducted by doing a numerical calculation of the navier-stokes equation as was done by J. Houser et al. for different architectures of a battery cell[1].
The pressure drop over a regular pipe is better understood theoretically and is given below:

$$\Delta P = \frac{\lambda L}{D}\frac{\rho}{2\omega^2}, \tag{2.1}$$

Where ΔP is the pressure drop over a pipe of length L, width D and flow coefficient λ. The fluid has density ρ and flow velocity ω. For practical reasons we also are interested in how the pressure drop relates to the incoming and outgoing pressure over an object:

$$\Delta P = (P_1^2 - P_2^2)/2P_1. \tag{2.2}$$

Since the measurement device used does not give values of pressure in pascals but in volts, we are also interested in a calibration measurement for the pressure relation to volts. For this we conduct a calibration measurement as described in section 2.3. There we will measure the pressure due to a Column of fluid of height h above a point. The theoretical relation for hydro-static pressure is given by:

$$P = \rho g h, \tag{2.3}$$

where ρ is the density of the fluid, g the gravitational potential taken to be aprox. 9.81 and h the height of the collumn in meters.

2.2 Materials required

This section consist of a list required to do the experiment with pictures.
Pressure measurement device (M) illustrated in figure: 2.1 and 2.2.
3 pipes with outside diameter 4.7mm:
1. 161cm
2. 135cm
3. 85 cm

400 mL of demiwater
Cylindrical container 1000mL, 18cm height (C)
Oscilloscope (O) illustrated in figure: 2.4
Peristaltic pump(P) illustrated in figure: 2.5
Voltage meter (V)
T-Junctions
Valves

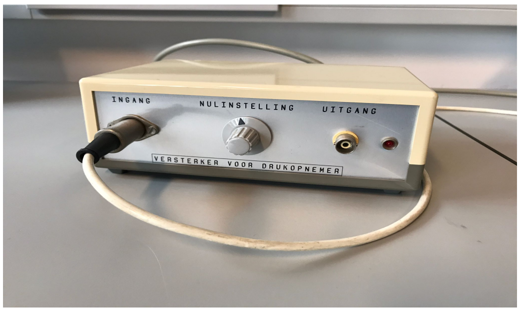

Figure 2.1: Amplifier of the pressure measurement device. The "nulinstelling" knob and "uitgang" output are of interest. "nulinstelling" knob should be calibrated to 0 volts at atmospheric pressure, and the output should be connected to a voltage meter.

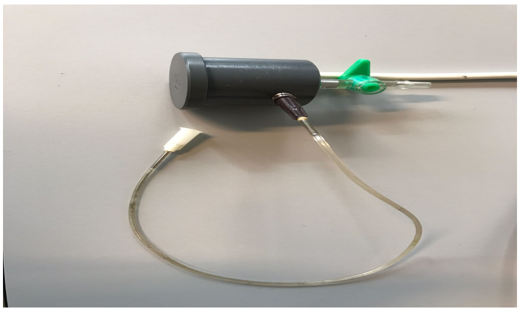

Figure 2.2: Measurement device. The small transparent wire is connected to the measured system, and the Green valve is operated to equalize the pressure across the device.

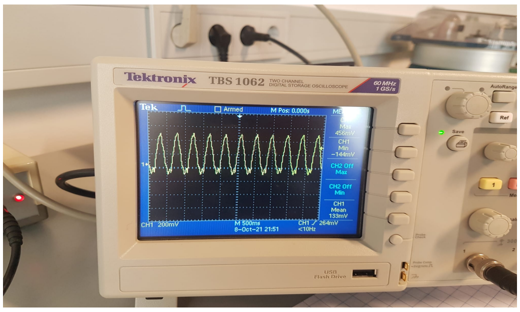

Figure 2.3: Using the "Scale" button in the vertical axis, you have to make sure that all the periods of your wave are shown in the screen. Otherwise the measurement won't be correct. The mean, max and min values appear on screen.

Figure 2.4: You connect the pressure measurement devise in channel 1. Using the position buttons you make sure that the wave you see is centered. In order to take measurements you press "Measure".

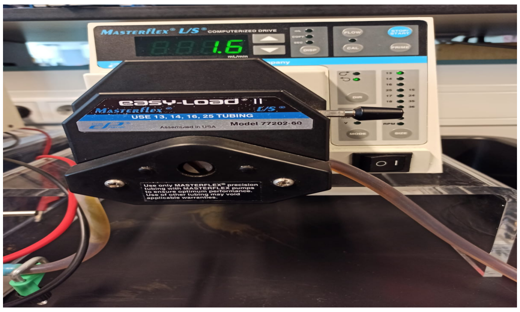

Figure 2.5: Peristaltic pump used. Put the tube in the corresponding clamp and close it with the lever, change the fluid flow rate with the arrows.

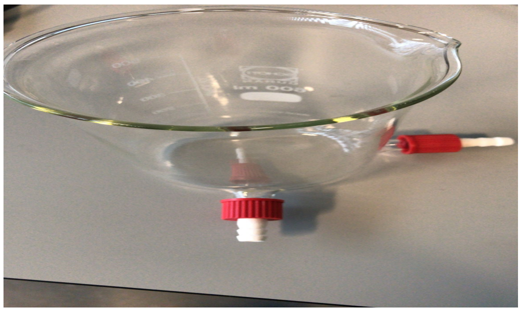

Figure 2.6: Fluid container, the tubes can be attached to the designated openings, or the tubes can be laid over the top of the wall of the container as we did.

2.3 Calibrating the Pressure measurement

The pressure measurement device in use registers the pressure of the fluid in a pipe. The output of the Pressure measurement is in (V) volts. To relate the amount of volts to a pressure in Pascal (Pa), we need to calibrate the device with a known amount of pressure. By measuring several pressures which are of a known value, we know what amount of volt relates to the pressure by assuming a linear scale. For this we use a vertical column of water which we vary in height h with discrete linear steps of fixed size. With these data-points we can relate the voltage to the pressure. By taking multiple measures at the same parameters we increase the accuracy of the measurements. We can relate the uncertainty of the experiment by the standard deviation as follows:

$$\sigma = \sqrt{1/n \sum_{i=0}^{n} (x_i - \mu)^2}, \tag{2.4}$$

for n measurements with respective values x_i and mean value μ.

How to calibrate the measurement device.

1. connect the voltage meter to the pressure measurement device amplifier as displayed in picture 2.1.
2. connect the a tube of sufficient length to the measurement device with the attached transparent wire.
3. place the measurement device on the group, and the amplifier on a table.

4. turn on the devices 5. calibrate the "nulinstelling knob" to 0 volts.
6. do the measurements for discrete steps of water height above the measurement device, by filling the tube and fixing the tube to a tripod with clamp.
6b. read out 5 measurements of the voltage for each height, and put the values in the Mathematica program.

The schematics of the measurement:

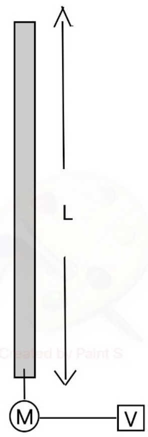

Figure 2.7: Calibration setup schematics.

Using the mathematica file:
A Mathematica file is added in which you only need to add the measured values of the height column, measured voltage at each height, flow rates of the pump and the measured mean voltages for the actual experiment. Only replace values if stated so, the other parts produces plots for your experiment. Also a function is provided, so you can switch from voltage to pressure manually.

2.4 Reference measurement

The pressure drop over a battery cell can be simplified to the pressure drop over a pipe. By changing the flow velocity ω of the fluid we expect a pressure drop related to the theoretical values of relation 2.1. For practical considerations the pressure drop is measured by means of incoming and outgoing pressure with relation 2.2. The fluid velocity will now be varied from 2 to 6 (ml/min) with steps of 1, and the resulting pressure drop will be measured. For this measurement we keep the entire setup at level such that the uncertainty due to gravitational pressure is minimized. The total setup is displayed below in figure:2.8 The setup is as symmetrical as practically possible such that the effect of measuring on either side is minimized.

How to conduct the measurements step by step:
1. You fill the container with 400mL demiwater (enough to fill the circuit and allow the pipes to have a constant flow)
2. You put one end of pipe 1 in the container and attach it to the pump. Make sure the clump lever of the pump is in the right direction.
3. You connect pipe 1 with 2 and pipe 2 with 3, with T-junctions (at points M1 and M2), with attached valves.
3. You connect the pressure measuring device and the Oscilloscope (O), you set the Oscilloscope as explained in figure 2.4
4. Attach the (M)-(O) system at the T-junction of M1.
5. Changing the flow-rate of the pump you take different measurements of the mean, max and min mV from the

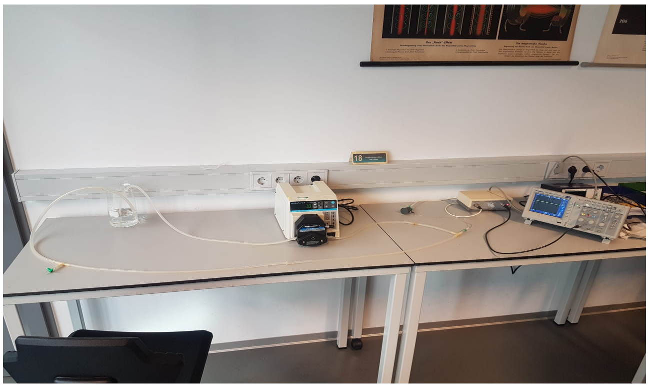

Figure 2.8: Setup to measure pressure drop over an object.

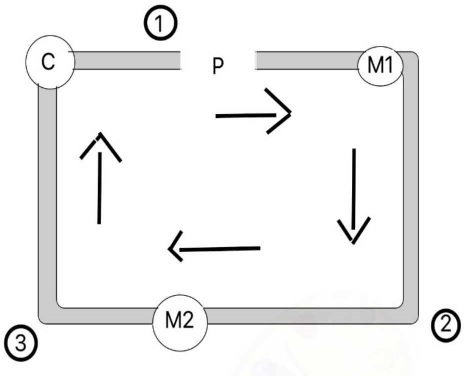

Figure 2.9: Reference setup schematics, symbols as explained in section 2.2.

(O), you can see how to set up the wave in order to take the measurements in 2.3

6. You attach the (M)-(O) system at the M2 T-Junction, and repeat step 5

2.5 Measurement Results

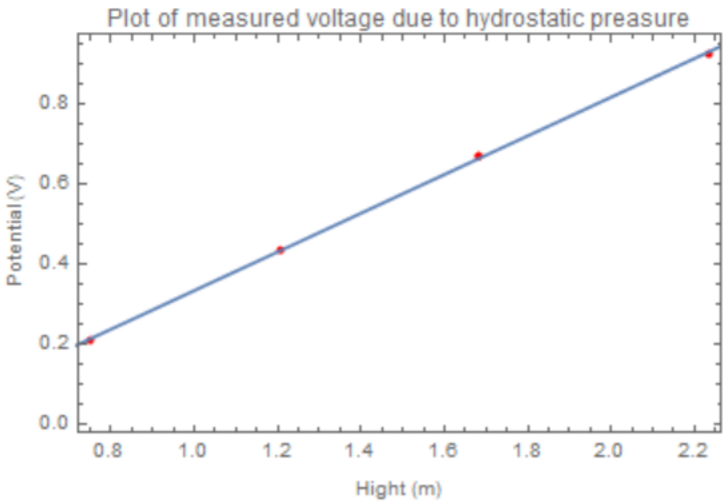

Figure 2.10: In this figure we see the measured voltages for different heights (red) and the best fit through this data (blue), such that we now know the relation between volts and pressure.

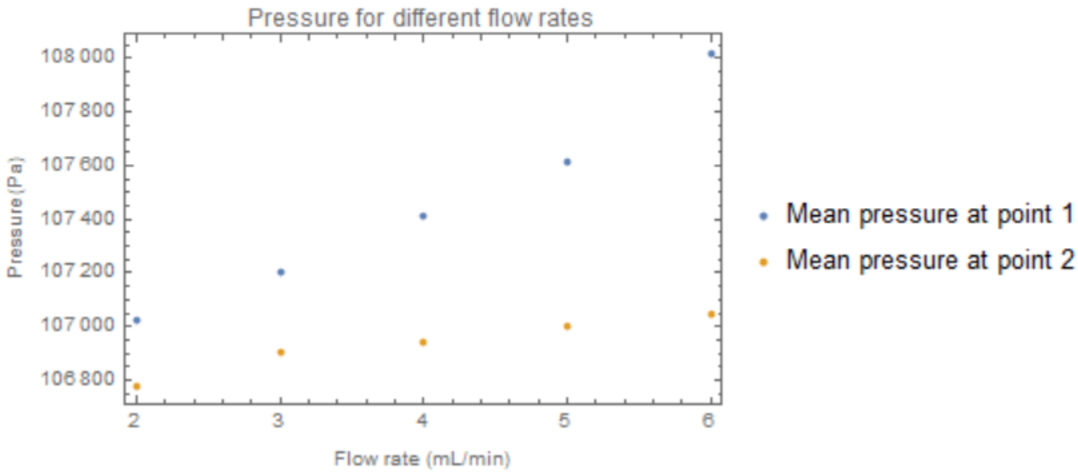

Figure 2.11: In this figure we see the mean pressure for different flow rates.

2.6 Conclusion

We where able to calibrate our measurement device and found a linear relation between voltage and pressure:

$$P_a + \rho g (V - b)/a, \tag{2.5}$$

where a and b are parameters set by the fitted model. For our fit, $a = 0.481336$ and $b = -0.14711$. This relation was then used to measure the pressure drop for the reference measurement. The reference measurement was used to compare the pressure drop due to the battery cell with that of only the pipes used. We measured the pressure drop for different flow velocities over a pipe of length L. The experiment was done to get a better understanding of the fluid dynamics in a battery cell which has a significant influence on the performance of the battery.