THICKNESS MEASUREMENTS OF THE GAS DISTRIBUTION LAYER FOR A DIRECT METHANOL FUEL CELL

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INTRODUCTION

The subject of an ongoing collaboration between the University of North Florida (UNF) and the University of Florida (UF) is the development of a new direct methanol fuel cell. The objective of the research is to create a cell that can power portable electronic products with increased energy density and portability.

In current commercially-available direct methanol fuel cells, water filtration from the cathode to the anode side of the cell is performed by an active process. This process requires large, power-consuming components such as a water pump, water separator, and condenser. UNF has developed a gas distribution layer (GDL) which performs the water filtration tasks passively. This passive water filtration enables the elimination of several components found in a conventional fuel cell, which, in turn, increases the volumetric energy density to levels comparable to lithium ion batteries.

To support this development effort, UF has performed measurements on the GDL to determine the manufacturing quality. The GDL is comprised of two components. The first is carbon fiber paper (CFP) that controls the amount of oxygen flowing through the system. The second is an ink coating that is applied to the CFP and provides the necessary water filtration in the cell. The system performance is sensitive to the thickness of the GDL. If it is too thick, then too little oxygen passes through. Conversely, a thin GDL allows more water than desired to flow through the system.

This paper describes the design and calibration of the thickness measurement device and example measurement results. The thickness was determined using a capacitance probe setup which measures the voltage differential between a reference point and the sample. The GDL was held in place by a vacuum chuck that was designed and built at UF to hold the samples flat during testing. Thickness maps of GDLs (120 mm × 220 mm) are provided in order to characterize the GDL thickness variation. A variation in the thickness as a function of ink loading was observed. Additionally, a validation of the capacitance probe setup was conducted using a micrometer.

EXPERIMENTAL SETUP

Capacitance probe

Capacitance probes enable non-contact measurements, a requirement for the thickness evaluation of the GDL. These sensors measure the difference in capacitance between a reference and sample by applying an alternating voltage to each conductive object and measuring the response. The response is inversely proportional to the distance between the sensor and target. The change in capacitance is multiplied by an appropriate calibration factor to determine the thickness of the sample.

Vacuum chuck

It is necessary that the target surface be as flat as possible during measurement to avoid convolving this non-flatness with the actual thickness variation in the GDL. To achieve this, a vacuum chuck was developed which enabled the GDLs to be uniformly suctioned against its surface. To cover the 120 mm × 220 mm GDL surface area, an aluminum block was machined with over ten thousand 0.8 mm diameter holes; see Fig. 1. The small hole diameter was chosen because the GDL was flexible enough that any larger-sized hole would have caused localized errors in the thickness measurements. As seen in Fig. 1, the chuck was placed on two stacked programmable stages to enable capacitance difference calculations to be completed.

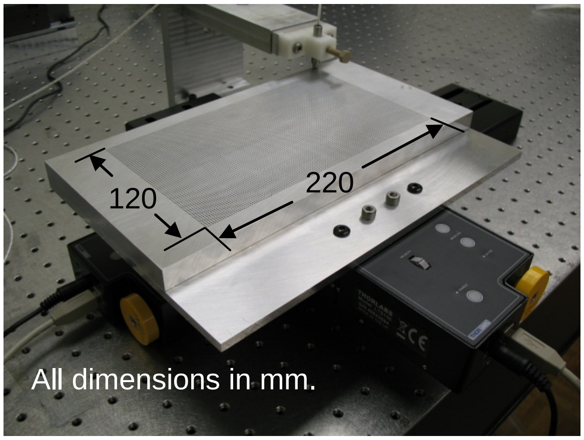

FIGURE 1. Vacuum chuck located on two stacked positioning stages. The capacitance probe is also shown.

RESULTS

To determine the GDL thickness maps (see Fig. 2), two measurements were performed. First, the vacuum chuck flatness was determined by scanning the measurement area. Second, the GDL was inserted and measured. The two measurements were then differenced to isolate the GDL thickness. The capacitance probe sensor used for this project had a 3.2 mm sensing diameter over which it averaged the capacitance of the sample. Considering this averaging effect, the stage was stepped along the y-axis in 1.5 mm increments and scanning was initiated in the x-axis at a rate of 37,000 samples per line (220 mm distance).

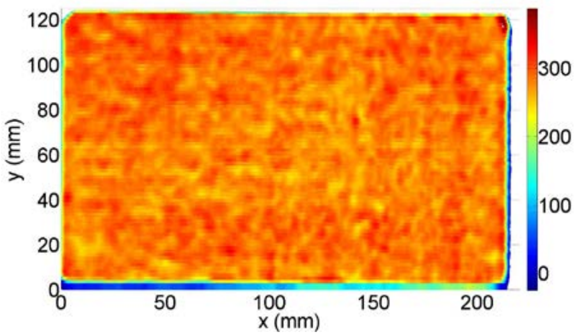

FIGURE 2. Surface map of an eight ink coat GDL. Colorbar units are in µm. The GDL had an average thickness of 282.7 µm and a standard deviation of 13.2 µm.

Another GDL feature of interest was the thickness change with progressive ink loading. Eight individual ink coats were applied to the CFP and the thickness between each subsequent coat was measured. See Fig. 3. In the ink coating process, the carbon fiber paper is cut from a large roll down the middle to create both a left and a right piece. A systematic difference in barrier thickness between the left and right piece was observed.

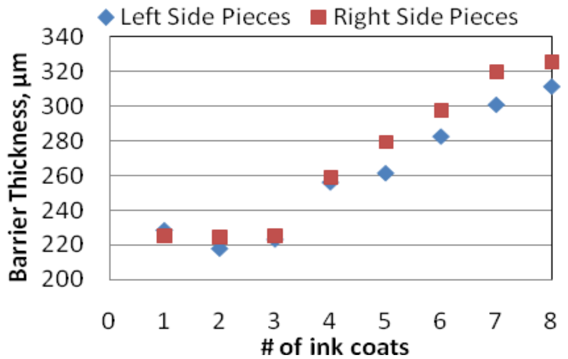

FIGURE 3. GDL thickness versus number of ink layers.

The constant variation was investigated by conducting performance tests on GDLs from each side of the roll. These tests are comprised of a diffusion test, which measures the methanol diffusivity of the cell, and a capillary pressure test that quantifies the water transport capacity. The capillary benchmark is the easier of the two to satisfy and each side of the roll passed every time. The methanol diffusion is the more difficult target to achieve and could fail despite having conducted the painting process in the correct manner. It was found that simply adding a thicker coat or painting nine coats of ink on the left side pieces would overcome this challenge. A total of 22 GDLs were scanned and the mean thickness and standard deviation for each are presented in Table 1. GDLs 1-16 were measured as part of the progressive ink loading experiment, while GDLs 17-22 had the full eight ink layers.

TABLE 1. GDL thickness data.

GDL #	Mean Thickness (µm)	Std. Deviation (µm)
1	228.6	12.9
2	225.1	12
3	218	12.1

4	224.5	11.4
5	223.3	13.2
6	225.1	12.2
7	256.2	13.8
8	258.9	14.3
9	261.5	13.5
10	279.2	13.5
11	282.7	13.2
12	297.7	13.1
13	311.5	14.9
14	325.6	14.3
15	301	13.7
16	319.9	13.6
17	286.5	14.8
18	276.9	13.8
19	301.7	14.1
20	245.4	12.7
21	279.7	12
22	277.9	12.1
Average		13.2

COMPARISON TESTS

The measurement technique presented is unique due to the vacuum chuck flattening. Therefore, a validation of the capacitance probe data was needed to confirm the results. It was found that the GDL could not be directly compared to scanning white light interferometer (SWLI) results due to the lower lateral resolution of the capacitance probe data. An example of the GDL SWLI data is given in Fig. 4.

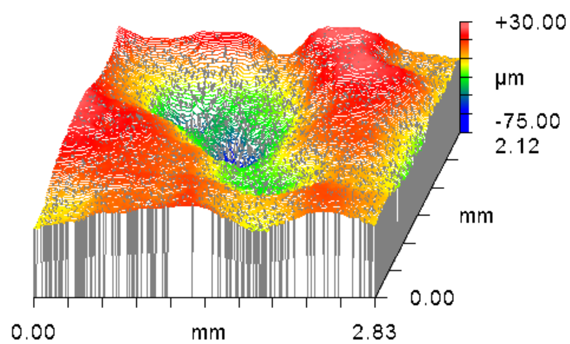

FIGURE 4. SWLI height map of GDL. The scanned area is 2.83 mm long by 2.12 mm wide.

As seen in Fig. 5, the capacitance probe data does not have comparable resolution to the SWLI measurement. The data displays a smoothing effect due to the averaging over the capacitance probe sensing area.

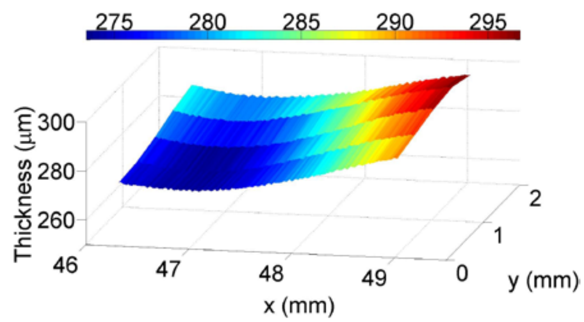

FIGURE 5. 3-D plot from the capacitance probe data. Colorbar units are in µm. This image is a small fraction of the size of Fig. 2.

Validation was conducted by measuring a sample of known thickness. A 1.27 mm thick gage block was measured by three devices, including the capacitance probe setup (Fig. 6), a SWLI (Fig. 7), and a micrometer (Table 2).

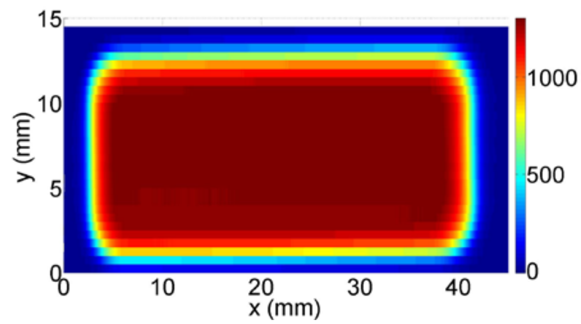

FIGURE 6. Height map of the 1.27 mm thick gage block and surrounding area from the capacitance probe setup. Note the averaging effect near the gage block edges

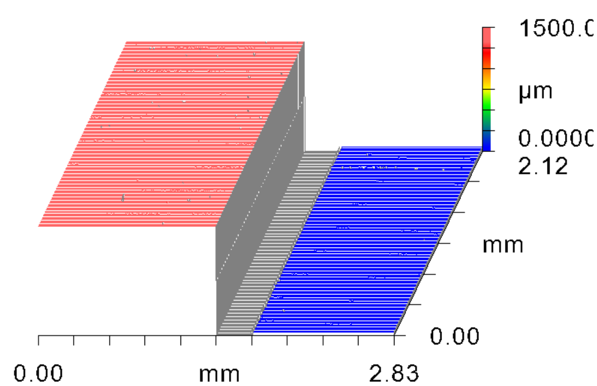

FIGURE 7. The 1.27 mm gage block thickness profile from the SWLI.

The mean thickness and standard deviation for each measurement type is included in Table 2. The micrometer result, which was averaged from three measurements at various locations on the block, was closest to the specified thickness of 1270 µm. The SWLI data was several micrometers thicker and was found by placing the 1.27 mm gage block on top of a second gage block and completing a 1500 µm upward scan. The capacitance probe results were 20 µm thicker than the expected value. All measurements were performed in a temperature controlled environment.

TABLE 2. Micrometer, SWLI, and capacitance probe thickness data of 1.27 mm thick gage block.

Measure Type	Mean Thickness (µm)	Std. Dev. (µm)	Percent Diff. (%)
Micro-meter	1270	0.5	0
SWLI	1278.0	0.17	0.63
Cap. Probe	1290.2	22.5	1.59

One potential explanation for the SWLI measurement difference is that the gage blocks were not wrung together and debris was likely present between the two surfaces. This would lead to an increased thickness. For the capacitance probe data, it is believed that the calibration factor applied to convert the voltage into displacement was too large. This offset could be corrected for subsequent measurements. Also, the thickness was determined by differencing the voltage response of the gage block and the vacuum chuck surface. Small burrs or dust on the chuck surface would cause a larger gap between the sample and reference planes and lead to a thicker measurement. Polishing of the chuck surface would likely result in a more accurate measurement for the rigid sample. Note that this measurement was different than the GDL measurements because the GDL conformed to the chuck surface when the vacuum was applied.

DISCUSSION

A measurement apparatus was constructed to determine the thickness of the gas distribution layer in a direct methanol fuel cell. The device was developed to determine the manufacturing quality and repeatability of the ink application to the surface of the GDL. It was found that the ink application is evenly applied to a standard deviation of 13.2 µm over the surface of the GDLs.

Alternate deposition methods, which include spraying and rod coating, will be investigated for two reasons. The first is to decrease the standard deviation of the thickness, thereby increasing the likelihood that the GDL will pass the diffusion and capillary performance tests. The second is a cost-benefit issue. The labor cost of the ink painting process is extremely high. GDL batches are currently manufactured in lots of eleven pieces. From these eleven pieces, four laptop-sized batteries can be constructed if each piece passes the performance tests. The formulation of the ink and deposition onto the carbon fiber paper takes, at minimum, 7 hours for one worker to complete. Design scale-up is a significant concern for this project and the painting procedure is ineffective for high volume production.

CONCLUSIONS

It was found that painting the ink onto the GDL yielded an average 13.2 µm standard deviation in thickness over the 22 tested samples. The painting technique is a satisfactory method for small scale production of direct methanol fuel cells. However, scale-up will require research into alternate ink deposition procedures.

ACKNOWLEDGEMENTS

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