FUEL-CELL PERFORMANCE DEGRADATION IN HEAVY-DUTY APPLICATIONS

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1. Introduction

H_2/O_2 proton exchange membrane fuel cells (PEM-FCs) are emerging as a viable alternative in clean energy applications, particularly in transportation. They use hydrogen and oxygen to produce electricity through electrochemical reactions, producing only water as a product. However, the performance of PEM-FCs degrade over time. As a result, the lifespan of today's fuel cells fall short of the requirements for commercial automotive applications [1]. A contributing factor in the degradation of fuel cells is the degradation of platinum, which is commonly used as a catalyst. Performing Pt degradation tests can help maximize fuel cell lifespan. However, running practical Pt-degradation tests are both expensive and time-consuming. Instead, to predict Pt-degradation in a time and cost effective manner, theoretical degradation models can be used.

The aim of this project was therefore to analyze the impact of temperature-induced Pt degradation in fuel cells used for heavy-duty applications using a theoretical one-dimensional degradation model and evaluate its effects on performance and longevity.

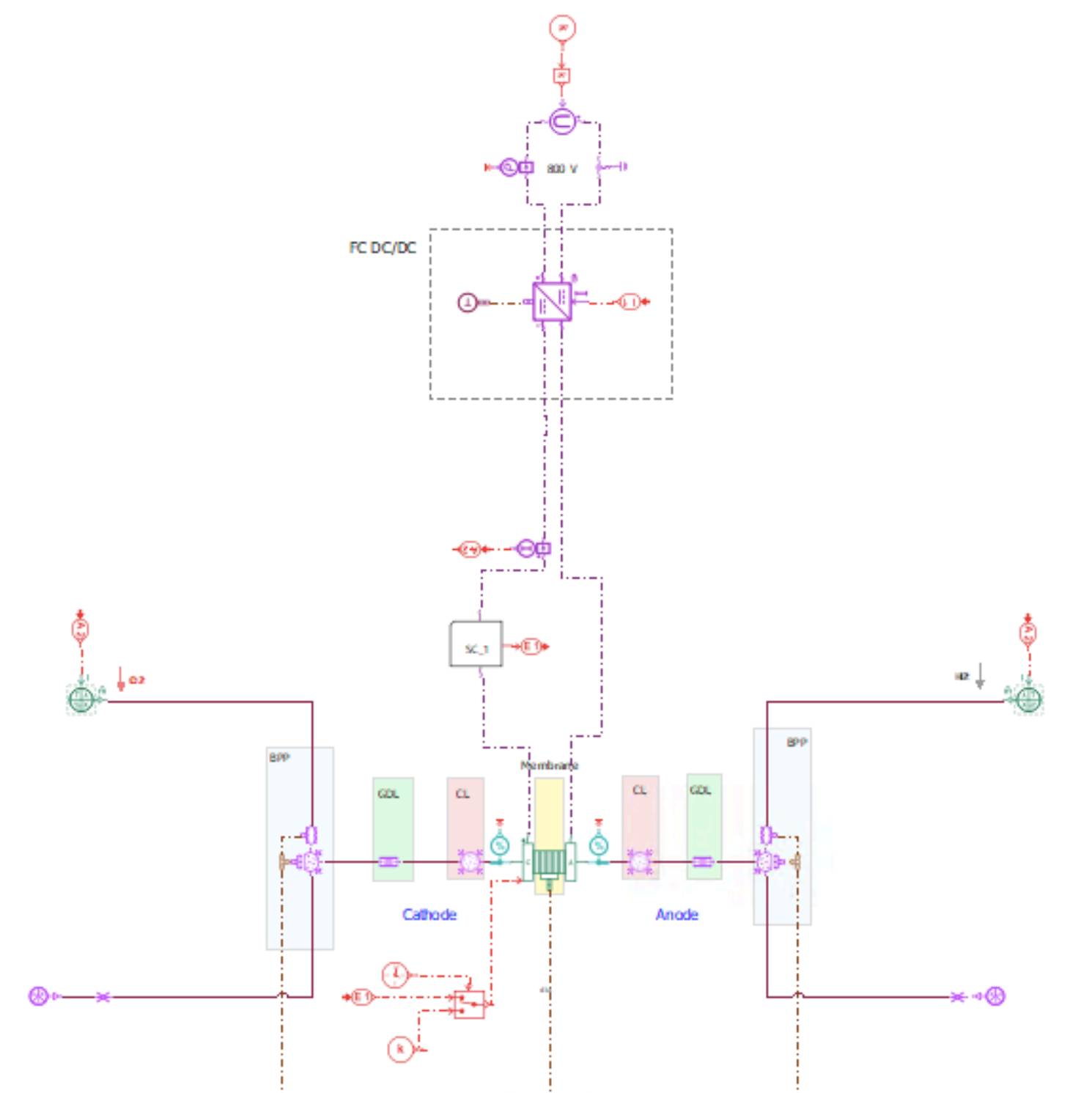

Figure 1a: Heavy-duty fuel cell stack using 500 cells modeled in Simcenter Amesim.

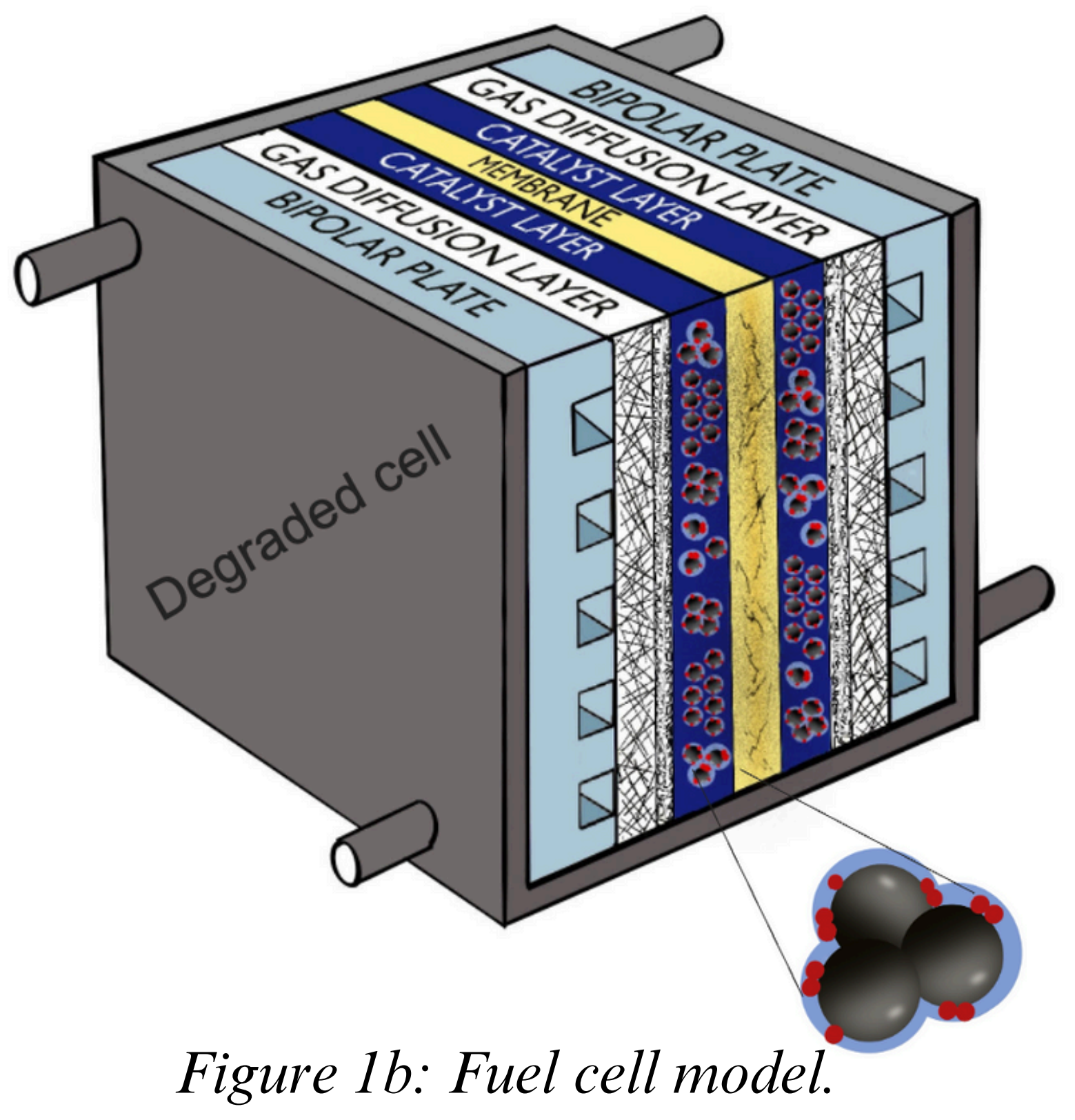

Figure 1b: Fuel cell model.

2. Background

Platinum degradation in the catalyst layer happens due to four main mechanisms: platinum dissolution, particle detachment, Ostwald ripening, and agglomeration. In platinum dissolution and particle detachment, platinum particles and clusters leave the catalyst layer and re-deposit somewhere else. In Ostwald ripening, the dissolved Pt-particles re-deposit onto other Pt-particles on the catalyst layer. In agglomeration, Pt-particles are amassed into larger groups. All of these processes eventually lead to a decrease in electrochemical surface area (ECSA) on the catalyst layer, worsening catalytic activity and decreasing fuel cell performance.

A change in temperature impacts the reaction rate of the dissolution mechanism. As temperature increases, the activation barrier for the reactions decreases, resulting in higher reaction rates. Consequently, mechanisms like platinum dissolution and Ostwald ripening occur at a higher rates.

In this project, three one-dimensional equations were implemented to model Pt degradation. The first equation (eq. 1) modeled the rate of platinum oxidation. The second equation (eq. 2) modeled the total platinum surface tension. The third equation (eq. 3) modeled the platinum dissolution [2].

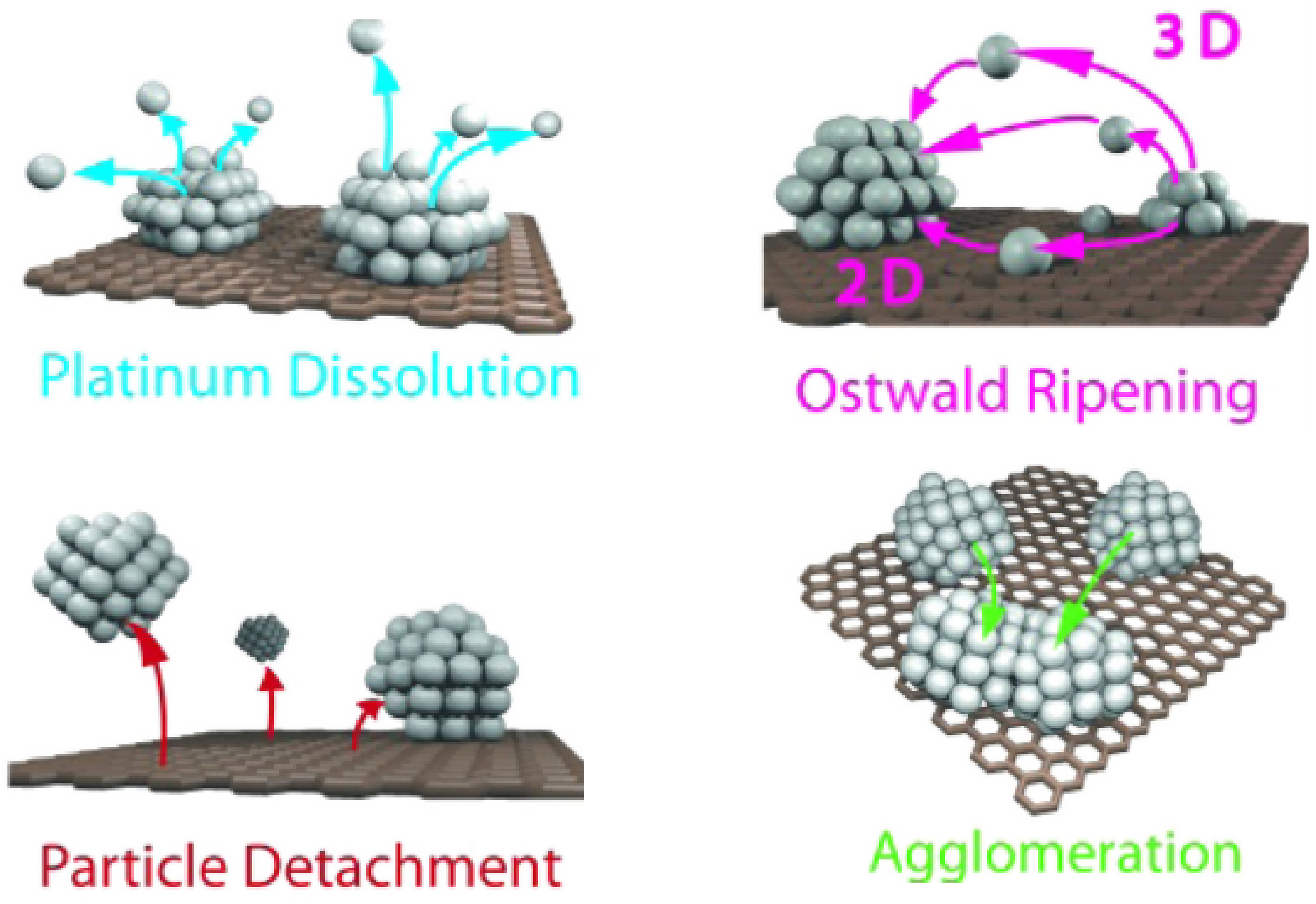

Figure 2: Platinum degradation mechanisms.

3. Methodology

The simulation was run in Simcenter Amesim (Version 2310) to analyze how Pt degradation is affected at different temperatures. The chosen temperatures were 60, 70, 80, and 90 degrees; while all other parameters were kept constant. To model real world driving conditions, the fuel cells were tested using the Worldwide harmonized Light duty Test Cycle (WLTC). In the simulation the cycle ran repeatedly for 2000 hours. Figure 1 shows the Amesim heavy-duty fuel cell stack model. Figure 3 shows the submodel where the specific degradation equations were implemented (eq. 1, eq. 2, eq. 3). By running the fuel cell degradation model, it was possible to get the particle size distribution, electrochemical surface area of platinum (ECSA), the polarization curve, and platinum dissolution curve for the different mentioned temperatures.

Submodel

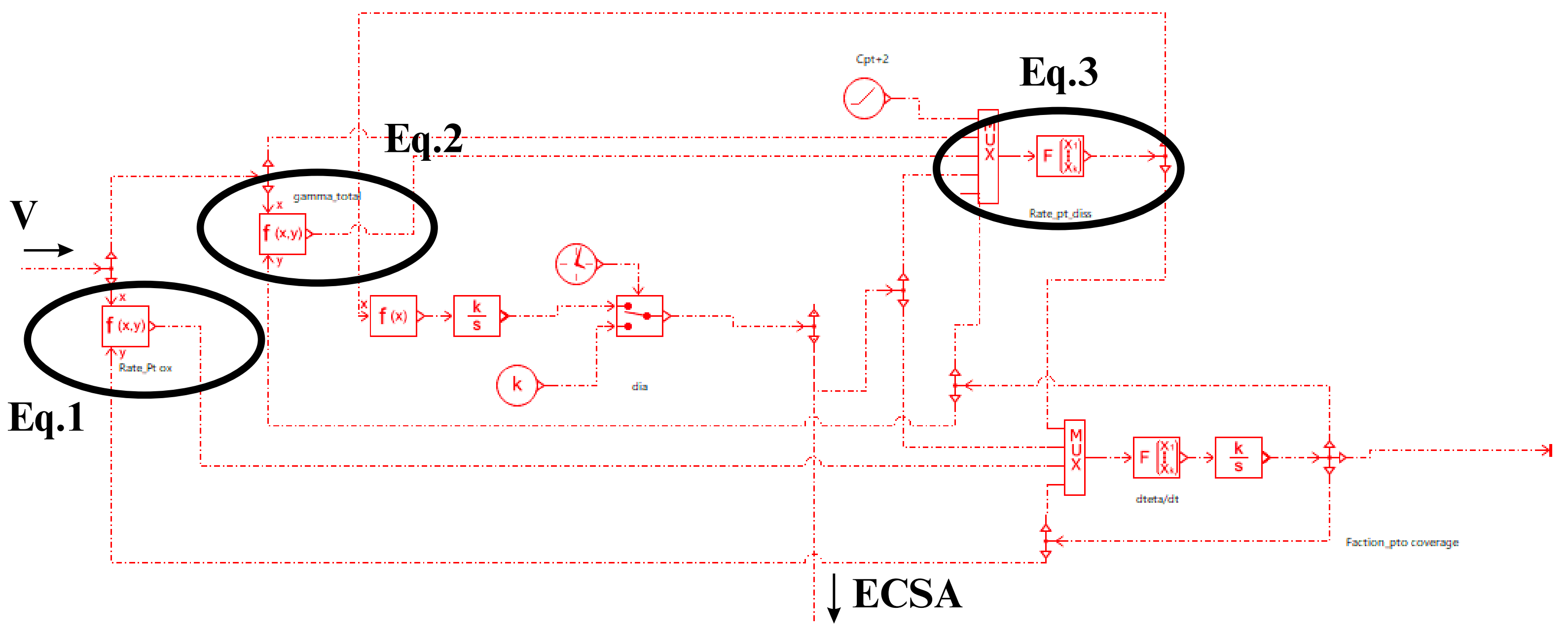

Figure 3: Degradation submodel of the fuel cell model with implemented equations. The voltage input was supplied to the model according to the WLTC-cycle.

5. Conclusion

By changing the temperature inside of the fuel cell, a reduction in the fuel cell performance was observed over 2000 hours. An increase in temperature will reduce the ECSA as shown in figure 4; making the fuel cell less effective overall. This is further supported by the particle size distribution, which shows that mean particle diameter increases with higher temperatures. This also correlates to the higher platinum dissolution effect in the fuel cell. The decrease in overall fuel cell performance is evident by the polarization curve, figure 5, when compared between BOL and EOL (where a reduction in cell voltage can be observed over stack current density). Our results show an importance in choosing the right operating temperature inside of the fuel cell to get maximum performance and longevity.

4. Results

The simulation results was analyzed with a variation of four different temperatures at 60°C, 70°C, 80°C, 90°C.

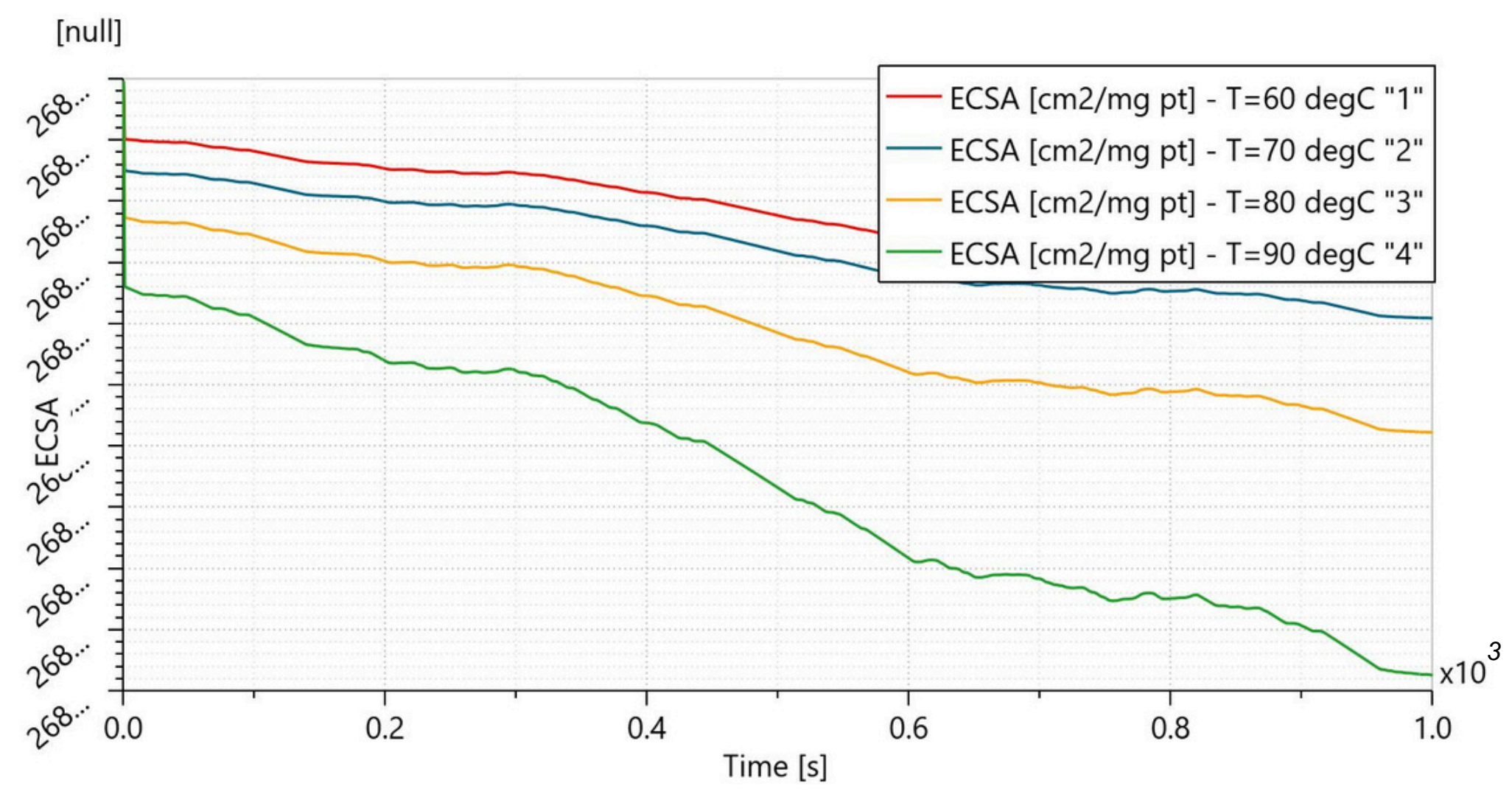

Figure 4: Electrochemical surface area of Platinum.

The variation in temperature shows ECSA reduction with increased temperatures for one WLTC-cycle, resulting in a less effective catalyst layer.

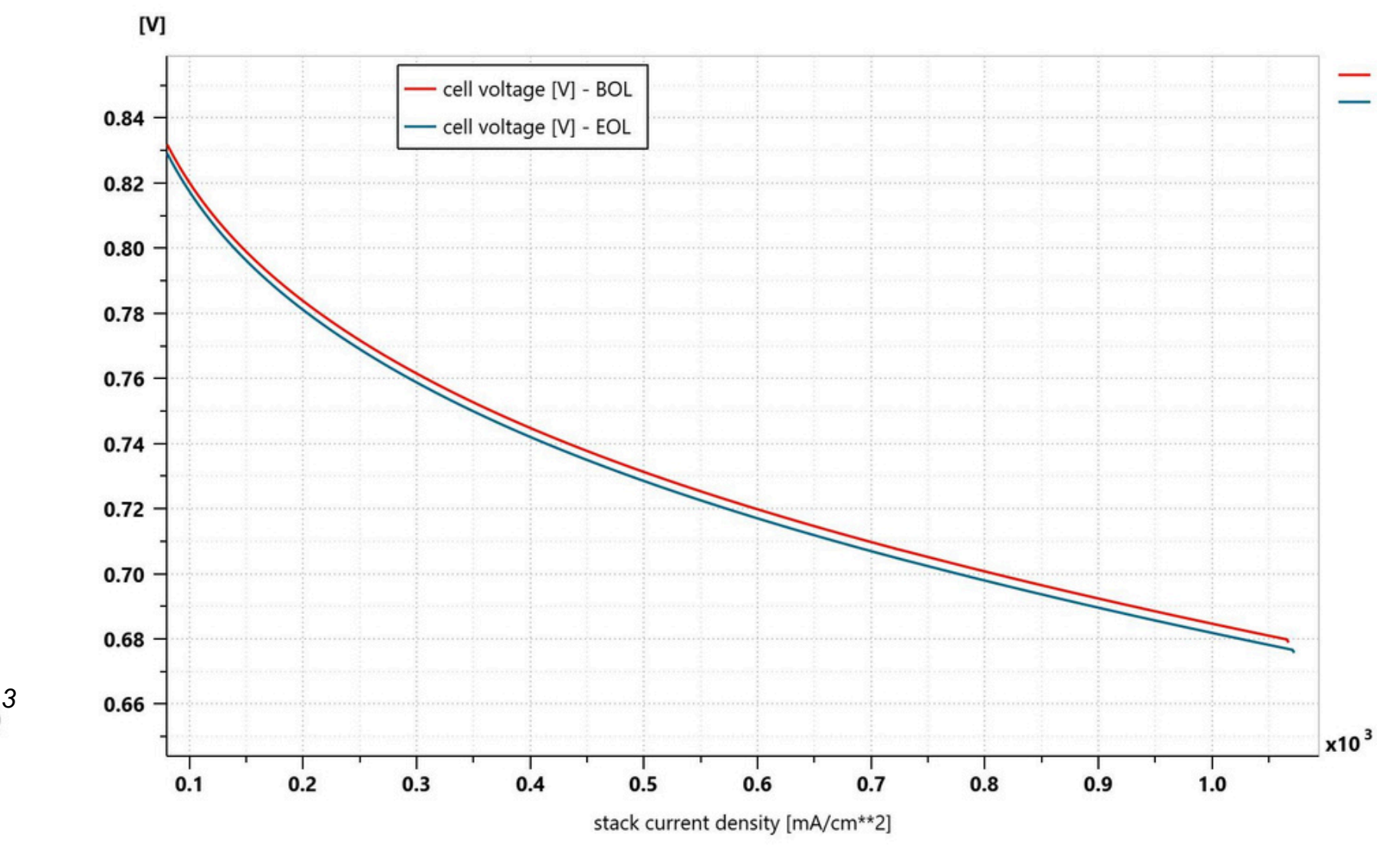

Figure 5: Polarization curve BOL and EOL.

The polarization curve analysis shows less losses at the Beginning of Life (BOL) compared to the End of Life (EOL).

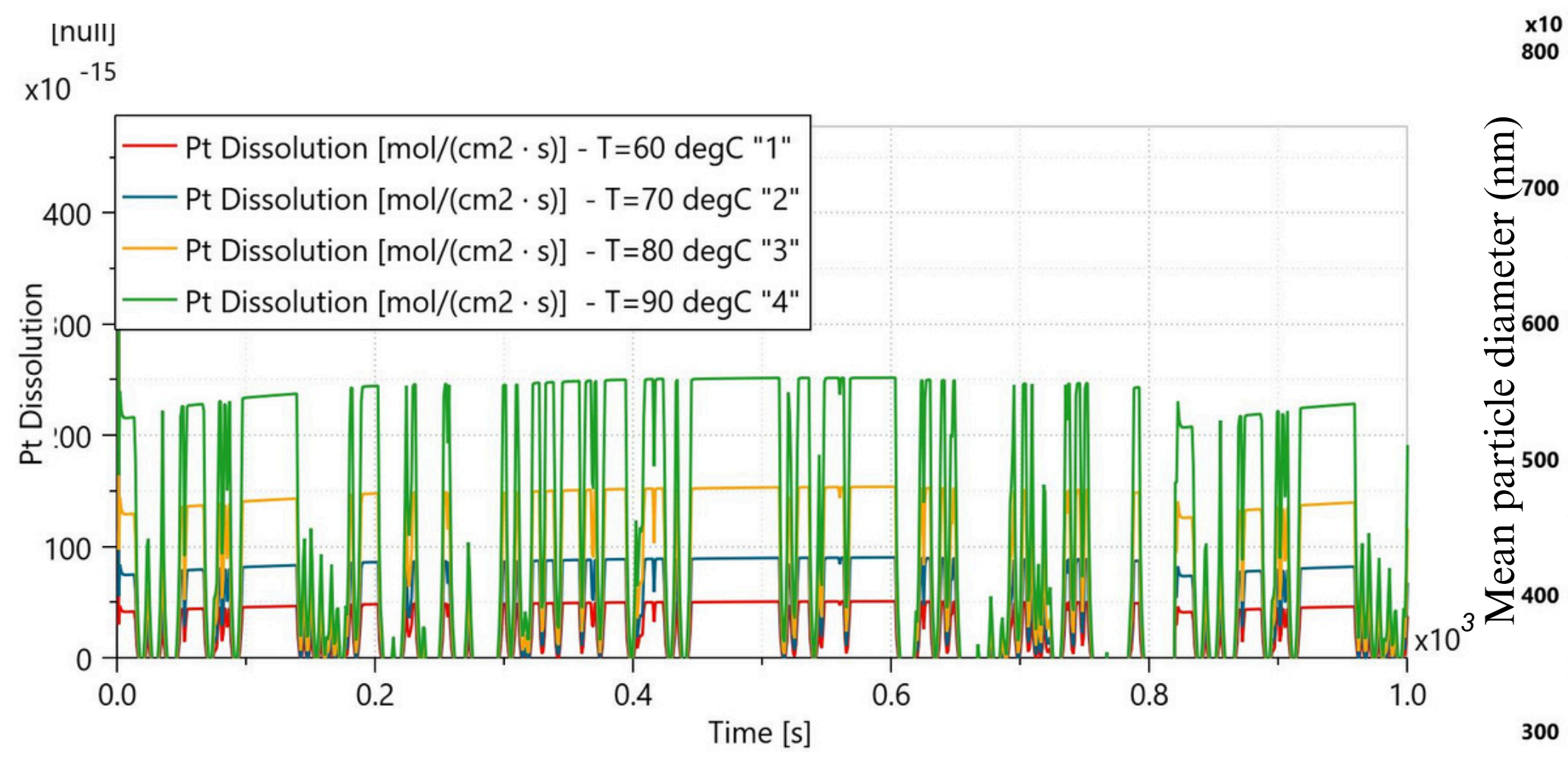

Figure 6: Platinum dissulotion respect to time.

The higher temperature, through the WLTC test, showcases platinum (Pt) dissolution with respect to time, which shows catalyst degradation.

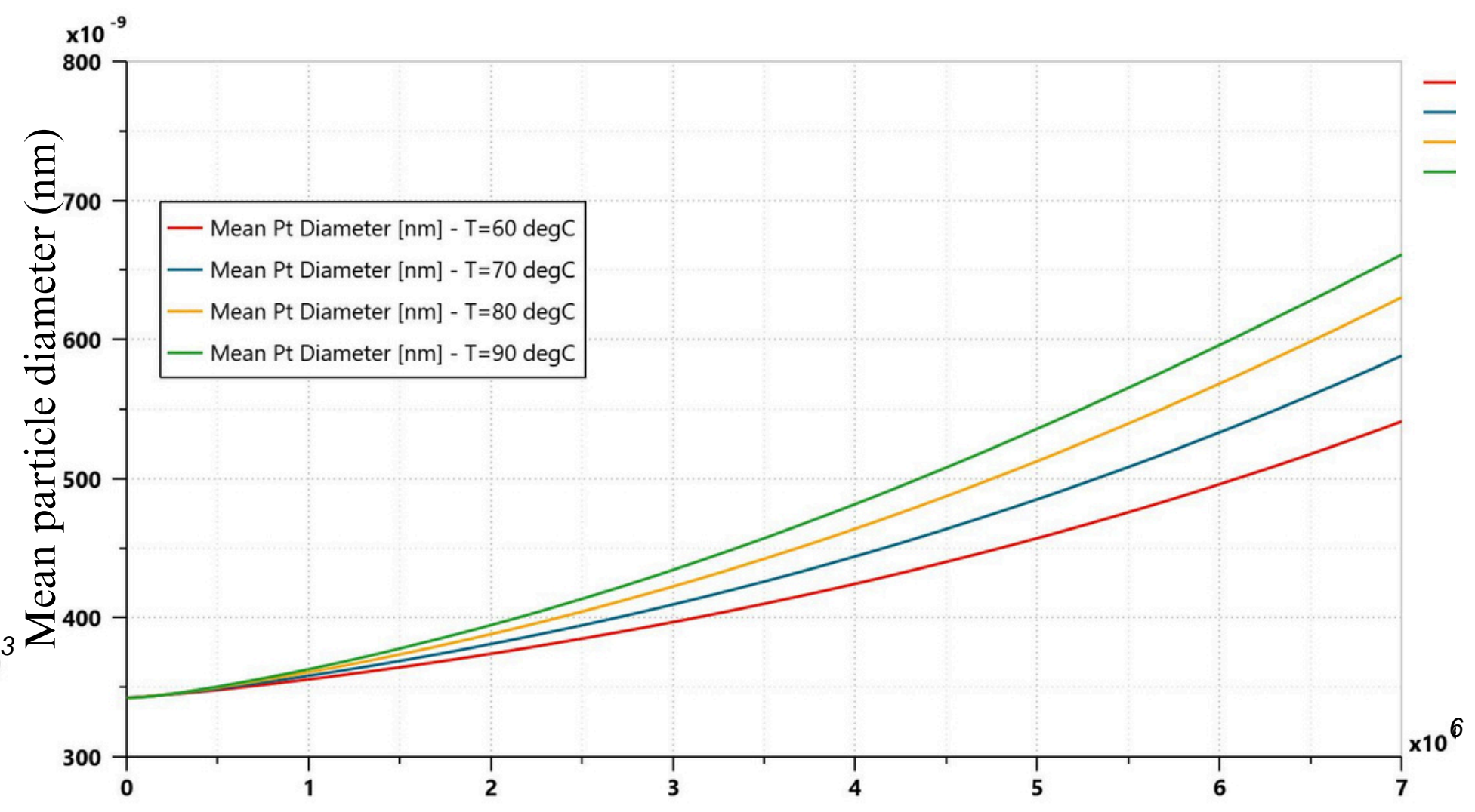

Figure 7: Mean particle size distribution.

The increase in temperature lead to an increase in mean Platinum (Pt) particle size, a process caused by Ostwald ripening.

Related Literature

[1] Arrigoni A, Arosio V, Peressut A, Latorrata S, Dotelli G. Greenhouse Gas Implications of Extending the Service Life of PEM Fuel Cells for Automotive Applications: A Life Cycle Assessment. Clean Technologies. 2022, 4(1), 132-148; https://doi.org/10.3390/cleantechnol4010009

[2] Li Y, Moriyama K, Gu W, Arisetty S, Wang CY. A one-dimensional pt degradation model for polymer electrolyte fuel cells. Journal of The Electrochemical Society. 2015;162(8): F834–F842. https://doi.org/10.1149/2.0101508jes.