Modelling of the Oxygen Consumption of Cells in the Cell Culturing Platform

Ayda Niazi, Carl J. Anthony
School of Mechanical Engineering, Biomedical and Micro Engineering Group, University of Birmingham, Birmingham, United Kingdom, B15 2TT

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Introduction: A device for monitoring the oxygen consumption of cells has been developed, which consists of two parts; a cell culturing platform (CCP) and an oxygen sensing chip (Figure 1).

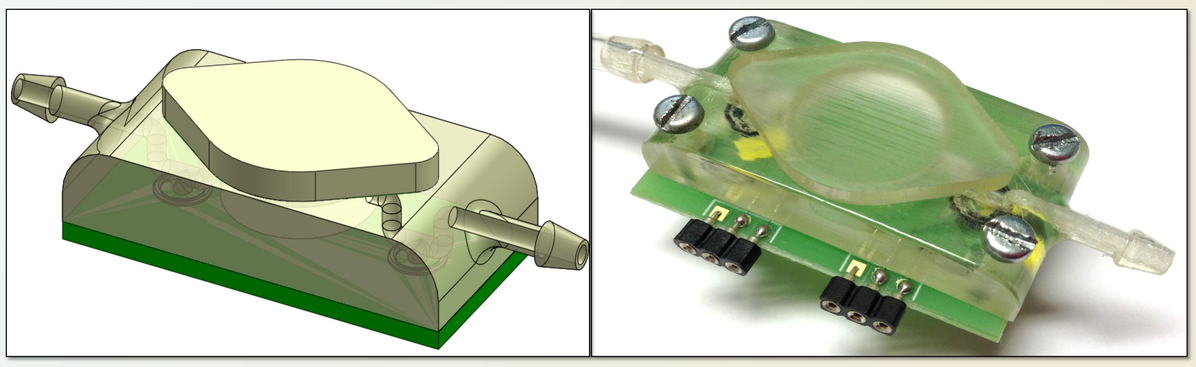

Figure 1. Cell culturing platform and the sensor platform

The CCP possesses inlet and outlet pipes to direct the fluid under the test to the cell culturing chamber through the inlet pipe and goes out of the outlet pipe after being partially consumed by the cells (Figure 2). In this poster, the oxygen consumption of the cells in the CCP has been modelled.

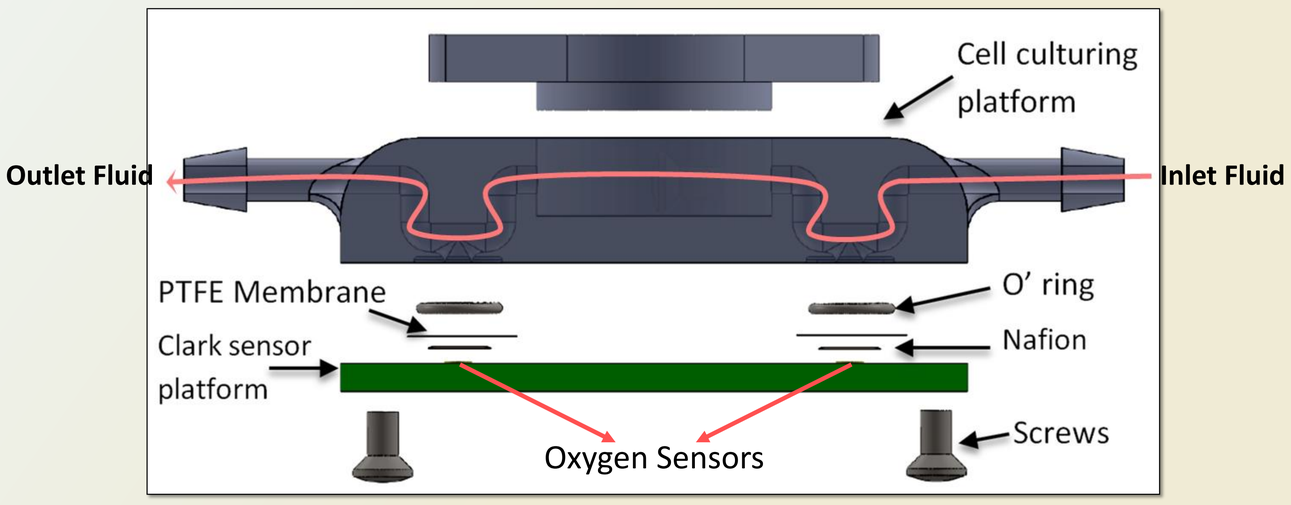

Figure 2. Assembly of sensor platform and the cell culturing platform

Computational Methods: Without considering the effect of oxygen sensors, the sum of the oxygen consumed by the cells and the output dissolved oxygen of the fluid is equal to the input dissolved oxygen of the fluid.

$$(N \times [O2]\ cell) + (F \times [O2]\ output) = (F \times [O2]\ input)$$

Where:

- N = Number of cells
- F = Input flow rate
- [O2] input = Dissolved oxygen in input fluid
- [O2] output = Dissolved oxygen in output fluid
- [O2] cell = Oxygen consumption rate of cell

A laminar inflow condition is considered for the inlet, as a pre-established laminar flow profile. To model the oxygen transport according to the normal convection diffusion equation, a coupling of laminar flow and transport of diluted species interfaces has been set, which assumes that the oxygen is very dilute with respect to water.

Variable	Name	Value	Units
Mean Inlet Velocity	V_in	1	mm/s
Inlet Mass Flux	m_O2_in	3.2x10^(-05)	kg/(m2.s)
Cell Rate Constant	k_cell	10^(-12)	m/s
Inlet Oxygen Concentration	cO2_in	200x10^(-6)	mol/L

Table 1. Parameters used for the modelling of oxygen consumption

The model is solved with the given data (Table 1) and the diffusional equation as described by Fick's 2nd law and mesh consists of 50,429 elements.

$$\frac{\partial c}{\partial t} + \nabla.(-D\nabla c) = R$$

Results: A 3D model of the dissolved oxygen concentration is shown in colour, from red showing high concentration to blue indicating low concentration as shown in the colour legend (Figure 3). Figure 3 shows oxygen consumption of 10,000 cells in the stationary study. According to a literature review, each cell consumes about 10^-16 (Mole/s) of oxygen [1,2].

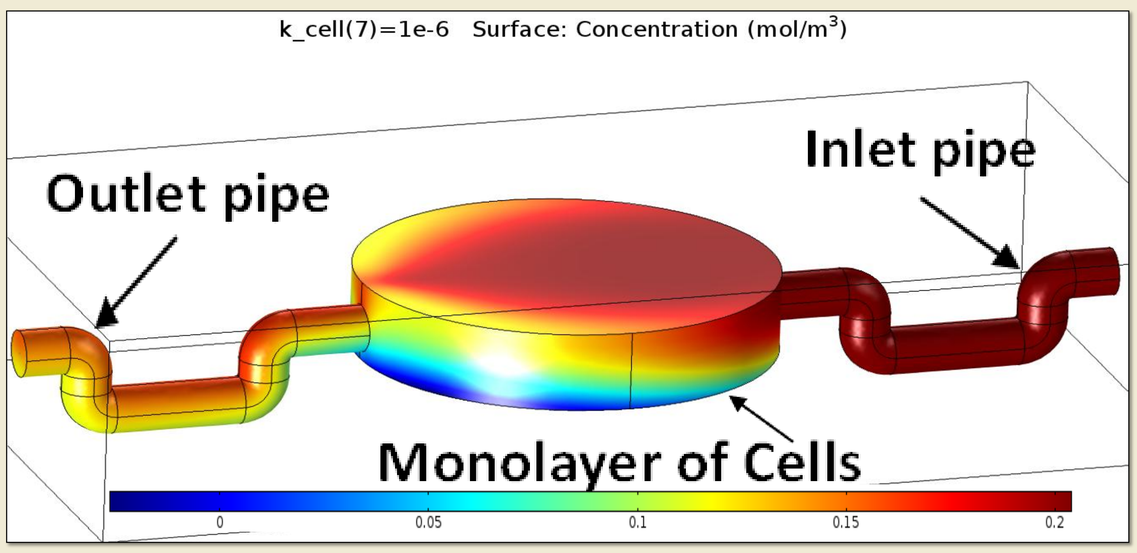

Figure 3. Reduction of oxygen in the cell culturing chamber

The flux through the cell layer is set to be oxygen consumption rate (k-cell) by 10,000 cells, 1e^-12(m/s) multiplied by the density of oxygen, which is variable in the fluid and evaluated locally and solved for in the transport of diluted species model. Figure 4 shows the development of the concentration profile in the reaction chamber over the course of time.

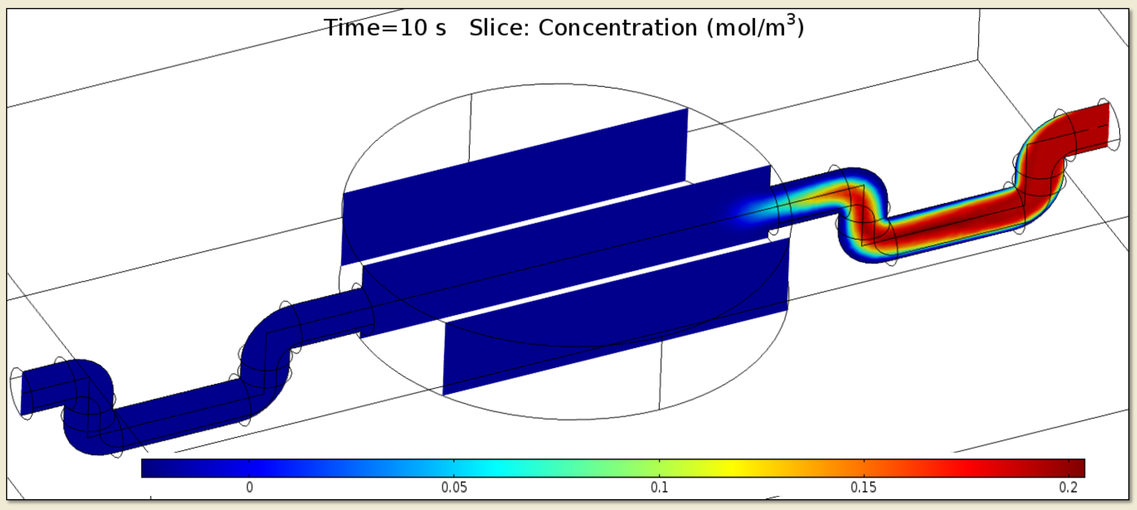

Figure 4. Transient Reduction of oxygen in the cell culturing chamber in 10 second

Conclusions: To verify the reasonableness of this result, one relevant velocity in this system is the ratio of the inlet flow rate to the catalytic area, which is about 1.44e-5(m/s). Significant depletion of O2 cannot be expected if the surface reaction velocity is in orders of magnitude less than this. However reducing the inlet velocity will increase this amount. Therefore by reducing the inlet velocity, there will be more oxygen consumption by cells, which is feasible since the slower flow rate will give more time to cells to react with the fluid and consume more oxygen (Figure 5).

Figure 5. Comparison of O2 concentration between inlet and outlet pipes while increasing the inlet velocity

References:

1. M. Brischwein, D. Grundl, X. Zhang, Wolf. Finite Element Modelling of Microphysiometry on Cellular Specimen. World congress on medical physics and biomedical engineering, September 7-12, 2009, Munich, Germany, Volume 25/8, 30-33.
2. A. R. Oller, C. W. Buser, M. A. Tyo, W. G. Thilly. Growth of mammalian cells at high oxygen concentrations. Centre for Environmental Health Sciences, Massachusetts Institute of Technology, Cambridge MA 02139, USA.

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